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SECOND EDITION

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190 end-of-chapter PPL-style questions

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FOREWORD TO THE SECOND EDITION.

INTRODUCTION.

Whether you are planning to fly microlights, space shuttles, gliders, combat aircraft, airliners or light aircraft, it is essential that you have a firm grasp of the theoretical knowledge which underpins practical piloting skills. This Oxford Aviation Academy "Skills for Flight" series of text books covers the fundamental theory with which all pilots must come to grips from the very beginning of their pilot training, and which must remain with them throughout their flying career, if they are to be masters of the art and science of flight.

JOINT AVIATION AUTHORITIES PILOTS' LICENCES.

Joint Aviation Authorities (JAA) pilot licences were first introduced in Europe in 1999. By 2006, almost every JAA member state, including all the major countries of Europe, had adopted this new, pan-European licensing system at Air Transport Pilot's Licence, Commercial Pilot's Licence and Private Pilot's Licence levels, and many other countries, world-wide, had expressed interest in aligning their training with the JAA pilot training syllabi.

These syllabi, and the regulations governing the award and the renewal of licences, are defined by the JAA's licensing agency, 'Joint Aviation Requirements - Flight Crew Licensing', (JAR-FCL). JAR-FCL training syllabi are published in a document known as 'JAR-FCL 1.'

The United Kingdom Civil Aviation Authority (UK CAA) is one of the founder authorities within the JAA. The UK CAA has been administering examinations and skills tests for the issue of JAA licences since the year 2000, on behalf of JAR-FCL.

The Private Pilot's Licence (PPL), then, issued by the UK CAA, is a JAA licence which is accepted as proof of a pilot's qualifications throughout all JAA member states.

Currently, the JAA member states are: *United Kingdom, Denmark, Iceland, Switzerland, France, Sweden, Netherlands, Belgium, Romania, Spain, Finland, Ireland, Malta, Norway, Czech Republic, Slovenia, Germany, Portugal, Greece, Italy, Turkey, Croatia, Poland, Austria, Estonia, Lithuania, Cyprus, Hungary, Luxembourg, Monaco, Slovakia.*

As a licence which is also fully compliant with the licensing recommendations of the International Civil Aviation Organisation (ICAO), the JAA PPL is also valid in most other parts of the world.

The JAA PPL in the UK has replaced the full UK PPL, formerly issued solely under the authority of the UK CAA.

Issue of the JAA PPL is dependent on the student pilot having completed the requisite training and passed the appropriate theoretical knowledge and practical flying skills tests detailed in 'JAR-FCL 1'. In the UK, the CAA is responsible for ensuring that these requirements are met before any licence is issued.

EUROPEAN AVIATION SAFETY AGENCY.

With the establishment of the European Aviation Safety Agency (EASA), it is envisaged that JAA flight crew licensing and examining competency will be absorbed into the EASA organisation. It is possible that, when this change has taken place, the PPL may even change its title again, with the words "EASA" replacing "JAA". However, we do not yet know this for certain. In the UK, such a step would require the British Government to review and, where necessary, revise the Civil Aviation Act. But, whatever the future of the title of the PPL, the JAA pilot's licence syllabi are unlikely to change fundamentally, in the short term. So, for the moment, the JAA Licence remains, and any change in nomenclature is likely to be just that: a change in name only.

OXFORD AVIATION ACADEMY AND OAAMEDIA.

Oxford Aviation Academy (OAA) is one of the world's leading professional pilot schools. It has been in operation for over forty years and has trained more than 15 000 professional pilots for over 80 airlines world-wide.

OAA was the first pilot school in the United Kingdom to be granted approval to train for the JAA ATPL. OAA led and coordinated the joint-European effort to produce the JAR-FCL ATPL Learning Objectives which are now published by the JAA, itself, as a guide to the theoretical knowledge requirements of ATPL training.

OAA's experience in European licensing, at all levels, and in the use of advanced training technologies, led OAA's training material production unit, OAAmedia, to conceive, create and produce multimedia, computer-based training for ATPL students preparing for JAA theoretical knowledge examinations by distance learning. Subsequently, OAAmedia extended its range of computer-based training CD-ROMs to cover PPL and post-PPL studies.

This present series of text books is designed to complement OAAmedia's successful PPL CD-ROMs in helping student pilots prepare for the theoretical knowledge examinations of the JAA PPL and beyond, as well as to provide students with the aviation knowledge they require to become safe and competent pilots.

The OAA expertise embodied in this series of books means that students working towards the JAA PPL have access to top-quality, up-to-date, study material at an affordable cost. Those students who aspire to becoming professional pilots will find that this series of PPL books takes them some way beyond PPL towards the knowledge required for professional pilot licences.

THE JAA PRIVATE PILOT'S LICENCE (AEROPLANES).

The following information on the Joint Aviation Authorities Private Pilot's Licence (Aeroplanes); (JAA PPL(A)) is for your guidance only. Full details of flying training, theoretical knowledge training and the corresponding tests and examinations are contained in the JAA document: **JAR–FCL 1, SUBPART C – PRIVATE PILOT LICENCE (Aeroplanes) – PPL(A).**

The privileges of the JAA PPL (A) allow you to fly as pilot-in-command, or co-pilot, of any aircraft for which an appropriate rating is held, but not for remuneration, or on revenue-earning flights.

For United Kingdom based students, full details of JAA PPL (A) training and examinations can be found in the CAA publication, **Licensing Administration Standards Operating Requirements Safety (LASORS),** copies of which can be accessed through the CAA's Flight Crew Licensing website.

Flying Training.

The JAA PPL (A) can be gained by completing a course of a minimum of 45 hours flying training with a training organisation registered with the appropriate National Aviation Authority (the Civil Aviation Authority, in the case of the United Kingdom).

Flying instruction must normally include:

- **25 hours** dual Instruction on aeroplanes.

- **10 hours** supervised solo flight time on aeroplanes, which must include **5 hours** solo cross-country flight time, including one cross-country flight of at least 150 nautical miles (270km), during which full-stop landings at two different aerodromes, other than the aerodrome of departure, are to be made.

The required flying instructional time may be reduced by a maximum of 10 hours for those students with appropriate flying experience on other types of aircraft.

The flying test (Skills Test), comprising navigation and general skills tests, is to be taken within 6 months of completing flying instruction. All sections of the Skills Test must be taken within a period of 6 months. A successfully completed Skills Test has a period of validity of 12 months for the purposes of licence issue.

Theoretical Knowledge Examinations.

The procedures for the conduct of the JAA PPL (A) theoretical knowledge examinations will be determined by the National Aviation Authority of the state concerned, (the Civil Aviation Authority, in the case of the United Kingdom).

The JAA theoretical knowledge examination must comprise the following 9 subjects: *Air Law, Aircraft General Knowledge, Flight Performance and Planning, Human Performance and Limitations, Meteorology, Navigation, Operational Procedures, Principles of Flight, Communication.*

A single examination paper may cover several subjects.

The combination of subjects and the examination paper titles, as administered by the UK CAA, are, at present:

1. Air Law and Operational Procedures.
2. Human Performance and Limitations.
3. Navigation & Radio Aids.
4. Meteorology.
5. Aircraft (General) & Principles of Flight.
6. Flight Performance and Planning.
7. JAR-FCL Communications (PPL) (i.e. Radiotelephony Communications).

The majority of the questions are multiple choice. In the United Kingdom, examinations are normally conducted by the Flying Training Organisation or Registered Facility at which a student pilot carries out his training.

The pass mark in all subjects is 75%.

For the purpose of the issue of a JAA PPL(A), a pass in the theoretical knowledge examinations will be accepted during the 24 month period immediately following the date of successfully completing all of the theoretical knowledge examinations.

Medical Requirements.

An applicant for a JAR-FCL PPL(A) must hold a valid JAR-FCL Class 1 or Class 2 Medical Certificate.

THE UNITED KINGDOM NATIONAL PRIVATE PILOT'S LICENCE (AEROPLANES).

One of the aims of the United Kingdom National Private Pilot's Licence (UK NPPL) is to make it easier for the recreational flyer to obtain a PPL than it would be if the requirements of the standard JAA-PPL had to be met. The regulations governing medical fitness are also different between the UK NPPL and the JAA PPL.

Full details of the regulations governing the training for, issue of, and privileges of the UK NPPL may be found by consulting LASORS and the Air Navigation Order. Most UK flying club websites also give details of this licence.

Basically, the holder of a UK NPPL is restricted to flight in a simple, UK-registered, single piston-engine aeroplane (including motor gliders and microlights) whose Maximum Authorized Take-off Weight does not exceed 2000 kg. Flight is normally permitted in UK airspace only, by day, and in accordance with the Visual Flight Rules.

Flying Training.

Currently, 32 hours of flying training are required for the issue of a UK NPPL (A), of which 22 hours are to be dual instruction, and 10 hours to be supervised solo flying time.

There are separate general and navigation skills tests.

Theoretical Knowledge Examinations.

The UK NPPL theoretical knowledge syllabus and ground examinations are the same as for the JAA PPL (A). This series of books, therefore, is also suitable for student pilots preparing for the UK NPPL.

THE UNITED KINGDOM FLIGHT RADIOTELEPHONY OPERATOR'S LICENCE.

Although there is a written paper on Radiotelephony Communications in the JAA PPL theoretical knowledge examinations, pilots in the United Kingdom, and in most other countries, who wish to operate airborne radio equipment will need to take a separate practical test for the award of a Flight Radiotelephony Operators Licence (FRTOL). For United Kingdom based students, full details of the FRTOL are contained in LASORS.

NOTES ON CONTENT AND TEXT.

Technical Content.
The technical content of this OAA series of pilot training text books aims to reach the standard required by the theoretical knowledge syllabus of the JAA Private Pilot's Licence (Aeroplanes), (JAA PPL(A)). This is the minimum standard that has been aimed at. The subject content of several of the volumes in the series exceeds PPL standard. However, all questions and their answers, as well as the margin notes, are aimed specifically at the JAA PPL (A) ground examinations.

An indication of the technical level covered by each text book is given on the rear cover and in individual subject prefaces. The books deal predominantly with single piston-engine aeroplane operations.

Questions and Answers.
Questions appear at the end of each chapter in order that readers may test themselves on the individual subtopics of the main subject(s) covered by each book. The questions are of the same format as the questions asked in the JAA PPL (A) theoretical knowledge examinations, as administered by the UK CAA. All questions are multiple-choice, containing four answer options, one of which is the correct answer, with the remaining three options being incorrect "distracters".

Students Working for a Non-JAA PPL.
JAA licence training syllabi follow the basic structure of ICAO-recommended training, so even if the national PPL you are working towards is not issued by a JAA member state, this series of text books should provide virtually all the training material you need. Theoretical knowledge examinations for the JAA PPL are, however, administered nationally, so there will always be country-specific aspects to JAA PPL examinations. 'Air Law' is the most obvious subject where country-specific content is likely to remain; the other subject is 'Navigation', where charts will most probably depict the terrain of the country concerned.

As mentioned elsewhere in this Foreword, this series of books is also suitable for student pilots preparing for the United Kingdom National Private Pilot's Licence (UK NPPL). The theoretical examination syllabus and examinations for the UK NPPL are currently identical to those for the JAA PPL.

Student Helicopter Pilots.
Of the seven book in this series, the following are suitable for student helicopters pilots working towards the JAA PPL (H), the UK NPPL (H) or the equivalent national licence:

Volume 1: 'Air Law & Operational Procedures'; Volume 2: 'Human Performance'; Volume 3: 'Navigation & Radio Aids'; Volume 4: 'Meteorology', and Volume 7: 'Radiotelephony'.

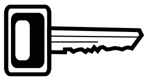
The OAAmedia Website.
If any errors of content are identified in these books, or if there are any JAA PPL (A) theoretical knowledge syllabus changes, Oxford Aviation Academy's aim is to record those changes on the product support pages of the OAAmedia website, at:
www.oaamedia.com

Grammatical Note.

It is standard grammatical convention in the English language, as well as in most other languages of Indo-European origin, that a single person of unspecified gender should be referred to by the appropriate form of the masculine singular pronoun, *he*, *him*, or *his*. This convention has been used throughout this series of books in order to avoid the pitfalls of usage that have crept into some modern works which contain frequent and distracting repetitions of *he or she*, *him or her*, *etc*, or where the ungrammatical use of *they*, and related pronouns, is resorted to. In accordance with the teachings of English grammar, the use, in this series of books, of a masculine pronoun to refer to a single person of unspecified gender does not imply that the person is of the male sex.

Margin Notes.

You will notice that margin notes appear on some pages in these books, identified by one of two icons:

a key  or a set of wings .

The key icon identifies a note which the authors judge to be a key point in the understanding of a subject; the wings identify what the authors judge to be a point of airmanship.

The UK Theoretical Knowledge Examination Papers.

The UK CAA sets examination papers to test JAA PPL (A) theoretical knowledge either as single-subject papers or as papers in which two subjects are combined.

Two examination papers currently cover two subjects each:

- **Aircraft (General) & Principles of Flight**: The 'Aircraft (General) & Principles of Flight' examination paper, as its title suggests, covers 'Principles of Flight' and those subjects which deal with the aeroplane as a machine, 'Airframes', 'Engines', 'Propellers' and 'Instrumentation', which JAR-FCL groups under the title 'Aircraft General Knowledge'.

- **Flight Performance & Planning:** The examination paper entitled 'Flight Performance & Planning' covers both 'Aeroplane Performance, and 'Mass & Balance'.

When preparing for the two examinations named above, using this Oxford series of text books, you will need **Volume 5, 'Principles of Flight'**, which includes 'Aeroplane Performance', and **Volume 6, 'Aeroplanes'**, which includes 'Mass & Balance' as well as 'Airframes', 'Engines', 'Propellers', and 'Instrumentation'. So to prepare for the 'Aircraft (General) & Principles of Flight' examination, you need to take the **'Aeroplanes'** infomation from **Volume 6** and the **'Principles of Flight'** information from **Volume 5**. When you are preparing for the 'Flight Performance & Planning' examination you need to take the **'Aeroplane Performance'** information from **Volume 5** and the **'Mass & Balance'** information from **Volume 6**.

It has been necessary to arrange the books in this way for reasons of space and subject logic. The titles of the rest of the volumes in the series correspond with the titles of the examinations. The situation is summed up for you in the table on the following page:

JAA Theoretical Examination Papers	Corresponding Oxford Book Title
Air Law and Operational Procedures	Volume 1: Air Law
Human Performance and Limitations	Volume 2: Human Performance
Navigation and Radio Aids	Volume 3: Navigation
Meteorology	Volume 4: Meteorology
Aircraft (General) and Principles of Flight	Volume 5: Principles of Flight Volume 6: Aeroplanes
Flight Performance and Planning	Volume 5: Aeroplane Performance Volume 6: Mass and Balance
JAR-FCL Communications (PPL)	Volume 7: Radiotelephony

Regulatory Changes.

Finally, so that you may stay abreast of any changes in the flying and ground training requirements pertaining to pilot licences which may be introduced by your national aviation authority, be sure to consult, from time to time, the relevant publications issued by the authority. In the United Kingdom, the Civil Aviation Publication, LASORS, is worth looking at regularly. It is currently accessible, on-line, on the CAA website at **www.caa.co.uk**.

Oxford,
England

August 2011

TO THE PILOT.

Man first flew in a powered heavier-than-air flying machine in 1903.

Very soon after that date, as aircraft began to fly greater and greater distances from their home airfields, pilots became concerned with the problem of finding their way in the air.

During the First World War, from 1914 to 1918, aeroplanes were used as fighting machines, participating in offensive patrols and bombing missions, operating far into enemy territory, and so the art and science of navigation became an integral part of flying.

After Word War I, the air transport industry was born, and the first intercontinental flights were made by airlines such as Imperial Airways, from Great Britain, and by individual men and women whose names have gone down in history, such as Alcock and Brown, Charles Lindbergh, Amelia Earhart, Amy Johnson and Charles Kingsford-Smith.

World War II saw immense progress in navigational science, especially in the development of radar and radio aids to navigation.

With the expansion of private flying after the Second WW2, navigation skills needed to be learnt by private pilots, who mainly operated light aircraft which lacked the sophisticated instrumentation of military and commercially-operated aircraft. The private pilot's need then was to learn visual navigation techniques based on mentally deduced reckoning (commonly known a mental dead-reckoning or MDR), and backed up by map-reading.

Very soon, however, the development of the transistor, micro-chip and computer, meant that the radio-navigation aids regularly used by professional aviators became available to the private pilot.

Nowadays, most light aircraft, even if entirely club-owned, are fitted with a radio-navigation suite which, forty years ago, would have been the envy of commercial airliners. So, today, VOR, ADF, DME, and ILS radio-navigation systems are fitted to most light aircraft. More recently, these systems have been complemented by Global Navigation Satellite Systems which greatly simplify the pilot's task of finding his way in the air.

Nevertheless, it is still not possible, nor would it be desirable, to gain a private pilot's licence (PPL) without demonstrating adequate knowledge and skill in both the theory and practice of dead-reckoning visual navigation techniques. Consequently, dead-reckoning navigation techniques make up the greater part of the subject of navigation as it is taught and tested for the award of the private pilot's licence all over the world.

One of the primary aims of this book is to teach students mental dead-reckoning visual navigation techniques which will enable them to become competent pilot-navigators and, thus, help prepare them for the practical navigation skills test of the European Aviation Safety Agency (EASA) PPL (A). A further main objective of this book is that students should learn all the theory they need to prepare for the EASA PPL (A).

PREFACE TO GENERAL NAVIGATION

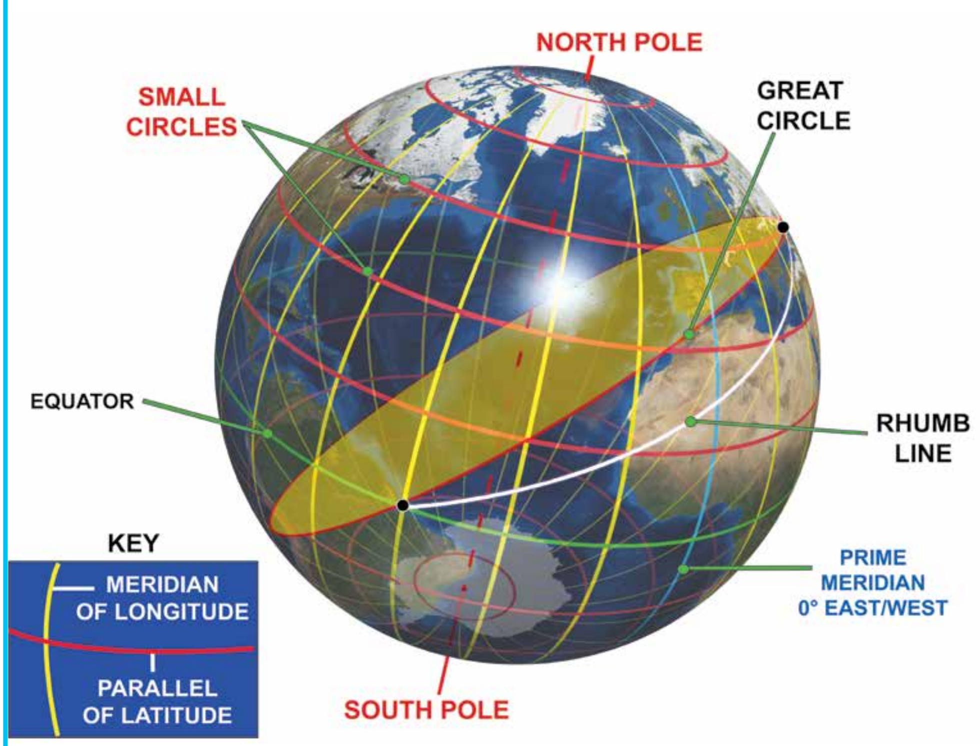
In order to be fully prepared for the PPL theoretical knowledge examinations in Navigation, you will need to know how to use the Dalton-type analogue navigation computer. This instrument is the one you must use during the examination to calculate heading, groundspeed, track error, etc.. There is a chapter in this book devoted to the use of the navigation computer, and also an accompanying CD-ROM which will give you full instruction in all the functions of the instrument.

Despite the emphasis on dead-reckoning visual navigation techniques for the PPL navigation skills test, the use of certain radio-navigation aids is permitted during the test, as a supplement to visual navigation techniques. The subject of Radio Aids is also examined at an elementary level in the PPL theoretical knowledge examinations, the full title of the examination paper being Navigation & Radio Aids.

The subject matter covered in this book meets the syllabus requirements of the Part Flight Crew Licensing (Part-FCL) section of EASA for the PPL theoretical knowledge examinations in the subject of Navigation & Radio Aids.

Students preparing for PPLs issued by organisations other than EASA, primarily examinations set by national aviation authorities, should also find that this book meets their requirements.

CHAPTER 1
FORM OF THE EARTH



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THE EARTH'S ORBIT AND ROTATION.

The Earth orbits the Sun once every year. The plane in which the Earth orbits the Sun is known as the orbital plane. *(See Figure 1.1.)*

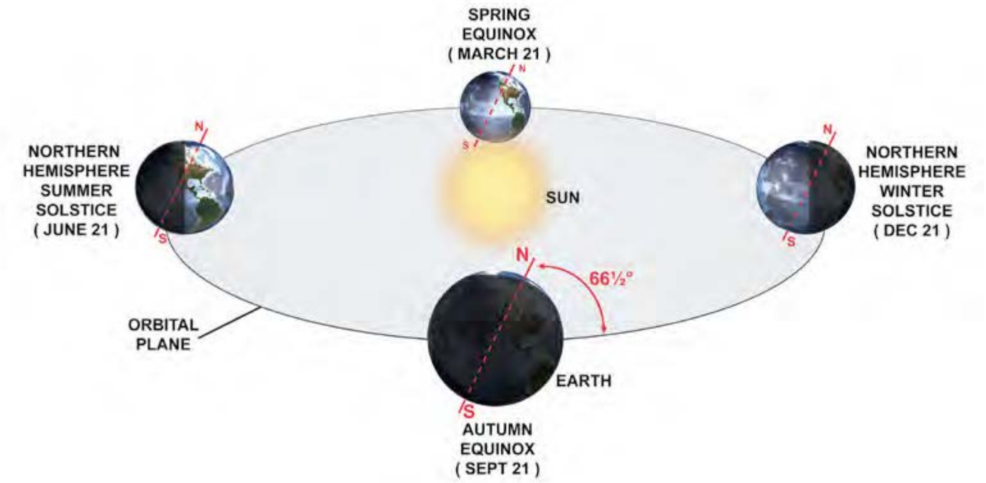

Figure 1.1 The Earth's plane of orbit around the Sun and the Northern Hemisphere seasons.

As well as orbiting the Sun, the Earth spins on its own axis, the extremities of this axis being the North and South Geographical Poles. *(See Figure 1.2.)* The Earth's axis is inclined, or tilted, at an angle of 66½° to the orbital plane, sometimes expressed as being 23½° to a line passing normally through the orbital plane.

The Earth spins on its axis from West to East which explains the phenomena of day and night and why the sun "rises" in the East and "sets" in the West. The inclination of the Earth's axis is the underlying cause of seasonal change, and of the changing time interval between sunrise and sunset throughout the year.

The Earth's spin axis is inclined at an angle of 66½° to the orbital plane. This is the underlying cause of the seasons, and of the changing lengths of daylight and darkness.

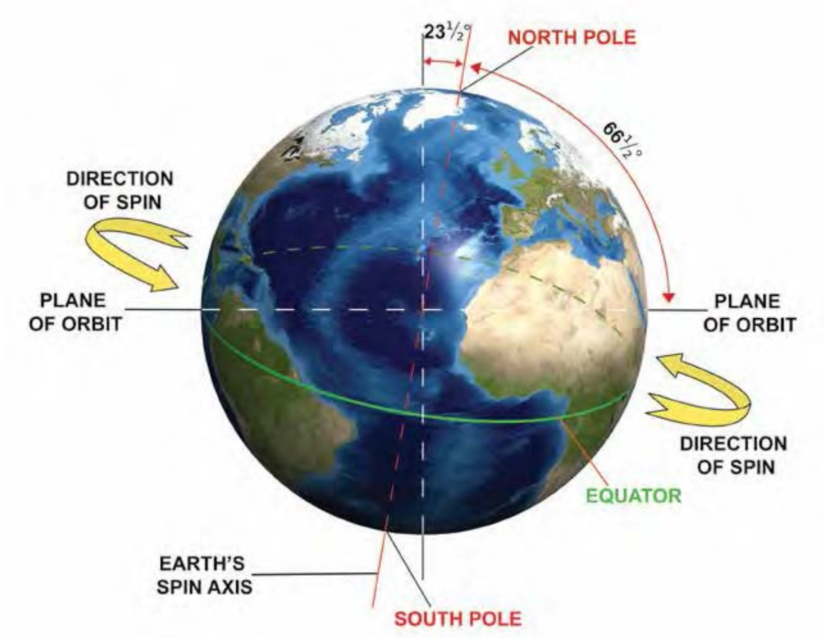

Figure 1.2 Earth's Axis.

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MERIDIANS OF LONGITUDE AND PARALLELS OF LATITUDE.

Meridians of Longitude.

The position of any point on the surface of the Earth is defined using the latitude and longitude system.

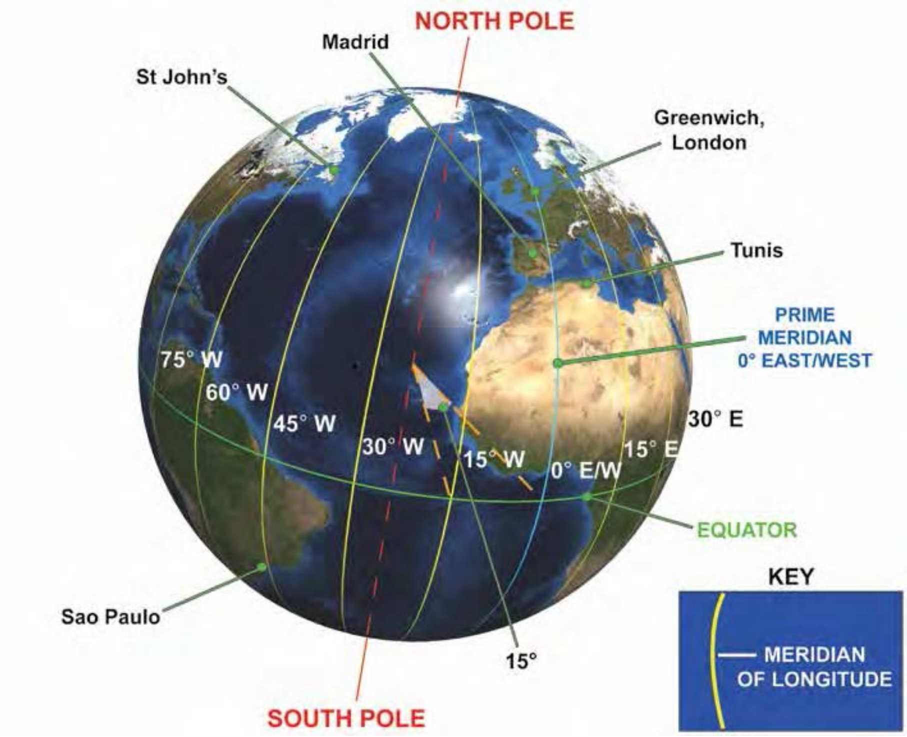

Figure 1.3 Meridians of Longitude.

Longitudes East and West are measured with respect to the Prime Meridian, designated 0° East/West, which passes through Greenwich in London.

Imaginary lines joining the North and South Poles are called meridians of longitude. The meridians of longitude are used to determine position East and West of the Prime Meridian. The Prime Meridian is the meridian passing through Greenwich, in London, England. The Prime Meridian is designated 0° East/West and is the datum used for defining longitude. Meridians of longitude extend to 180º East and 180º West. 180° East and 180° West are one and the same meridian. Tunis lies at just over 10° East (that is, 10° East of the Prime Meridian) and Madrid, is situated at about 4° West.

It is not, however, sufficient to designate the meridians of longitude in whole degrees only, as this would not be precise enough. Because the Earth is of spheroid shape, the distance between, for example, the meridians marking 10º East and 11º East is greater at the Equator, where it is 60 nautical miles, than at the North Pole, where the distance is zero. You can see, therefore, that at the Equator and the mid-latitudes, we need a smaller unit of measurement than the degree if we are to define a particular point on the Earth's surface.

Degrees of Longitude and Latitude are divided into minutes and seconds.

Consequently, each degree is divided into 60 minutes and each minute is divided into 60 seconds.

Minutes are represented by the symbol (') and seconds by the symbol ("). In an atlas, you will find that, measured exactly, Columbus, Ohio, lies at 83°, 1' West.

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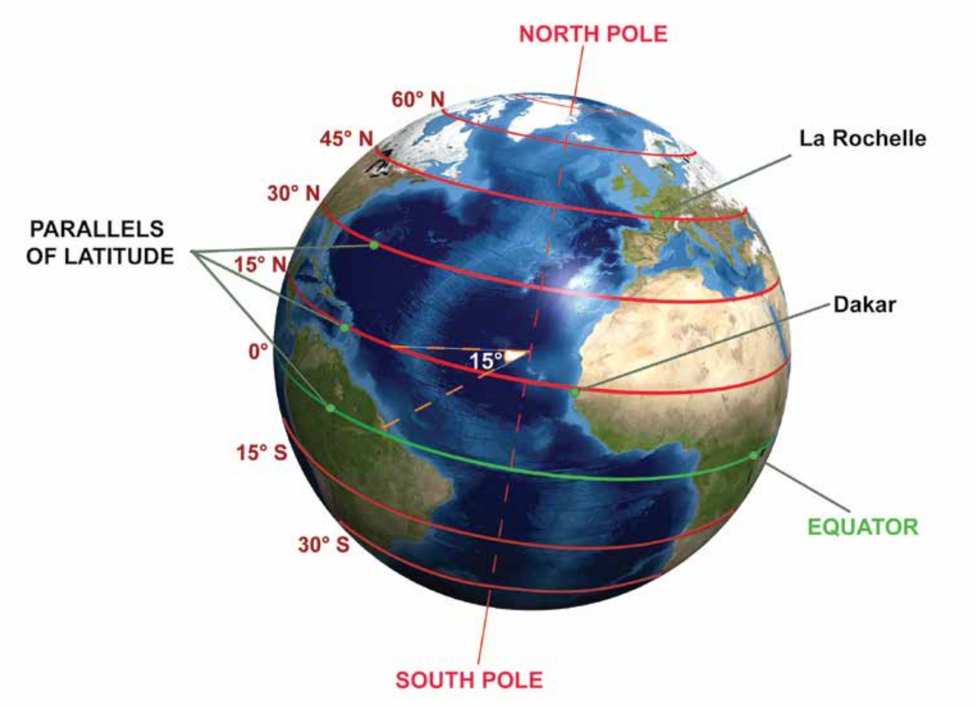

Figure 1.4 Parallels of Latitude.

The Equator is the datum from which latitude North or South is measured.

Parallels of Latitude.

Imaginary east–west lines that are parallel with the Equator are known as parallels of latitude. The Equator is the datum from which latitude North or South is measured. Parallels of latitude extend from the Equator, which is designated 0° North/South, to 90º at the geographical poles.

One minute of latitude is one nautical mile. One degree of latitude is 60 nautical miles.

Because the parallels of latitude are spaced equally between the Equator and the Poles, each degree, minute and second of latitude represents the same distance on the Earth's surface all over the globe: one degree of latitude is 60 nautical miles; one minute of latitude is one nautical mile, and one second represents 34 yards (31 metres). This latter relationship between degrees, minutes and seconds and distances on the Earth's surface also holds true for all distances measured along a great circle.

Dakar, Senegal, lies at 14° 38' North, and La Rochelle, France is situated at 46° 10' North.

Defining the Location of Any Point on Earth.

Using latitude and longitude as the reference, any point on the Earth's surface can be defined. For example, in Figure 1.3, Tunis lies at 36° 47' North, 10° 10' East, and Sao Paulo lies at 23° 52' South, 46° 37' West. Madrid is situated at 40° 23' North, 3° 46' West and St John's, Newfoundland, lies at 47° 37' North, 52° 45' West.

The shortest distance between any two points on the Earth's surface is along a great circle route.

Great Circles.

Any circle on the surface of the Earth whose centre and radius are those of the Earth itself is called a great circle. Such a circle is called great because a disc that cuts through the Earth in the plane of a great circle will have the largest possible circumference that can be obtained. *(See Figure 1.5.)* A line drawn on the surface of the Earth between two points lying on a great circle represents the shortest distance between those two points. All the meridians of longitude are great circles. The Equator is also a great circle.

Small Circles.

Any circle on the surface of the Earth whose centre and radius are not those of the Earth itself is called a small circle. All parallels of latitude, except the Equator, are small circles.

A rhumb line is a line which cuts meridians of longitude and parallels of latitude at the same angle.

Rhumb Line.

A rhumb line is a straight line which cuts the meridians of longitude and parallels of latitude at the same angle everywhere on the surface of the Earth. (*See Figure 1.5.*) An aircraft or ship navigating over the surface of the Earth on a fixed compass heading would be following a rhumb line.

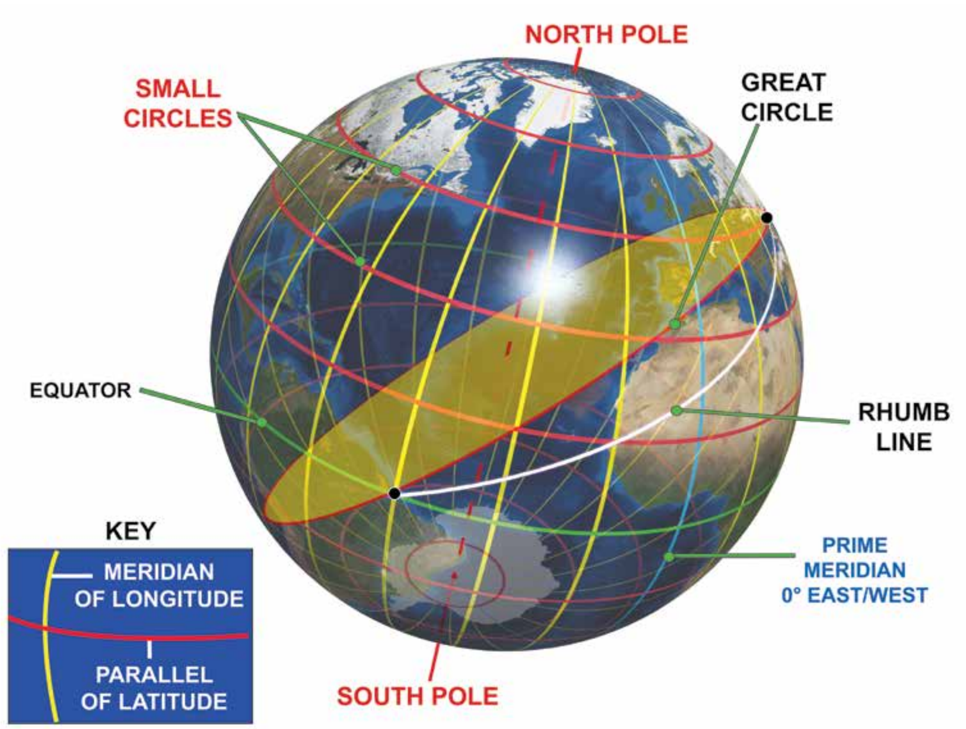

Figure 1.5 A Rhumb Line and a Great Circle.

The details of the Earth's surface cannot be perfectly accurately represented on a flat surface.

THE PROBLEM OF MAKING NAVIGATIONAL CHARTS.

The curved meridians of longitude, parallels of latitude and the Earth's land surfaces, as depicted on the globe, cannot be fully accurately represented on a flat chart, except over quite small areas. Therefore, when the first seafarers began to venture away from sea coasts to set out on long sea voyages, using primitive charts, they found, by following a rhumb line over long distances, that the rhumb line could not be taken as straight. This discovery led eventually to the realisation that the shortest distance between two points on the surface of the Earth is a great circle, and that charts were required on which the straight lines would represent great circles.

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The early seafarers also realised that a method needed to be devised to produce, on a flat surface, a chart on which directions were reliably represented.

Modern 1:500 000 and 1:250 000 aeronautical charts used by general aviation pilots are charts in which angles, bearings and direction are indicated accurately, at the price of some distortion of distance. Over the small distances represented by these charts, however, the inaccuries of distance are negligible.

Modern aeronautical charts represent angles, bearings and direction accurately.

THE EARTH'S HEMISPHERES.

The Earth has four identifiable hemispheres. The most well known ones are the Northern and Southern Hemispheres which lie to the North and South of the Equator. Less well known are the Eastern and Western Hemispheres which lie to the East and West of the Prime Meridian. *(See Figure 1.6.)*

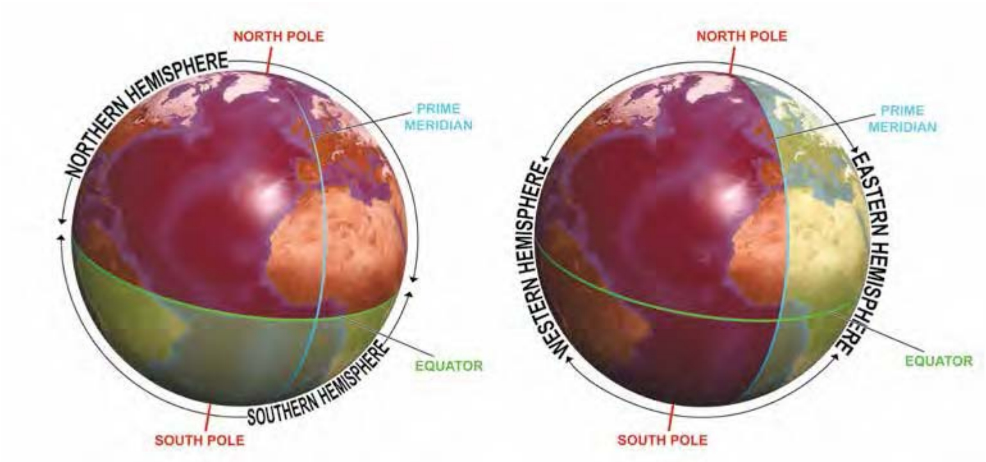

Figure 1.6 Hemispheres on the Earth.

BASIC DIRECTION ON THE EARTH.

Navigators in ancient times found their way on the sea, by reference to the position and apparent motion of the Sun and the stars. Meteorological indications of direction were also used, most notably the directions from which regular and steady winds blew. Sailors distinguished between the cold winds from the North and warm winds from the South. The ancients gave names to 8 principal winds, which were represented as 8 equally spaced points of a wind rose *(the rosa ventorum)*.

North, South, East and West.

The four cardinal points of North, South, East and West were also established several thousand years ago, the great age of these concepts being recognised by the equally great age of the words used to describe them.

East was the name given to the point on the horizon where the Sun rises at the vernal (spring) and winter equinoxes. (The Romans called the East, or morning, '*oriens*', hence our word orient). West (Latin 'occidens'), was the name for the point on the horizon where the sun sets at the equinoxes.

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North and South were determined as directions lying at 90° to East and West, measured by the shadows cast by the noon-day Sun. This first designation of North and South gave man the concept of the Earth's geographical North and South Poles, which mark the two ends of the axis about which the Earth spins.

The Sun, Moon and stars all rise in the East and set in the West. But the stars in the Northern Hemisphere appear to rotate about an apparently fixed star which always lies in the direction of North as viewed from the Earth's surface. This star became known as the Pole Star, and the Earth's North and South Poles were seen to be the markers of the Earth's spin axis.

True North and Magnetic North.

Directions measured with respect to the North Geographical Pole are "true" directions.

"Magnetic" directions, indicated by a compass, are not the same as "true" directions.

In air navigation, direction is expressed in degrees with respect to either True or Magnetic North.

The direction in which the geographical North and South Poles lie later became known as True North, and True South, because, in the 15th Century, it became apparent that North as indicated by a magnetic compass needle, did not point to the "true" North Pole from all locations on the Earth's surface. "Magnetic" North differed from "True" North by a varying number of degrees depending on the observer's location, and the difference became known as "magnetic variation". (See Chapter 3.) It is of the greatest importance in navigation that the difference between true indications and magnetic indications of direction should always be allowed for.

We still use the astronomical concepts of North, South, East and West to indicate direction, though the subdivision of the original, four cardinal points has been much refined. For instance, the midway directions between North (N), East (E), South (S) and West (W) are designated North-East (NE), South-East (SE), South-West (SW), and North-West (NW), known as the ordinal points. There are also further sub divisions such as West North West (WNW) and North North West (NNW), which need not concern us too much here. *(See Figure 1.7.)*

However, in air navigation, instead of referring to direction by using the names of the cardinal points and their sub divisions, bearings, headings or tracks are indicated in degrees with respect to either True or Magnetic North. Compass indication cards are graduated clockwise from 0° (or 360°), which marks North, to 359°.

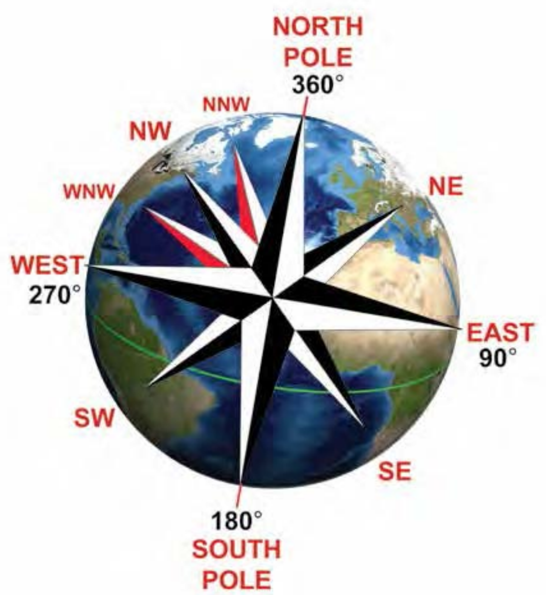

Figure 1.7 The Points of the Compass.

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Dividing by Sixty.

The system of dividing the compass into 360° is known as the sexagesimal system, because it is based on 60. This system was chosen by the navigators and scientists of old, because 60 is a number which makes division easy, being divisible by 2, 3, 4, 5, 6, and 10. If North is defined as 000°, East becomes 090°, South becomes 180°, and West becomes 270°. Continuing the rotation back to North makes North 360° *(see Figure 1.8)*. In practice, the use of 000° or 360° for North is often a personal choice. However, an air traffic controller is likely to refer to North as 360°.

When the datum point for direction, measured in degrees, is the North Geographic Pole, the direction is referred to as true direction. When the datum is the Earth's Magnetic North Pole, (see Chapter 3) direction is referred to as magnetic direction.

Note that a 3-figure group is always used to indicate direction (e.g. 000°, not 0° and 090°, not 90°). The use of 3-figure groups for directions has been adopted to avoid ambiguity, particularly in transmitting messages by Radiotelephony.

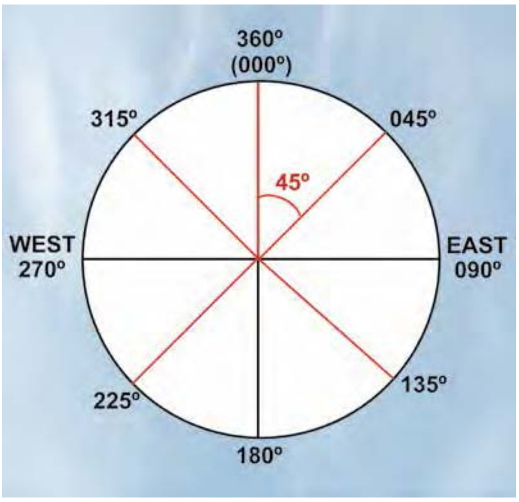

Figure 1.8 Measuring direction by degrees: 0° to 360°.

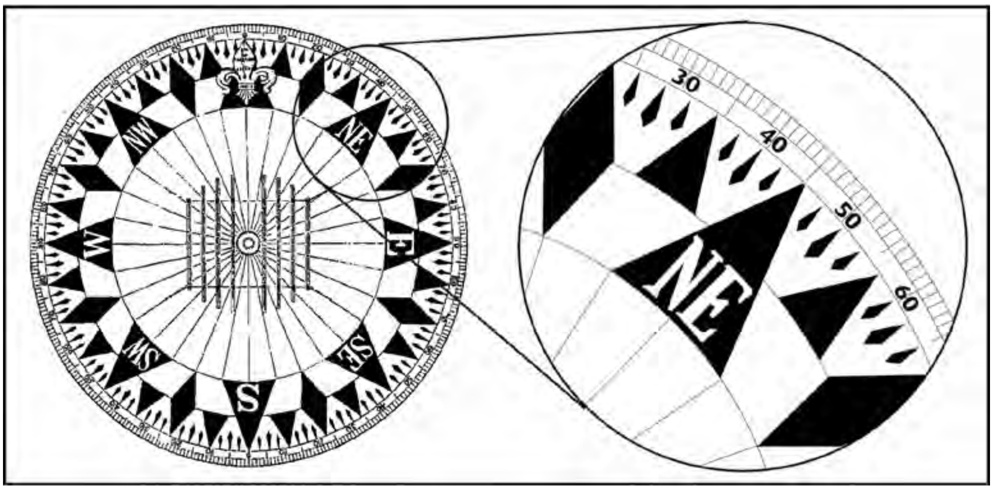

Figure 1.9 A compass rose showing cardinal points, ordinal points and degrees.
(Image by courtesy of Dave Gittins.)

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Representative PPL - type questions to test your theoretical knowledge of the Form of the Earth.

1. What is the angle of inclination of the Earth's orbit to its orbital plane?

   a. 23½°
   b. 66½°
   c. 90°
   d. 33½°

2. The meridian passing through Greenwich is known as?

   a. Main meridian
   b. Equator
   c. Prime meridian
   d. Great meridian

3. A Rhumb line is?

   a. A regularly curved line on the Earth's surface which represents the shortest distance between two points
   b. A line showing True North
   c. A line on the surface of the Earth whose centre and radius are those of the Earth
   d. A regularly curved line on the Earth's surface which cuts all meridians at the same angle

4. What type of line will always be the shortest distance between two points on the Earth?

   a. A Rhumb line
   b. A Great Circle
   c. A Small Circle
   d. A parallel of latitude

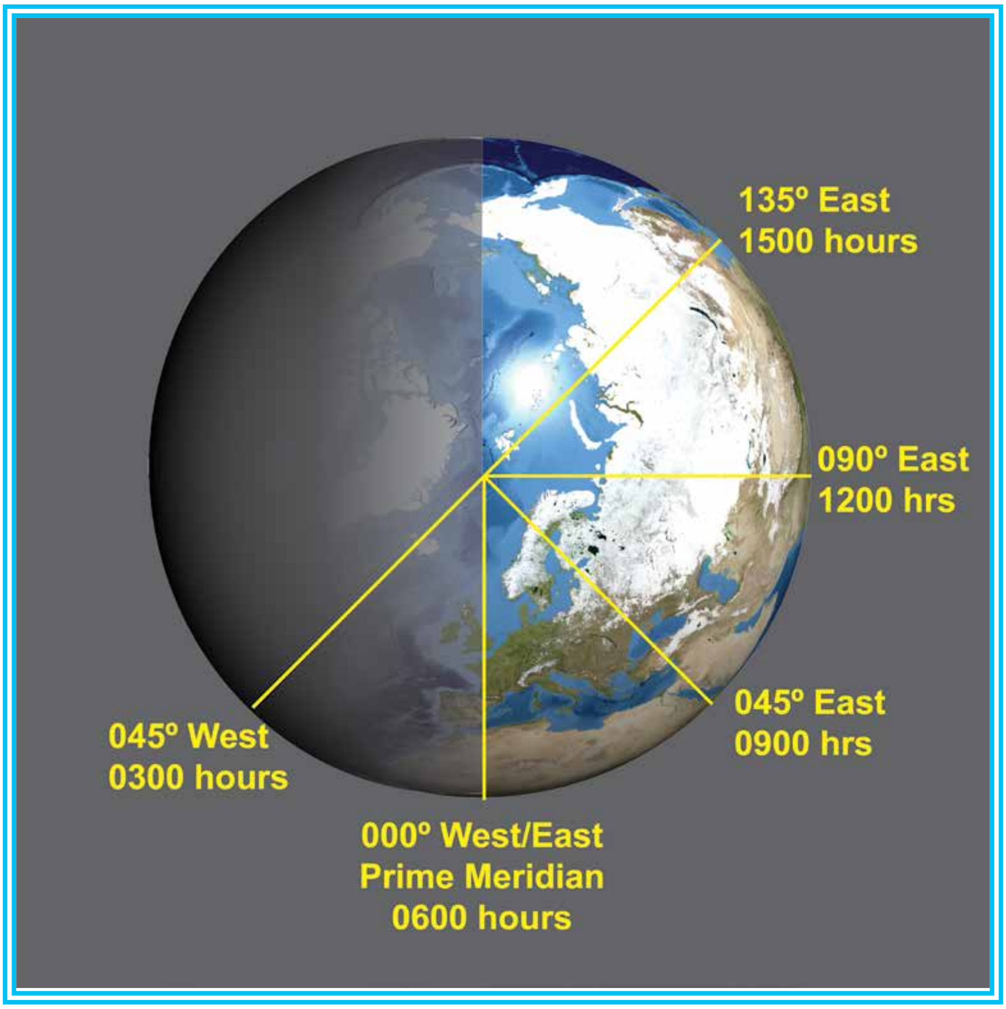
5. What item identifies the difference between True North and Magnetic North?

   a. A Rhumb line
   b. A meridian of Longitude
   c. Degrees magnetic
   d. Magnetic variation

Question	**1**	**2**	**3**	**4**	**5**
Answer					

The answers to these questions can be found at the end of this book.

CHAPTER 2
TIME



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INTRODUCTION.

Timing in flying, as in many activities, is of crucial importance. Therefore, pilots need to have a good understanding of both the nature and measurement of time.

When flying cross country, a pilot must regularly check that his aircraft is on heading, on track, on speed, and that its progress along the desired track is on time. If ground features confirm that an aircraft has covered the planned distance, on track, in the planned time, a pilot knows exactly where he is, and is confident that the forecast wind and his own flying are accurate. This knowledge assures him that his Estimated Time of Arrival (ETA) at destination, or at the next waypoint, will be as predicted, and that he does not need to worry about running short of fuel or running out of daylight.

Even if a pilot arrives early or late at a particular ground fix along his route, if he knows how early or how late he is, he is able to update ETAs, recalculate groundspeed and revise his fuel management, so that the flight can be continued in safety, and future events remain under his control.

In either case, the correct and competent management of time helps the pilot to remain in control of the navigational task.

Correct and competent management of time helps the pilot to remain in control of the navigational task.

An understanding of the nature of time also helps the pilot to appreciate the larger scale passage of time and its consequences.

The times of sunrise and sunset change continuously throughout the year, varying with the changing seasons and with different altitudes. Knowledge and understanding of this phenomenon enable the pilot to plan his flying day and not get caught in the dark, whether by staying airborne too late, or by being fooled that the Sun, still visible at high altitude, might also still be illuminating the Earth's surface beneath him.

The Nature of Time.

Defining the nature of time has been a challenge to philosophers and sages throughout the ages. Does time require space in which it must exist and through which it flows, or can time exist without space? Would time exist anyway, even if there were no material universe? Is the "now" ever present, or does it come into existence only when the time flow reaches it? Such questions show that time can be classified as a philosophy.

This philosophy is of little concern to the air navigator. However, the unstoppable flow of time, by which we are all being carried along, is marked by our clear perception that, with the passage of time, things change. The seasons come and go and man is born, grows old and dies. Change accompanies the flow of time, and regular, cyclic change enables man to measure time, and measuring time is a practical matter with which the pilot navigator is concerned.

Regular and cyclic change enables us to measure time.

A complete rotation of the Earth on its axis gives us the solar day; one orbit of the moon around the Earth takes a lunar month, and a complete revolution of the Earth about the Sun gives us the year. These time periods provide us with natural units of time, which man has used over countless centuries.

Conversely, the time divisions which we call the week, the hour, the minute and the second are man-made time divisions. These divisions, though old, are less ancient.

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In the navigation skills test for the PPL, a candidate must arrive at the destination, or at a waypoint, within 3 minutes of the declared ETA.

For the pilot flying cross-country, it is the hour, the minute and the second which are of importance, more especially the minute.

In the navigation skills test for the PPL, a candidate must arrive at his destination, or at a waypoint, within 3 minutes of the declared ETA.

THE MEASUREMENT OF TIME.

Defining the nature of time is difficult, but measuring time is not. Although there are different systems and zones of time that a pilot must know about, these are not difficult to learn.

The direction of the Earth's rotation causes the Sun, the Moon and the stars to appear to rise in the East and set in the West. The interval of time between two successive apparent passages of the Sun across any meridian of longitude on which an observer is located is the solar day.

The sidereal day is the time interval between two successive apparent passages of a given star across a given meridian. There is a difference of only minutes between a solar day and a sidereal day.

A sundial will indicate solar time, and, as every one knows, although the length of the solar day has for a long lime been divided by man into twenty-four hours, the length of the periods of daylight and darkness change continually as the seasons progress.

The Length of the Day and the Seasons.

The progression of the seasons and the changing duration of the periods of daylight and darkness, in the 24-hour day, result from the tilt of the Earth's axis with respect to its orbital plane, and the Earth's rotation about the Sun. *(See Figure 2.1.)*

The progression of the seasons and the changing duration of the periods of daylight and darkness are caused by the tilt of the Earth's axis and the rotation of the Earth about the Sun.

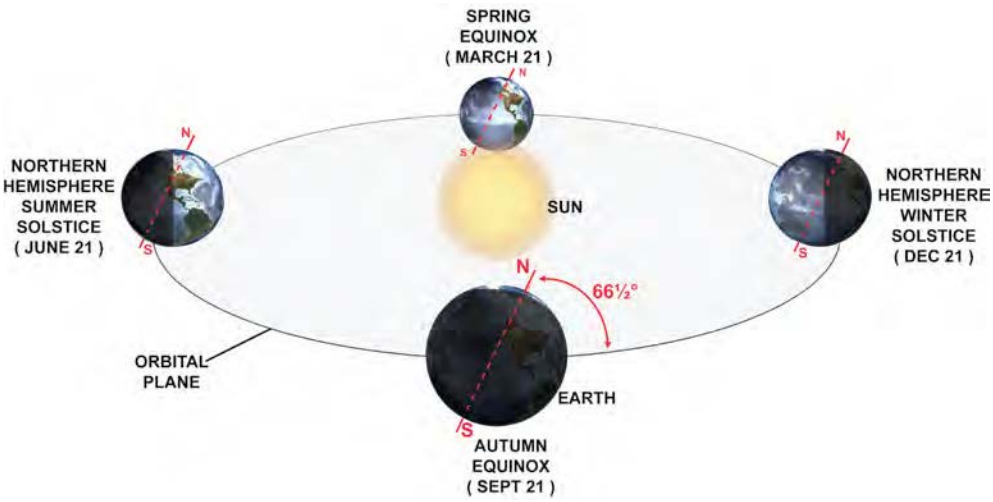

Figure 2.1 The Northern Hemisphere Seasons, and the changing length of daylight and night.

The Earth, which is inclined at 66½° to its orbital plane, rotates about its own axis once in 24 hours to give us our solar day. The Earth also revolves around the Sun once every 365. 2422 days to give us our year. Possessing the characteristics of a

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gyroscope, the Earth's axis always maintains the same orientation (i.e. points in the same direction) in space. On one particular day in its orbit around the Sun, which modern man labels as 21st June, the Earth's North Geographical Pole is tilting directly towards the Sun. In this position, not only is the Northern Hemisphere in midsummer and the Southern Hemisphere in midwinter, but the Northern Hemisphere days are at their longest and the Southern Hemisphere days at their shortest. Six months later the North Geographical Pole is pointing directly away from the Sun; at this point in the Earth's orbit, the Northern Hemisphere is experiencing its shortest day in midwinter while the Southern Hemisphere is in midsummer and experiencing its longest day. Through all the Earth's intermediate orbital positions, seasonal change progresses and the periods of daylight and darkness vary continually in length, with the times of apparent sunrise and sunset changing daily. At the Equator, the length of daylight and darkness is very nearly equal the whole year long, while at 50° North or South the period of daylight varies between 8 hours, in the Winter, and 16 hours in the Summer. At the North and South Poles, the periods of daylight and darkness are each of 6 months' duration.

At the Equator, the length of daylight and darkness is nearly equal, the whole year long. At the North and South Poles, daylight and darkness last 6 months each.

The Calendar, Years and Leap Years.

In order to keep the modern Gregorian calendar in phase with the seasons, (basically to keep the vernal equinox, in the Northern Hemisphere, as close as possible to March 21) each normal calendar year has 365 days, with every fourth year (i.e. every year divisible by 4, called a leap year) having 366 days, the "extra" day being 29th February. Centennial years, such as 1800, 1900, etc., are, however, not leap years, unless they are divisible by 400. So, the year 2000 was a leap year, but the years 1800 and 1900 were not.

In an any given season, the relative lengths of daylight and darkness at a particular location on Earth depend on that

THE TIME OF DAY – MEASURING TIME BY THE CLOCK OR CHRONOMETER.

You may be able to deduce from *Figure 2.1* that, at any moment in the Earth's period of rotation, one half of the Earth is illuminated by the Sun and is in daylight, while the other half of the Earth is in the shadow that we call night. Depending on the season, the relative length of the periods of daylight and darkness at any particular location on the Earth's surface depends on that location's latitude.

Daylight and darkness are, of course, natural phenomena. But man has divided the day into 24 hours, and has subdivided hours into minutes and seconds, which are arbitrary and artificial units of time. Nevertheless, hours, minutes and seconds, measured by clocks and chronometers, regulate our life, and are of immense importance to navigation. We must, therefore, examine "clock time" in some detail.

There are various systems of clock time in use throughout the world that we must look at. But we can begin by stating that local time at any given locality on Earth will depend on longitude.

Local Mean Time.

Local Mean Time at any specified meridian of longitude is referenced to the Sun. If we consider a particular meridian of longitude (it does not matter which one we chose), when the Sun crosses that particular meridian, all places on that meridian have the time 1200: that is, midday or noon, while the local mean time on the meridian displaced by 180° to the meridian that we are considering (its antipodal point) has the time 2400: that is, midnight. Meridians of longitude to the East of our meridian

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The Local Mean Time at any given locality on Earth depends on that locality's longitude.

Local Mean Time advances by 4 minutes per degree of longitude, counting eastwards, and regresses by 4 minutes per degree of longitude, counting westwards.

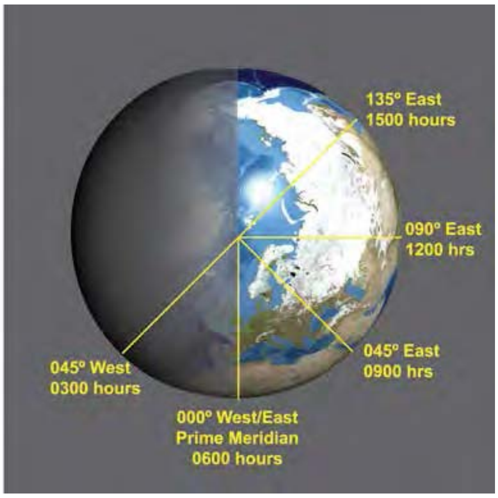

Figure 2.2 Time of day - the Earth viewed from the North Pole at one of the equinoxes.

will already have a local mean time later than noon, and meridians to the West of our meridian will have a local mean time earlier than noon. *(See Figure 2.2.)*

Local mean time, then, depends on longitude. As there are 24 hours in a day, and the Earth, in one rotation, turns through 360°, local mean time advances by four minutes per degree of longitude, counting eastwards, and regresses by four minutes per degree of longitude counting westwards. (24 x 60 = 1440 minutes ÷ 360 = 4).

Every meridian of longitude, then, has a different local mean time. For example, in the United Kingdom, Birmingham lies approximately on the 2° West meridian, and Swansea is on the 4° West meridian. When the Sun transits the 2° West meridian, the local mean time at Birmingham is 12 o'clock midday; at the same moment, the local mean time in Swansea, 2° further West, is behind that of Birmingham by 8 minutes (2° x 4 minutes), making Swansea's local mean time 11:52, or eight minutes to midday.

Time Zones and Standard Time.

It may seem obvious to us, nowadays, that local mean time is not at all convenient for a nation to work to. Having different times in Swansea and Birmingham would make it extremely difficult for government and commerce to regulate their affairs. Nevertheless, before the advent of the railways, local time was computed in that way. 12 o'clock noon was the moment when the Sun was at the highest point in the sky that it would reach according to the season (its zenith), wherever a person happened to be.

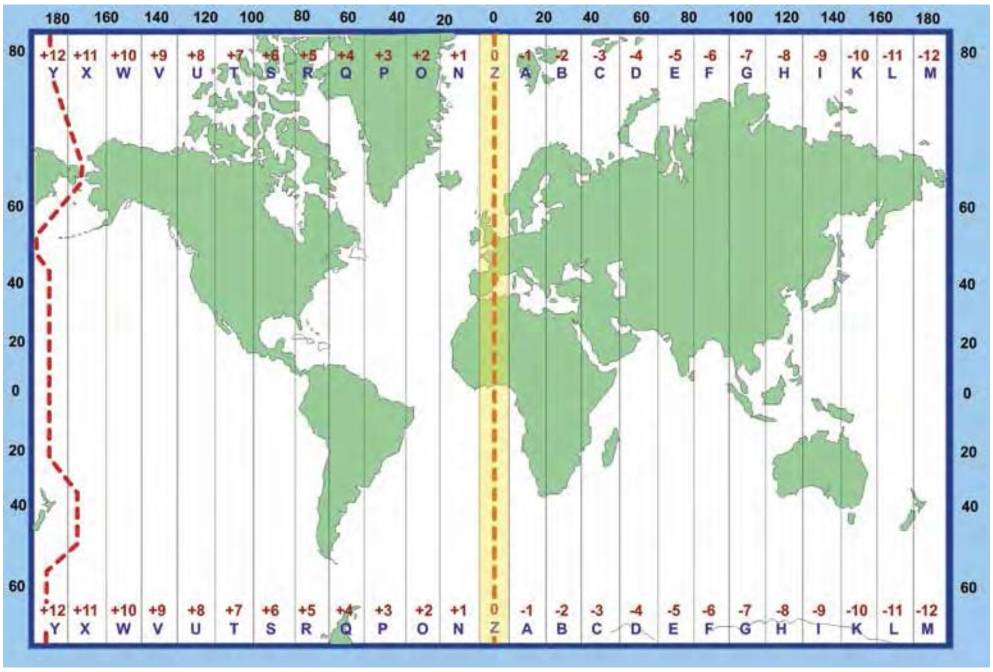

Figure 2.3 Time Zones

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This situation changed in 1878 when, by international agreement, the Earth was divided into time zones, *see Figure 2.3*, within which all localities had the same local time, which was designated the standard time for that zone, thus enabling large regions of the world, most often including complete nations, to work to the same standard time. There are 24 time zones each centred on meridians of longitude spaced at 15° intervals, 15° being the angle which subtends the longitudinal arc that the Sun appears to trace out in one hour.

All localities within a given time zone have the same local time which is designated "standard time".

A few years later, in 1884, again by international agreement, the meridian of longitude passing through the Royal Observatory in Greenwich, London, was designated the prime or zero meridian. (The red numbers in *Figure 2.3* are corrections to apply to local time to obtain GMT/UTC).

The Earth's 24 time zones are centred on meridians of longitude spaced at 15° intervals, 15° being the angle which subtends the longitudinal arc through which the Sun appears to move in one hour.

Seven and a half degrees either side of the Greenwich Meridian (7½° West to 7½° East) was designated as a given time zone, and the other 23 time zones were set out after that pattern. The standard time in the time zones to the East of Greenwich is <u>ahead</u> of Greenwich by one hour for every 15° of longitude, and standard time in zones to the West of Greenwich is <u>behind</u> Greenwich by one hour for every 15° of longitude.

Time zones to the East of Greenwich are <u>ahead</u> if Greenwich by one hour for every 15° of longitude. Time Zones, to the West of Greenwich are <u>behind</u> Greenwich by one hour for every 15° of longitude.

The time difference between the various time zones is, therefore, a whole number of hours. Minutes and seconds within all zones are the same. For instance, when the standard time is 6:45 in the afternoon in Sofia, Bulgaria, the standard time in London, England is 4:45 in the afternoon.However, as you can see from the map of European Time Zones at *Figure 2.4*, *below*, the exact boundaries of time zones are set by governments to make allowance for national borders and physical geography. The boundary lines of time zones, therefore, sometimes deviate considerably from the line of the meridian of longitude on which the time zone is based.

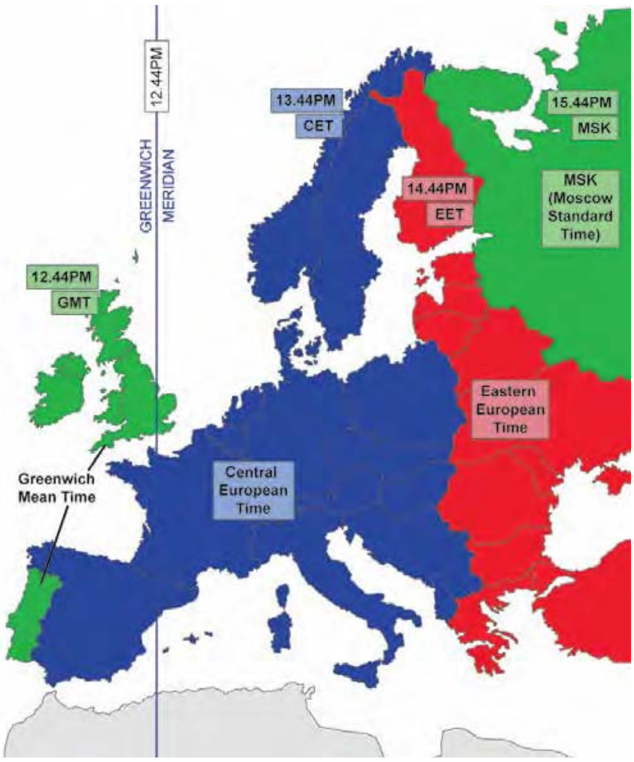

Figure 2.4 European Time Zones

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In the United Kingdom, the standard time throughout the year is Greenwich Mean Time (GMT), though the UK does also shift to British Summer Time from March to October. GMT has now been superseded by Coordinated, Universal Time (UTC), which, however, is, as near as makes no difference, the same as GMT.

The borders of nations whose territory covers extensive areas of the Earth's surface encompass several time zones. The continental United States of America cover four time zones, each having its own standard time: Eastern Time, Central Time, Mountain Time and Pacific Time. *(See Figure 2.5.)*

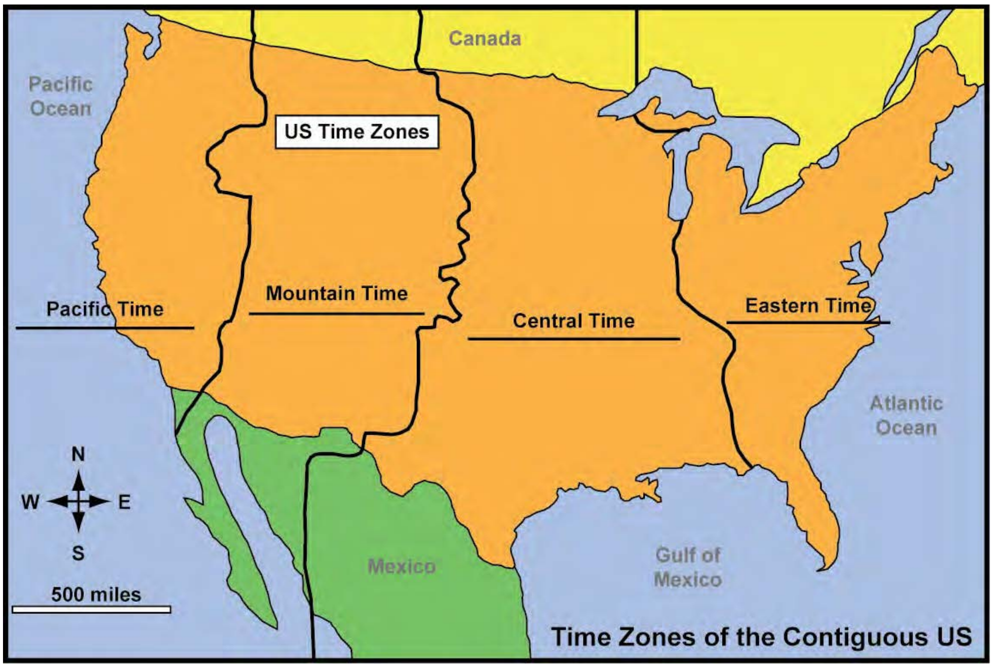
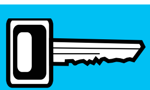


Figure 2.5 Time Zones of the Continental U.S.A.

The International Date Line.



The International Date Line in the mid-Pacific Ocean separates two consecutive calendar days in a practical way.

The 180° East meridian, in the mid-Pacific Ocean, is the same meridian as 180° West. This is the meridian across which one day changes to another. In order that the Earth's inhabitants may live with this change-over of days, an imaginary line called the International Date Line is considered as existing on and around the 180° meridian. The International Date Line, then, is a crooked line (so that it does not cut through inhabited areas) in the mid-Pacific Ocean which separates two consecutive calendar days *(see Figure 2.6)*.

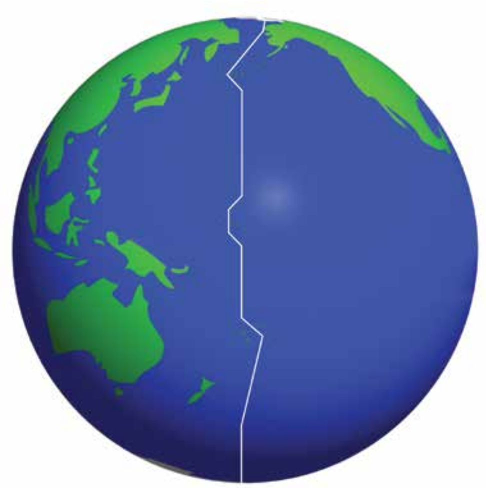


Figure 2.6 The International Date Line.

Immediately to the West of the International Date Line, the date is always one day ahead of the date (or day) immediately to the East of the International Date Line. So at 1000 hours local mean time, exactly on the date line, the local mean time of a location 1° to the East would be 1004

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on say, Monday 22nd April, while at a location 1° to the West of the date line, the local mean time would be 0956 on Tuesday 23rd April.

In the above situation, for a traveller moving westwards across the International Date Line a day is lost, in the sense that he moves immediately from 1000 hours Monday 22nd April to 1000 hours Tuesday 23rd April (so he apparently loses a day in time), while a traveller moving eastwards across the the date line moves immediately from 1000 hours, Tuesday 23rd April to 1000 hours, Monday 22nd April, thereby gaining a day (that is, he apparently “wins” a day by apparently moving backwards in time).

This phenomenon was very important to the story ‘Around the World in Eighty Days.’ In Jules Verne’s, book the travellers journeyed in an easterly direction without realising its significance. Thus, they thought at the end of their journey that they had missed the eighty-day deadline by one day, and had lost their bet. But they had not taken into account the fact that they had experienced one sunrise more than the people who had stayed at home, and, eventually, realising their mistake, they were able to claim their winnings, after all.

In travelling westwards across the International Date Line, a day is lost. In travelling eastwards, a day is gained.

Greenwich Mean Time (Zulu Time).

In the 19th Century, local mean time at Greenwich was chosen as the world’s standard time, referred to as Greenwich Mean Time (GMT), and GMT became the standard by which the clocks were set to local mean time in all other time zones.

In the mid 20th Century each time zone came to be identified by a letter of the alphabet. Z (Zulu) was allocated to the zone containing the prime meridian; the letters A to M (with the exception of J) were allocated to time zones running East of the prime meridian to the 180° meridian, and the letters N to Y to the zones running West, M & Y sharing the zone straddling the International Date Line. (*See Figure 2.3.)*

The allocation of identifying letters to the time zones led to local time in the respective zones being identified by the appropriate letter of the Phonetic Alphabet. Hence the use of “Zulu” to refer to GMT.

The 24-hour Clock and the 12-hour Clock.

By internationally agreed convention, the day begins at midnight and is of 24 hours duration. There are two basic systems for measuring time by the clock: the 24-hour system and the 12-hour system.

In the 24-hour system, hours and minutes are given as a four-digit number. Thus 0018 means eighteen minutes past midnight, and 1218 means eighteen minutes past noon. 2400 hours on 22 April is the same as 0000 hours on 23 April. 0750 is ten minutes to eight in the morning and 1950 is ten minutes to eight in the evening.

In the 12-hour system, the day is divided into two sets of 12 hours, those from midnight to noon, designated am (ante meridiem = before noon), and those from noon to midnight designated pm (post meridiem = after noon). To designate midnight, either the word midnight is used alone, or the expression 12 midnight (12 o’clock midnight). To designate midday, the expressions midday, noon, 12 noon may be used. The 12-hour system is the system which tends to be more popular for everyday use, but the 24 hour system is used in aviation.

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The atomic time scale by which Coordinated Universal Time (UTC) is measured, is approximately that of the former Greenwich Mean Time. UTC is still often referred to as GMT, or Zulu time, because of the Phonetic Alphabet letter used to label the time zone referenced to Greenwich.

Coordinated Universal Time.

Greenwich Mean Time (GMT), the local mean time at the prime meridian, Greenwich, and referenced to the rotation of the Earth, was the world's standard time until 1928. In 1929, the term Universal Time was adopted to refer to GMT. Until the 1950s, broadcast time signals throughout the world were based on Universal Time.

By the 1960s, the system of Universal Time (UT) had evolved by rather a tortuous route into a world-wide system known as Coordinated Universal Time (UTC). UTC is an atomic time standard with uniform seconds and so-called leap seconds incorporated at irregular intervals into the length of the UTC year to compensate for the slowing rotation of the Earth.

UTC couples GMT, which is based solely on the Earth's inconsistent rotation rate, with high-precision atomic time, UTC, like GMT, being set at the prime meridian. When the difference between Earth time and atomic time approaches one second, a leap second is calculated into UTC.

UTC's atomic time scale, then, is approximately that of the former GMT, and, UTC is still often popularly referred to as GMT. The local mean times of time zones around the world are expressed as being in front of or behind UTC in the same way as they used to be expressed with reference to GMT.

Like GMT before it, UTC is often also referred to as Zulu time.

In aviation, all communications refer to UTC, and, consequently, it is important for a pilot to be able to convert from UTC to the local mean time or standard time of wherever he happens to be flying.

Date-Time Groups.

Meteorological services and civil aviation authorities often disseminate time information for flight planning purposes in the form of a six-figure date-time group, e.g. **270650**. In this date-time group, **27** refers to the day of the month, in this instance, the 27th of the month, and the following four figures, **0650**, represent the time in UTC, in this instance six-fifty or ten to seven, am. Notice that, in the six-figure date-time group, the month and the year are not mentioned.

A pilot consulting a METAR issued on 8th February 2007 at a quarter past four, pm, for Birmingham Airport, Elmdon, England might see the first few codes expressed as:

METAR EGBB 081615Z 03014G20KT.......

081615Z is the six-figure date-time group for the date and time just cited. The **Z** confirms that the time is expressed in UTC; *(see above)*. As GMT is used in the **United Kingdom** in February, British Standard Time and UTC are the same.

If, however, the **METAR** had been for Birmingham, Alabama, USA, and had read: **METAR KBHM 152353Z 20009KT**, the local standard time in Alabama (Central Standard Time) would have been six hours behind the UTC time of 2353, at 1753 local, 17: 53 pm , or seven minutes to six in the afternoon.

Sometimes, the date-time group may include the month, in which case eight figures would be used, for example: **02081615Z**.

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Sunset and Sunrise.

Sunrise and sunset at a particular location on Earth are generally defined as the times when the upper edge of the disc of the Sun is on the unobstructed horizon. Atmospheric conditions are assumed to be average, and the location assumed to be a level region on the Earth's surface.

As you learnt earlier in the chapter, the tilt of the Earth's axis relative to its orbital plane about the sun is not only the cause of seasonal change through the course of a year, but also the reason why there is continual change from day to day in the length of the periods of daylight and darkness. In other words, the tilt of the Earth's axis is the reason why sunrise and sunset occur not only at different times each day for a given location on Earth, but also at different points on the horizon.

The nature and the timing of the variation in sunrise and sunset constitute crucial knowledge for a general aviation pilot, most especially for a pilot who does not possess either an Instrument Rating or a Night Qualification. When planning a flight, a basically qualified general aviation pilot must not, in the United Kingdom, get airborne until half an hour before sunrise, and he must be on the ground by half an hour after sunset.

In the United Kingdom, night is defined as lasting from half an hour after sunset to half an hour before sunrise.

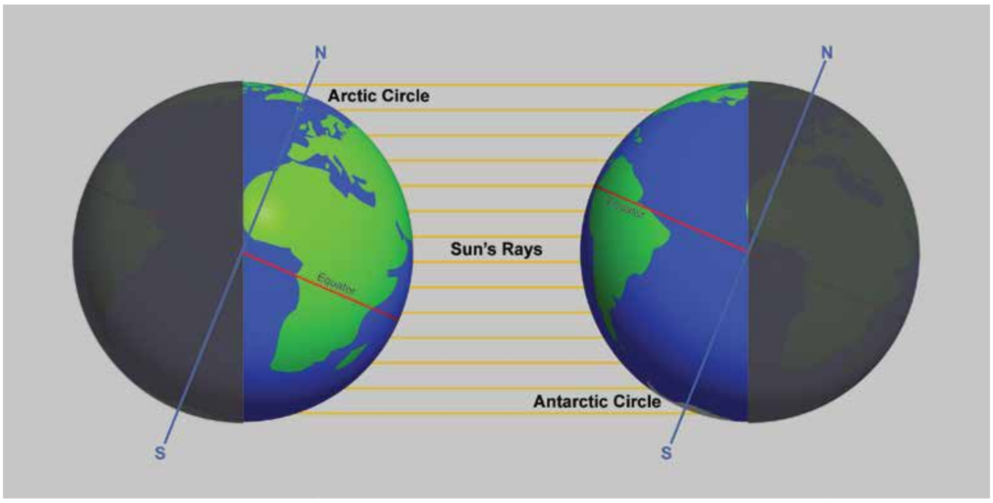

Figure 2.7 Summer and Winter in the Northern and Southern hemispheres.

The left hand globe in *Figure 2.7, above,* illustrates that in Summer in the Northern Hemisphere, when the North Pole is tilted towards the Sun, the days are longer in the Northern Hemisphere than in the Southern Hemisphere, which is experiencing Winter, the South Pole being tilted away from the Sun.

In *Figure 2.7,* the days can be seen to be longer in the Northern Hemisphere during the northern summer by the fact that a smaller area of the Earth, North of the Equator, is in shadow. It should also be clear, that in the northern summer, at the very high latitudes, the Sun is always visible above the horizon, and that there is no night in those latitudes.

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In the northern summer, around 21 June, near the North Pole, the passage of the Sun across the horizon would appear something like the illustration in *Figure 2.8.*

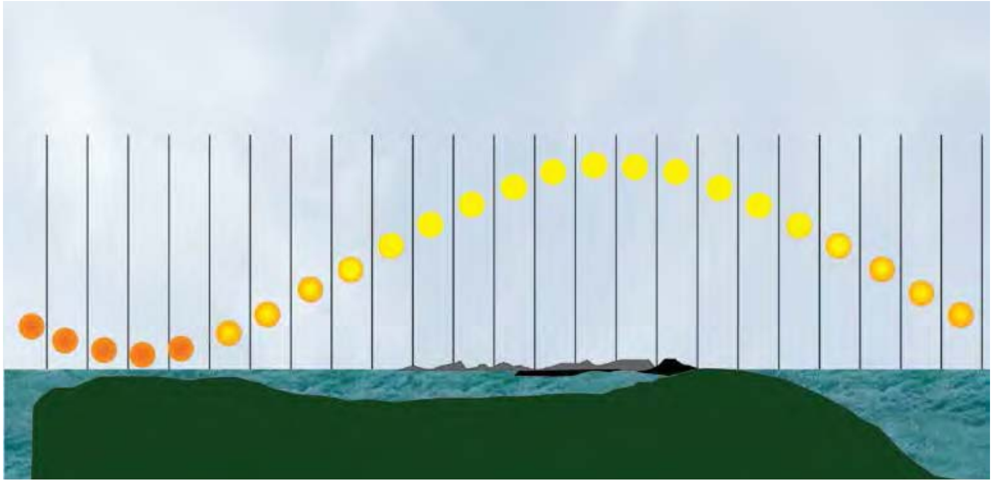

Figure 2.8 Mid-summer near the North Pole. The passage of the Sun across the sky in a 24 hour period.

At a slightly lower latitudes than the North Pole, the passage of the Sun across the horizon, at the height of the northern summer, might look like that shown in *Figure 2.9*, where night lasts for a very short period.

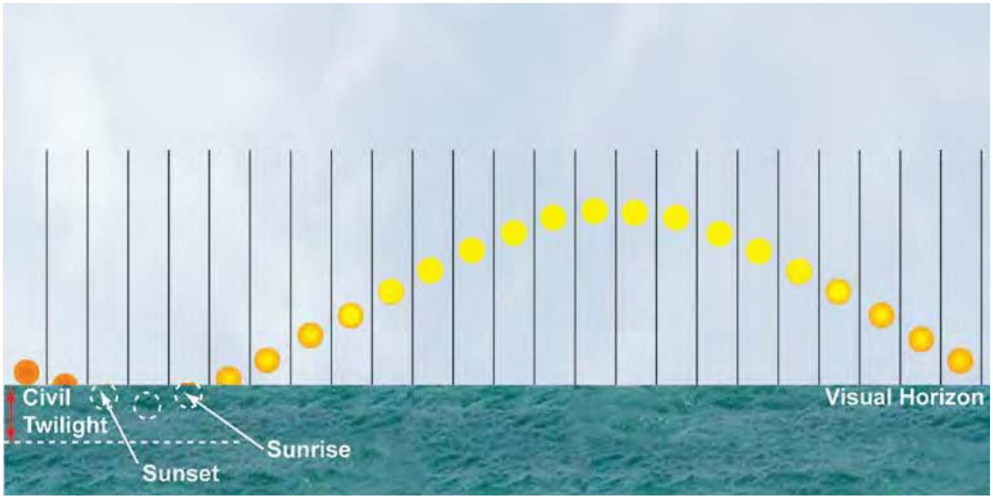

Figure 2.9 Mid-summer at slightly lower latitudes, but still in the far North. Night lasts for only a very short period.

You should note that, exactly at the geographical poles, the Sun sets once a year only.

In the northern summer, it is, of course, winter in the Southern Hemisphere and, as you can see from the left-hand globe in *Figure 2.7*, the South Pole is experiencing darkness which will last for 6 months.

Six months later, the situation is reversed with the South Pole experiencing a six-month long period of daylight, in the southern summer, and the North Pole plunged into a six month night, as depicted in the right hand globe in *Figure 2.7.*

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How the Time of Sunrise and Sunset Varies.

In contrast to the situation at the geographical poles, daylight and darkness are always of approximately the same duration at the Equator, lasting about 12 hours each. The further one moves from the Equator towards the poles, the greater is the difference between the duration of daylight and darkness. At the poles, as you have already learned, the difference between the length of day and night is the greatest. At the poles, in summer, the Sun does not set, and there is no night, and, in winter, the Sun does not rise, and there is no daylight; daylight and darkness may be said to last 6 months each.

When it is summer in the Northern Hemisphere, then, moving southwards from the North Pole we see that, considering periods of 24 hours, we are passing from 24 hours of continuous daylight, where the Sun does not set, into regions where the Sun rises ever later and sets ever earlier with the period of daylight became shorter and shorter until at the South Pole the Sun does not rise at all and we have 24 hours of continuous darkness. As you have already learnt, this phenomenon of varying lengths of daylight and darkness is explained by the tilt of the Earth's axis. If the Earth's axis were perpendicular to its orbital plane about the Sun, the Sun would always rise at 0600 Local Mean Time (LMT) and always set at 1800 LMT.

But because the Earth's axis is tilted at 66½° to its orbital plane, the length of daylight and darkness varies with latitude. At any given moment, a meridian of longitude has the same local mean time along its whole length, from pole to pole, but, on a given day along that meridian, sunrise and sunset will occur at different times in any given location, depending on the latitude of that location. In other words, local mean time is the same at all locations situated on a given meridian of longitude, but the Sun rises and sets at different local mean times along that meridian depending on the parallel of latitude.

Local Mean Time is the same at all locations situated on a given meridian of longitude, but the Sun rises and sets at different Local Mean Times along that meridian, depending on latitude.

On any specified day of the year, the Sun will, however, rise and set at the same local mean time at all locations of the same elevation on a given parallel of latitude, the duration of daylight being tied to the maximum elevation that the Sun achieves in the sky.

On any given parallel of latitude, and on any specified day of the year, the Sun will always rise and set at the same Local Mean Time at locations of the same elevation.

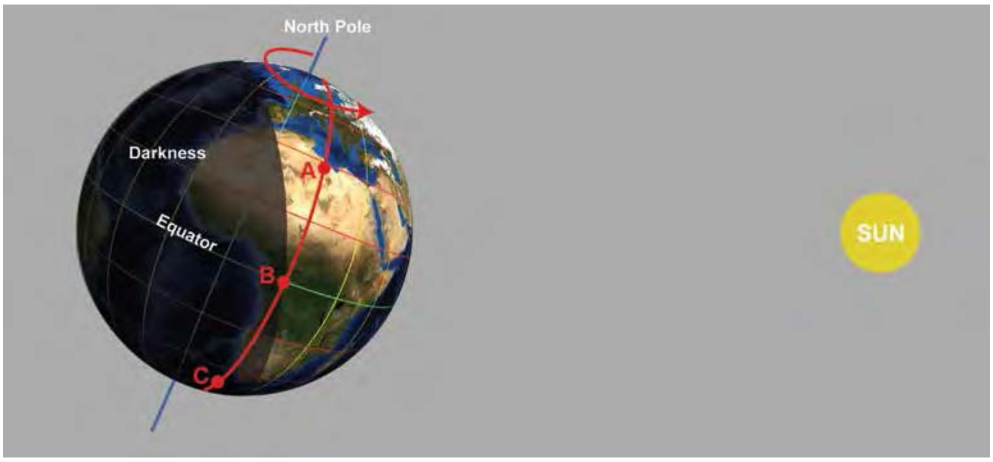

Figure 2.10 On any given date, the relative duration of daylight and darkness depends on the latitude.

Figure 2.10 depicts the Earth in a Northern Hemisphere summer and shows three locations: A, B and C, situated on different parallels of latitude along a given meridian of longitude, about 20° East.

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All three locations will have the same local mean time. As *Figure 2.10* shows, as the Sun rises at location **B**, on the Equator, at location **A**, at approximately 30° North, the Sun has already risen and **A** has been in daylight for over an hour, while at location **C**, at about 30° South, the Sun has not yet risen, that location still lying in the darkness of the Earth's shadow.

On a given day, then, the times of sunrise and sunset at a particular spot on Earth are a function of that location's latitude.

And, as you have already learnt, at a given latitude, the hours of sunrise and sunset vary with seasonal change. The position of the sunrise and sunset on the horizon will also vary with the seasons. For instance, as the seasons progress, because of the Earth's axial tilt, sunrise in the Northern Hemisphere occurs in the northeast quadrant from the March (vernal) equinox to the September (autumn) equinox, and in the southeast quadrant from the September equinox to the March equinox. In the southern counties of the United Kingdom, around 52° North, the elevation of the Sun changes by about 50° between midwinter and midsummer.

Twilight.

Before sunrise, there is a short period lasting about half an hour during which it becomes light, and, after sunset, there is a short period of similar duration during which it remains light before darkness sets in. These two periods are called, respectively, morning and evening twilight. Although the Sun is below the horizon, the refraction of the Sun's rays by the atmosphere gives rise to twilight.

The period of twilight between sunset, and the moment when the centre of the Sun's disc is 6° below the horizon is called evening civil twilight, and the period, in the morning, from the moment when the centre of the Sun's disc is 6° below the horizon to sunrise, is called morning civil twilight.

The International Civil Aviation Organisation's (ICAO) definition of night is the period from the end of evening civil twilight to the beginning of morning civil twilight. During civil twilight, if the sky is not too cloudy and there is no high ground to the East or West, natural illumination is good enough for daylight tasks to be carried out without artificial lighting. For instance, it should be possible to fly a safe visual approach to an unlit runway during civil twilight.

The ICAO definition of night is: "the period between the end of evening civil twilight and the beginning of morning civil twilight, or such other period between sunset and sunrise as may be described by the appropriate authority. Note that the UK CAA definition of night is different from ICAO's.

You should note that the actual wording of the ICAO definition of night is: "the period between the end of evening civil twilight and the beginning of morning civil twilight, or such other period between sunset and sunrise as may be described by the appropriate authority". The United Kingdom has registered a difference with ICAO over the definition of night and, in the United Kingdom, the Air Navigation Order defines night lasting from half an hour after sunset to half an hour before sunrise. VFR flight in the United Kingdom is not permitted during those hours.

VFR Flight in the United Kingdom is not permitted at night.

When planning a flight, it would be very unwise for a pilot without an Instrument Rating or Night Qualification to plan to land at sunset + 30 minutes, as there would exist absolutely no margin for error in the timing of the flight. And if the sky were overcast, or visibility otherwise poor, darkness may have descended before the onset of "official" night. Planning for this possibility, especially on long navigation flights, is good airmanship.

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Standard Time and Daylight Saving Time.

In mid latitudes, or temperate regions, both north and south of the equator, there is great variation in the amount of daylight and darkness as the seasons progress. In order, therefore, that the most effective use can be made of the hours of daylight in summer time, nations in the mid latitudes often adjust the local standard time forwards by one hour during the spring, summer and early autumn months. By doing this, there are fewer hours of darkness in the period when most inhabitants are awake.

The adjustment of the local standard time forwards by one hour is called summer time, or daylight saving time. As we mention above, British Summer Time lasts from March to October. Central European Summer Time is of similar duration.

Natural and Man-made Divisions of Time.

The year, the lunar month, and the day are natural divisions of time, though, as you have learnt, the year does not consist of whole days. Therefore, synchronising the days, and, thus, our calendar, with the seasons, was only really effectively solved by the introduction of the Gregorian Calendar in the 16^{th} Century.

The calendar months, the week, the hour, the minute and the second are artificial man-made divisions of time. A chronometer measuring hours, minutes and seconds is, however, one of the most essential tools of the pilot navigator. So, where do hours, minutes and seconds come from?

The Egyptians are thought to be the first people to have divided the day up into sub-units which they marked onto shadow clocks as early as 1300 BC. The day was divided up by the Egyptians into ten divisions of daylight, from sunrise to sunset, two divisions of twilight and twelve divisions of night. This, then, was the origin of the 24-hour day. No one knows why this division was based on twelve, but twelve is about the number of cycles of the Moon in a year (a year contains 12.4 lunar months), so twelve may have been a number of special significance to the ancients.

Between about 300 and 100 BC, the Babylonians were carrying out astronomical calculations using the sexagesimal (base-60) system. The sexagesimal system was extremely convenient for simplifying division, because 60 is divisible by 2, 3, 4, 5, 6, and 10.

The first-level sexagesimal division of the hour was what, in English, is now called a minute, and the second-level sexagesimal division was what we now call a second.

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Time and Dead Reckoning Navigation.

As we defined at the beginning of this book, the pilot-navigator is concerned with finding his way to a destination or turning point by determining the heading to fly in order follow a desired track. The pilot-navigator determines his progress along that track by assessing groundspeed, and, after flying for a given time, using the calculated distance flown to update his position.

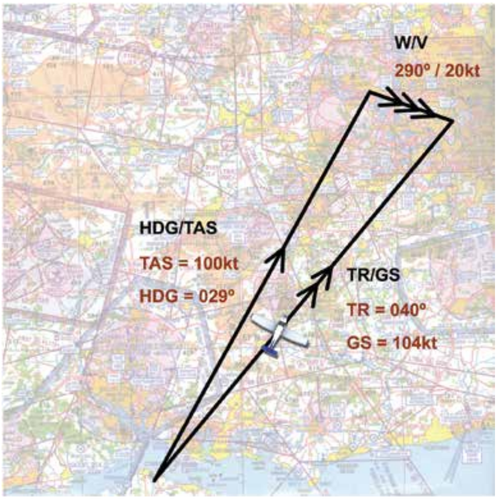

Figure 2.11 Triangle of Velocities.

In dead reckoning navigation, a pilot determines his present position from an accurately logged history of heading, speed and time. If, after the passage of a given amount of time, at the assumed ground speed, the calculated position is not confirmed by a ground feature, groundspeed, and estimated times of arrival (ETAs) at future checkpoints and the eventual destination, have to be updated.

Time and timing, therefore, are of crucial importance in navigation. Once a pilot has drawn the desired track on a chart and assessed the probable heading and groundspeed of his aircraft from the wind forecast, he will identify suitable ground features along the track and calculate the time required to reach those features. Once airborne, by referring to his chart and stop watch, the pilot will either confirm his position along track or update his groundspeed and ETAs.

In light aircraft navigation, the most important of the divisions of time about which you have learned in this chapter is the minute. Confirming the aircraft's position along track by taking a fix from a planned ground feature is typically made every 5 to 10 minutes, at light aircraft speeds.

In the navigation part of the PPL skills test, a pilot is required to arrive at his destination or declared turning points, within 3 minutes of his ETA. ETAs may, however, be updated along track if an en-route fix (against a planned ground feature) is either early or late.

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Representative PPL - type questions to test your theoretical knowledge of Time.

1. What is the ICAO definition of night?

   a. From half an hour after sunset to half an hour before sunrise
   b. The period between the end of evening civil twilight and the beginning of morning civil twilight, or such other period between sunset and sunrise as may be described by the appropriate authority
   c. From sunset to sunrise
   d. Any period decided upon by a national aviation authority

2. What is the United Kingdom Civil Aviation Authority's definition of night?

   a. From half an hour after sunset to half an hour before sunrise
   b. The period between the end of evening civil twilight and the beginning of morning civil twilight, or such other period between sunset and sunrise as may be described by the appropriate authority
   c. From sunset to sunrise
   d. Any period decided upon by a national aviation authority

3. Which of the following statements is correct?

   a. Flight at night in accordance with the Visual Flight Rules is not permitted in the United Kingdom
   b. Flight at night in accordance with the Visual Flight Rules is permitted in the United Kingdom, but only in VMC
   c. Flight at night in accordance with the Visual Flight Rules is permitted in the United Kingdom, but only if the pilot holds a valid Instrument Rating
   d. Flight at night in accordance with the Visual Flight Rules is permitted in the United Kingdom, but only if the pilot holds a valid Instrument Rating or IMC Rating

4. What is the cause of annual seasonal change on the Earth and the changing lengths of the periods of daylight and darkness throughout the year?

   a. The fact that the Earth completes one rotation on its axis in 24 hours
   b. The tilt of the Earths axis at 23½° to its orbital plane and the fact that the Earth spins on its own axis
   c. The fact that the Earth completes one orbit of the Sun every 365.2422 days
   d. The tilt of the Earths axis at 66½° to its orbital plane, the fact that the Earth completes one rotation on its axis in 24 hours, and one orbit of the sun every 365.2422 days

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5. What determines the local mean time of sunrise and sunset at any location on Earth?

   a. The time of year and the longitude and elevation of the location
   b. The time of year only
   c. The time of year, the location's latitude and the elevation of the location
   d. The latitude only

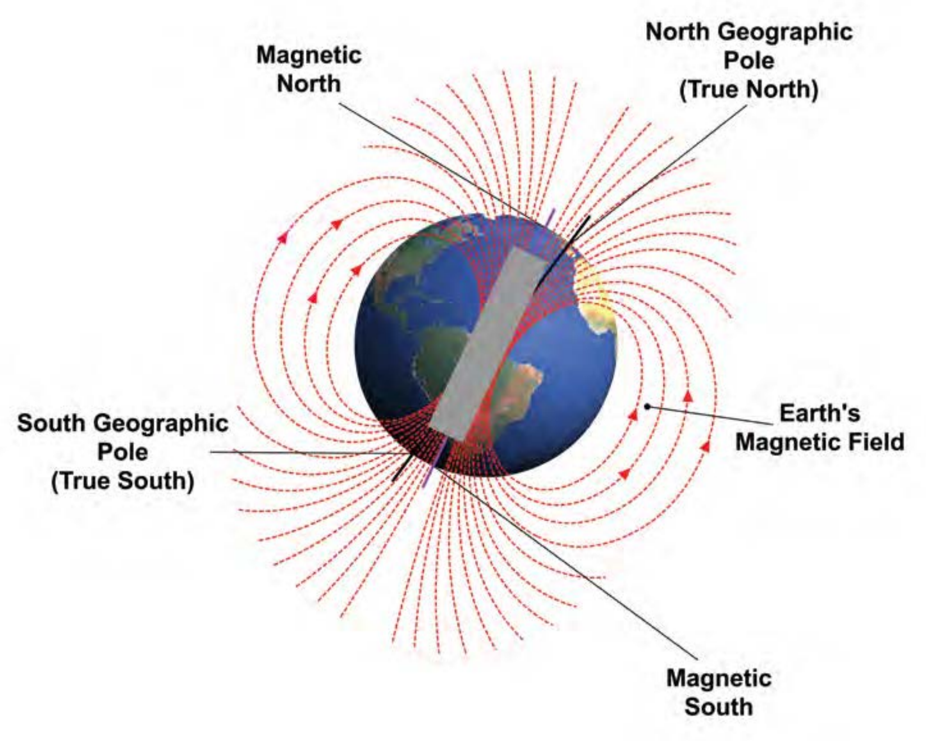
6. Which of the following statements is correct?

   a. At any given spot on Earth, the Sun will sink below the horizon earlier at sea-level than at altitude
   b. Sunrise and sunset will occur at the same local mean time at all locations of the same elevation along a given meridian of longitude
   c. At any given spot on Earth, the Sun will sink below the horizon later at sea-level than at altitude
   d. The local mean time of sunrise and sunset at any location along a parallel of latitude is independent of elevation

Question	1	2	3	4	5	6
Answer						

The answers to these questions can be found at the end of this book.

CHAPTER 3
DIRECTION



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INTRODUCTION.

In Chapter One, you learned that position is determined on the Earth by reference to latitude and longitude. For instance, the location of Madrid, the capital of Spain, is defined as 43° 23' North, 3° 43' West. Meridians of longitude run between the Earth's Geographic North and South Poles and the parallels of latitude, running East and West, lie at 90° to the meridians of longitude.

Directions which are referenced to the Earth's geographical poles are known as true directions.

The grid lines on aeronautical charts which run between North and South, and East and West, represent, respectively, the meridians of longitude and parallels of latitude; therefore, the North, South, East and West directions represented by the grid lines are true directions. The 1:500 000 aeronautical chart is a Lambert Conformal Conic Projection so the lines of longitude on this chart converge as they extend towards the pole. Over a small surface area, however, such as that represented by each individual chart, this convergence is negligible.

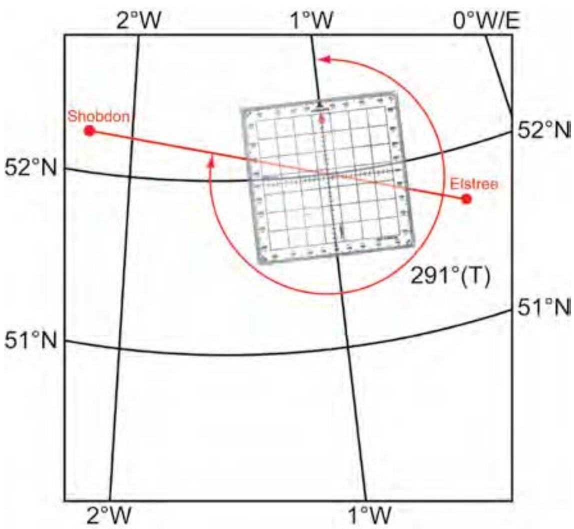

Figure 3.1 The 1:500 000 Chart. Meridians of longitude converge towards the geographical pole. A straight line is a great circle.

When a pilot is planning a navigation flight, he draws a straight line on his chart to represent the track along which he wishes to fly and, using a navigation protractor, measures the bearing of the track line as being between 0° and 359° from North, as represented by the vertical grid lines. The bearing of the track that the pilot wishes to fly is, therefore, given as a bearing with respect to True North. Such a bearing is called a true bearing.

A straight line joining two locations on the 1:500 000 aeronautical chart, *Figure 3.1*, represents a great circle on the surface of the Earth, being the shortest distance between the two points. So the straight line actually cuts the meridians of longitude at a slightly different angle. That is why it is good practice to measure a bearing at or near the mid point of track. (*See Figure 3.1.*) Over short distances of less than about 200 nautical miles, however, any variation in angle is negligible.

So, if a pilot was planning to fly from Oxford Airport to Wellesbourne Mountford via Ledbury, he would find, after drawing his desired tracks on the chart, that the first leg of his required track, from Oxford to Ledbury, was 286° True while the second leg, from Ledbury to Wellesbourne Mountford, was 072° True. (*See Figure 3.2a* and *Figure 3.2b*.)

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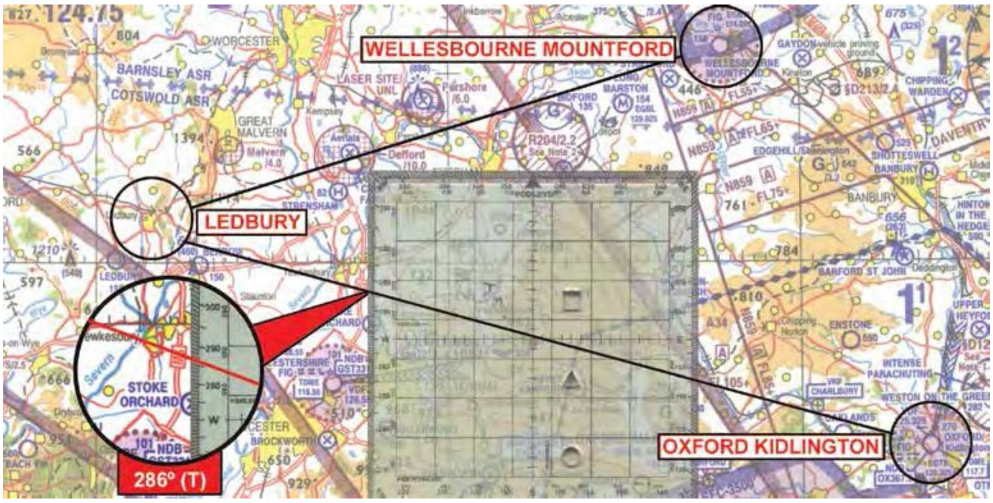

Figure 3.2a Measuring the true bearing of a track line from Oxford aerodrome to Ledbury.

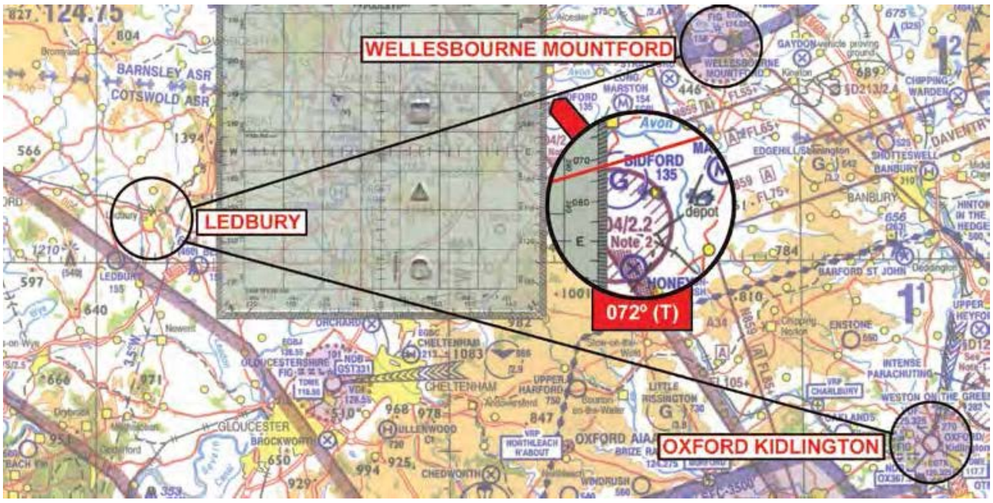

Figure 3.2b Measuring the true bearing of a track line from Ledbury to Wellesbourne Mountford.

In summary, the bearing of any track line drawn on a chart measured with respect to the chart's vertical grid lines is a <u>true</u> bearing referenced to <u>True</u> (Geographic) North.

TRUE NORTH AND MAGNETIC NORTH.

The Direct Indicating Magnetic Compass is usually the main magnetic heading reference in light aircraft.

However, the magnetic compass, the primary direction finding instrument used by the pilot-navigator of a light aircraft does not indicate True North. The heading information given by an aircraft's magnetic compass is not referenced to True (Geographic) North but to Magnetic North. So, if an aircraft's compass indicated that the aircraft was heading in a direction of, say, 270°, that heading would not be 270° True (which would be due West) but 270° Magnetic, which is quite another thing.

It is of the greatest importance in navigation that the difference between true indications and magnetic indications of direction should always be allowed for.

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Magnetic North is quite a different concept from True (Geographic) North. The Earth acts as if a giant magnet passes through its centre, whose axis lies at an angle to the line joining the Earth's North and South Geographical Poles (i.e. the Earth's spin axis), as depicted in *Figure 3.3*.

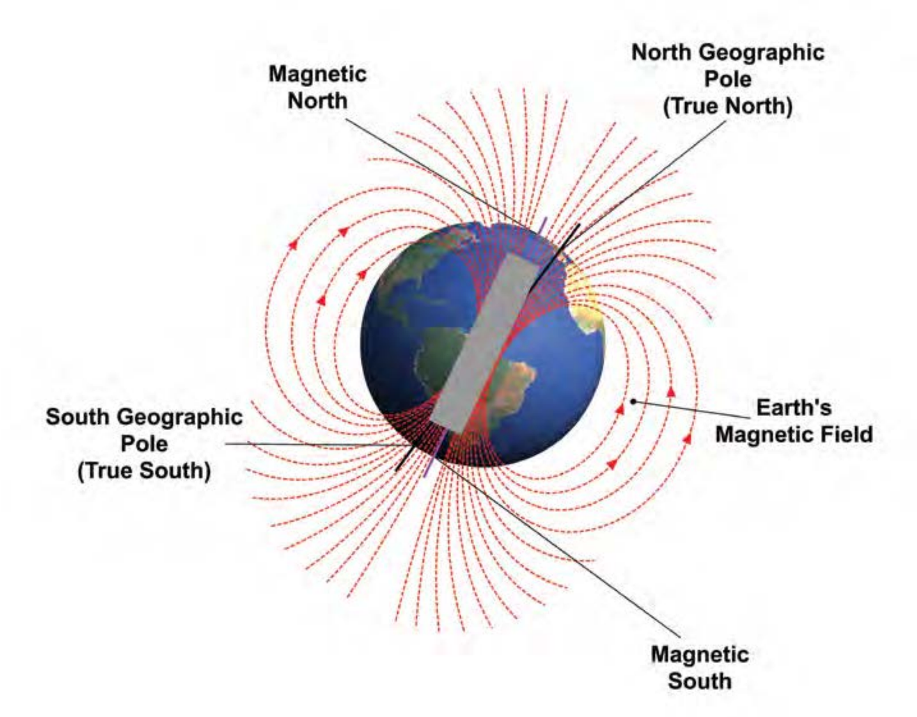

Figure 3.3 The Earth's Magnetic Poles do not coincide with its Geographical North and South Poles.

Because of the angle between the axis of the imaginary magnet and the Earth's spin axis, the poles of the imaginary Earth magnet do not coincide with the Geographical North and South Poles. The Canadian Geological Survey estimates that the 2005 position of the Earth's North Magnetic Pole was 82.7° North, 114.4° West, to the west of Ellesmere Island, the biggest of the Queen Elizabeth Islands in Canada. The Magnetic South Pole's estimated 2005 position was at 64.7° South, 138° East. The magnetic poles wander around significantly, and so extrapolation of their previous positions in order to predict future positions is not easy.

Because of the magnetic properties of the Earth, a magnetic field, also depicted in *Figure 3.3*, surrounds the planet. **Under the influence of this magnetic field, the north-seeking end of the needle of a magnetic compass indicates the direction of Magnetic North.**

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MAGNETIC VARIATION.

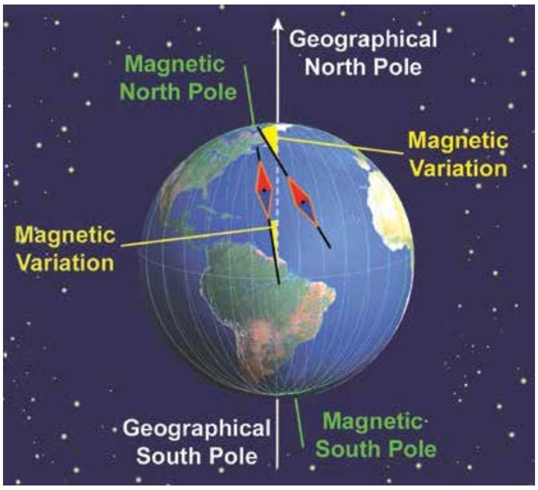

Figure 3.4 Magnetic Variation.

At any point on the Earth's surface, the angular difference between Magnetic North, indicated by a compass needle, and the direction of True (Geographic) North is called magnetic variation. The angle of magnetic variation is different in different locations on the surface of the Earth, as illustrated in *Figure 3.4.*

Furthermore, again depending on where on the Earth's surface a compass reading is taken, Magnetic North may lie either to the West, South or to the East of True North. (*See Figure 3.5.*) Magnetic variation may range from 0° to 180° East or West of True North.

Magnetic Variation is the angle between True North and Magnetic North, and can be East or West of True North.

Figure 3.5 View from above the North Geographic and Magnetic Poles. Magnetic Variation varies depending on location on the Earth's surface. Magnetic Variation may be either East or West.

As we have mentioned, the Earth's magnetic poles are wandering constantly, and so magnetic variation changes not only with location on the Earth's surface but also with time. The North Magnetic Pole is currently moving at a rate of more than 22 nautical miles per year. Its rate of movement has varied considerably since records began, in 1831. The Geological Survey of Canada keeps track of the North Magnetic Pole, by periodically carrying out magnetic surveys to redetermine the Pole's location.

Across the British Isles, magnetic variation currently (July 2010) ranges from about 7° West, to the West of Northern Ireland, to 1° West, off the East Anglian coast. In the British Isles, magnetic variation is changing (decreasing) at the rate of about 7' per year (i.e. 1° in about 8 years).

Isogonals and Agonic Lines.

On aeronautical charts, locations on the Earth's surface which have the same magnetic variation are joined by lines called isogonals. *Figure 3.6a* depicts representative isogonals lying across the British Isles in early 2007. *Figure 3.6b* shows the isogonal, just to the East of Plymouth, which, in 2006, joined points in the United Kingdom where the magnetic variation was 3.5° West.

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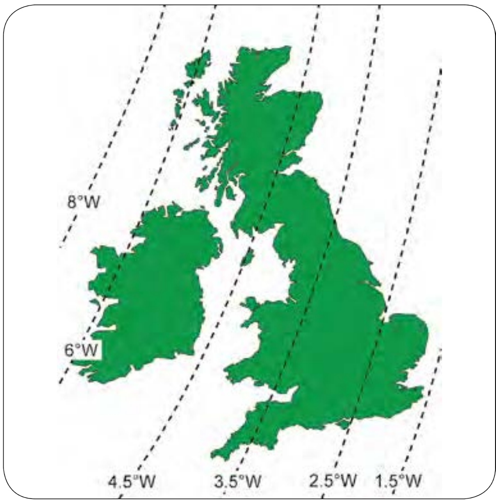

Figure 3.6a Representative isogonal across the British Isles in early 2007.

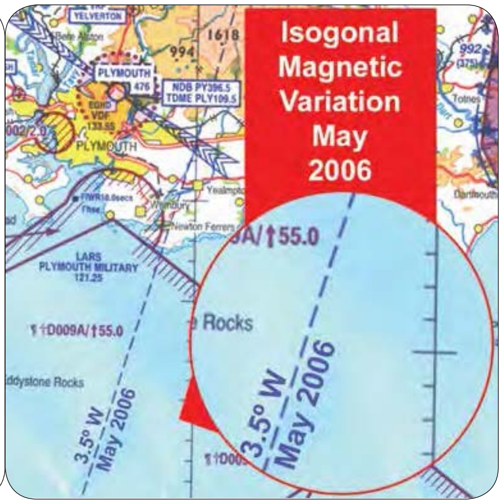

Figure 3.6b The isogonal 3.5° West, to the East of Plymouth, England, May 2006.

Isogonals which indicate a magnetic variation of zero degrees (i.e. where Magnetic North is in the same direction as True North) are called agonic lines.

MAGNETIC HEADING.

As we mentioned above, when a pilot is planning a cross-country flight, he draws the track lines he wishes to fly along on an aeronautical chart and measures the bearing of each track with reference to the vertical grid lines marked on the chart. You have already learned that these vertical lines represent meridians of longitude, and a bearing measured from one of these lines, at the mid-track position, will give the heading of the desired track, with reference to True North.

But, as we have learned, once in the air, the instrument on which a pilot relies to give him the heading to steer is the magnetic compass, and compass headings are referenced to Magnetic North not True North.

What action, then, must a pilot take to convert the true heading that he has measured from the chart into a heading that he can steer, once airborne, using the indications of his compass?

The answer to this question is that the pilot must convert the true headings into magnetic headings. It is crucial that the pilot-navigator should understand that this is so. It does not matter that, once in the air, he may use the gyroscopic Direction Indicator to steer headings; the Direction Indicator (DI) is aligned to the magnetic compass, so the DI readings are referenced to Magnetic North, too.

Let us return to our example of the planned flight from Oxford Airport to Wellesbourne Mountford via Ledbury, to illustrate how to determine the magnetic headings that a pilot must fly when airborne. For the time being we will ignore the effect of wind on our planned headings. You will learn how to allow for wind in later chapters.

We have already seen that the first leg of the flight from Oxford to Ledbury requires us to fly a true heading of 286°(T). (We will add (T) or (M) to heading information to make clear the distinction between true and magnetic headings.)

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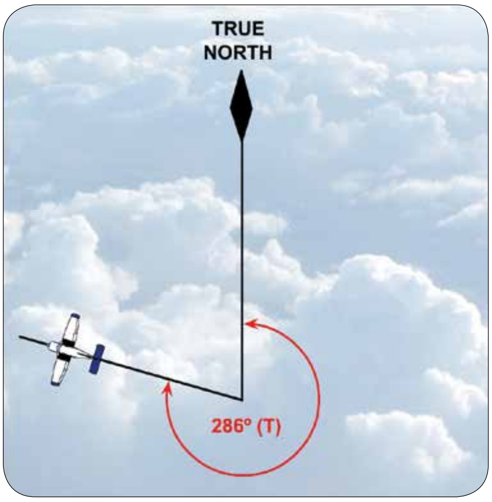

Figure 3.7a The Heading of 286° (T).

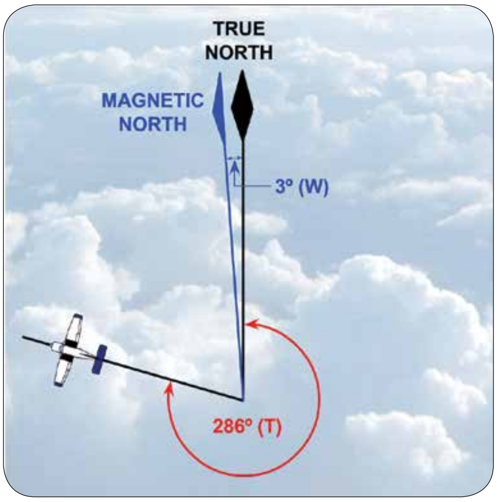

Figure 3.7b Magnetic North, here, lies 3° to the West of True North.

Now, we know that 286°(T) is referenced to True North. This is depicted in *Figure 3.7a*. In order to find the magnetic heading, we must determine the value of magnetic variation for the region in which the flight is to take place. You will recall that the magnetic variation for a given region is the difference, measured in degrees, between the direction of True North, in that region, and the direction of Magnetic North. Referring to our aeronautical chart, we see that our route lies between the two isogonals, 2.5° West and 3.5° West (for mid-2006). It is a reasonable assumption, then, that 3° West will be a fairly accurate magnetic variation to apply to our heading calculations.

We have determined, then, that, in our region, Magnetic North lies 3° to the West of True North. This is depicted in *Figure 3.7b*.

Considering the situation for a few moments (*see Figure 3.7c*), we realise that in, our case, in order to make good our desired track, we must add the magnetic variation of 3° West to the true heading of 286°(T) that we have measured, and fly a magnetic heading of 289° (M).

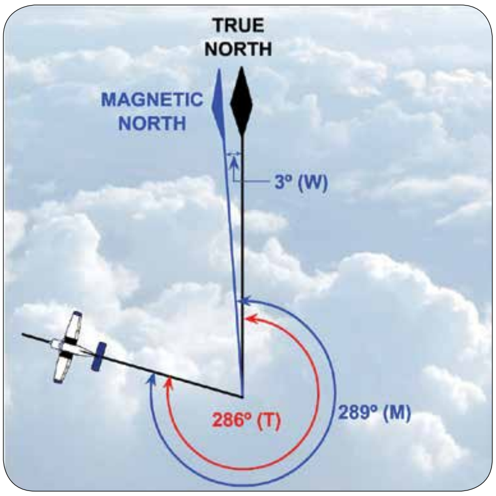

Figure 3.7c Magnetic Variation is 3° West. We add this to our True Heading of 286° (T) to obtain a Magnetic Heading of 289° (M).

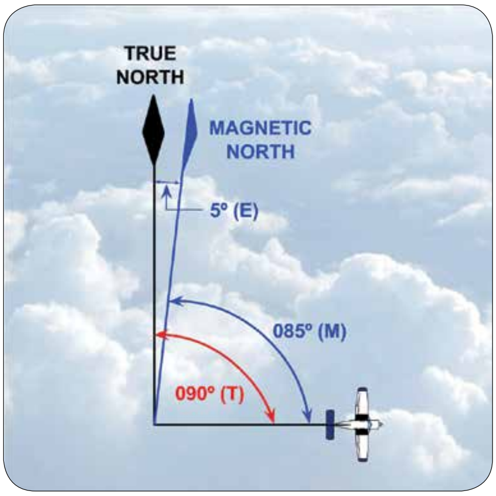

Figure 3.7d If Magnetic North lay to the East of True North we would subtract Magnetic Variation from True Heading to obtain the Magnetic Heading.

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By examining *Figure 3.7c*, we can see that whenever magnetic variation is West, that is, whenever Magnetic North lies to the West of True North, we must add the magnetic variation to any true heading in order to obtain the magnetic heading. In other words, when magnetic variation is West, the magnetic heading is always greater than the true heading.

If we were in a location where Magnetic North lay to the East of True North, we would have to subtract the magnetic variation from any true heading in order to obtain the magnetic heading. (*See Figure 3.7d.*)

It is now straightforward to determine that, in order to make good the true heading of 072° (T) from Ledbury to Wellesbourne Mountford, we must add the magnetic variation of 3° West and steer 075° (M).

The sense in which magnetic variation is applied to true heading in order to obtain magnetic heading may be remembered from the rhyme:

VARIATION WEST, MAGNETIC BEST.
VARIATION EAST, MAGNETIC LEAST.

If there were absolutely no wind blowing on the day a pilot wished to fly cross country, and if the indications of his magnetic compass were entirely error free, he could calculate the magnetic heading to fly, in the way that we have just demonstrated, and steer that heading on his compass. In real life, however, there is almost always wind to allow for. But, allowing for wind is a reasonably straightforward thing to do, and you will learn how to include a correction for wind in your calculation of magnetic heading in a subsequent chapter. For the moment, we will look at the possible errors which may be displayed by a magnetic compass so that, knowing your magnetic heading, you may be confident about the heading to steer on the compass.

THE MAGNETIC COMPASS.

The direct indicating magnetic compass of the type illustrated in *Figure 3.8,* is fitted to all aircraft, from the simplest light aircraft to the most modern glass cockpit airliner. In airliners, the magnetic compass is a standby instrument, while in many light aircraft it is still the primary instrument for indicating direction.

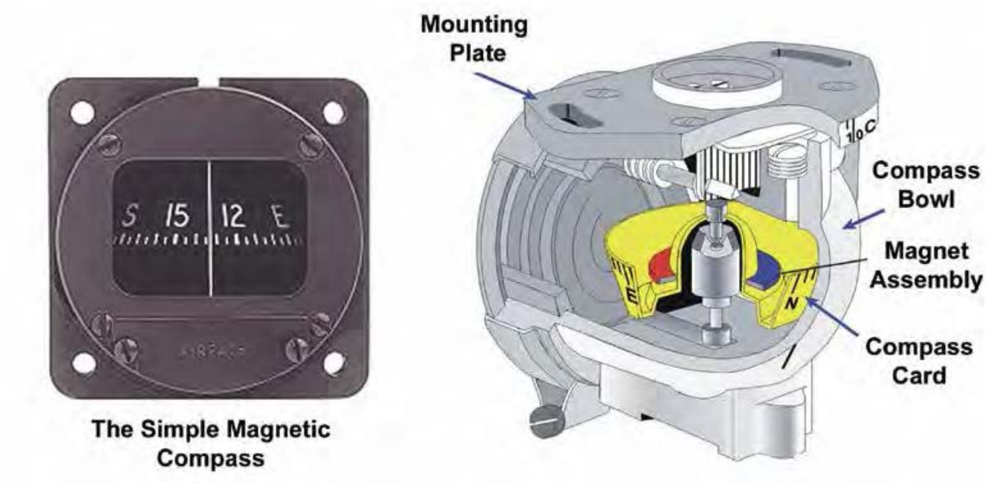

Figure 3.8 The Simple Magnetic Compass.

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A vertical lubber line on the glass window of the bowl enables the heading to be read from the compass card. The direct indicating magnetic compass is designed to indicate direction relative to the Earth's magnetic poles.

In ideal conditions, the magnet at the heart of the aircraft's magnetic compass, will point at all times to the Earth's Magnetic North and South Poles. Theoretically, as the aircraft changes direction the compass magnet remains aligned with the Earth's magnetic field, and the pilot is, thus, able to read off his aircraft's magnetic heading. However, as we learn below, there are several reasons why the magnet inside the compass may not always lie North-South, leading to errors in compass indications.

The main causes of error in the indications of the magnetic compass are:

- the presence within the aircraft of magnetic influences such as those produced by metal components, and the electrical fields of certain items of equipment.
- compass dip.

COMPASS DEVIATION.

The Magnetic Compass is not only sensitive to the Earth's magnetic field but also to the magnetic fields of electrically driven instruments and metallic objects within the cockpit. The presence of these "secondary" magnetic fields within the cockpit will cause the Magnetic Compass to deviate from pointing towards Magnetic North.

The angle between Magnetic North and the direction which is indicated by the magnetic compass is called the angle of deviation or, simply, deviation.

Another way of expressing this idea is to say that local magnetic influences within the aircraft cause the compass to indicate Compass North and not Magnetic North. Deviation, then, is the angular difference between Magnetic North and Compass North.

Deviation can be East or West of Magnetic North as depicted in *Figures 3.9a* and *3.9b*. A deviation of 2° to the West of Magnetic North can be written as 2°W or +2°. Deviation to the East of Magnetic North of 2° can be written as 2°E or -2°.

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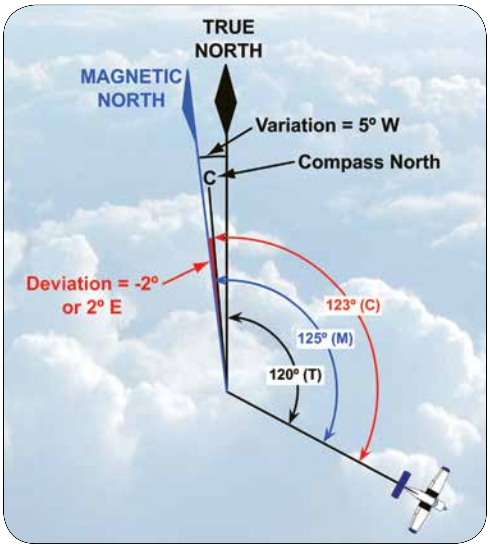

Figure 3.9a True Heading, Magnetic Heading and Compass Heading. Deviation = -2°.

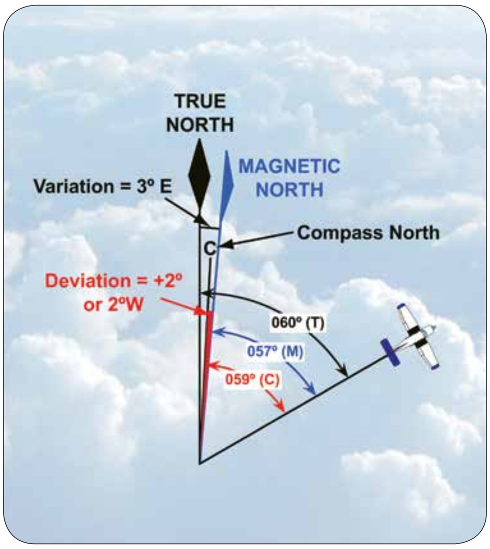

Figure 3.9b True Heading, Magnetic Heading and Compass Heading. Deviation = +2°.

When the aircraft is turning, because the compass magnet attempts to remain aligned in a North-South direction, the relative position of the compass magnet and the magnetic materials within the aircraft changes.

Therefore deviation varies with indicated magnetic heading.

Consequently, the extent of compass deviation has to be measured on a series of different headings if it is to be corrected. This is usually done by conducting what is called a compass swing. Measured deviation is then eliminated as far as possible by making adjustments to the compass itself by means of correcting screws. Once deviation has been reduced as far as possible, the residual deviation is recorded on a compass deviation card or a "heading to steer" card, which is located in close proximity to the compass. (*See Figure 3.10.*)

Figure 3.10 Compass Deviation Card, in the form of "headings to steer."

In *Figure 3.10* the compass deviation card indicates that for the aircraft to take on a magnetic heading of 270°(M) (West), the pilot must steer 269° by the compass. The compass deviation card in *Figure 3.10* also tells the pilot that he must steer 093° by the compass to obtain a magnetic heading of 090° (M) (East).

There are other deviation corrections on the card in *Figure 3.10*, but notice that magnetic headings of 180° (M), 360° (M) (North) and 060° (M) require no correction.

Always remember to check your compass deviation card when setting your magnetic heading on a cross-country flight. Compass deviation errors are usually small, and

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it is difficult, if not impossible, to fly to an accuracy of one degree using the magnetic compass, but a pilot should strive to achieve the highest degree of accuracy he can in navigating his aircraft. For instance, if a pilot did not notice the 3° deviation error for a magnetic heading of 090° (M), that could mean the pilot being 3 nautical miles off track, after 60 nautical miles, even if he could fly with 100% accuracy.

The heading that the pilot finally steers by his compass in order to eliminate deviation is often called the compass heading. In *Figure 3.10*, in order to make good a magnetic heading of 120°(M), the pilot must steer 122° (C) by the compass, the deviation being +2°.

The Relationship Between True Heading, Magnetic Heading, and Compass Heading.

In practice, when embarking on a cross-country flight, having measured true heading from your chart, and determined magnetic heading by applying the local magnetic variation and wind, you do not have to calculate compass deviation. That will already have been done when the aircraft last underwent a compass swing. As the pilot, what you have to do, as we have already mentioned, is to refer to the compass deviation card when setting heading, so that you know what compass heading to steer to make good your calculated magnetic heading.

Compass deviation on the deviation card may appear either as in *Figure 3.10* as a heading to steer, or in the form of +1, +2, -1, -2, etc. If the deviation is given as plus, you add that number of degrees to your magnetic heading to get compass heading. If the deviation is given as minus, you subtract that number of degrees from your magnetic heading to get compass heading. Remember also to check before flight that the card is valid (within 3 years of the date of compass swing).

However, pilots should make a point of knowing the relationship between true heading, magnetic heading and compass heading. When recalculating heading and groundspeed, mid track, for example, after discovering that the forecast wind was inaccurate, such knowledge can help tremendously with in-flight mental dead reckoning. Be aware, too, that questions on this relationship are much loved by those who devise questions for examination papers.

Having measured **True heading** (that is the true bearing of your desired track), **magnetic Variation** is applied to obtain the **Magnetic heading**; finally **compass Deviation** is applied to the magnetic heading to arrive at the **Compass heading**.

If you remember the line, "**T**hanks **V**ery **M**uch **D**ear **C**hap", the initial letters will remind you of the sequence to be followed to convert a **True heading** into a **Compass heading**.

Remember, it does not matter whether we are talking about variation or deviation, "East is always least and West is always best." In an examination, make a point of sketching the relative angles as in *Figure 3.9a* and *3.9b*; then it will be obvious whether you need to add or subtract.

Here is an example calculation:

If the true heading is 075°(T), the magnetic variation is 4°W and the deviation 1°E, what is the compass heading?

Apply "Thanks Very Much Dear Chap", and "East is least and West is best".

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The sequence we must work through then starts at true heading; then we apply variation to get magnetic heading, followed by deviation to get compass heading.

Magnetic variation is West so magnetic heading is better (in other words larger) than true heading; that makes the magnetic heading 075° + 4° = 079°(M). Deviation is East so compass heading is less than magnetic heading. That makes the compass heading 079° – 1° = 078° (C).

At other times, an examination question may express compass deviation in terms of plus and minus sign, e.g. -1°, +2°. You should note that, when expressed in this way, a deviation of -1° means that Compass North is East of Magnetic North. The reasoning behind this is that when Compass North moves East, headings measured relative to Compass North are smaller. Conversely, a deviation of +2° means that Compass North is West of Magnetic North. This is because when Compass North moves West, headings measured relative to Compass North are larger.

If you are required to relate compass heading to true heading, starting with the compass heading, then work the other way round: compass heading corrected for compass deviation gives magnetic heading which, when corrected for magnetic variation, gives true heading.

This sequence of operations can be remembered by memorising the words: "Cadbury's Dairy Milk, Very Tasty".

Here is an example of this sequence of working.

If the compass heading is 276°, the magnetic variation is 3°W and the deviation is -1°, what is the true heading?

Apply "Cadbury's Dairy Milk, Very Tasty", and "East is least and West is best".

Here, the sequence we work through starts at compass heading; then we apply deviation to get magnetic heading, followed by variation to get true heading.

Deviation is -1° which means 1° East. Because "East is least", compass heading must be the smaller number; therefore, magnetic heading must be larger than compass heading. So magnetic heading is 276° +1° = 277(M). Variation is West *so the magnetic heading must be greater than the true heading. True heading is, therefore, smaller than magnetic heading; so true heading is 277° - 3° = 274°(T).*

As mentioned above, if you draw out the situation for any calculation you are asked to perform, in the format of *Figures 3.9a* and *3.9b*, you should be able to confirm the correctness of your answer.

Of course, in real life, when you climb into your aircraft, applying deviation from the compass deviation card is straight forward, and there is no need to work your compass heading out from first principles, as we have been doing here. You must, however, understand the principle of the calculations.

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MAGNETIC DIP.

The angle between the vertical and horizontal components of the Earth's magnetic field is the Angle of Dip.

A second principal cause of error in the indications of the magnetic compass is the phenomenon of magnetic dip. Magnetic dip gives rise to the acceleration and turning errors in compass indications that you will learn about below.

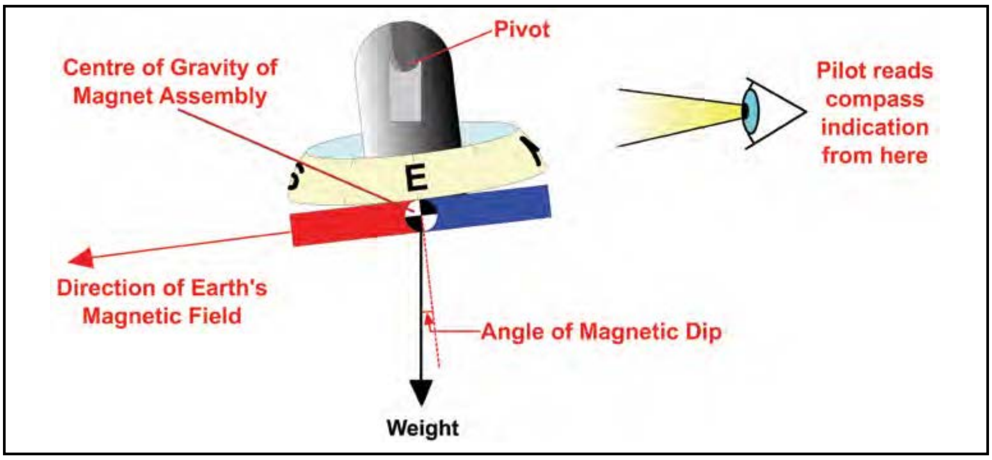

Figure 3.11 Dip in a magnetic compass.

Magnetic Dip.

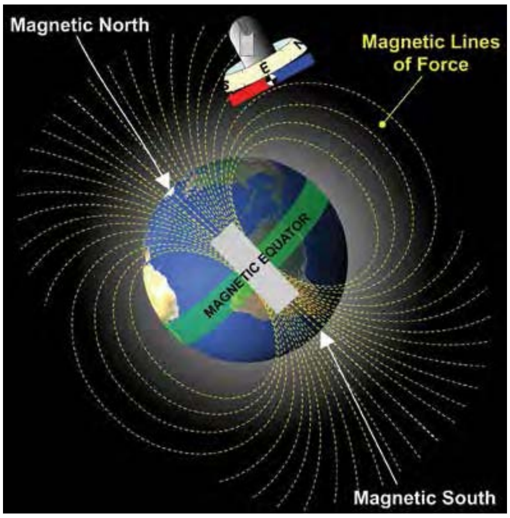

Figure 3.12 Magnetic Dip.

Except near the Earth's 'magnetic equator', where the Earth's magnetic lines of force are parallel to the Earth's surface, one end of a freely-suspended magnet will dip below the horizontal, pointing to the nearer magnetic pole. For example, to the North of the Magnetic Equator, the north-seeking pole of a compass magnet will dip, as shown in *Figure 3.11 and 3.12*.

The closer to the Earth's magnetic poles that a freely-suspended magnet is located, the greater will be the magnetic dip. Magnetic dip in the United Kingdom is about 66° to the vertical. Over the magnetic poles, the dip is 90°.

LINEAR ACCELERATION ERRORS IN THE MAGNETIC COMPASS.

As a result of magnetic dip, the indications of the magnetic compass are subjected to errors when the aircraft is either accelerating or decelerating linearly, or executing a turn.

Acceleration Errors.

Direct reading magnetic compasses are subject to errors during linear acceleration and linear deceleration.

Most manoeuvres which cause the centre of gravity of a freely-suspended magnet

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assembly to move away from its position beneath the pivot - *See Figure 3.13* - will produce an error in the indication of a compass so as to show an apparent turn when no turn is present.

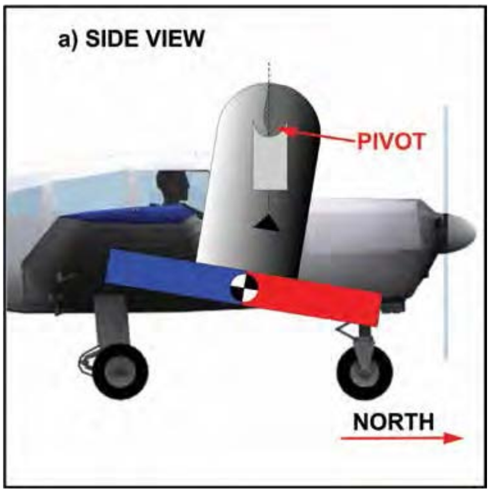

Figure 3.13 In the Northern Hemisphere, a magnetic compass with dip as shown here. The C of G of the magnet assembly is beneath and behind the pivot.

However, if the manoeuvre displaces the centre of gravity to the North or South of its usual position beneath the pivot, so that the centre of gravity and pivot are still in the plane of the magnetic lines of force, the magnet assembly merely changes its north-south dip angle, with no rotation in azimuth, and consequently no error. There are, therefore, no linear acceleration errors in compass indications when the aircraft is on a heading of 360º or 180º. Conversely, as you might expect, linear acceleration errors are greatest when the aircraft is heading 090º or 270º.

Note, that turning and linear acceleration errors occur only where there is significant magnetic dip, so acceleration errors are very small near the Magnetic Equator.

When dip is present, the centre of gravity of the pendulously suspended magnet is not directly under the pivot. *(See Figure 3.14.)* Therefore, when an aircraft accelerates on an easterly or westerly heading, the inertial reaction at the magnet's centre of gravity causes the suspended magnet to be "left behind" so that the compass's plane of rotation is no longer horizontal; the magnet can now rotate partly in the vertical plane, and this position allows the magnet to tilt downward to follow the earth's magnetic field. This rotation is seen as an apparent turn towards North.

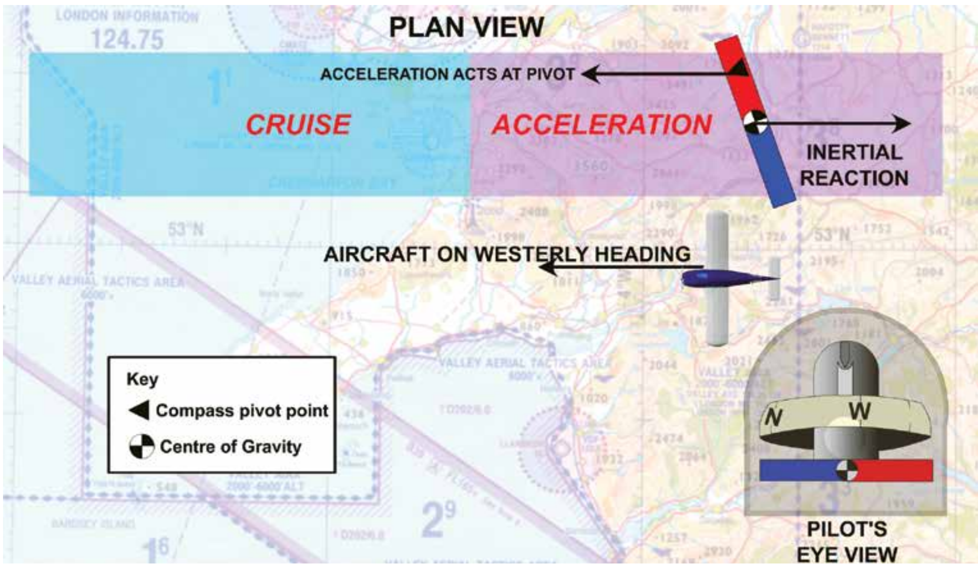

Figure 3.14 During acceleration on a westerly or an easterly heading, a magnetic compass indicates an apparent turn towards North.

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Once linear acceleration is complete and the aircraft is again flying at constant speed on the easterly or westerly heading, no acceleration force acts on the magnet's centre of gravity, and the compass reading is again steady and correct. (*See Figure 3.15.*)

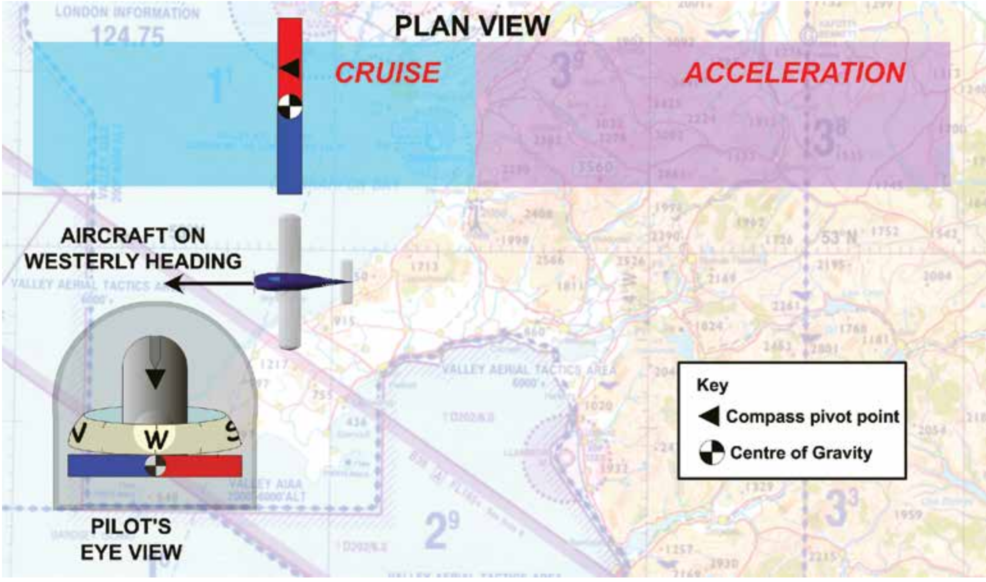

Figure 3.15 At constant speed, compass reading is again correct.

Accelerations on both westerly and easterly headings will result in an erroneous indication towards North. Conversely, decelerations will indicate an apparent turn towards South.

The table below summarises the acceleration errors of the magnetic compass in the Northern Hemisphere.

LINEAR ACCELERATION ERRORS IN THE NORTHERN HEMISPHERE		
Heading	**Acceleration**	**Deceleration**
Northerly	No Error	No Error
Southerly	No Error	No Error
Easterly	Indicates apparent turn North	Indicates apparent turn South
Westerly	Indicates apparent turn North	Indicates apparent turn South

Figure 3.16 Table of linear acceleration errors for a magnetic compass in the Northern Hemisphere.

Turning Errors in a Magnetic Compass.

A turning error in a compass indication is a particular type of acceleration error. When an aircraft turns at a constant speed, it is subject to centripetal acceleration towards the centre of the turn. This acceleration, which is a result of the aircraft continuously changing direction, is caused by the centripetal force generated by the banked wings of the aircraft. The centripetal force acts on all parts of the aircraft, including the centre of gravity of the compass magnets and on the magnet pivot point. This situation leads to the magnetic compass displaying indication errors during turns.

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Turning errors are maximum when turning through North and South, and a minimum when turning through East and West.

Away from the regions of the magnetic equator, because of the effect of magnetic dip, the compass's centre of gravity will be displaced from a position directly beneath the pivot point. In a turn, the aircraft accelerates towards the centre of the turn, and therefore an acceleration force acts through the pivot towards the centre of the turn, while the inertial reaction force acts outwards through the centre of gravity. This situation results in the magnet assembly tending to 'swing out' from the turn, rotating the magnet assembly around the pivot point and producing a turning error. (*See Figure 3.17.*)

Turning errors are usually more significant than linear acceleration errors for two reasons. Firstly, because they are inherently of greater magnitude, (up to about 30deg passing North/South headings), resulting from the greater displacement of the magnet assembly in turns; and, secondly, turns are likely to last longer than linear accelerations. However, prolonged turns that pass through East and West will eventually reduce the error to zero.

Turning Through North and South.

Whenever the pilot turns through the nearer pole (that is, the North Pole in the Northern Hemisphere, or the South Pole in the Southern Hemisphere), the aircraft and compass magnet rotate in the same direction. (*See Figure 3.17.*) In this situation, the relative movement between the compass card (attached to the magnet) and the compass housing will be small, and the compass card will appear to react sluggishly. Therefore, the pilot must roll out of the turn early, just before the indicated heading is reached. *Figure 3.17* shows an aircraft turning from 045° onto a heading of 315°, in the Northern Hemisphere. The pilot must roll out "early", at an indication of about 335°. If turning from 315° back to 045°, the pilot could roll out "early" at about 025°. Such conditions are typical in rate 1 turns.

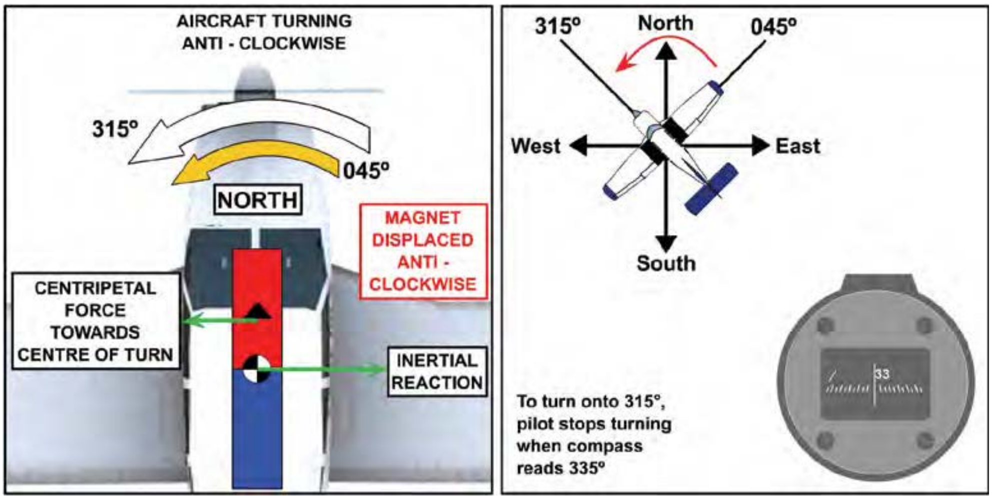

Figure 3.17 Turning through North in the Northern Hemisphere. Roll out "early" onto heading.

Whenever the pilot turns through the further pole (that is, the South Pole in the Northern Hemisphere, or the North Pole in the Southern Hemisphere), the aircraft and the compass rotate in opposite directions. (*See Figure 3.18, overleaf.*) In this situation, the relative movement between the compass card and the compass housing will be large and the compass card will react in a lively manner. Therefore, the pilot must roll out of the turn just after the indicated heading is reached. *Figure 3.18* shows an aircraft turning from 135° onto a heading of 225°, in the Northern Hemisphere. The

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pilot must roll out "late", at an indication of about 245°. If turning from 225° onto 135° the pilot would also roll out "late", at an indication of about 115°.

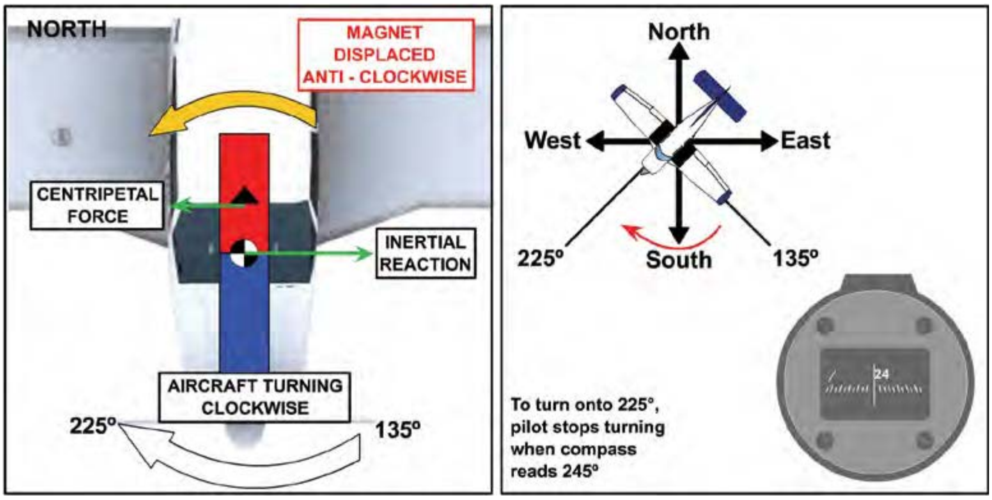

Figure 3.18 Turning through South in the Northern Hemisphere. Roll out "late" onto heading.

Summary of Compass Turning Errors in the Northern Hemisphere.

In the Northern Hemisphere, when rolling out of a turn onto a magnetic heading, using a direct indicating magnetic compass, the pilot should memorise the mnemonic **"NESL"**: NORTH (rollout) EARLY, SOUTH (rollout) LATE. Errors will be zero passing East and West, up to 30 degrees passing North and South and pro rata in between.

COMPASS SERVICEABILITY CHECKS.

Prior to take off, the following checks of the magnetic compass should be carried out. The checks are done before engine start, during taxying or after lining up on the runway, as appropriate.

Prior to Engine Start.

Check that there is no obvious damage to the compass body or glass, such as dents or cracks, and that the compass is securely mounted.

Check that the compass liquid is free from sediment and discolouration, either of which would indicate corrosion, resulting in increased pivot friction.

The compass liquid should also be free from bubbles, which would probably indicate a leaking seal. Turbulence and manoeuvres would cause any bubbles to move about, creating eddies which could disturb the magnet system.

The compass reading can also be checked for gross errors when you first enter the aircraft by verifying that the compass is giving a sensible reading.

During Taxying.

Check the compass reading while taxying the aircraft. The compass readings should decrease when turning left, and increase when the aircraft is turning right.

After lining up.

Just before take-off, check the compass reading against the runway heading.

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THE DIRECTION INDICATOR.

The indication errors to which the magnetic compass is susceptible, caused by the presence of extraneous magnetic fields, and by accelerations and turning manoeuvres, make the magnetic compass difficult to interpret exactly in any flight condition other than straight and level, in the climb, or descent. Consequently, many pilots prefer to set and hold headings with reference to the direction indicator (sometimes also referred to as the directional gyro or heading indicator).

Being driven by a gyroscope and relying on the principles of gyroscopic rigidity in space, the direction indicator (DI) is free from the errors suffered by the magnetic compass, and is much easier and more accurate to use, especially for executing precise turns onto desired headings.

The construction, principle of operation, and errors of the DI are covered in detail in Chapter 15 of the 'Aeroplanes' volume of this series.

Figure 3.19 A Direction Indicator.

In most modern aircraft, heading information is displayed by the DI in the form of the plan view of an aeroplane, whose nose indicates the direction in which the aircraft is heading, set against a rotating disc featuring a compass card graduated in degrees. (*See Figure 3.19.*) The aircraft image is stationary and, as the aircraft turns, the gyroscopically stabilised mechanism of the DI causes the compass card to rotate, with respect to the aircraft image, to give an accurate indication of aircraft heading.

As the DI possesses no north-seeking property or mechanism, the heading indicated by the DI must be synchronised with the magnetic compass. Headings read from the DI are, thus, magnetic headings.

Errors of the Direction Indicator (DI).

The gyroscope inside the DI is spun either electrically, or by air from a vacuum pump. Because the Earth rotates on its axis at approximately 15° per hour, while the DI's gyroscope remains fixed in space, and because of small imperfections in the gyroscope, itself, the DI will drift or wander, over time, causing errors in its indications.

Consequently, the DI must be <u>periodically resynchronised</u> with the magnetic compass, usually about every 10 to 15 minutes, and after manoeuvres such as steep turns.

During resynchronisation, the aeroplane must be in straight and level, unaccelerated flight, or else the pilot will not obtain an accurate reading from the compass. Resynchronising the compass normally cages the DI gyro too, so this <u>must</u> be done in straight and level, unaccelerated flight.

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Pilot Serviceability Checks for the Direction Indicator.

Before take-off, but after engine start, check that the vacuum gauge is indicating sufficient suction for the gyroscope rotor to operate at the correct rotational speed. As soon as practicable, set the Direction Indicator heading to the compass magnetic heading. While taxying, check that the Direction Indicator shows an increasing reading when the aircraft is turned to the right, and a decreasing reading when the aircraft is turned to the left.

Synchronising Direction Indicator and Magnetic Compass.

The DI must be resynchronised against the magnetic compass every 15 minutes. The aircraft must be in level, steady, unaccelerated flight during resynchronisation.

Having learned about the indication errors to which the magnetic compass is susceptible, you are now in a position to appreciate why the aircraft must be flown at a constant speed, with wings level, whenever the Direction Indicator is to be synchronised with the Magnetic Compass. As we have mentioned, resynchronisation should be carried out by the pilot, every 10 to 15 minutes or so, normally as part of the FREDA checks.

THE FREDA CHECK.

Fuel	-	contents sufficient and correct tank selected.
Radio	-	correct frequency selected, and next frequency pre-selected, if appropriate.
Engine	-	temperatures and pressures within limits. Mixture correctly set. Carburettor heat, as appropriate.
DI	-	synchronised with compass.
Altimeter	-	correct altimeter sub-scale setting selected.

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Representative PPL - type questions to test your theoretical knowledge of Direction.

1. The angle between the horizontal and vertical components of the Earth's magnetic field is known as:

    a. Angle of Inclination
    b. Magnetic angle
    c. Angle of Dip
    d. Angle of Incidence

2. Magnetic Variation is the angle between:

    a. True North and the nearest line of Longitude
    b. True North and Magnetic North
    c. Magnetic North and the aircraft's magnetic heading
    d. Magnetic North and the aircraft's true heading

3. Which of these statements is correct?

    a. Variation best - magnetic west: variation least - magnetic east
    b. Variation west - magnetic best: variation east - magnetic least
    c. Variation west - magnetic least: variation east - magnetic best
    d. Variation least - magnetic west: variation best - magnetic east

4. An Isogonal is a line joining points of:

    a. Equal magnetic deviation
    b. Zero magnetic variation
    c. Equal magnetic variation
    d. Zero magnetic deviation

5. An Agonic line joins points of:

    a. Equal magnetic deviation
    b. Zero magnetic deviation
    c Equal magnetic variation
    d. Zero magnetic variation

6. Compass Deviation is the angle between:

    a. True North and the heading indicated by the compass needle
    b. Magnetic heading and the heading indicated by the compass needle
    c. The heading indicated by the compass needle and the Earth's magnetic field
    d. The indications of the aircraft's main and standby compasses

7. Which of these statements is correct?

    a. Deviation west – compass best: deviation east – compass least
    b. Deviation west – compass least: deviation east – compass best
    c. Deviation west – true heading best: deviation east – true heading least

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d. Deviation best– compass west: deviation least – compass east

8. With a calculated heading of 246º True, a local magnetic variation of 5ºW and a compass deviation of 1ºE, the compass heading is:

a. 252º
b. 242º
c. 241º
d. 250º

9. With a compass heading of 110º, a compass deviation of -3º and magnetic variation of 6ºW, what is the True heading?

a. 107º
b. 113º
c. 101º
d. 119º

10. Which of the following statements is not correct?

a. Turning errors are maximum when turning through North and South
b. Acceleration errors are maximum on East/West headings
c. Turning errors are maximum when turning through East and West
d. Acceleration errors are minimum on North/South headings

11. Which of the following statements is correct?

a. During a turn through the pole which is physically nearer the aircraft the compass will be sluggish. It is therefore necessary to roll out late on the indication given by the direct reading compass
b. During a turn through the pole which is physically further from the aircraft the compass will be sluggish. It is therefore necessary to roll out early on the indication given by the direct reading compass
c. During a turn through the pole which is physically further from the aircraft the compass will be lively. It is therefore necessary to roll out early on the indication given by the direct reading compass
d. During a turn through the pole which is physically nearer the aircraft the compass will be sluggish. It is therefore necessary to roll out early on the indication given by the direct reading compass

12. A direct-reading compass in an aircraft executing a level turn, at a constant rate, in the Northern Hemisphere, will be subject to the largest turning error as the aircraft turns through:

a. East and West
b. North and South
c. Northeast and Northwest
d. Southeast and Southwest

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13. When turning anti-clockwise onto a southerly heading in the Northern Hemisphere the turn should be stopped:

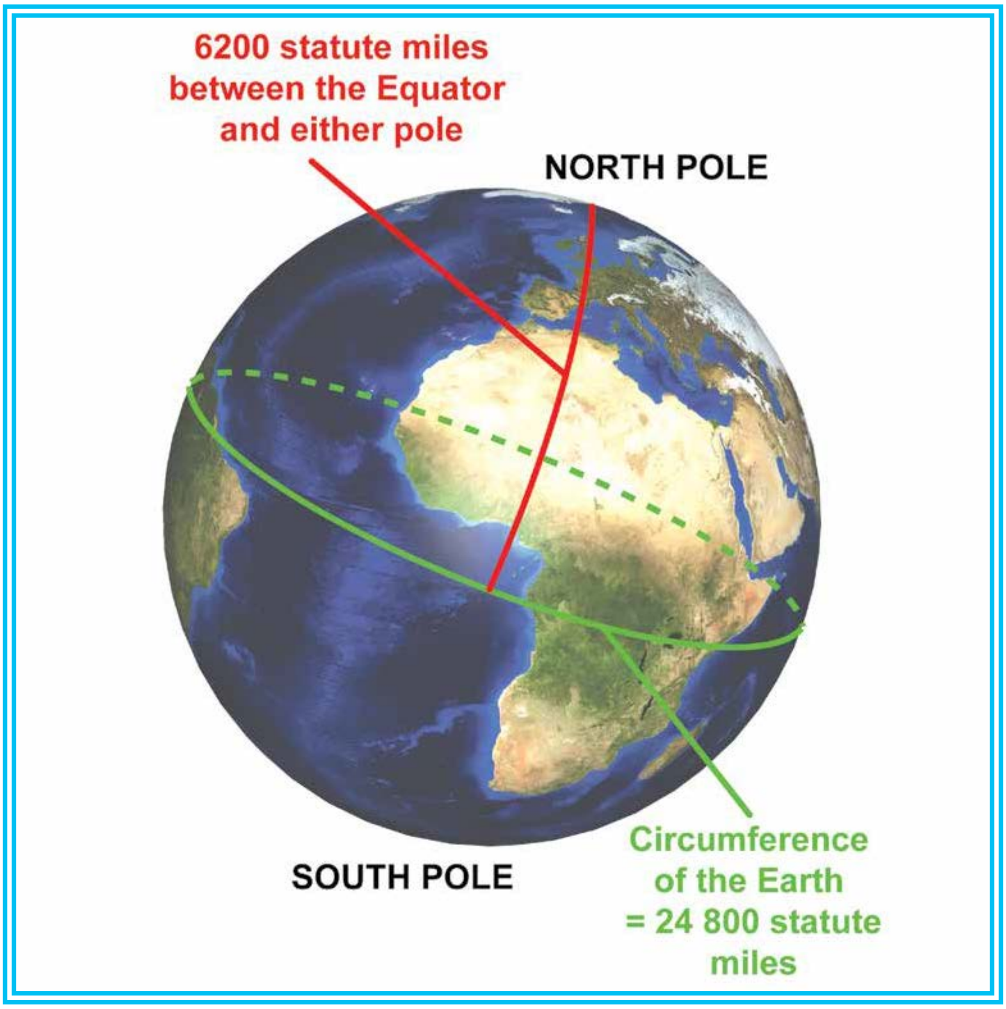
    a. Before the required heading is indicated
    b. When the compass slows down
    c. After the required heading is indicated
    d. Exactly on the required heading is indicated

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Answer											

Question	**12**	**13**
Answer		

The answers to these questions can be found at the end of this book.

CHAPTER 4
SPEED, DISTANCE AND TIME



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INTRODUCTION.

The basic method of visual navigation, which is most commonly called dead reckoning, involves the pilot determining his present position based on an accurate history (kept in the flight log) of heading, airspeed and time.

As you will learn in a later chapter, by taking into account the direction and speed of the wind (i.e. the wind velocity), the above information can be converted into groundspeed and distance travelled along a desired or observed track, and the changing position of the aircraft may be monitored relative to its starting point.

Computations involving speed, distance and time are, thus, central to dead reckoning navigation and the pilot-navigator needs to be confident that he can make such computations accurately.

One of the prime considerations in ensuring the accuracy of navigation calculations is that the units used for speed and distance are the correct ones. Speed is simply the expression of distance covered in a given amount of time. But for calculations to be accurate, the units of speed, distance and time must match one another.

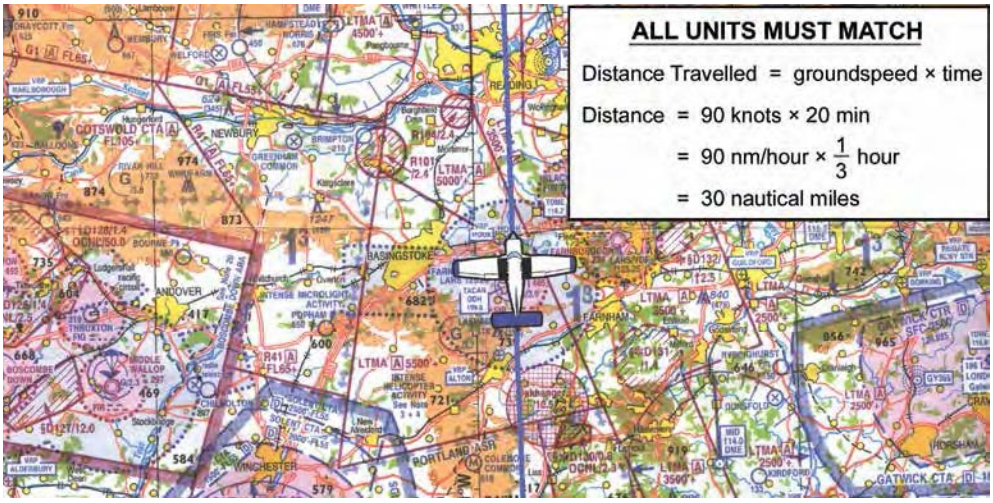

Figure 4.1 The basic method of visual navigation involves the pilot determining his present position based on an accurate history of heading, speed and time. All units must match one another.

SPEED, DISTANCE AND TIME CALCULATIONS.

Mathematically, it is straight forward to prove that:

$$\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}\ ; \qquad \textbf{distance} = \textbf{speed} \times \textbf{time}\ ; \qquad \textbf{time} = \frac{\textbf{distance}}{\textbf{speed}}$$

For the pilot navigator whose primary concern is to measure progress along a desired track, the speed in question is groundspeed. The above equations thus become:

$$\textbf{distance} = \textbf{groundspeed} \times \textbf{time};$$

$$\textbf{groundspeed} = \frac{\textbf{distance}}{\textbf{time}}\ ; \qquad \textbf{time} = \frac{\textbf{distance}}{\textbf{groundspeed}}$$

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The pilot-navigator would be wise to commit these simple equations to memory and, when he uses the equations in navigation calculations, he must take great care to make sure that the units match. He should find, however, that by using the flight navigation computer (see Chapter 11), speed, distance, time calculations are not difficult.

A student who wishes to learn more about the underlying Physics of speed, distance and time calculations, as well as about the basic science which explains many of the phenomena of flight, may wish to refer to OAAmedia's CD-ROM, 'Essential Physics 2' - Motion, Forces, Energy and Astronomy.

OAAmedia's 'Essential Physics 2' - Motion, Forces, Energy and Astronomy.

SPEED.

groundspeed = $\frac{\text{distance}}{\text{time}}$

We will begin with the equation: $$\textbf{groundspeed} = \frac{\textbf{distance}}{\textbf{time}}$$

A certain number of miles covered by an aircraft, along track, in a known number of hours, will enable you to determine groundspeed in miles per hour. For instance, from the above equation, a journey of 200 miles covered in 4 hours gives a groundspeed of 50 miles per hour.

$$\textbf{groundspeed} = \frac{\textbf{distance}}{\textbf{time}} = \frac{\overset{50}{\cancel{200}}\ \textbf{miles}}{\underset{1}{\cancel{4}}\ \textbf{hours}} = \textbf{50 miles per hour}$$

Note, however, that if the time is given in minutes, groundspeed will be in miles per minute and will need <u>converting</u> into miles per hour. Thus, if 40 miles is covered in 20 minutes, the equation gives us the following information:

$$\textbf{groundspeed} = \frac{\textbf{distance}}{\textbf{time}} = \frac{\overset{2}{\cancel{40}}\ \textbf{miles}}{\underset{1}{\cancel{20}}\ \textbf{minutes}} = \textbf{2 miles per minute}$$

In order to convert to miles per hour, we must multiply by 60 (there being 60 minutes in an hour).

$$\textbf{groundspeed} = \frac{\textbf{distance}}{\textbf{time}} = \frac{40}{20}\ \textbf{miles per minute} = \frac{40}{20} \times 60\ \textbf{miles per hour}$$

$$= \frac{\overset{120}{\cancel{240}}}{\underset{1}{\cancel{20}}} = \textbf{120 miles per hour}$$

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If distances are given in kilometres, the formula groundpeed = distance / time will give kilometres per hour or kilometres per minute, or per second.

If distance is given in nautical miles, the most common unit of distance in aviation, the formula groundspeed = distance / time will give nautical miles per hour or nautical miles per minute, or per second.

Note that nautical miles per hour are called knots. For example, an airspeed or groundspeed of 100 nautical miles per hour is referred to as 100 knots.

*The most common unit of speed in aviation is the **knot**. **100 knots** is **100** nautical miles per hour.*

DISTANCE.

If a given groundspeed is maintained by an aircraft for a given time, a resulting distance will be covered in that time.

distance = groundspeed × time

The distance covered along track = groundspeed × time.

A groundspeed of 160 miles per hour maintained for 2 hours will, according to the above formula, result in a distance of 320 miles being covered.

distance = groundspeed × time = 160 miles per hour × 2 hours = 320 miles

But, what distance would be covered if 160 miles per hour were maintained for 30 minutes? This is where units become crucial. In the formula distance = groundspeed × time, if the speed is in miles per hour, then in order to get a sensible answer for distance, the time must be in hours. We could not, for instance, get a sensible answer if we calculate as follows.

distance = groundspeed × time = 160 miles per hour × 30 minutes = ???

For the distance to be in miles, the time must be in hours. A simple expression of unit analysis illustrates why.

distance = groundspeed × time = 160 miles per hours × 2 hours = 320 miles

$$\textit{distance} = \frac{\textit{miles}}{\cancel{\textit{hours}}} \times \cancel{\textit{hours}} = \textit{miles}$$

The second equation above, in which only the units are shown, is the unit analysis equation. You can see that the hours cancel out, leaving miles as the unit of the answer.

As shown below, unit analysis does not work out if we consider 160 miles per hour for 30 minutes.

$$\textit{distance} = \frac{\textit{miles}}{\textit{hours}} \times \textit{minutes} = ???$$

So, to return to our problem of how much distance is covered in 30 minutes by an aircraft whose groundspeed is 160 miles per hour, we must <u>convert</u> the minutes into hours by dividing by 60. We may now write:

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$$\textbf{distance} = \textbf{groundspeed} \times \textbf{time} = 160 \times \frac{\overset{1}{\cancel{30}}}{\underset{2}{\cancel{60}}} = \frac{\overset{80}{\cancel{160}}}{\underset{1}{\cancel{2}}} \times 1 = 80 \textbf{ miles}$$

This is an answer that appears sensible.

Nautical Miles and Knots.

So how much distance would an aircraft with a groundspeed of 90 knots cover in 2 hours? 90 knots, remember, is 90 nautical miles per hour. Here is the equation.

distance = groundspeed × time = 90 × 2 = 180 nautical miles

And how far would the same aircraft travel in 20 minutes? Remember, if we want the distance in nautical miles, because the speed is in knots (i.e. nautical miles per hour) we must <u>convert</u> minutes into hours, by dividing by 60.

Thus,

$$\textbf{distance} = \textbf{speed} \times \textbf{time} = 90 \times \frac{\overset{1}{\cancel{20}}}{\underset{3}{\cancel{60}}} = \overset{30}{\cancel{90}} \times \frac{1}{\underset{1}{\cancel{3}}} = 30 \textbf{ nautical miles}$$

TIME.

The time taken for an aircraft to cover a given distance along track = $\frac{\text{distance}}{\text{groundspeed}}$

The time taken for an aircraft to cover a given distance along track is given by the equation:

$$\textbf{time} = \frac{\textbf{distance}}{\textbf{groundspeed}}$$

How long does it take an aircraft travelling at an average groundspeed of 70 miles per hour to cover 210 miles? Examining the units, we may deduce that, if speed is in miles per hour and distance is in miles, the time taken will be in hours.

$$\textbf{time} = \frac{\textbf{distance}}{\textbf{groundspeed}} = \frac{\overset{3}{\cancel{210}} \textbf{ miles}}{\underset{1}{\cancel{70}} \textbf{ miles per hour}} = 3 \textbf{ hours}$$

The following analysis of units shows that we may reasonably expect an answer in hours.

So:

$$time = \frac{distance}{speed} = \frac{miles}{\frac{miles}{hour}} = \cancel{miles} \times \frac{hour}{\cancel{miles}} = hour$$

(Mathematics teaches us that dividing by a fraction is the same as multiplying by the inverse of that fraction.)

But, what if we needed to have the answer in minutes? How many minutes would it take for an aircraft whose groundspeed is 120 miles an hour to cover 30 miles? As before, we must make the units match one another. If we want the time in minutes, and all distances are in miles, then speed must be in miles per minute.

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$$\textbf{120 miles per hour} = \frac{\overset{2}{\cancel{120}}}{\underset{1}{\cancel{60}}} = \textbf{2 miles per minute}$$

$$\textbf{time} = \frac{\textbf{distance}}{\textbf{groundspeed}} = \frac{\overset{15}{\cancel{30}}\textbf{ miles}}{\underset{1}{\cancel{2}}\textbf{ miles per minute}} = \textbf{15 minutes}$$

Of course, we could have kept the original figures, obtained a time in hours and then converted that answer to minutes by multiplying by 60.

$$\textbf{time} = \frac{\textbf{distance}}{\textbf{groundspeed}} = \frac{\overset{1}{\cancel{30}}}{\underset{4}{\cancel{120}}} = \frac{1}{4}\textbf{ hour}$$

$$\frac{1}{4}\textbf{ hour} \times 60 = \textbf{15 minutes}$$

We may use any system of calculation which suits us, as long as we think about units, and make sure that they match.

Some Examples.

Let us do a couple more examples.

How many seconds does it take a car travelling at an average speed of 120 kilometres an hour to cover 100 metres?

$$\textbf{time} = \frac{\textbf{distance}}{\textbf{speed}}$$

Firstly, we must think about the units that we are using.

Distance is in metres, speed is in kilometres per hour, and we want the time in seconds.

Let us, therefore, <u>convert</u> speed into metres per second. We can do that in three steps:

1. 160 kilometres per hour = 120 × 1 000 = 120 000 metres per hour.

2. 160 000 metres per hour = $\frac{120\,000}{60}$ **meters per minute = 2 000 metres per minute.**

3. 2 000 metres per minute = $\frac{2\,000}{60}$ **metres per second = 33.33 metres per second.**

Now, applying the equation **time =** $\frac{\textbf{distance}}{\textbf{speed}}$ we get:

time = $\frac{100}{33.33}$ **metres per second = 3 seconds, approximately.**

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Let us work out one final problem.

An aircraft has a groundspeed of 100 knots; how long will it take the aircraft to cover 20 nautical miles?

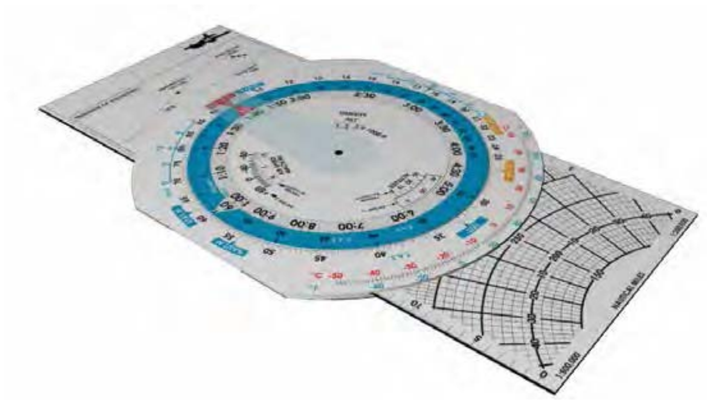
Obviously, the time taken is going to be less than an hour, so it would be reasonable to express the answer in minutes. In the equation, then, we might consider converting 100 knots (that is, 100 nautical miles per hour) to nautical miles per minute, by dividing that term by 60.

$$\textbf{time (minutes)} = \frac{\textbf{distance}}{\textbf{groundspeed}} = \frac{20}{\frac{100}{60}} = 20 \times \frac{60}{100} = \frac{60}{5} = \textbf{12 minutes}$$

Never forget that navigation calculations require that we continually bear in mind the importance of units, when carrying out speed, distance, time calculations.

When carrying out calculations with speed, distance and time, make sure that the units match one another.

As long as you remain aware of the importance of matching the units to one another, you should have no difficulty in carrying out speed, distance, time calculations using the navigation computer. (See Chapter 11 and enclosed CD-ROM.)



The Navigation Computer. See Chapter 11 and the accompanying CD-ROM.

You should also practise rounding distance, speed and time figures up or down to convenient whole numbers, so that you can carry out calculations mentally, in order to be able to calculate revised groundspeeds and update ETAs during in-flight navigation. Also check mentally that your results are reasonable (a 'gross error check').

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THE PRINCIPAL UNITS OF DISTANCE.

The principal units of distance in aviation are the nautical mile, the statute mile and the kilometre. The nautical mile is by far the most widely-used unit of distance because of its direct relationship to degrees of latitude; but the Federation Aéronautique Internationale, which keeps and awards records of distance and speed in aviation, and which regulates badge awards in the sport of gliding, uses the kilometre as the standard distance.

Kilometre.

The kilometre, which is 1 000 metres, is naturally based on the smaller unit, the metre. The metre was historically defined by the French Academy of Sciences, in 1791, as being 1 / 10 000 000 of the quadrant of the Earth's circumference running from the North Pole, through Paris, to the Equator. That definition makes the distance from the North Pole to the Equator, through Paris, 10 000 kilometres. The metre is now defined as equal to 1 650 763.73 wave lengths of the orange-red line in the spectrum of the Krypton-86 atom, under specified conditions.

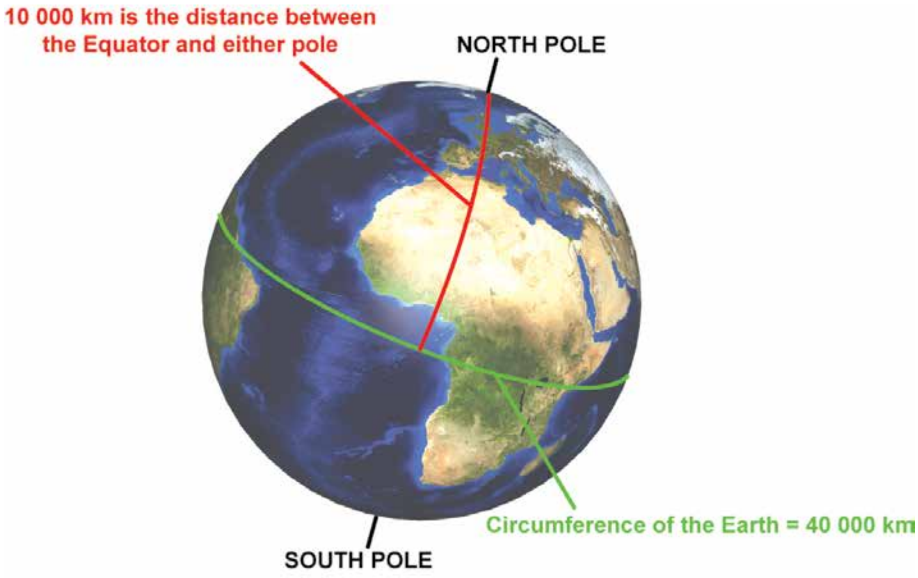

Figure 4.2 The kilometre.

The kilometre is used as the standard unit of distance throughout most of the world, except in Britain and the United States. In professional aviation, however, the standard unit of distance is the nautical mile.

Statute Mile.

The original mile was based on the Roman measure of *"mille passus"* which means "a thousand paces". This first mile measured 4 840 feet. During the reign of Queen Elizabeth I, in 1593, the mile was re-defined by royal statute (hence the name statute mile) to be 8 furlongs of 660 feet each, making the mile equal to 5 280 feet; this is its present definition.

The mile is the standard unit for measuring road distances in Britain and the United States of America, but it is now little used in aviation. However, some older light aircraft, e.g. Tiger Moth, have ASIs calibrated in MPH, which can have a significant effect if a navigation exercise has been planned in knots without allowance for conversion of units.

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The average distance from the Equator to either pole is 6 200 statute miles. The circumference of the Earth is 24 800 statute miles.

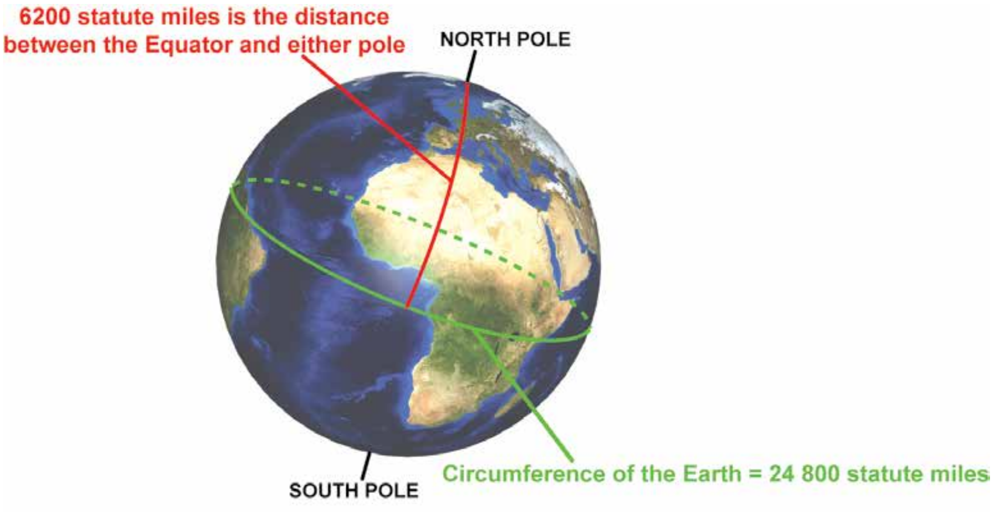

Figure 4.3 The Statute Mile.

Nautical Mile.

The nautical mile is the most commonly used, large-scale measure of distance in aviation.

The nautical mile is the length on the Earth's surface, measured along a great circle, of an arc subtended by an angle of one minute at the centre of the Earth. Therefore, one degree of latitude is sixty nautical miles on the Earth's surface. Because of its direct relationship with latitude, the nautical mile has been the standard unit of distance for seafarers for several hundred years. One nautical mile is also defined as 1 852 metres or 6 080 feet.

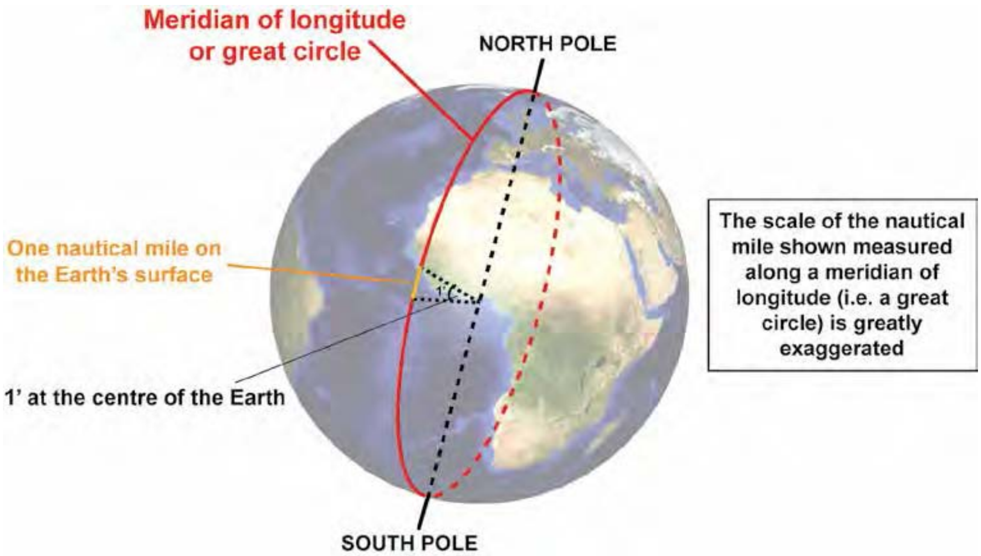

Figure 4.4 The Nautical Mile is the length on the surface of the Earth, measured along a great circle, of an arc subtended by an angle of one minute at the centre of the Earth. (Scale is greatly exaggerated.)

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The nautical mile and the knot (the nautical mile per hour) are used almost exclusively throughout the world of professional aviation and in marine transport.

IMPERIAL AND METRIC UNITS.

The smaller distances in current use in aviation are also a mixture of metric units and the older imperial units. Imperial units have evolved from English units of measure.

The standard unit of measure of altitude is the foot, the system of Flight Levels being based on altitude in feet measured from a pressure datum of 1013.2 hectopascals (millibars). Conversely, visibility is measured in metres and kilometres. Runway lengths are given in metres.

Figure 4.5 is a table showing the principal conversion factors which are used when converting between imperial and metric units and vice versa. You should note, however, that most of these conversions can be made with sufficient accuracy using the navigation computer (See Chapter 11).

Conversion Table for Units of Distance			
1 statute mile	**1.61 kilometres (km)**	**0.87 nautical miles**	**5 280 feet**
1 nautical mile	**1.85 km**	**1.15 statute miles**	**6 080 feet**
1 kilometre	**0.54 nautical miles**	**0.62 statute miles**	**3280 feet**
1 metre	**3.28 feet**		
1 foot	**0.3048 metres**		
1 inch	**2.54 centimetres**		
1 yard	**3 feet**		

Figure 4.5 Conversion Table for Units of Distance.

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Representative PPL - type questions to test your theoretical knowledge of Speed, Distance and Time.

1. Which of the following is the correct practical definition of a kilometre?

   a. It is 1/15 000th of the average distance on the Earth between the equator and either pole
   b. It is 1/20 000th of the average distance on the Earth between the equator and either pole
   c. It is 1/10 000th of the average distance on the Earth between the equator and either pole
   d. It is 1/000th of the average distance on the Earth between the equator and either pole

2. Approximately how long would an aircraft whose groundspeed was 100 knots take to fly 100 kilometres?

   a. Approximately 1 hour
   b. Approximately 33 minutes
   c. Approximately 45 minutes
   d. Approximately 100 minutes

3. If the groundspeed of an aircraft is 90 knots, how far will it fly in 20 minutes?

   a. 1800 nautical miles
   b. 4½ nautical miles
   c. 30 nautical miles
   d. 45 nautical miles

4. What is the definition of a nautical mile?

   a. The nautical mile is the length on the Earth's surface, measured along a great circle, of an arc subtended by an angle of one degree at the centre of the Earth
   b. The nautical mile is the length on the Earth's surface, measured along a great circle, of an arc subtended by an angle of one minute at the centre of the Earth
   c. The nautical mile is the length on the Earth's surface, measured along any line of latitude, of an arc subtended by an angle of one minute at the centre of the Earth
   d. The nautical mile is the length on the Earth's surface, measured along a great circle, of an arc subtended by an angle of one second at the centre of the Earth

5. What is the groundspeed of an aircraft which has taken 10 minutes to cover 20 nautical miles?

   a. 200 nautical miles per hour
   b. 200 kilometres per hour
   c. 180 knots
   d. 120 knots

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6. How long would it take for an aircraft whose groundspeed was 80 knots to cover 20 nautical miles?

   a. 4 minutes
   b. 15 minutes
   c. 20 minutes
   d. 4 hours

7. What distance would an aircraft travelling at a groundspeed of 116 knots cover in 45 minutes?

   a. 87 nautical miles
   b. Approximately 2½ nautical miles
   c. 116 nautical miles
   d. 75 nautical miles

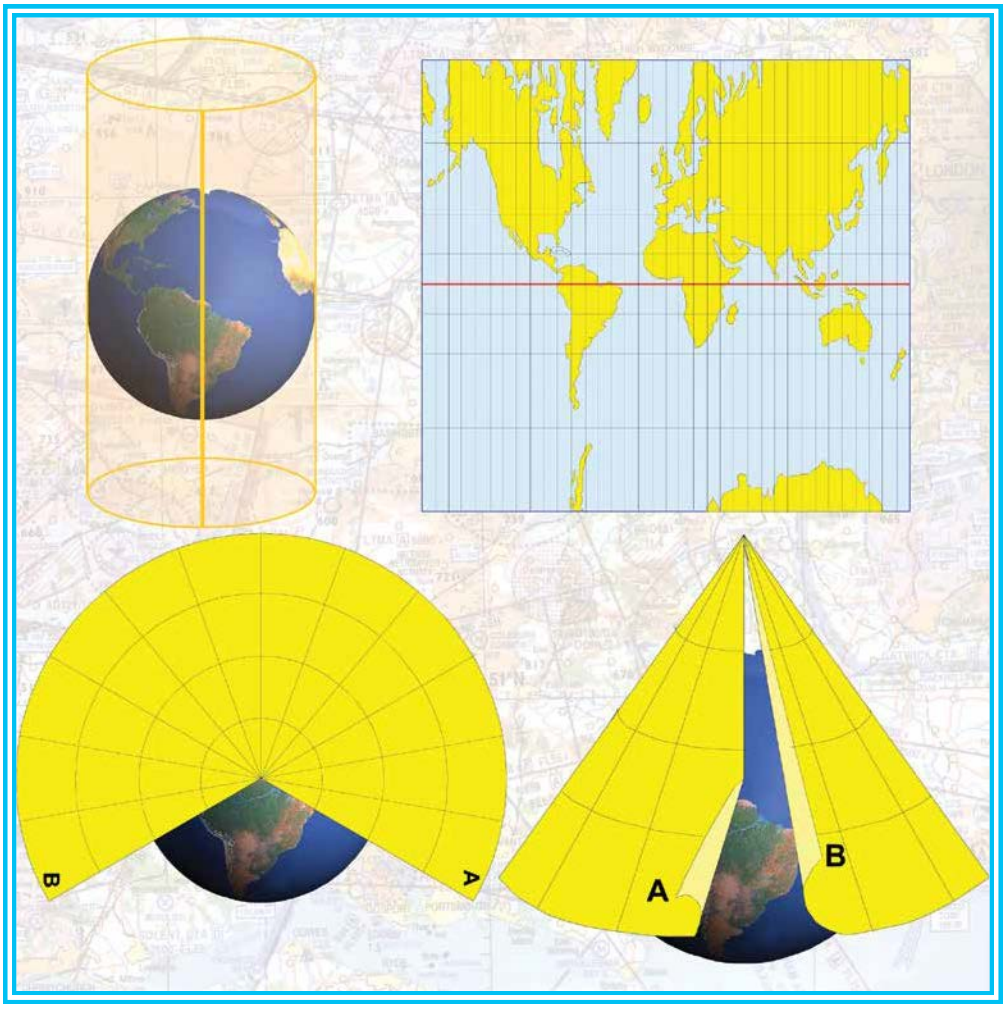
8. The distance of the first leg of a cross country flight is 40 nautical miles. Your calculated groundspeed is 100 knots. How long should it take you to complete the leg?

   a. About 2½ hours
   b. About 15 minutes
   c. 24 minutes
   d. About 40 minutes

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Answer								

The answers to these questions can be found at the end of this book.

CHAPTER 5
AERONAUTICAL CHARTS AND CHART-MAKING



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AERONAUTICAL CHARTS AND CHART MAKING.

INTRODUCTION.

In order to navigate an aircraft, a pilot needs to be able to determine the position of the starting point and destination of any planned flight, and to calculate bearings which tell him the direction in which to fly between departure and destination airfields.

The pilot also needs to be able to measure the distance between departure and destination, so that he can work out times to checkpoints, turning points and destination based on known airspeeds and wind speeds, and calculated groundspeeds.

Determining direction and fixing position require a chart which displays known locations and enables bearings to be measured.

In Chapter 3, we have already taken a brief look at how, in principle, a pilot uses an aeronautical chart in order to determine the heading to fly in order to make good a required direction or track. You will learn the actual method of measuring track in Chapter 7, but, in this chapter, we will first take a general look at charts and chart making.

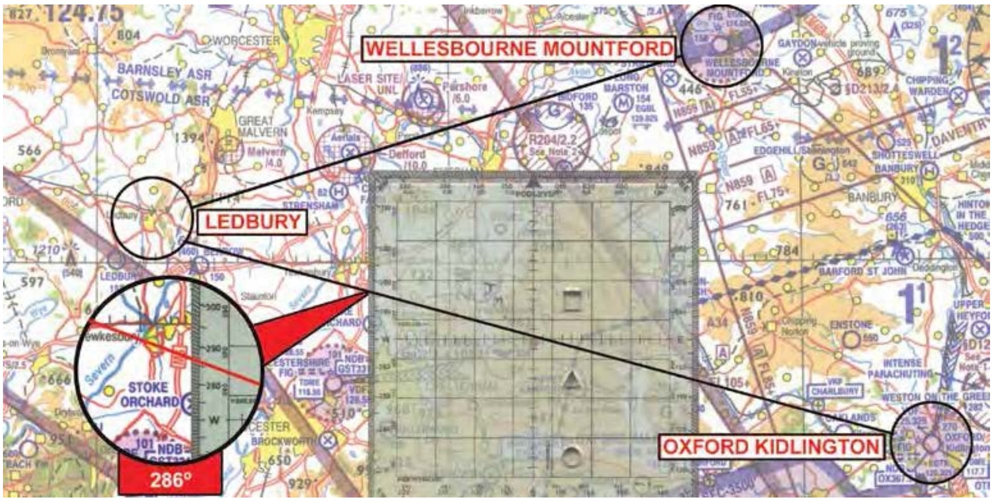

Figure 5.1 Using an aeronautical chart to plan a navigational flight.

MAPS AND CHARTS.

You will notice that in aviation we refer to the term charts, not maps.

Although there is no formal definition of the difference between a map and a chart, it is generally accepted that the difference is essentially one of detail.

When driving, we use road maps because we require details which enable us to identify, for example, road numbers and distances between villages, towns and cities which are joined by roads. However, a pilot flying over the sea, requires a chart which contains none of the detail found on a road map, but which allows tracks to be plotted with great accuracy, and which includes only details of such things as coastlines airways and radio navigation features. On a small-scale Atlantic Chart, only the general shape of large land masses make the chart recognisable as a type of map. *(See Figure 5.2, overleaf.)*

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A large-scale road map with detailed ground features. *Figure 5.2* *A small-scale aeronautical chart of the North Atlantic.*

Aeronautical Charts for Visual Navigation.

The chart that many VFR pilots use for visual navigation is the **ICAO 1:500 000 scale chart**, which is quite detailed, but does not contain the same detail of ground features as a road map. When navigating, a light aircraft pilot does not need to know the name of every small town or the numbers of the roads, only their relative locations. He does, however, need to know other details concerning regulated airspace and radio-navigation aids.

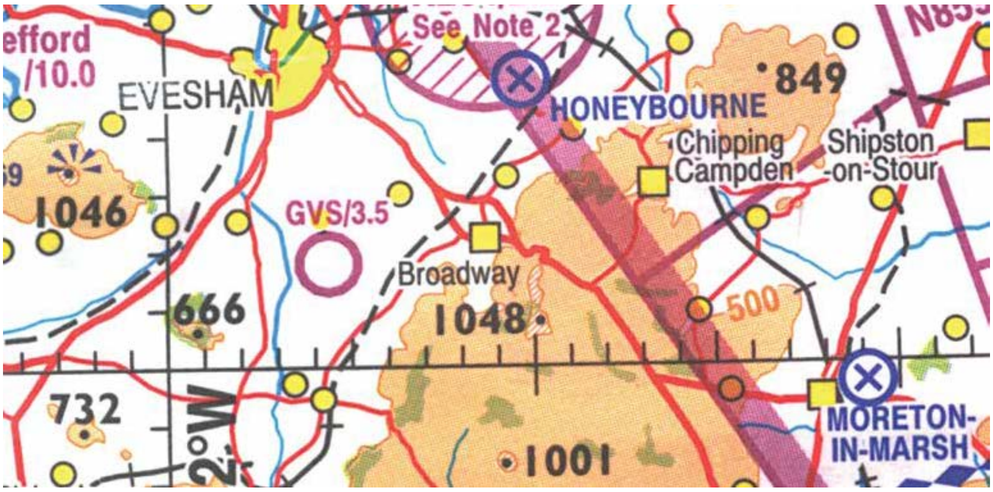

Figure 5.3 An ICAO 1:500 000 aeronautical chart showing Broadway, a small town situated between a disused railway track and an escarpment, with a road running through the town in a NW-SE direction.

Aeronautical charts need to contain ground features that pilots may use as checkpoints or fixes.

On a visual navigation trip, for instance, a pilot might wish to use a small town as a checkpoint, or in order to fix his position, and to recognise that a main road runs through it in, say, a NW to SE direction. (*See Figure 5.3.*) But, the detail on an aeronautical chart need only be enough to indicate the presence of a small town situated, say, at the foot of an escarpment, a major road running in a particular direction and, perhaps, a disused railway track running parallel to the escarpment.

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We will return to visual navigation charts later, and to the features they need to show, but let us first take a look at the problems which chart makers faced in attempting to project the spherical surface of the globe of the Earth onto the flat surface of paper or parchment.

THE PROBLEM OF CHART MAKING.

It is not too difficult to appreciate that the spherical surface of the Earth can never be represented on a two-dimensional chart without the Earth's surface undergoing deformation in one way or another. The challenge to the chart-maker, then, was to project the Earth's surface onto a flat chart in such a way that, despite the inevitable deformations, the projection conserved as many of the characteristics of the Earth's surface as possible that were useful to the navigator.

The spherical surface of the Earth cannot be represented on a flat chart without some degree of deformation in area, scale, shape or angles.

The type of desirable properties needing to be conserved were:

- **Conservation of surface area.**
- **Conservation of angles (bearings).**
- **Conservation of distance.**

The problem faced by chart makers, then, is not simple, as can be seen from *Figure 5.4* which depicts a method of chart-making called the cylindrical projection.

The Cylindrical Projection.

The most famous cylindrical projections were made by Gerardus Mercator onto a cylinder of paper wrapped around a reduced Earth, and touching at the Equator. In a cylindrical projection of this kind, meridians of longitude and parallels of latitude are straight and perpendicular to each other, but there is much east-west and north-south stretching, and significant distortion of scale with increasing distance from the Equator; for example, Iceland appears as large as India. However, rhumb lines, lines making constant angles with meridians of longitude, are represented by straight lines on a Mercator Projection, which made the Mercator Chart very suitable for navigation by ocean-going ships. Despite the significant distortion in land mass proportions near the poles, bearings measured from Mercator Charts are accurate. This latter property, which preserves accuracy of angles, makes the chart "conformal" in chart-makers' speech.

Straight lines drawn on a cylindrical transverse projection, such as a mercator projection, are rhumb lines.

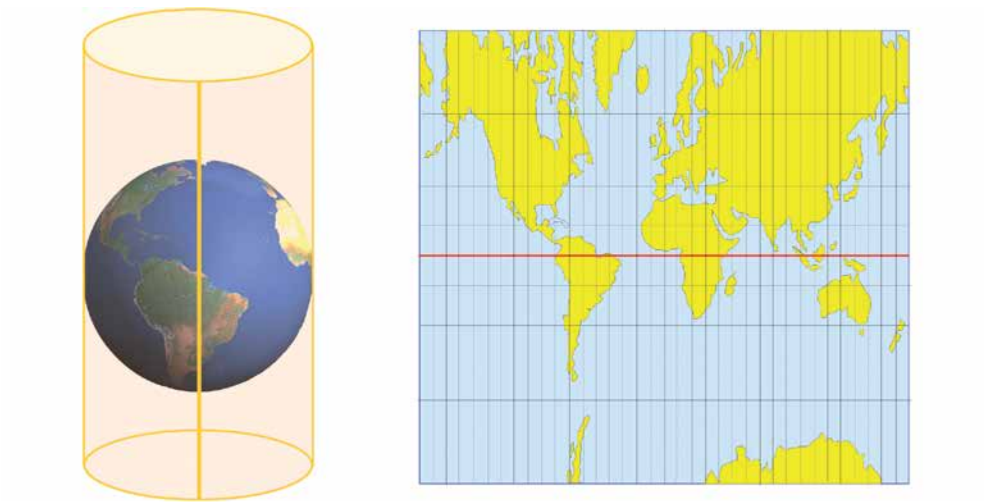

Figure 5.4 The Mercator Cylindrical Projection.

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The Transverse Mercator Projection is an adaptation of the original Mercator projection. Both projections are cylindrical and conformal. However, in a Transverse Mercator Projection, the cylinder is rotated 90° (transverse) relative to the Equator so that the projected surface is aligned with a meridian of longitude rather than with the Equator, as depicted in *Figure 5.5*. In both the original and the Transverse Mercator Projection, there is little distortion of scale in the region on the chart where the projected surface touches the meridian.

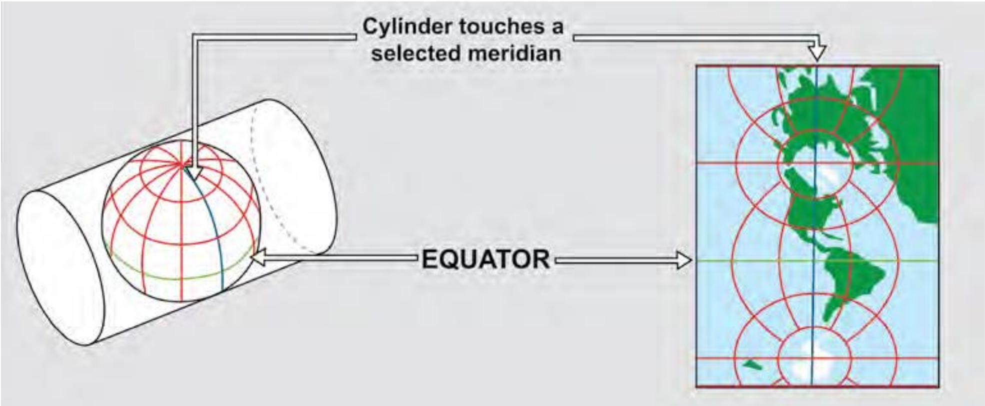

Figure 5.5 A Transverse Mercator Projection.

The UK 1:250 000 aeronautical chart is a Transverse Cylindrical Projection based on the 2° West Meridian of Longitude.

The UK CAA 1:250 000 Chart series *(See Figure 5.6)*, is constructed from a Transverse Mercator Cylindrical Projection, based on the 2° West meridian of longitude. Angles and bearings taken from the 1:250 000 chart are accurate. Shape and scale over the small area represented by each of the 8 charts covering the UK are conserved to a high practical accuracy, and a straight line marking the track between any two places represents a rhumb line.

Figure 5.6 A section from one of the eight 1:250 000 aeronautical charts covering the United Kingdom.

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The Conical Projection.

Conical projections involve placing a cone of paper over the reduced Earth, and projecting latitude and longitude graticules onto the cone, by placing a light source in the centre of the reduced Earth. Subsequently, the cone is slit along one side and opened to produce a flat sheet of paper.

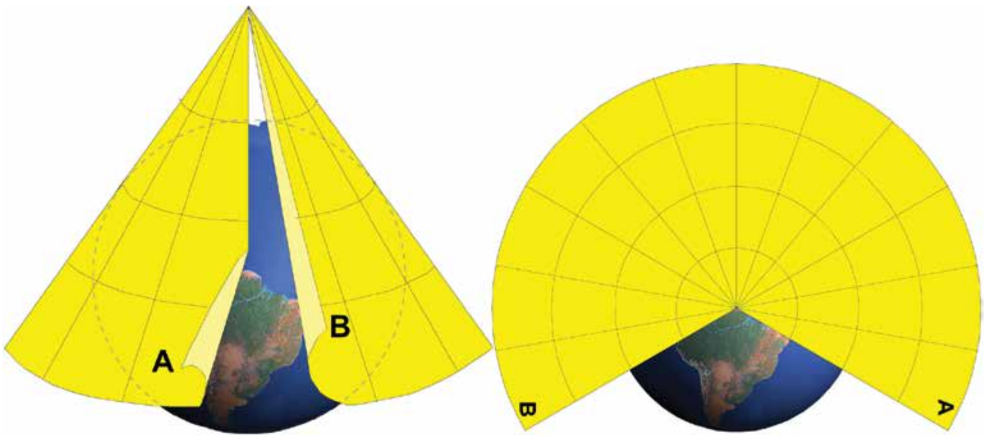

Figure 5.7 Conical Projection.

Conical (or conic) projections are usually made with the axis of the cone parallel to the axis of the Earth. Using this procedure, the projection on the cone is perfectly tangential (where the paper touches the earth) along one or two parallels of latitude, true scale being obtained along those parallels.

In a conical projection, meridians of longitude appear as radiating straight lines and parallels of latitude as concentric angles. Deformation is uniform along any parallel of latitude, and levels of distortion are low in the mid latitudes. *Figure 5.8* depicts a simple conical projection, with the parallel of tangency (parallel of origin) being 45° North.

In conical projections, angles and bearings are conserved.

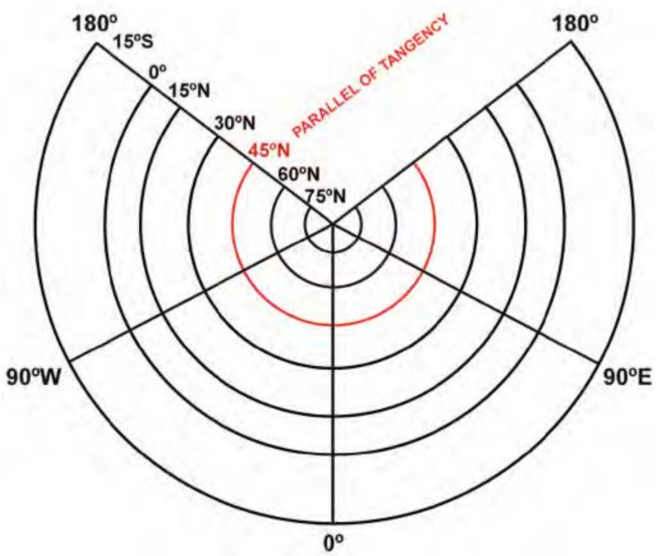

Figure 5.8 A Simple Conical Projection onto a flat surface.

One of the most common conical projections is the Lambert's Conformal Conical Projection in which angles and bearings, measured from the chart, are conformal with angles on the surface of the Earth, together with distances, over an area of about 160 nautical miles in an East-West direction and about 270 nautical miles North to South. For this reason, the Lambert's Conformal Conical Projection is used in aeronautical charts, which cover large areas of the Earth's surface, such as the 1:1 000 000 scale world series.

The ICAO 1:500 000 Chart series *(See Figure 5.9)*, perhaps the most widely-used of all charts for visual navigation, is also constructed from a Lambert's Conformal Conical Projection.

On a Lambert's Conical Projection, great circles, which represent the shortest distance between two points on the Earth's surface, appear as straight lines, at or near the parallel of origin. Moving away from the parallel of origin, great circles will appear slightly curved, concave to the parallel of origin. However, the curvature is not pronounced, and for practical purposes, on any Lambert's Chart representing a small area of the Earth's surface, such as Southern England, for instance, a straight line drawn on the chart represents a great circle.

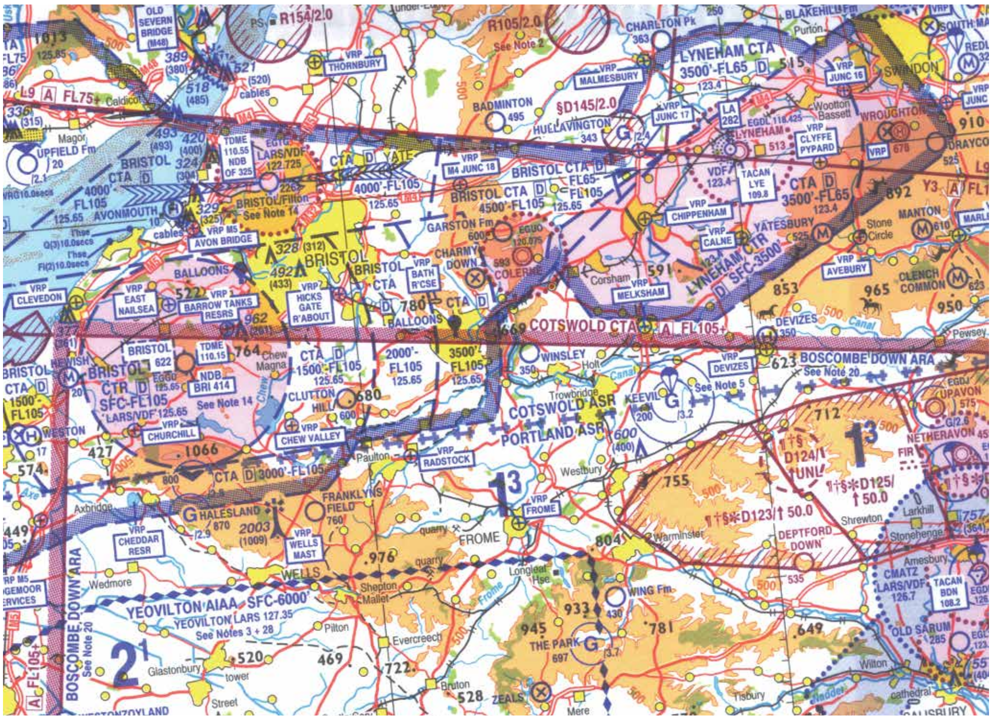

Figure 5.9 Section from an ICAO 1:500 000 chart of the United Kingdom - a Lambert's Conformal Conical Projection.

The 1:500 000 chart of the UK is a Lambert's Conical Projection. Straight lines drawn on this chart are great circles. Therefore, bearings must be taken at the mid-track position.

Being a Lambert's Conical Projection, the meridians of longitude on the UK 1:500 000 chart converge towards the North Pole. A straight line drawn on the 1:500 000 chart represents a great circle on the Earth's surface, cutting the different meridians of longitude at a slightly different angle. This is hardly noticeable over the small areas covered by the 1:500 000 charts, but nevertheless, when measuring true headings, bearings should always be taken from the mid-track position.

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SCALE.

Distances read from a chart (along track lines, for instance) must be related to the real distances on the surface of the Earth by a fixed proportional factor. For example, on the ICAO 1:500 000 charts, one unit of distance on the chart, whether it be an inch, a centimetre or any other unit, represents a distance of 500 000 of those units on the Earth's surface. On the UK CAA 1:250 000 charts, one unit measured on the chart represents 250 000 such units on the surface of the Earth. Thus, there is a known relationship between a distance measured on the chart and the real physical distance over the Earth.

This relationship is called scale.

As you will have deduced for yourself, the two terms 1:500 000 and 1:250 000 are both expressions of scale.

Scale may be expressed by the relationship:

$$\textbf{Scale} = \frac{\textbf{distance on the chart}}{\textbf{distance on the Earth}}$$

It is absolutely crucial, when using scales to compute distances, either on the chart or over the Earth's surface, that both terms of the above fraction be in the same units.

If, for example, you were to chose one inch to represent a given terrestrial distance on a 1:500 000 chart, that inch would represent 500 000 inches (ins) on the Earth's surface.

$$\textbf{500 000 ins} = \frac{\textbf{500 000}}{\textbf{12}}\ \textbf{feet} = \textbf{41 667 feet} = \frac{\textbf{41 667}}{\textbf{6076}}\ \textbf{nautical miles} = \textbf{6.9 nm}$$

If, on the other hand, you were to chose one centimetre to represent a given terrestrial distance, on a 1:250 000 chart, that centimetre would represent 250 000 centimetres (cm) on the Earth's surface.

$$\textbf{250 000 cm} = \frac{\textbf{250 000}}{\textbf{100 000}}\ \textbf{kilometres} = \textbf{2.5 kilometres} = \frac{\textbf{2.5}}{\textbf{1.852}} = \textbf{1.35 nm}$$

Distances, both on the chart and on the surface of the Earth, can be easily calculated, depending on the scale of the chart, by using a flight navigation computer. The CD-ROM which comes with this volume will teach you how to do this.

The scale of a chart is usually located in the legend box of the chart; that is, the box which explains the symbols and provides other important information about the chart. On the 1:500 000 chart of the United Kingdom, the scale appears in the legend box in the bottom left-hand corner of the chart.

A scale can be printed in a variety of ways. It can be expressed as a ratio, such as 1:500 000, a term with which you are now familiar, or it may even be shown as a length on a linear scale next to other lengths. Both of these methods of indicating scale are depicted on the UK 1:500 000 Chart.

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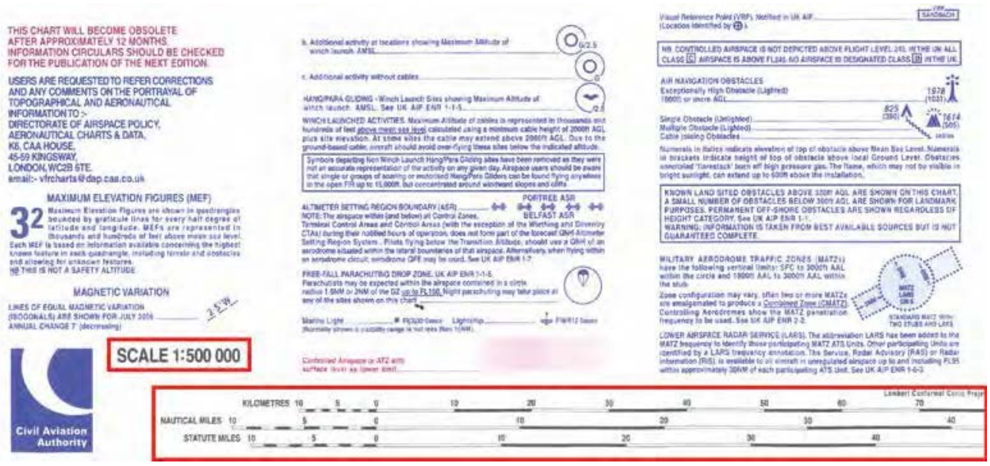

Figure 5.10 Two ways of indicating scale, shown on a 1:500 000 aeronautical chart.

Scale may also be written in words such as "One centimetre equals one kilometre" or "One inch equals one mile".

Charts are often referred to as large scale or small scale. A large scale chart is one which shows greater detail because the fraction expressing the scale, for instance, 1/50 000, is a fraction of greater value than that expressing the scale of a small scale chart, for instance 1/500 000. You will remember from your mathematics lessons that the larger the number on the bottom line of a fraction, the smaller the value of the fraction. Maps of the world which fit onto two pages of an atlas are of very small scale, 1:100 000 000 being typical.

In your VFR cross-country flying, you will doubtless be using the 1:500 000 scale chart quite often; three of these charts cover the United Kingdom. You will find that the 1:500 000 chart (popularly known as the "half mil") is divided into rectangles of half a degree (30') of latitude and longitude. As one minute of latitude measured along a meridian of longitude is equal to one nautical mile, the marks along the lines of longitude, which indicate latitude, can be used for measuring distance, by employing a pair of dividers.

Figure 5.11 Graduations along a meridian of longitude: – one minute of latitude equals one nautical mile; 30' equals 30 nm.

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PROPERTIES OF AN IDEAL AERONAUTICAL CHART.

Although, as you have seen, the spherical surface of the Earth can never be represented on a two-dimensional chart without the Earth's surface undergoing some deformation, a high degree of accuracy can be achieved amidst the inevitable distortions. If the ideal chart could ever be produced, its properties might be summed up as follows.

- Land masses should be represented with their true shape on the chart.
- Areas on the Earth's surface should be shown as proportionally equal areas on the chart. If the shape and area of features on a chart are not accurate, scaled-down versions of the same areas on the Earth's surface, then the chart may confuse the navigator.
- Angles on the Earth's surface should be represented by the same angles on the chart.
- Scale should be constant and correct.
- Rhumb Lines should be straight lines.
- Great Circles should be straight lines.
- Latitudes and Longitudes should be easy to plot.
- Adjacent sheets should fit correctly.
- Coverage should be worldwide.

VFR Aeronautical Charts.

The two most widely used charts used in visual air navigation, in the United Kingdom, are the ICAO 1:500 000 series of charts and the UK CAA 1:250 000 series.

As we have seen, both types of chart, which, if we take individual sheets from the series, cover only relatively small areas of the Earth's surface, achieve quite a high level of success in reproducing many of the ideal properties of an aeronautical chart.

On both charts, a straight line drawn to represent the desired track between two locations, represents a straight line on the Earth's surface for the area covered by the chart. A straight line on a UK CAA 1:250 000 series chart is a rhumb line. On the ICAO 1:500 000 chart, a straight line represents a great circle on the Earth. However, over the area represented by each 1:500 000 sheet, there is no discernable difference between a great circle and a rhumb line.

Distances are accurate over both charts, and, in practical terms, shape and scale are conserved.

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CONCLUSION.

All navigation charts, then, are projections which, though the task is not perfectly achievable, attempt to conserve on a flat surface as many of the characteristics of the true surface of the Earth as possible, to a greater or lesser degree of accuracy. For a navigator, the most desirable characteristic is to conserve accuracy of direction with respect to meridians of longitude and parallels of latitude because, if their coordinates are accurate, it is relatively easy for the navigator to determine where he is on the Earth's surface and to plot bearings and tracks to get from one place to another. If there is distortion of surface area and distance, those are disadvantages but not major ones.

Both the ICAO 1:500 000 series of charts and the UK CAA 1:250 000 series exhibit many of the properties of an ideal chart.

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Representative PPL - type questions to test your theoretical knowledge of Aeronautical Charts and Chart-Making.

1. One inch on a 1:500 000 scale map represents:

    a. Approximately 10 nautical miles
    b. Approximately 5 nautical miles
    c. Approximately 8 nautical miles
    d. Approximately 7 nautical miles

2. Three centimetres on a 1:250 000 scale chart represents:

    a. Approximately 2.5 nautical miles
    b. Approximately 4 nautical miles
    c. Approximately 2.5 kilometres
    d. Approximately 7.5 nautical miles

3. On a chart with a scale of 1:1 000 000, 20 cm represents:

    a. 116 nm
    b. 86 nm
    c. 40 nm
    d. 108 nm

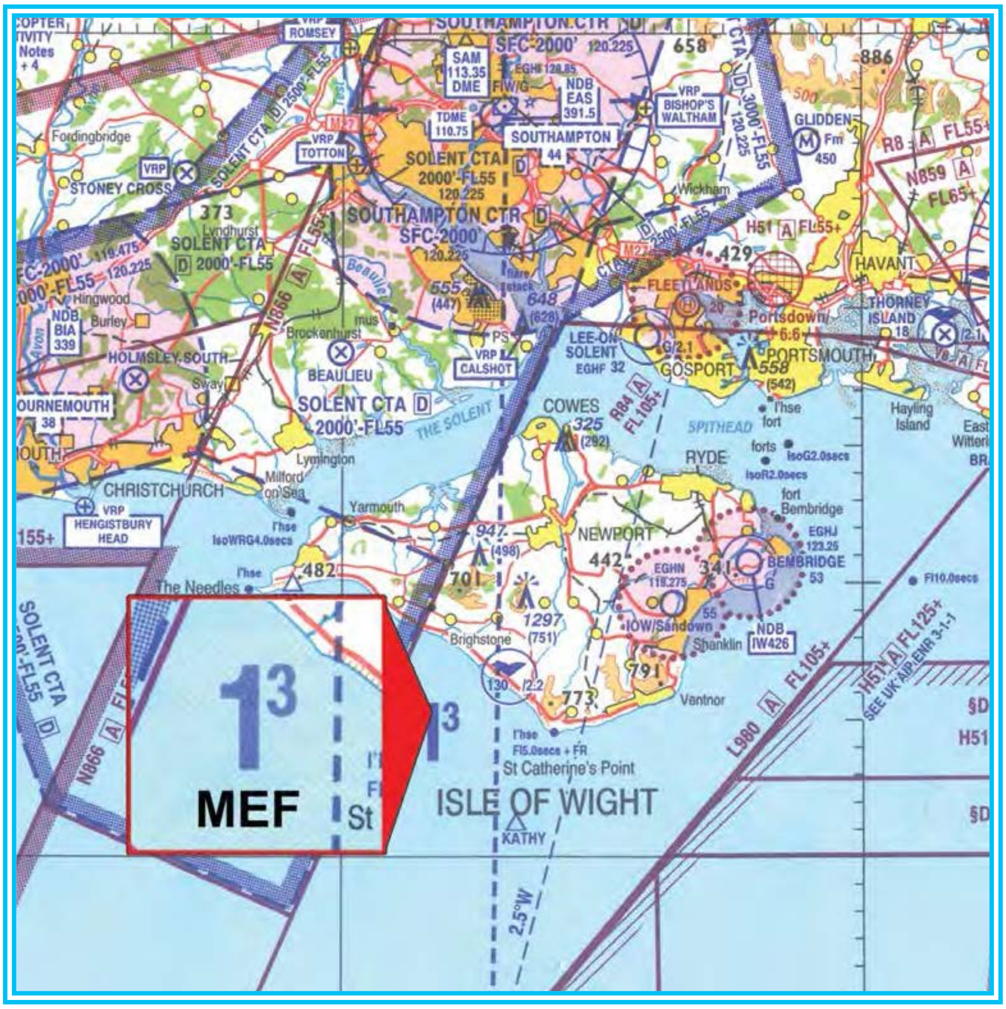
4. Given a chart scale of 1:1 000 000 what is represented by a chart distance of 8 inches?

    a. 103 nm
    b. 110 nm
    c. 115 nm
    d. 153 nm

Question	**1**	**2**	**3**	**4**
Answer				

The answers to these questions can be found at the end of this book.

CHAPTER 6
FEATURES ON AERONAUTICAL CHARTS



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INTRODUCTION.

By using aeronautical charts, pilots are able to measure and mark their desired track to a destination or turning point and to determine their position along that track. En-route navigation aids and relevant radio frequencies can be identified from the chart, as can the boundaries of controlled airspace, possible diversion airfields and other useful aeronautical information, such as terrain and obstacle elevation, essential to the safe conduct of the flight.

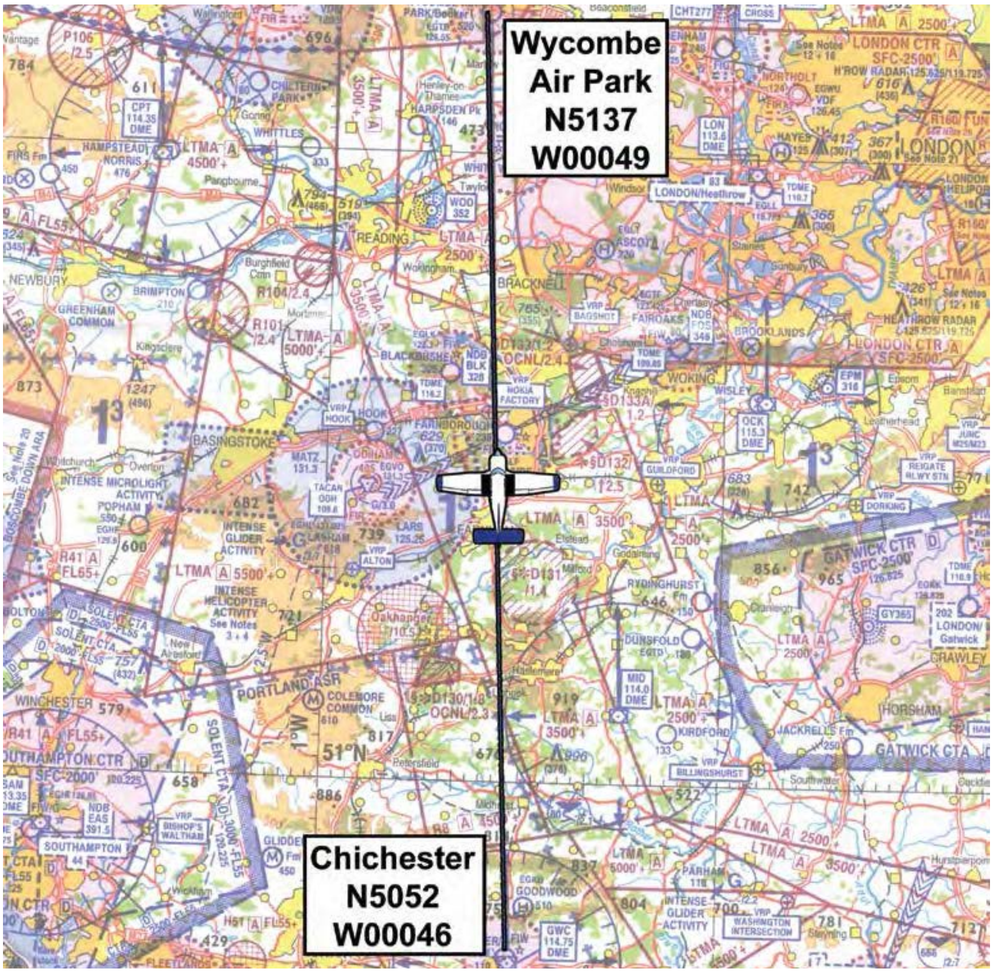

Figure 6.1 Aeronautical charts enable pilots to determine track and position. Aeronautical charts contain details of controlled airspace, terrain elevation and other information essential to the safe conduct of the flight.

As we have seen, the two most common aeronautical charts used by pilots for visual navigation, the ICAO 1:500 000 and UK CAA 1:250 000 charts, contain many of the characteristics required of an ideal chart. However, apart from an aeronautical chart needing to be accurate in terms of angles and distances, one other very important quality that a VFR pilot requires in an aeronautical chart is that it should clearly display all the necessary features and aeronautical information that he needs for visual navigation. The pilot must be able to read and interpret information from the chart rapidly and with ease, in order that he can pinpoint his position along track, recognise any deviation from track, and continue to conduct his flight safely without infringing controlled airspace.It is impractical that aeronautical charts should show every detail of ground features, in the way that road maps and Ordnance Survey maps

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do. Aeronautical charts must contain only those features and items of information which are essential for the pilot to carry out a successful, safe navigation flight. Such information will include, for instance, high ground and obstacles, to enable the pilot to maintain safe vertical separation from the ground. Regulated airspace is also marked, so that the pilot knows where he can and cannot fly. Motorways, railway lines, large towns, and rivers are clearly shown, so that the pilot can pinpoint his position.

Figure 6.2 Aeronautical charts must contain only those features and items of information which are essential for the pilot to carry out a successful, safe navigation flight.

THE ESSENTIAL FEATURES MARKED ON AN AERONAUTICAL CHART.

On the **1:500 000** and **1:250 000 aeronautical charts**, these essential features appear in the form of symbology which, for the most part, is recognised internationally.

This symbology represents the following principal features, among others:

- **topography**, (terrain detail and relief, including spot heights of terrain and obstacles).
- **hydrography**, (water features: rivers, canals, lakes, seas and oceans).
- **man-made constructions**, (cities, conglomerations, towns, villages, roads, railways, obstructions, forests, and even “white horses”).
- **details of controlled and uncontrolled airspace** (control zones, control areas, airways, air traffic zones, danger areas, prohibited areas, restricted areas etc).
- **radio navigation aids**, (VOR/DME beacons, NDBs, VDF equipped airfields, TACANs etc).

Both the 1:500 000 and the 1:250 000 aeronautical charts are topographical charts. As the scale of the 1:500 000 chart is particularly suited to the speeds and altitudes flown by general aviation aircraft, on VFR cross country flights, that is the chart to which we refer primarily in this book. The particular sheet we shall be using is 2171CD, Southern England and Wales.

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If it is necessary to have greater detail than that shown on the 1:500 000 chart, for instance, if a difficult-to-spot feature is needed as a fix, or if a pilot is approaching an unknown aerodrome or airfield, the 1:250 000 chart may be used.

For the study of this and subsequent chapters in the General Navigation section of this book, you should have your own up-to-date 1:500 000 aeronautical chart at hand. You should study your chart closely and regularly, and familiarise yourself with the detail of its symbology which is explained in the key or legend usually situated in the bottom left-hand corner of the chart.

You should particularly endeavour to become familiar with and recognise, as early as possible in your flying career, the following characteristics and features of the aeronautical chart that you use regularly.

- Terrain relief and elevation of terrain and obstacles.
- Spot elevations.
- Maximum Elevation Figures (MEF).
- Controlled airspace (control zones (CTR) control areas (CTA and TMA) and airways).
- Aerodrome traffic zones (ATZ).
- Prohibited areas.
- Danger areas.
- Restricted areas.
- Bird sanctuaries.
- Military low flying areas.
- Areas of intense aerial activity.
- Radio navigation facilities (VOR/DME beacons, NDBs, TACANs etc).
- Magnetic information (isogonals).
- Sites of other aerial activities (microlights, gliding, ballooning, parachuting, etc.).

Terrain and obstacle elevation, knowledge of which is essential to a pilot in order that he may calculate and maintain a safety height, is covered in a little more detail, later in this chapter, as is regulated and controlled airspace. Magnetic information has been dealt with in Chapter 3.

In the navigation skills test, after the first leg has been flown, you may be asked to confirm your position by reference to radio-navigation aids, and could be tasked by the examiner with basic radio-navigation tracking.

Radio-Navigation Aids on the 1:500 000 Chart.

Radio navigation is covered in the second part of this book. Learn the symbology for radio-navigational aids well *(See Figure 6.3 overleaf).* In the navigation skills test, after the first leg has been flown, you may be asked to confirm your position by

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Figure 6.3 Radio-navigation aids shown on a 1:500 000 aeronautical chart.

reference to radio-navigation aids, and could be tasked by the examiner with basic radio-navigation tracking. Seek your flying instructor's advice on these tests and procedures.

Figure 6.3 includes details of several radio-navigation aids. Consult your own chart, in order to examine the detail. This section of the 1:500 000 chart includes the Daventry VOR/DME with its compass rose orientated on magnetic north and its VHF frequency of 116.4 MHz; this VOR/DME, as you see, is not situated at an aerodrome, though many are, but serves as a beacon for IFR traffic in the Daventry Control Area. There is also the NDB at Oxford Kidlington with its frequency of 367.5 kHz, and the Terminal DME on 108.35 MHz.

The converging line symbol to the North of Oxford Kidlington, containing a series of "chevrons" pointing towards the aerodrome, indicates that there is an instrument approach procedure at Oxford Kidlington. This symbol is attached to aerodromes outside regulated airspace which have one or more instrument approach procedures. It is strongly recommended that pilots contact the aerodrome's Air Traffic Services Unit if flying within a radius of 10 nautical miles of such an aerodrome.

The Oxford Kidlington NDB is not indicated by the standard NDB symbology of concentric broken circles; but standard symbology does indicate the NDB, BZ386 (386 kHz is its frequency) at Royal Air Force Brize Norton. RAF Brize Norton also has a military radio-navigation aid called TACAN (TACtical Air Navigation). The DME facility of the TACAN is also useable by civilian traffic.

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Finally, you will notice that the chart indicates that the VHF frequency of 124.275, Brize Radar's frequency, providing a Lower Airspace Radar Service (LARS), also gives the pilot access to a VHF Direction Finding (VDF) service.

As mentioned, the majority of these radio-navigation aids are covered in the second part of this book. However, for the PPL theoretical knowledge examinations and skills test, a pilot needs only a basic knowledge of, and competence in, the use of radio-navigation aids. Those pilots who wish to make a deeper study of radio-navigation, perhaps in order to prepare for an IMC Rating, may wish to consult OAAmedia's interactive CD-ROM entitled 'The IMC Rating & Instrument Flying'.

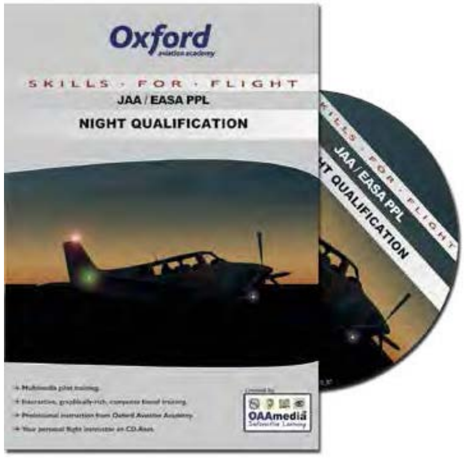

Figure 6.4 OAAmedia's interactive CD-Rom on 'The IMC Rating & Instrument Flying'.

The other items in the list on *Page 85* are dealt with in the Air Law & Operational Procedures volume in this series of manuals.

It is only through study of the aeronautical chart itself, and of its legend, that you will learn to recognise instantly the features on your chart which are essential to safe visual navigation.

It is only through study of the aeronautical chart itself, and of its legend, that you will learn to recognise instantly the features on your chart which are essential to safe visual navigation.

Always Carry an Up-to-Date Chart.

The aeronautical chart should be a pilot's constant companion; not that he needs continuously to read the chart in flight, but it should always be within reach, and the pilot needs to be fully familiar with the information it contains, be able to read it fluently, whenever necessary, and to use it in accordance with sound navigational techniques. **Remember, however, that features may not stand out so prominently on the ground during an actual flight as they appear on the chart, especially if visibility is poor or the ground is in cloud shadow.**

Both the 1:500 000 and the 1:250 000 scale charts are updated regularly, the current version of the chart being detailed in Aeronautical Information Circulars.

Some changes of importance (e.g. airspace changes) take place between chart issues. Details of such changes are contained in NOTAMs and in the Aeronautical Information Publication (AIP). In this case, it is prudent to make a hand-drawn amendment of your chart until the next issue becomes available.

Chart updates are published on the United Kingdom CAA website, currently at **www.caa.co.uk**, under "airspace policy" and "aeronautical charts".

Be aware that the law requires you always to carry with you up-to-date versions of all the charts required to carry out any flight, including charts containing details of diversions.

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Be aware that the law requires you always to carry with you up-to-date versions of all the charts that are required to carry out any flight, including charts containing details of deviations.

Differences in Information Shown on the 1:500 000 and 1:250 000 Charts.
1:500 000 aeronautical charts depict topographical features above 500 feet above mean sea-level, and obstacles above 300 feet above ground level. Aeronautical information, such as details of controlled airspace, is contained in the 1:500 000 chart up to Flight Level 195.

The UK CAA 1:250 000 aeronautical chart depicts surface topographical detail similar to that contained in the 1:500 000 chart, though the 1:250 000 chart shows terrain contours above 200 feet above mean sea-level. However, controlled airspace is depicted only up to 5000 feet altitude or Flight Level 55 if vertical limits are given as flight levels.

The 1:250 000 chart should, therefore, be used only for that part of a cross-country flight which takes place below an altitude of 5000 feet. (Beware, too, that if the pressure at sea-level is below 1013.2 millibars, the pressure datum for flight levels, the base of controlled airspace not shown on the chart may be below 5000 feet). (*See Chapter 10* on Altimetry.)

Both the 1:500 000 and the 1:250 000 charts also include local magnetic variation in the form of isogonals, and details of radio frequencies.

TERRAIN AND OBSTACLE ELEVATION ON THE 1:500 000 AERONAUTICAL CHART.

Terrain Elevation and Depiction of Terrain Relief.
The elevation of terrain and obstacles is, by definition, measured from mean sea level, whereas the height of an obstacle is measured from ground level.

Portrayal of Relief.
Figure 6.5 depicts a section of the 1:500 000 chart which features Snowdonia in Wales, together with a key to terrain elevation which is printed in the legend at the bottom left corner of the chart. Tinted colours and contours are used to show ground relief and elevation. Contours are shown for 500 foot intervals.

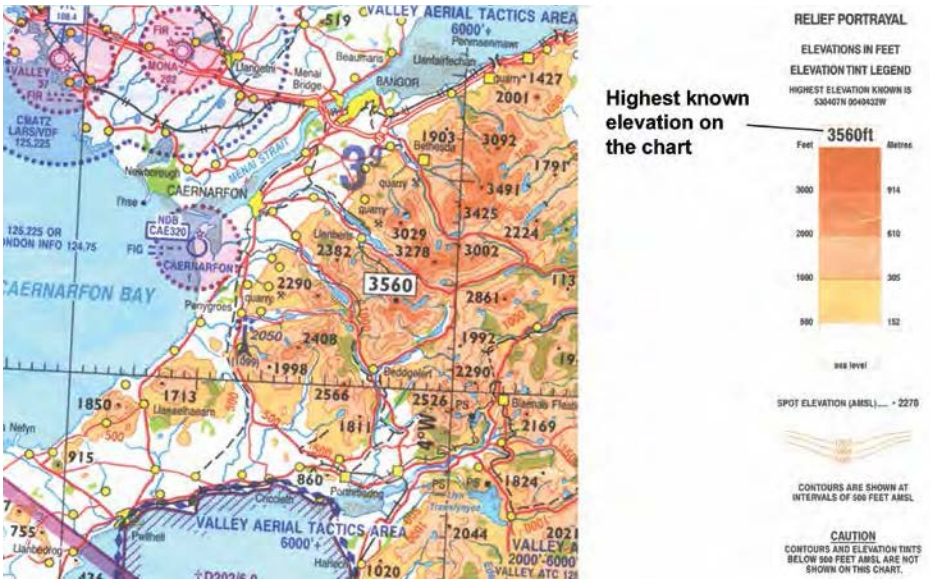

Figure 6.5 Depiction of terrain elevation.

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The coloured tints make it easier to see changes in ground relief when map reading. Different shades of colour are used for the various bands of terrain elevation. Note that the chart legend depicts the value of the highest known elevation on the chart, in this case, the elevation of the summit of Mount Snowdon. On the chart itself, other significant elevations (the summits of other mountains) are shown as spot elevations.

As you have learnt, no contours or elevation tints are shown for terrain below 500 feet. Consequently, all the white areas on the chart depict terrain lower than 500 feet above mean sea level.

Note that the green areas on the chart indicate wooded areas, and built-up areas are coloured yellow. These two colours have nothing to do with elevation.

Maximum Elevation Figures (MEF).

The 1:500 000 chart is divided into quadrangles bounded by black graticule lines, every ½ degree of latitude and longitude. Maximum Elevation Figures (MEF) are shown, in blue, within each quadrangle, in thousands and hundreds of feet. Each MEF is based on the highest obstacle or terrain elevation within the quadrangle. If the object is a man-made obstruction, e.g. a television mast, its elevation will be precisely known so the elevation is simply rounded up to the next 100 feet to give the MEF. In *Figure 6.6,* the MEF is 1^3 because the highest point in that quadrangle is a mast whose elevation is 1 297 feet. If the highest point is a spot elevation, 300 feet is added to the elevation and then the figure is rounded up to the next 100 feet. 300 feet is added because an obstacle of up to 300 feet in height may be constructed on the summit of a hill or mountain without any requirement to notify the authorities.

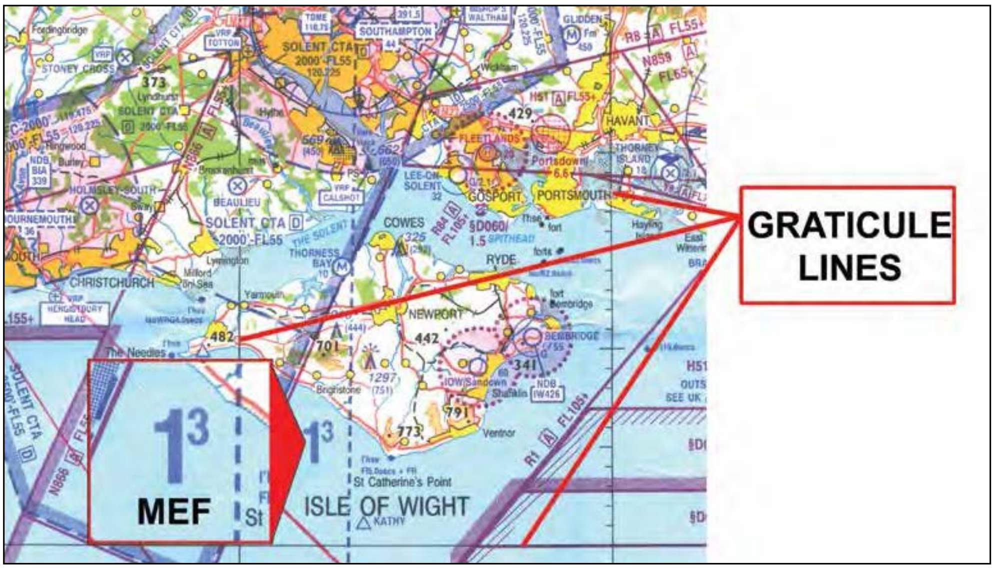

Figure 6.6 Maximum Elevation Figures.

Thus, any given MEF is either the highest obstacle, rounded up to the next 100 feet, or the highest spot elevation plus 300 feet, rounded up to the next 100 feet. For instance, in *Figure 6.5*, as the summit of Mount Snowdon is 3 560 feet above sea level, 300 feet is added to that elevation and then rounded up to the next hundred feet to give 3 900 feet. Thus, the MEF for the quadrangle in which Mount Snowdon is located is shown as 3^9. Note that MEFs are not safety altitudes.

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Air Navigation Obstacles.

An MEF is NOT a Safety Altitude!

An Air Navigation Obstacle is a radio or TV mast, a high chimney or any other high obstacle other than high ground. All such obstacles that are more than 300 feet above ground level are shown on the 1:500 000 chart. Each obstacle has two figures beside it. The figure in bold type shows the elevation of the top of the obstacle. The figure in brackets shows its height above ground level. The mast in *Figure 6.6* rises to an elevation of 1 297 feet or to 751 feet above the ground.

REGULATED AIRSPACE.

The figure in bold type next to an obstacle gives its elevation above mean sea level. The figure in brackets gives its height above ground level.

Regulated airspace refers to all airspace in which the movement of aircraft is regulated in some way. Examples are airways, control zones, control areas, restricted areas, prohibited areas and danger areas. On the 1:500 000 chart, regulated airspace is shown only up to Flight Level 195.

The vertical limits of all regulated airspace on the chart are shown either as altitudes or flight levels. For instance, the Control Area (CTA) surrounding Lyneham *(See Figure 6.7)* stretches vertically from an altitude of 3 500 feet to Flight Level 65, (i.e. 6 500 feet with respect to the pressure datum of 1013.2 millibars).

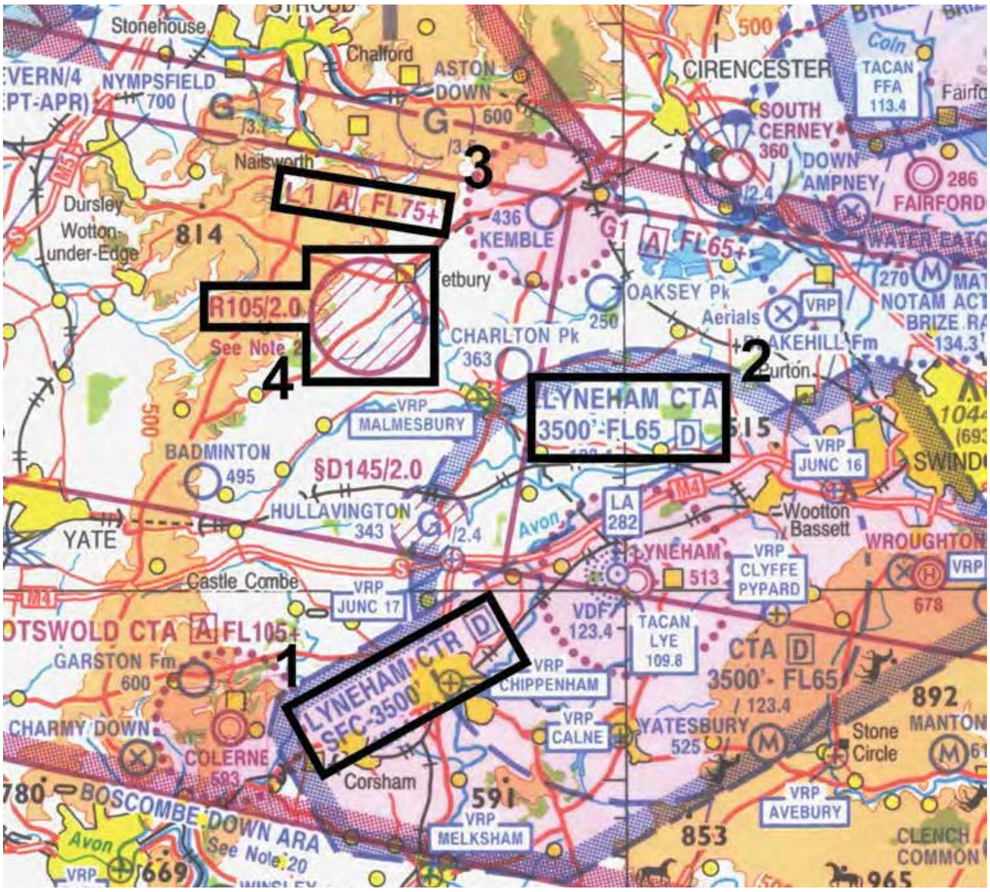

Figure 6.7 Four examples of Regulated Airspace on a 1:500 000 chart.

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Figure 6.7 highlights the following regulated airspace.

1. The Lyneham Control Zone (CTR) which has vertical limits from the surface to an altitude of 3 500 feet.
2. Lyneham CTA stretching from 3 500 feet to Flight Level 65 (FL65).
3. Airway Lima 1 which has a base of FL75 and which extends upwards to the ceiling of lower airspace at Flight Level 195. You will note that this vertical extent is marked as FL75+. The (+) sign means "up to FL195". The letter A denotes that the airway is Class A airspace.
4. Restricted Area R105 which has an upper limit of 2 000 feet. This restricted area is shown as R105/2.0. R105 identifies the restricted area itself, and 2.0 indicates "from the surface to 2 000 feet altitude".

Certain Restricted, Prohibited, Danger and High Intensity Radio Transmission Areas may have the phrase "See Note .." alongside; this refers to the notes in the Reference to Air Information section of the legend at the lower left corner of the Chart,, which gives additional information on certain areas of regulated airspace.

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Representative PPL - type questions to test your theoretical knowledge of the Features on Aeronautical Charts.

1. On the UK 1:500 000 aeronautical chart what does the symbol refer to?

   a. The direction of approach to the primary runway of a civil aerodrome
   b. The climb-out lane for IFR traffic departing the primary runway of a civil aerodrome
   c. The localiser of an Instrument Landing System
   d. A civil aerodrome, outside regulated airspace, which has one or more instrument approach procedures

2 . On the 1:500 000 aeronautical chart, in each quadrangle bounded by lines of latitude and longitude, at half degree intervals, there is a two-digit figure, the first digit being twice as large as the first. What does this two-digit figure denote?

   a. The minimum separation distance to be maintained from the highest obstacle in the quadrangle concerned, the first digit indicating thousands of feet and the second digit indicating hundreds of feet
   b. The safety altitude for the quadrangle concerned, the first digit indicating thousands of feet and the second digit indicating hundreds of feet
   c. The Maximum Elevation Figure for the quadrangle; but this is not a safety altitude; the first digit indicates thousands of feet and the second digit indicates hundreds of feet
   d. The safety height for the quadrangle concerned, the first digit indicating thousands of feet and the second digit indicating hundreds of feet

3. If the highest obstacle in a quadrangle on the ½ million chart is a TV mast of elevation 1 130 feet what would you expect the MEF to be?

   a. 1^2
   b. 1^3
   c. 1^4
   d. 1^5

4 . A vertical obstruction symbol on a 1:500 000 aeronautical chart of the United Kingdom has the following figures printed next to it: 656 (263). What is the meaning of these figures?

   a. The obstacle rises to 263 feet above mean sea level, and should be overflown at a minimum altitude of 650 feet
   b. The obstacle rises to 656 feet above mean sea level and 263 feet above ground level
   c. The obstacle rises to 656 metres above mean sea level and 263 metres above ground level
   d. The obstacle rises to 263 metres above mean sea level and should be cleared by a minimum separation distance of 656

Question	1	2	3	4
Answer				

The answers to these questions can be found at the end of this book.

CHAPTER 7
MEASURING TRACK ANGLE AND TRACK DISTANCE

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INTRODUCTION.

Having learnt something about aeronautical charts, direction, speed, distance and time, you are now ready to learn how to use this knowledge in order to develop the techniques and skills required to prepare a cross-country flight and to carry out effective visual navigation, in the air.

In this chapter, you will learn how to:

- measure the true bearing or true track angle of a desired track drawn on an aeronautical chart, between start point and destination.
- measure distance along track.
- plot your aircraft's position along track.
- identify the position of a location, using latitude and longitude.

In order to get the most out of this chapter, you will need a copy of a 1:500 000 scale aeronautical chart of Southern England, a navigation protractor and a navigation rule.

Measuring Track Angle.

The first thing to do if you are planning to fly directly from one location to another on the Earth's surface is to draw a line, or lines, on the chart to mark the track along which you wish to fly. The line drawn on the chart joining your point of departure to your destination or turning point is called the required track or true track. When there is more than one required track, each track is called a leg. Having drawn the track, or tracks, on your chart, begin by measuring the true bearing or true angle of each track; that is, the angle of the track with respect to True (geographical) North.

We will assume that you wish to fly a cross-country flight from Oxford Aerodrome to Wellesbourne Mountford Aerodrome via Ledbury.

In order to measure the true angles of the required tracks, use a navigation protractor of the type illustrated in *Figures 7.1a* and *7.1b*.

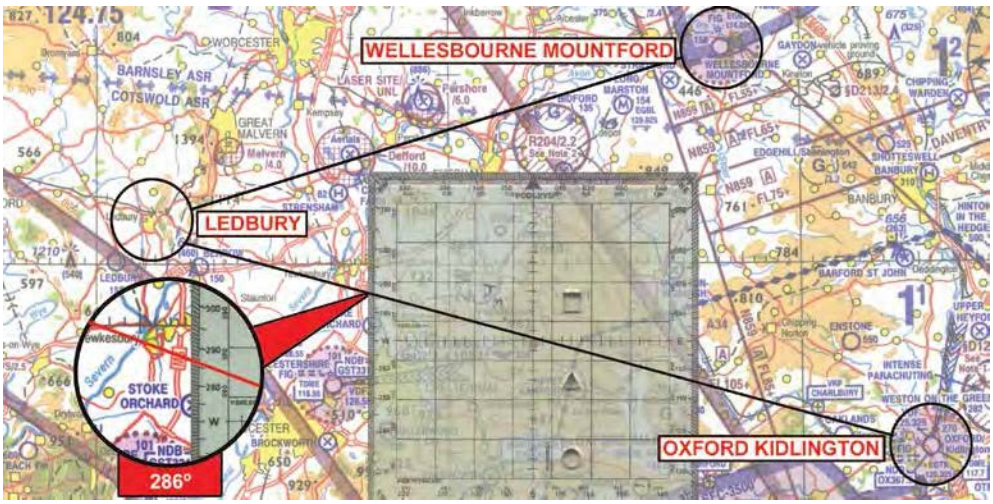

Figure 7.1a Measuring the True Track Angle from Oxford Kidlington to Ledbury: 286° (True).

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Measure the True Track Angle of your track lines from the mid-track position.

The protractor has a graticule on it which allows you to align it accurately with the North-South lines (that is, the meridians of longitude) on the chart.

On the 1:500 000 chart illustrated, straight lines represent great circles. Place the centre of the protractor over the approximate mid-point of the track from Oxford to Ledbury and align its North-South line with the mid-track line of longitude, making sure the north-pointer on the protractor is pointing North. Then, read off the true track angle from the markings at the edge of the protractor. You see that the track angle is 286° (True). (*See Figure 7.1a.*)

If there were no wind, if magnetic variation were zero, and if there were no compass deviation errors, the track angle of 286°(True) would be the heading you would fly to get from Oxford Kidlington to Ledbury. However, all those factors have to be taken into account, as you will learn in later chapters. For the moment, though, you must just measure your true track angle.

Follow the same procedure for the track from Ledbury to Wellesbourne Mountford. You may find that, when you place the protractor over the mid-point of the track, the edges of the protractor extend beyond the ends of the track, making it difficult to read the track angle correctly. In this case, move the protractor to the left along the track, keeping the protractor's north-south lines aligned with the meridians of longitude on the chart, until the track appears from under the edge of the protractor as shown in *Figure 7.1b*. The track angle for this leg of the flight is 072° (True).

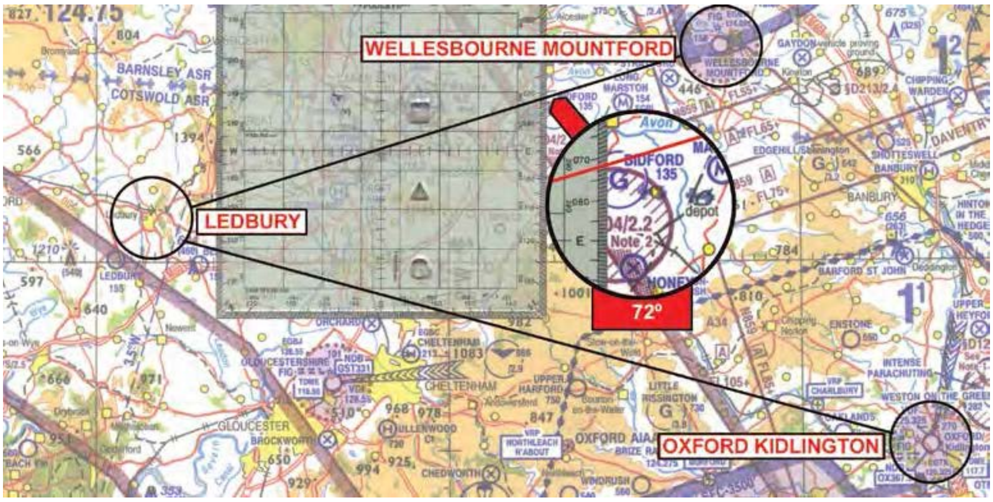

Figure 7.1b Measuring the True Track Angle from Ledbury to Wellesbourne Mountford: 072°(True).

Always make a gross error check of the Track Angles that you measure. It is easy to misalign a square protractor.

Always ensure that you make a gross error check on the bearing you have measured for your track. It is easy to misalign a square protractor, for example, to lay it on the chart with its North direction pointing East, West or South. A mistake of this nature, could put your track out by 90°, 180° or 270°.

Measuring Distance Along Track.

Measuring the distance between any two points along track is straightforward. Navigation rules are graduated in statute miles, nautical miles and kilometres, usually with scales for both 1:500,000 and 1:250,000 scales.

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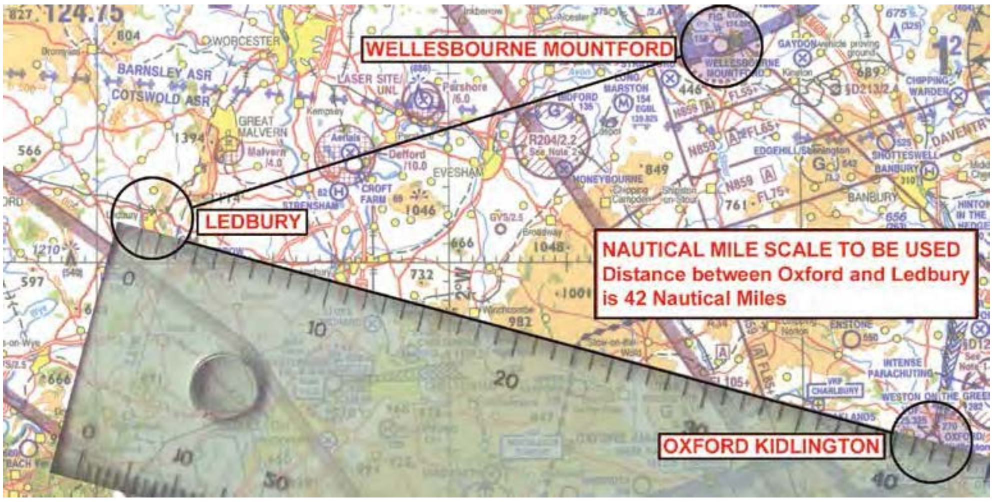

Figure 7.2 Measuring distance with a navigation rule.

To measure a distance with a navigation rule, select the scale and the distance marks you require, lay the rule along the track with zero at one end of the track, and read off the distance directly. *(See Figure 7.2.)* Nautical miles are the most commonly used unit of distance in aviation. You should find that the distance from Oxford to Ledbury is 42 nautical miles. The distance from Ledbury to Wellesbourne Mountford is 32 nautical miles.

Remember, too, that a minute of latitude equals one nautical mile. *(See Figure 7.3.)* So, if you have a pair of dividers, you can use them to measure the latitude minute marks along one of the whole-degree meridians of longitude on the chart, and then to measure track distance. Please be aware that under no circumstances should you work out distance measuring along a line of latitude.

Minutes of Latitude marked on the chart are at intervals of one nautical mile. Using dividers, these marks can be used to measure distance.

Figure 7.3 One minute of latitude is equal to one nautical mile.

Having determined the true track angle of each of the legs of your planned flight, and measured the distance along track, you may now enter these values in the flight log that you are preparing for your cross-country trip. The true track angle is entered into the column headed TK(T). (*See Figure 7.4.*)

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Enter the true tracks and distances in your flight log.

VFR FLIGHT LOG

DATE:		T/O:		LOG:			FLT TIME:						
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LEDBURY					286					42 nm		
LEDBURY	WELLESBOURNE MOUNTFORD					072					32 nm		
ALTERNATE													

FUEL	
TO DESTINATION	
TO ALTERNATE	
10% CONTINGENCY	
45 MIN HOLDING	
TOTAL REQUIRED	
TOTAL ON BOARD	
ENDURANCE	

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

Figure 7.4 A VFR Flight Log.

PLOTTING POSITION.

During your cross-country flight, you must be able to confirm your position at the appropriate times.

You will learn when you should check your position along track in a later chapter. It is an essential skill of the pilot-navigator that he be able to plot his position along track; for only then will he know if the forecast winds are correct, and/or if he is holding his heading and speed accurately. Determining position will either confirm that the flight planning assumptions were correct, or else enable the pilot to make the necessary corrections in heading and update estimated times of arrival at turning points and destination.

Marking Position Marks on the Chart.

Though they are not often used in visual air navigation, there are two position marks which we must introduce at this point, as you will often come across them in navigation theory.

Ground Position.

If in flight, you are able positively to confirm your position by reference to a ground feature, this position is marked by a small circle with a dot in the middle, as shown in *Figure 7.5.* This symbol is used to mark ground position. If the ground position is not on track but, say, to the left of track, as shown in *Figure 7.5*, and you have been flying accurately, then obviously the forecast wind strength and/or direction were incorrect.

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Figure 7.5 Ground position to the left of track.

Confirming **ground position** in this way is known as getting a fix.

Dead Reckoning Position.

If when you mark your ground position, you see that you are on-track, and have covered the distance calculated in the expected time, you will be confident that the forecast wind was accurate and that your flying has also been accurate. But, if you are happy with your flying accuracy but find that you are off-track and "off-distance", as depicted in *Figure 7.5*, then you will deduce that the forecast wind was not 100% correct. Nevertheless, based on the amount by which you are off-track and off-distance, you can make a revised estimate of wind strength and direction and, as you will learn to do later, calculate a new heading, and revise your groundspeed. You should do this in such a way as to be able to obtain a time over a new ground feature.

If after the newly calculated time, you still can not positively identify a ground feature in order to fix your position, you should determine a dead-reckoning position by calculating the track and distance flown since your previous fix, based on your best estimate of the wind, and mark the position you think you are at, with a small triangle with a dot in the middle. This symbol, depicted in *Figure 7.6*, is known as a dead-reckoning position symbol. Next to the dead-reckoning position, you should mark the time at which you believe you were at that position.

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Figure 7.6 Dead Reckoning Position Mark, when not able to obtain a Positive Fix on a ground feature.

The dead reckoning position can be used to help you find the ground feature you are seeking. When that ground feature is positively identified and you have a positive fix, you can mark your position with a ground position symbol and begin the next stage of the dead reckoning process from this point, by revising heading and groundspeed again.

READING LATITUDE AND LONGITUDE.

Latitude and longitude are used to identify positions on a chart accurately, in the way that we spoke about briefly in Chapter 1. The larger the scale of the chart the more accurately any given position can be identified. Parallels of latitude and meridians of longitude are clearly marked on the 1:500 000 aeronautical chart. *(See Figure 7.7.)*

Lines of latitude and longitude are drawn on the 1:500 000 chart at ½° intervals. The lines are numbered at 1° intervals, and each "whole-degree line" is subdivided into 60 minutes. The parallel of latitude shown in *Figure 7.7* is 52° North.

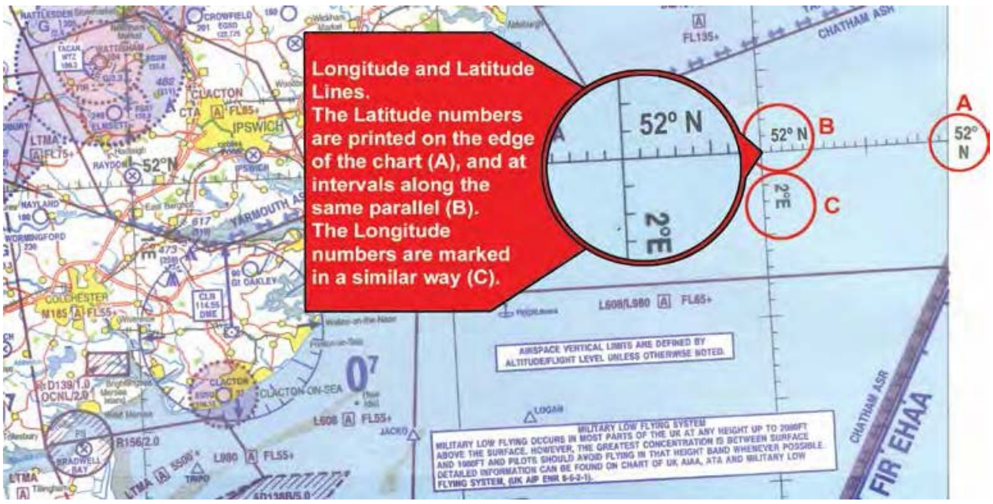

Figure 7.7 Latitude and Longitude Markings.

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Meridians of longitude are marked in a similar way to the parallels of latitude. The meridian of longitude indicated in *Figure 7.7* is 2° East.

When a position is defined by its latitude and longitude, latitude is given first, followed by longitude.

Figure 7.8 Latitude and Longitude Position.

For example, the position of Clacton aerodrome *(Figure 7.8)* is 51° 47' North (normally written as N5147) and 01° 08' East (E00108).

Note the abbreviation for latitude and longitude: N5147, E00108.

There are <u>three</u> digits making up the degrees of longitude, e.g. E00108, because longitude can range from 180°W to 180°E. With a little practice, you will easily learn both to locate and define positions by their latitude and longitude.

In defining position by latitude and longitude, latitude is given first, followed by longitude; e.g. N5147, E00108.

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Representative PPL - type questions to test your theoretical knowledge of Measuring Track Angle and Track Distance.

1. This question requires you to refer to the 1:500 000 ICAO chart of Southern England and Wales.

   With respect to the Air Navigation Obstacle at position N5033 W00400, which of the following statements is correct?

   a. It is a single obstacle (unlighted)
   b. The top of the obstacle is 2 317 feet Above Mean Sea Level and 643 feet above the ground
   c. It is a multiple obstacle (lighted)
   d. The top of the obstacle is 709 feet Above Mean Sea Level

2. Identify the location at N5056 W00359.

   a. Taunton
   b. Eaglescott airfield
   c. Okehampton
   d. Belle Vue airfield

3. Identify the location at N5130 W00102

   a. White Waltham aerodrome
   b. Goring
   c. Draycott airfield
   d. Whittles airfield

4. What is the true track angle of the direct track from Halton, EGWN, (N5147 W00044) to Leicester EGBG (N5236 W00102)?

   a. 165°(T)
   b. 348°(T)
   c. 258°(T)
   d. 075°(T)

5. What is the true track angle of the direct track from Shobdon, EGBS, (N5215 W00253) to Gloucester EGBJ (N5153 W00210)?

   a. 211° (T)
   b. 207° (T)
   c. 127° (T)
   d. 121° (T)

6. Give the latitude and longitude of EGDJ Upavon.

   a. N0145 W05115
   b. N5252 E00145
   c. N1551 E00200
   d. N5117 W00146

Question	1	2	3	4	5	6
Answer						

The answers to these questions can be found at the end of this book.

CHAPTER 8
MAP READING

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INTRODUCTION.

In a previous chapter, we explained the difference between a chart and a map, and have referred only to aeronautical charts. You will probably think us inconsistent, therefore, in calling this chapter 'Map Reading'. We do so, simply because the art of interpreting the information on aeronautical charts is called "map reading" by most speakers of English; so there is no point in our referring to it by any other name. Besides, though it is important for you as a pilot to understand the difference between maps and charts, you will already have discovered that the aeronautical chart that you must carry with you in the aircraft every time you fly is called a map by many pilots and instructors. Map reading, then, is what this chapter is about. From now on, we will use the terms chart and map interchangeably.

It is important for you to understand that when you fly using standard visual navigation techniques, you do not simply map read. That is, you do not find your way from starting point to destination by continuously following the progress of your aircraft on your chart. If you were to do this you would not have time to concentrate on flying accurate speeds, headings and times, or for the other en-route tasks such as keeping the flight log, preparing radiotelephony (RT) calls, monitoring altitude and fuel state, and scanning the airspace around you in order to avoid conflict with other traffic.

As we have stressed several times already in this book, in visual dead reckoning navigation, starting from a known location a pilot uses what he hopes is an accurate wind forecast to determine a heading to steer and, from his chosen true airspeed, calculates a groundspeed in order to predict an arrival time over a checkpoint, turning point or destination.

If the wind forecast is accurate, and your navigation calculations correct, flying accurate headings and speeds should result in your aircraft arriving over a checkpoint at the estimated time.

Visual dead-reckoning navigation, then, primarily involves flying accurate headings and speeds. If the wind forecast is accurate, and your pre-flight navigation calculations are correct, flying the calculated heading at the chosen airspeed and for the calculated time interval should result in your aircraft arriving over a checkpoint at the estimated time.

The map is consulted after the estimated time interval, usually every 5 to 10 minutes for a typical cross country flight in a light aircraft, in order to confirm position.

It is during the periodic consultations of the map that skill in map reading is crucial. A pilot needs to be able to confirm his position quickly, reading from map to ground, in order that he can make the right navigation decisions concerning the continuing of the flight. If the pilot sees that he is on track and has arrived at the predicted position on time, he can confidently continue with his calculated heading and speed, and maintain his estimated time of arrival (ETA) over the next checkpoint or at his destination.

But, if, after the calculated time, he sees that he is to the right or left of track and that the visual checkpoint is in front of or behind him, the pilot must update his heading, groundspeed and ETAs, based on his actual position, and what his actual position tells him about track and wind errors.

If the pilot is not on track and on time, he must revise his heading and ETA from the information he gleans from his actual position.

Map reading skill is, therefore, essential in order that the pilot can recognise ground features in order to check whether his aircraft is on heading, on track and on time, and so that he may update headings and timings, if necessary. The pilot must be fully familiar with the symbology of his map so that ground position may be recognised.

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STUDYING THE ROUTE.

When planning a cross-country flight, the pilot first of all draws a line on his chart. As part of the flight planning calculations (choosing routes and flight planning are covered in Chapter 12), the pilot will select appropriately prominent ground features along the route, that he will use to confirm position during the flight.

Before flight, the pilot must study the route in detail in order to extract from the chart those details of ground features, topography, airfields, airspace, etc., which are of importance to him for the safe conduct of the flight. The pilot must be able to interpret (i.e. read) the chart fluently in order to complete this task successfully. In this chapter, we are going to use a 1:500 000 chart of Southern England to demonstrate to you some important aspects of map reading.

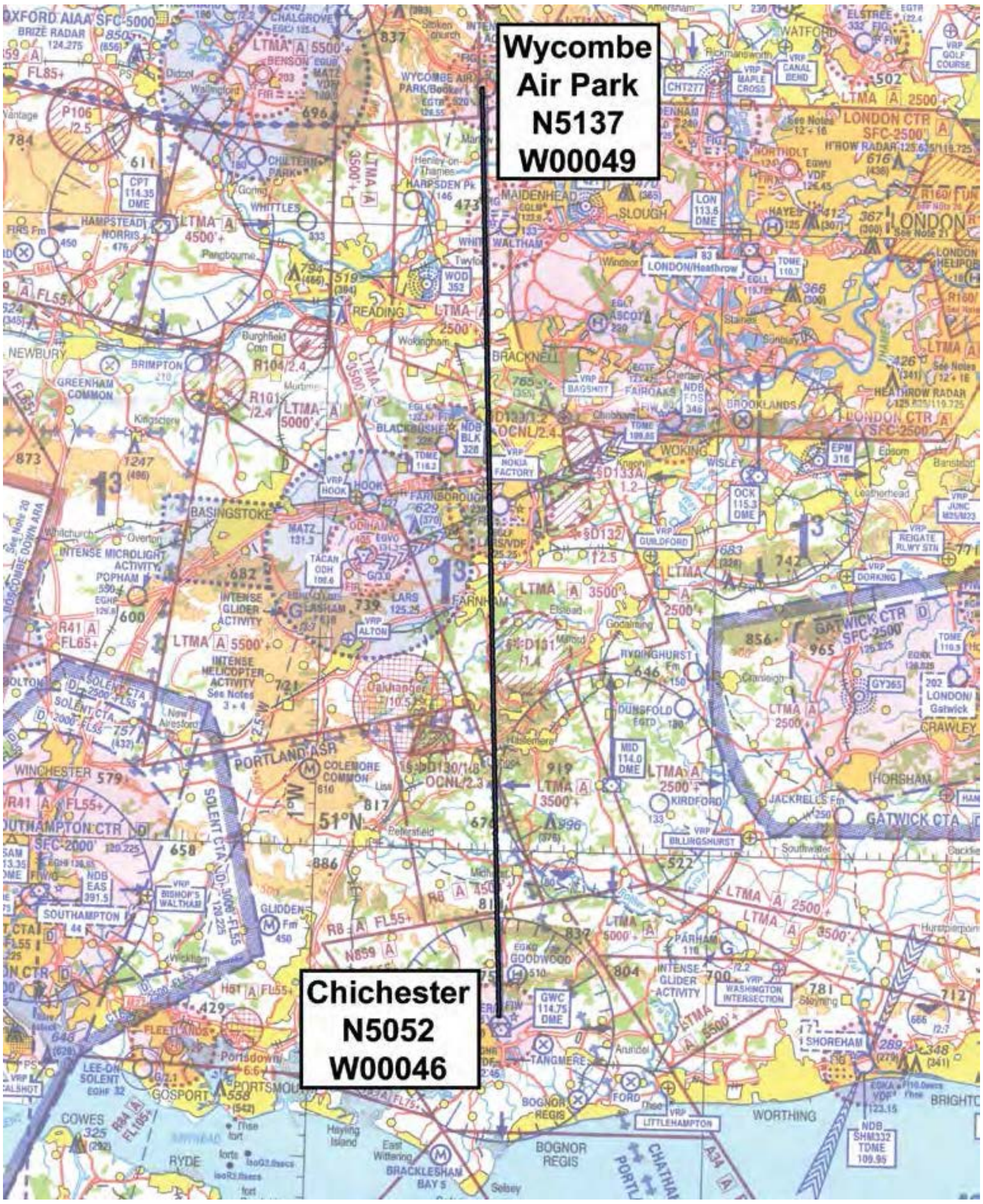

Figure 8.1 The route from Chichester to Wycombe Air Park.

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You have already been advised to study your own chart thoroughly, referring frequently to the legend in order to learn what the symbols on the chart mean. We will now take you through the study of the route of a flight from Chichester (Goodwood) Aerodrome to Wycombe Air Park *(see Figure 8.1)*, to give you practice in interpreting what the 1:500 000 chart has to tell you about that route. The study of the route is illustrated in the pages that follow, but reproducing a 1:500 000 chart in the pages of a book has its limitations, so you must have an actual chart open in front of you, if you wish to make the most of the exercise. As we move along the track from Chichester to Wycombe Air Park, we will point out relevant information contained on the chart, concerning the route being followed.

CHART LEGENDS.

As you can see in *Figure 8.2,* there are 3 main blocks of information, or **legends**, on the **1:500 000 chart of Southern England**.

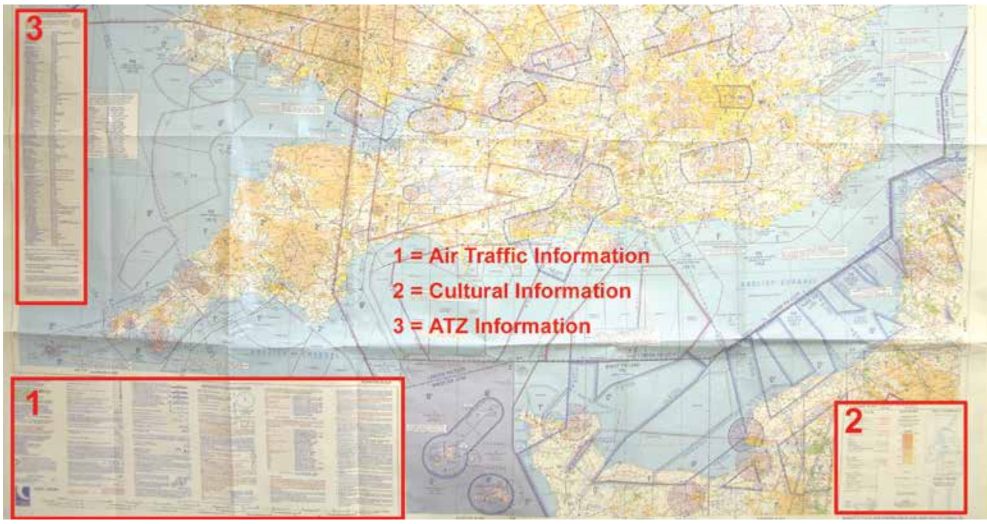

Figure 8.2 Legend boxes on the 1:500 000 aeronautical chart.

Block 1, 'Reference to Air Information', contains details of aeronautical symbols and a great deal of other pertinent aeronautical information, including regulated airspace designations.

Block 2 contains **cultural information;** that is, information on roads, railways, built-up areas and general features, as well as relief information.

Block 3 contains information on **aerodrome traffic zones (ATZs)** and gives the radio frequencies of the ATZs, both inside and outside controlled airspace. You will notice that the legend also identifies the air traffic service available within the ATZ as full Air Traffic Control Service (ATC), Airfield Flight Information Service (AFIS), or Air to Ground Radio Service (AGRS). Recent editions of the 1:500,000 chart have come with a card containing the Block 3 and Danger Area Information, facilitating easy retrieval of this information en-route.

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ROUTE INFORMATION.

Chichester Aerodrome.

First of all, let us take a brief look at the aerodrome of departure, Chichester (Goodwood). Normally, the departure aerodrome will be the one from which you conduct your local flying, and so you should know it well. But for the sake of this exercise, we will assume that Chichester is an aerodrome at which you have made an intermediate landing.

Figure 8.3 Chichester (Goodwood) Aerodrome.

The blue figure under the name Chichester / Goodwood, shows that the aerodrome has an elevation of 110 feet above mean sea level. The aerodrome lies at the centre of its own Aerodrome Traffic Zone.

A VOR/DME is located on the airfield, so if you were flying to Chichester you could back up your visual navigation using that radio aid. *(See Chapter 17 and 18).* Of course, you may also use this radio aid to help you in tracking away from Chichester; but this is not a subject for this section of the book. Chichester also has a VHF Direction Finding facility (VDF) on its ATZ frequency of 122.45.

To the South East of the aerodrome, there are three disused or abandoned airfields, and to the North North East there is a civil heliport with an elevation of 510 feet above mean sea level. The main feature of Chichester, from a navigational point of view, is that it is near the coast, and that the M27 and a railway line pass South of the airfield.

Flying North from Chichester.

Setting heading from overhead Chichester, neglecting wind, we will track 360° (M). (The true track angle is 358°(T) and the local magnetic variation, in 2007, is 2°W.)

Given the elevation of the terrain, and the base of controlled airspace along the route, 2300 feet should be a good altitude at which to fly the route.

As you fly North from the aerodrome *(see Fig 8.4a, below),* you will be flying over lightly wooded areas, with rising ground indicated by the change in relief colour from white to brown, and the presence of two spot heights, close to track, of 675 feet and then 814 feet elevation. *(See A in Figure 8.4a.)*

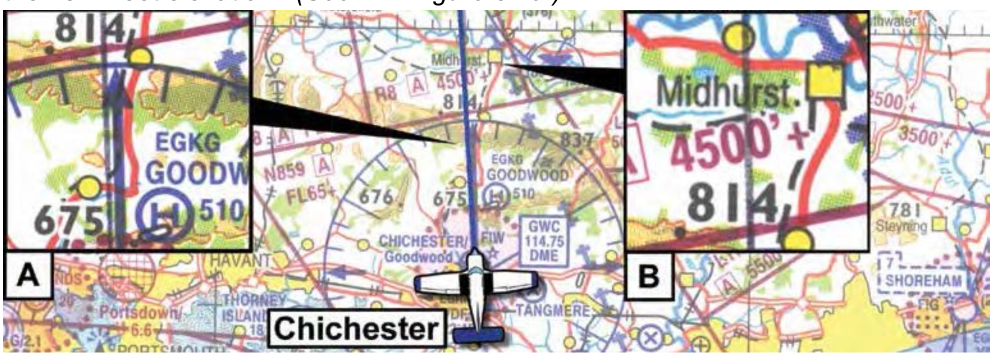

Figure 8.4a Heading North from Chichester (Goodwood).

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On leaving the ATZ, you pass Goodwood Heliport which lies to starboard. Also on the starboard side is a primary road running parallel to track which leads into the town of Midhurst, lying about 1 nautical mile to the right of track *(See Figure 8.4b, A)*. A disused railway line runs parallel to this road into Midhurst, while another disused railway line crosses your track just before Midhurst. Just to the North of Midhurst there is a river running approximately East-West. *(See Figure 8.4b, B.)*

Figure 8.4b Heading North from Chichester (Goodwood).

Controlled Airspace.

You will notice that the whole of your route is criss-crossed with maroon lines. These lines denote controlled airspace. *(See Figure 8.5.)* You must know how to determine the type of controlled airspace which lies on your route, and its vertical and horizontal limits, because you must not, under any circumstances, enter controlled airspace without a clearance from the controlling authority.

Figure 8.5 Controlled Airspace Information.

As you fly along this track, from Chichester to Wycombe Air Park, you must be aware of the lower limits of the various areas of controlled airspace that you will fly under. Further North, in the region of Bracknell and White Waltham Aerodrome, controlled airspace descends as low as 2500 feet above mean sea level, so it is important that you set your altimeter sub scale correctly with the appropriate QNH. But, for the moment, you are still in the area around Midhurst.

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Just above the 814 feet spot elevation, you will see the maroon lettering R8 A 4500'+. *(See Figure 8.5, A.)* This block of controlled airspace is the airway Romeo 8. Romeo 8 is Class A airspace with a lower limit of 4 500 feet above mean sea level. The plus sign denotes an upper limit of Flight Level 195. As long as you have Chichester Aerodrome QNH set on your altimeter, you will have the information you need to stay clear of Romeo 8.

As you pass the town of Liphook, you will pass from under Romeo 8 to fly beneath part of the London Terminal Control Area (LTMA) which has a lower limit of 3500 feet altitude. *(See Figure 8.5, B.)*

More Ground Features and Obstacles.

About 3 nautical miles to your right as you pass Midhurst, there is a hang-gliding and paragliding site. *(See Figure 8.6, A.)* The elevation of the site is 80 feet; winch launching operations take place up to an altitude of 2 100 feet. This fact is indicated by the symbol /2.1.

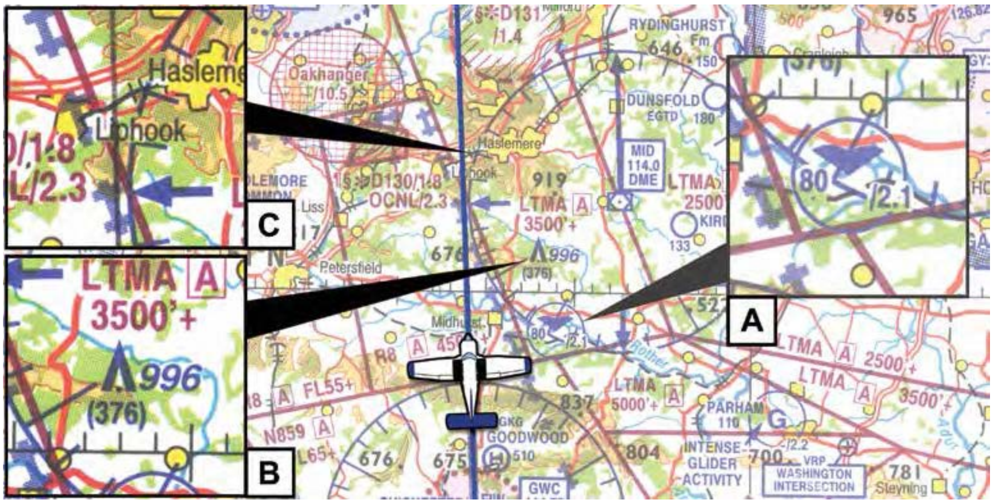

Figure 8.6 Ground Features and Obstacles.

About 3 nautical miles North of Midhurst, and 4 nautical miles right of track, is a mast, the top of which is 996 feet above mean sea level; the smaller figure in brackets gives you the height of the mast above ground level: 376 feet. *(See Figure 8.6, B.)*

Your track now takes you between the towns of Liphook and Haslemere where you cross first a dual track railway and then a dual carriageway road. *(See Figure 8.6, C.)*

Restricted Airspace.

As you pass Liphook, there are two areas of restricted airspace, close to your track, *(see Figure 8.7, opposite)*: the Oakhanger High Intensity Radio Transmission Area, which rises to an altitude of 10 500 feet AMSL (A), and the Danger Area D131 which extends to 1 400 feet altitude (B).

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Figure 8.7 Restricted Airspace Information.

The identifying letter or number of a Danger, Prohibited or Restricted Area may be preceded by one or more of a possible 3 symbols, as depicted in *Figure 8.8*.

The meanings of each symbol appear next to the symbol itself.

Civil and Military Airspace.

As you continue North towards Farnborough, you will see to the left of track a large blue circle with a "pan-handle" edged in dark blue dots. *(See Figure 8.9.)* This is the Odiham Military Air Traffic Zone (MATZ), up to 3 000ft above aerodrome level (aal). There is a contact frequency for Odiham printed under the letters, MATZ. The abbreviation LARS stands for Lower Airspace Radar Service, and the frequency applies to Farnborough, the LARS provider for this area. As your route takes you through or over the Farnborough ATZ (and you MUST have clearance to penetrate an ATZ, which is up to 2 000ft aal), you would have to call Farnborough Radar on 125.250.

Figure 8.8 Information Symbology.

Figure 8.9 Civil/Military Airfield Information.

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Farnborough can also update your QNH to help you keep clear of the London TMA, above you at 3 500 feet.

Note that there is a Visual Reference Point near your track crossing or entering the Farnborough and Blackbushe ATZs. into the Farnborough ATZ.

After passing Farnborough, your track takes you very close to the Blackbushe ATZ. Blackbushe has a Non Directional Beacon (NDB) and Distance Measuring Equipment (DME), in this case a low-powered Terminal DME. The frequencies for both these aids are shown, should you wish to use them to help back up your visual navigation techniques. *(See Figure 8.10, A)*.

Approaching Wycombe Air Park.

After passing Blackbushe, *(see Figure 8.10, A)* your track crosses over a dual carriageway linking Bracknell and Wokingham, under which pass dual track railway lines. Shortly afterwards, you cross the M4 *(Figure 8.10, B)*.

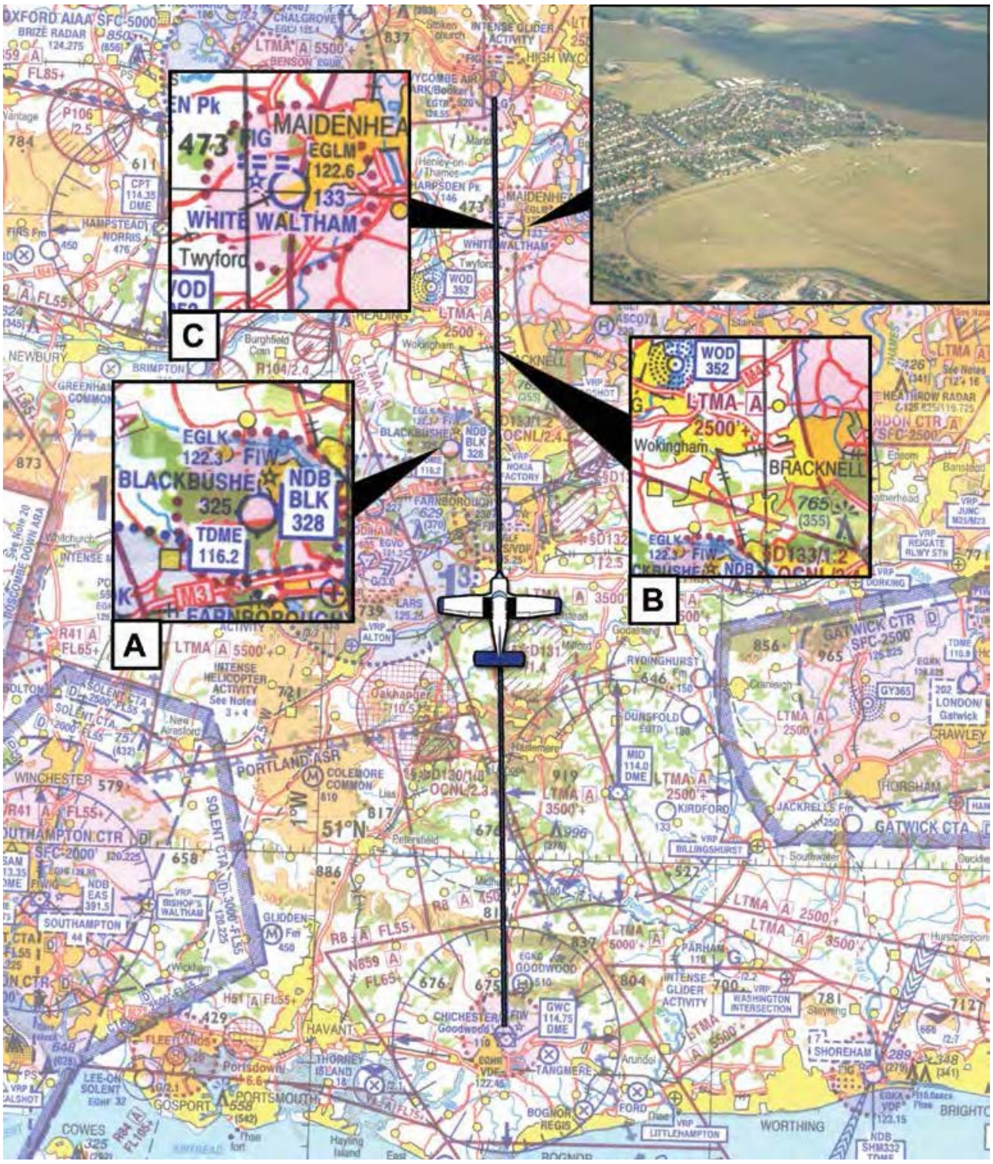

Figure 8.10 The route via Farnborough and White Waltham.

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Beyond the M4, you transit the White Waltham ATZ. You MUST call for permission from White Waltham to pass through the ATZ. *(See Figure 8.10, C.)*

Your track then crosses the River Thames, South West of Marlow, before entering the Wycombe Air Park ATZ.

MAP READING.

Having followed the route from Chichester to Wycombe Air Park, let us consider briefly the principal map-reading considerations that you should bear in mind when navigating visually. Remember, you will not be looking at your chart continuously, but consulting it to confirm your en-route position.

Map reading may be defined as visualizing the physical features of the ground, as represented on your aeronautical chart by symbols, and forming a mental picture of the terrain over which you are flying by relating symbols on the chart to features on the ground. This is known as reading map-to-ground, and is the basic technique used when you are confident that you are close to your track and to your planned time.

The reverse process - reading ground to map - is used when you are less certain of your position. Reading ground to map involves seeing an arrangement of features on the ground, being able to locate those features on the map and, thus, determining your position.

Map reading is a skill which you will acquire and hone with practice and experience. Several factors can make map reading easier for you, of which the following are the most important.

First and foremost, plan your flight thoroughly and study the route. For any cross-country flight, it is important that you plan as thoroughly and accurately as possible. You should also study position fixes, so that you are aware of the position of major features which you are likely to use for the planned route, as well as noting those features which you must avoid, such as tall masts. Time spent on flight planning and study of the route will make the task of airborne visual navigation that much easier and more enjoyable.

Time spent on flight planning, and study of the route will make the task of airborne navigation much easier.

Stay on Track.

Map reading is much more straightforward if you remain on track. If you stray off track, you can use one of the techniques for regaining track discussed in later chapters.

Always fly headings and speeds accurately, and keep a good lookout for other traffic.

Flight Management.

Remember that effective visual navigation is much much more than map reading. Above all, you must fly accurate headings and speeds and keep a good lookout for other traffic and deteriorating weather.

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MAP READING FROM WYCOMBE AIR PARK TO CHICHESTER.

Have the map orientated in the direction in which you are flying.

Before concluding this chapter, let us fly the route that we have just studied, in reverse, to see what considerations we need to bear in mind for the return journey.

First of all, when map reading, it is good practice to have the map orientated in the direction in which you are flying. For the flight from Wycombe Air Park to Chichester, you should plan to have the map orientated on your knee, in the cockpit, as shown in *Figure 8.11*.

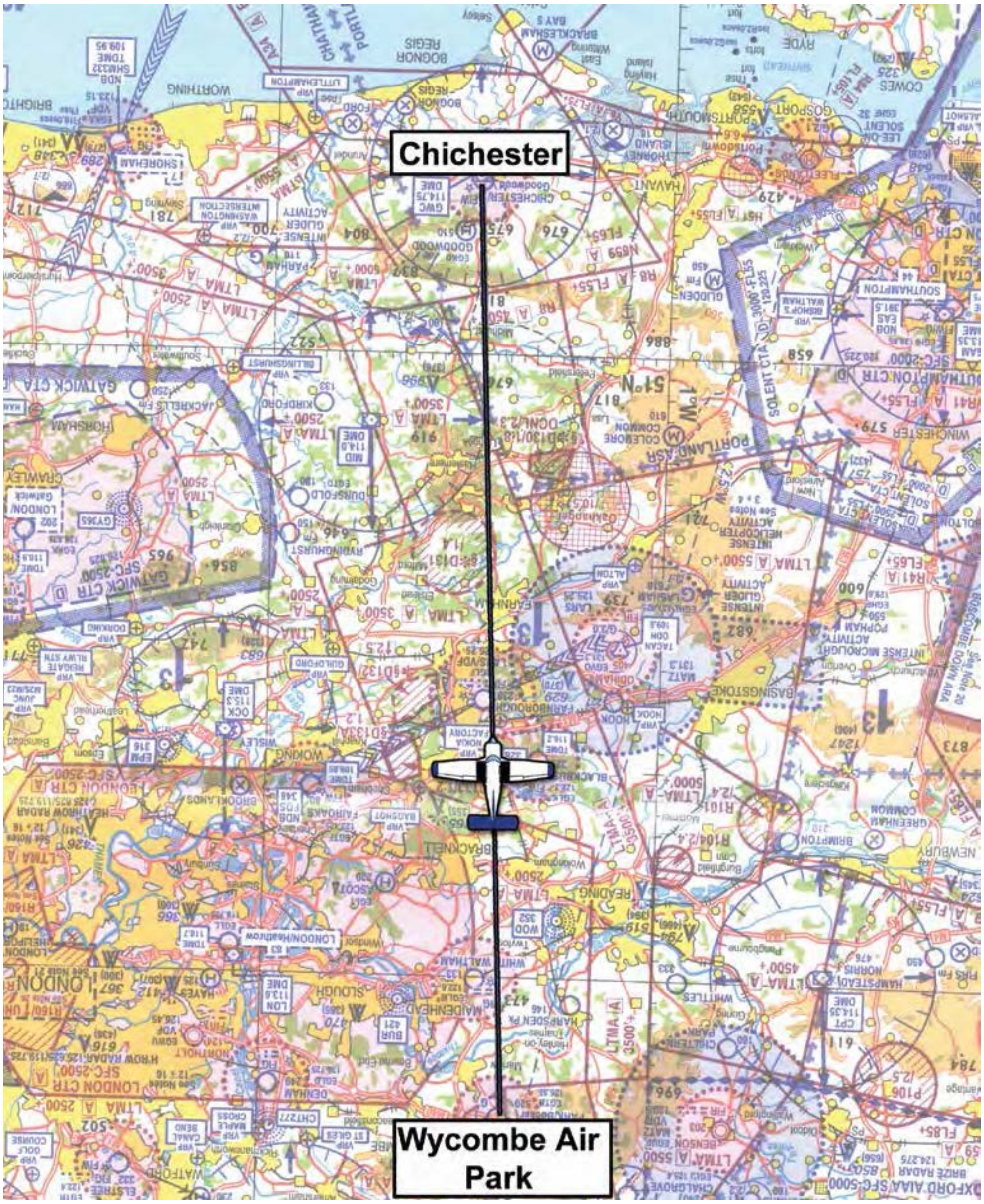

Figure 8.11 Orientate your map in the direction of flight.

Ideally, you should fold your map so that the whole route is visible. If this is not possible, then you must be able to reveal each section of the route without having to unfold the map more than necessary.

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Although the chart is now upside down, all the ground features are orientated relative to your track, in the order in which you expect them to appear, and lying to the correct side of track.

Take care that any annotations that you might write on the map during the flight planning stage are written with the map orientated in the direction of flight.

Visual Checkpoints Along the Route.

As we have mentioned, during flight planning, you should study the route and select visual checkpoints at about 10 minute intervals along your track. The ideal visual checkpoint will be recognisable from some distance away and, if possible, should be a unique and prominent ground feature.

Unique Features.

A checkpoint should not be able to be mistaken for a similar checkpoint in the same area. An airfield such as White Waltham should be a perfect checkpoint as there are no other airfields in the vicinity, *(see Figure 8.12)*. Blackbushe and Farnborough, though, further down-route, could possibly be confused with each other, as they lie close together.

Figure 8.12 Airfields make good visual checkpoints unless two or more airfields are close together.

Large Features.

Large features, such as towns, will be recognisable from some distance away but will be too large to use for precise navigation. Always use a distinct part of a large feature as your visual checkpoint.

For example, if using Bracknell as a checkpoint, which is about a third of the way from Wycombe Air Park to Chichester, use the road junction with a railway bridge next to it as your visual checkpoint. *(See Figure 8.13.)*

Note that, at White Waltham, you are on the western edge of the London Heathrow Control Zone (CTR). Take care not to infringe the CTR.

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Figure 8.13 When using large features, select a distinctive part of the feature as your visual checkpoint.

Features of Significant Vertical Extent.

Features which have significant vertical extent, such as TV masts *(See Figure 8.14)*, should always be identified for safety reasons, but they do not necessarily make good visual checkpoints as they may be difficult to see except in good visibility or at low level. *(See Figure 8.14.)*

Figure 8.14 Vertical features may be difficult to spot if you fly high.

You may not easily see a 400 feet high mast from above 2 500 feet agl.

CHOICE OF CHECKPOINTS.

Checkpoints do not have to be directly on track. In fact, it is better that they are not, because, if they are, they will disappear under the nose of the aircraft as you approach them and you will not be able to tell when you are overhead. Checkpoints which are 1 to 2 miles to the side of track are easier to use. You can check timings when you are abeam the feature.

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The distance from Wycombe to Chichester is 45 nautical miles. So, if we assume a groundspeed of 90 knots it will take 30 minutes to complete the journey. You will, therefore, need to select a maximum of 3 or 4 checkpoints, ideally, evenly-spaced for timing and heading correction purposes. *(See Figure 8.15.)*

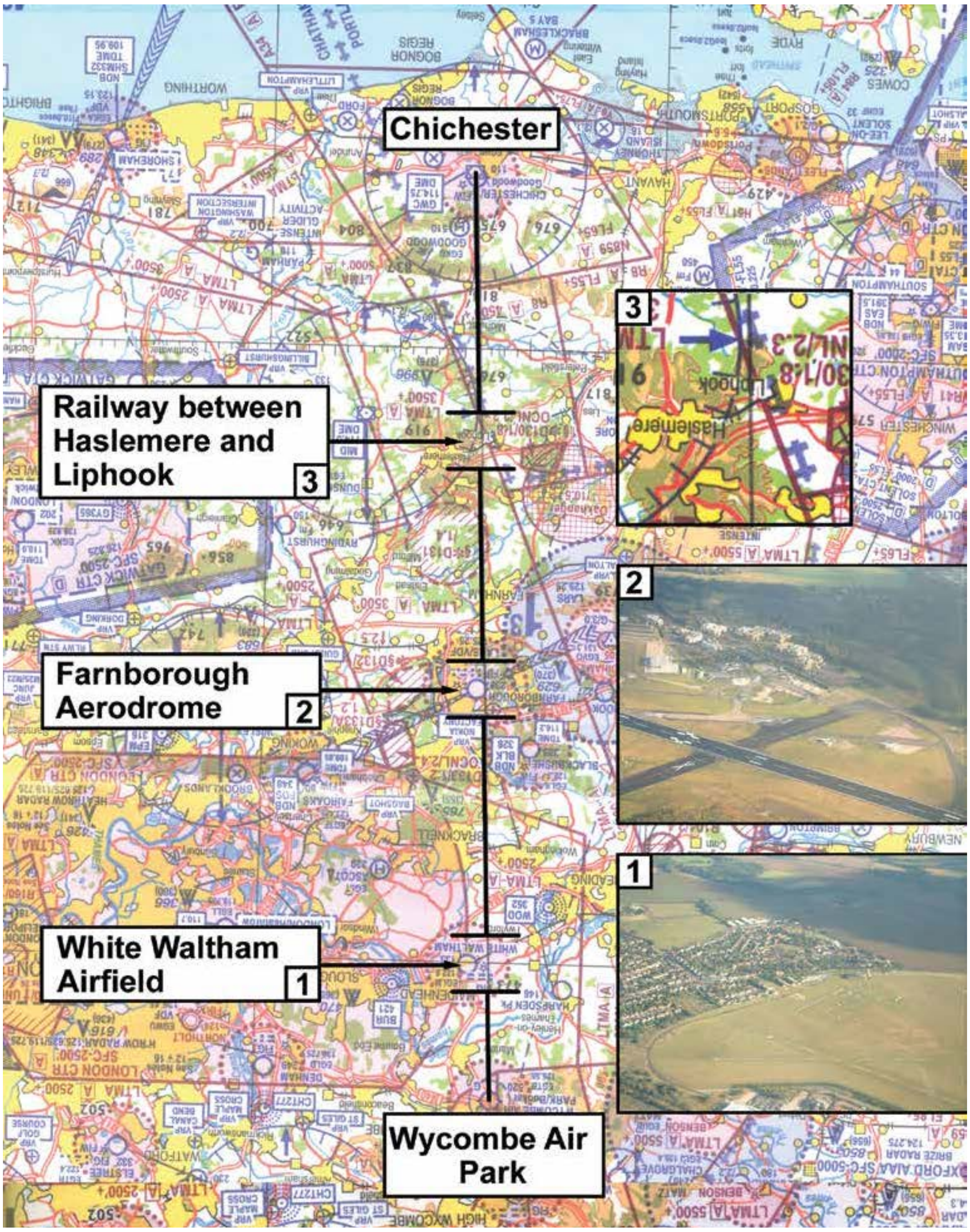

Figure 8.15 Checkpoints on the route from Wycombe Air Park to Chichester.

A suitable first checkpoint which would be easily identified, is White Watham airfield. White Waltham airfield. You will overfly White Waltham about 4½ minutes after setting off from Wycombe.

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After White Waltham, Farnborough airfield is just over 8 minutes further on and is a possible checkpoint. However, you must take care not to confuse Farnborough with Blackbushe which should be on the right of your track, slightly further away, and only 3 minutes from the road junction.

After Farnborough, the next suitable feature would be the railway line between Haslemere and Liphook, about 8 minutes from Farnborough. The railway line runs just to the South of, and parallel to, a dual carriageway. Both railway and dual carriageway lie across your track, and, so, will give you a good timing check. From here to Chichester aerodrome is about 9 minutes flying time, so there will be no need for a further checkpoint. It is now time to think about your arrival procedures as you approach your destination.

To sum up, your recommended checkpoints would be White Waltham Aerodrome, Farnborough Aerodrome and the railway line between Haslemere and Liphook. You would, therefore, mark these features on your map with the estimated flight time required to reach each checkpoint from Wycombe. Take care to mark checkpoints in such a way that the checkpoint itself is not obscured. One method is illustrated in *Figure 8.15.*

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Representative PPL - type questions to test your theoretical knowledge of Map Reading.

For questions 1 to 5, refer to the symbols on Page 121.

1. What is the symbol for an unlighted obstacle?

   a. 9
   b. 10
   c. 11
   d. 8

2. Which of the following is the symbol for an exceptionally high (over 1000 feet AGL) lighted obstruction?

   a. 6
   b. 9
   c. 11
   d. 7

3. What symbol is used to show an NDB on a map/chart?

   a. 5
   b. 7
   c. 6
   d. 10

4. Which is the symbol for a VOR?

   a. 4
   b. 6
   c. 11
   d. 3

5. What does symbol 3 represent?

   a. Lit obstacle
   b. Lighthouse
   c. VRP
   d. Aeronautical Light Beacon

For questions 6 to 7, refer to the chart beneath the questions.

6. The area you see on the chart, delineated by a rectangle of blue diamonds, is:

   a. Yeovilton Aircraft Information Advisory Area
   b. Yeovilton Area of Intense Aerial Activity
   c. Yeovilton Air Interdiction Activity Area
   d. Yeovilton Air Intelligence Advisory Area

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7. Where on the chart will you find a glider launching site co-located with a government heliport?

a. Yeovilton
b. Bournemouth
c. Bovington
d. Merryfield

Question	1	2	3	4	5	6	7
Answer							

The answers to these questions can be found at the end of this book.

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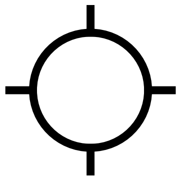
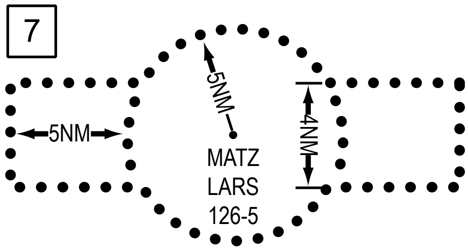
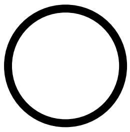
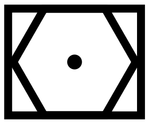
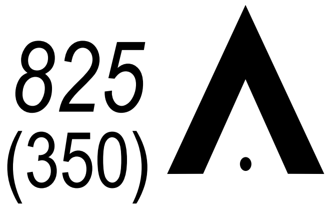
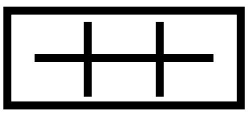
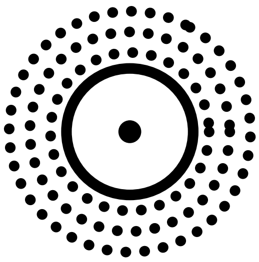
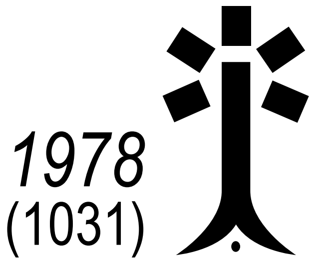
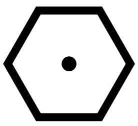
1 	7 
2 	8 
3 	9 
4 	10 
5 	11 
6 	

CHAPTER 9
PRINCIPLES OF DEAD RECKONING VISUAL AIR NAVIGATION

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INTRODUCTION.

In the previous chapter, you learnt about some of the skills of map reading that a pilot needs to acquire in order to fly a successful visual navigation trip.

However, the science of visual navigation does not involve simply map reading from ground feature to ground feature.

The most effective method of navigating visually cross-country is known as dead reckoning navigation.

In dead reckoning navigation, the pilot starts from a known location and uses a reliable wind forecast to calculate a heading to steer and an expected groundspeed (based on a chosen true airspeed) in order to predict an arrival time over a visual checkpoint, turning point or destination, along a desired track. The pilot then concentrates on flying an accurate speed and heading which, after a calculated time interval, he hopes will result in his aircraft arriving over the checkpoint, turning point or destination at the expected time.

Figure 9.1 depicts an aircraft which, by flying a particular heading, at a given airspeed, will achieve a given track over the ground, at a particular ground speed, depending on wind strength and direction.

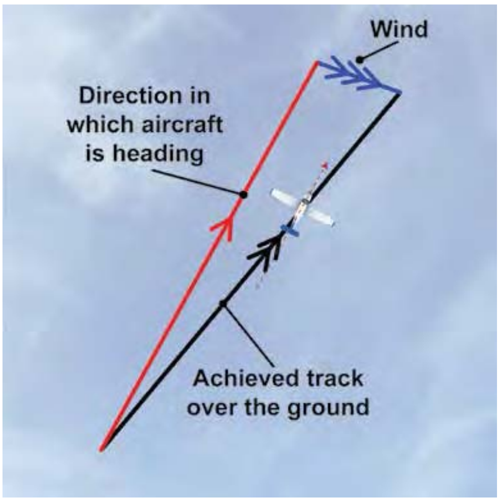

Figure 9.1 By flying a particular heading, at a given airspeed, an aircraft will achieve a given track over the ground, at a particular ground speed, depending on wind strength and direction.

The more thorough the pre-flight planning, the less demanding will be the navigation task in the air.

Headings to fly, true airspeeds and expected groundspeeds are calculated, and tracks, checkpoints and timings chosen, during pre-flight planning. The more thorough the pre-flight planning, the less demanding will be the navigation task in the air.

Mental dead reckoning, then, permits a pilot to estimate future position by calculating an expected direction, and distance travelled in that direction, over the surface of the Earth, in a pre-determined time; (usually every 5 to 10 minutes during a typical light aircraft cross country flight.). When that time has elapsed, the pilot consults his chart to confirm his ground position.

If examination of the checkpoints confirms the expected ground position, the pilot will know that his aircraft has covered the planned distance, over the planned track, in the planned time. The pilot will then know exactly where he is, and will be confident that the forecast wind and his own flying are accurate. Furthermore, if he is on track, on time and "on position", the pilot will also know that his estimated time of arrival (ETA) at destination, or at the next checkpoint or turning point, will be as predicted.

On the other hand, if he finds that he arrives early or late at a particular ground fix along his route, or if he sees from his ground fix that he is off track, the application of mental dead reckoning techniques will enable him to estimate a new heading to fly

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in order to rejoin track further along the route, or to fly directly to the destination from his observed position. The pilot will also be able to recalculate groundspeed, update ETAs, and revise his fuel management, so that the flight can be continued in safety, and future events remain under the pilot's control.

Visual air navigation then, is much more than map reading.

In this chapter, you will learn the basic principles of mental dead reckoning in air navigation.

As an aside, you should know that the CD-ROM which comes with this book will teach you how to carry out all the calculations associated with mental dead reckoning, on the navigation computer. There are many models of navigation computer, but for the current PPL theoretical knowledge examination in Navigation, the Dalton type navigation computer, sometimes referred to as the whiz-wheel, is required. (See Chapter 11.) The CD-ROM which accompanies this book will teach you all you need to know about this computer.

MENTAL DEAD RECKONING AND THE TRIANGLE OF VELOCITIES.

In dead reckoning navigation, the pilot starts from a known location and uses a reliable wind forecast to calculate a heading to steer, in order to follow a planned track over the ground towards a desired destination. Based on a planned true airspeed, the pilot also uses the wind to calculate a groundspeed along his planned track and is thus able to calculate the time required to reach his destination. The pilot then concentrates on flying an accurate speed and heading which, after a calculated time interval, he hopes will result in his aircraft arriving at destination at the expected time.

If the wind forecast is correct and the pilot has calculated the required headings and his groundspeed correctly, he will follow his planned track to his destination, and he will arrive at his destination at the calculated time. Pilots, however, come to realise very early in their flying career that wind forecasts tend not to be 100% exact (though they may be) and that the accuracy of their navigation calculations and flying may often be less than perfect. Corrections to planned headings and ETAs often have to be made, therefore. Obviously, visual checkpoints along the chosen route are identified from the chart during flight planning, in order that the pilot can confirm that he is on his desired track, or determine any track or timing error. But let us, for the moment, concentrate on the initial navigation calculations of how to get from starting point to destination.

The key to understanding how to calculate the heading required to arrive at your destination after following your planned track, and to determine the time of arrival at destination, is the <u>triangle of velocities</u>.

The Triangle of Velocities.

An aircraft flies through the air. This is rather an obvious statement, but consider for a moment the fact that the mass or block of air through which the aircraft flies will, itself, be moving over the surface of the Earth. A person standing on the surface of the Earth will sense this movement of the air as wind. If the mass of air is moving quickly, the person will say that the wind is strong, if it is moving slowly, the person will sense a light wind. But the important thing for the pilot to register is that his aircraft in flight is moving relative to the air mass in which it is flying, and that the air mass has

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its own independent movement over the ground. This poses a navigational problem to the pilot.

But let us imagine for a moment a day on which there is no wind blowing. This is a very rare occurrence in real life. But, on such a day, a pilot wishing to fly from **A** to **B** would draw his desired track on the map, and then, once airborne, simply leave **A**, pointing, or heading, his aircraft in the direction of **B**, along the line of the desired track. Because there is no wind, this action would be enough to ensure that the aircraft eventually arrives at **B**. *(See Figure 9.2.)*

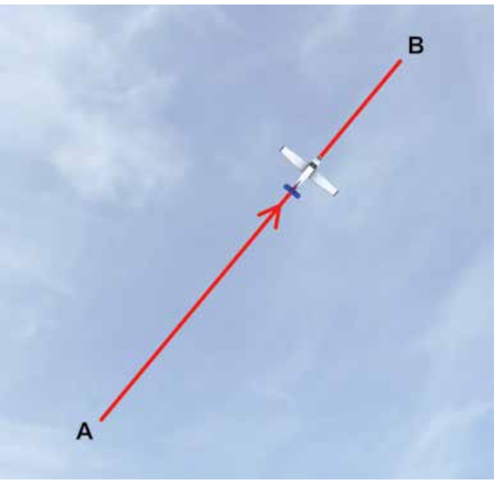

Figure 9.2 If the air mass through which an aircraft is flying is motionless, there is no wind, and the pilot flies from A to B by heading directly towards B.

On a normal day, however, there will be a wind for the pilot to reckon with; so let us assume that the wind is blowing in the direction indicated in *Figure 9.3*. On this day, if the pilot started off from **A** heading directly towards **B**, as he did before, he would not arrive overhead **B**, but would end up in the position marked as **C** in *Figure 9.3*. This is because, as we have stated, **the aircraft moves relative to the air mass and, because the air mass is also moving independently, its movement is imposed on that of the aircraft.**

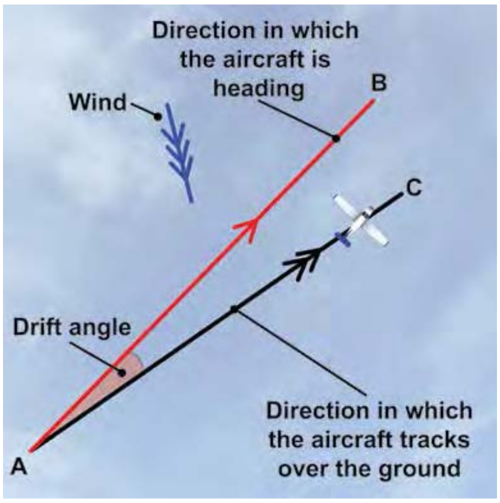

Figure 9.3 If there is a wind blowing, the air mass through which an aircraft is flying moves in the direction B-C, and an aircraft heading in the direction A-B would arrive at C.

Figure 9.3, shows what will happen to an aircraft which is flying within a block of air which is, itself, moving. In this situation, unless the wind is an "exact" headwind or tailwind, the aircraft will not be proceeding over the ground in the direction in which its nose is pointing but will be "drifting" away from that direction at a certain angle, called the drift angle.

In order to analyse this situation in more detail, we must ignore actual routes in terms of naming a starting point and destination, or considering distances, and simply consider the velocity of the aircraft and the velocity of the wind. If an aircraft sets off en-route, on a given heading, and at a given true airspeed, and is subject to a wind blowing across its track, that wind will cause the aircraft to follow (or, in pilot speech, to "make good") a track across the ground which lies in a different direction from the direction in which the aircraft's nose is pointing. The speed of the aircraft's progress over the ground will also be different from the speed at which it is moving through the air: its true airspeed.

If we now construct a triangle which depicts only speed and direction (of the aircraft and wind), we have what is called a triangle of velocities.

Velocity is a vector quantity, involving both magnitude (speed) and direction.

You should note that the term "velocity" refers both to direction and speed. In everyday speech, we tend to use the words speed and velocity as if they meant the same thing, but in science and mathematics (and the triangle of velocities belongs to the realms of both) the concepts of velocity and speed are different. Speed is defined by magnitude alone, for example, 90 knots, 167 kilometres per hour, or 104 miles per hour, whereas velocity involves both magnitude and direction, for example 90 knots due West, 104 miles per hour in a north-easterly direction, or 167 kilometres per hour in a direction of 245° True. In aviation, wind is always given as a velocity; 270°/20 knots, for instance, refers to a wind blowing from due West at 20 knots.

Let us, therefore, recreate the situation depicted in *Figure 9.3*, this time ignoring ground positions such as starting point, **A,** desired destination, **B**, and actual destination, **C**. Instead, we will construct a triangle of velocities, as illustrated in *Figure 9.4*.

In a triangle of velocities, the direction in which the lines are pointing (shown by the arrow heads) indicates direction of the aircraft and the wind in the real world, and the length of the lines represents the speed of the wind and of the aircraft. Direction and speed, considered together, give velocity.

In *Figure 9.4*, the red line marked with the single arrowhead represents the aircraft's heading and true airspeed, the arrowhead indicating the direction in which the pilot is pointing the nose of the aircraft, and the length of the line (drawn to a given scale) representing the aircraft's true airspeed. In a similar way, the length and direction of the blue line, marked with three arrowheads, represent the wind velocity, while the direction and length of the black line, marked with two arrowheads, represent respectively, the track along which the aircraft actually moves over the ground and the speed of the aircraft relative to the ground, the groundspeed. The angle between the red line and the black line is known as the drift angle.

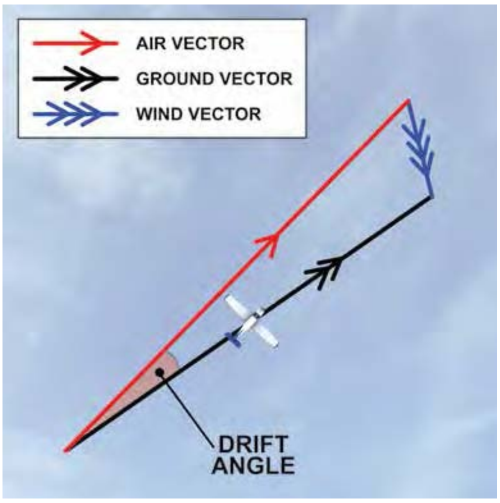

Figure 9.4 A triangle of velocities represents direction and speed of the aircraft through the air, the wind speed and direction, and the track and speed of the aircraft over the ground.

The Air Vector, Wind Vector and Ground Vector - Vector Addition.

In mathematics, each line representing the individual velocities is called a vector. The red line is the air vector. This vector, as we have seen, represents the path the aircraft follows relative to the block of air in which it is moving, and its speed through the air. By convention, the air vector is marked with a single arrowhead. The blue line, identified by convention with three arrow heads, is the wind vector, indicating the direction and speed of the block of air as it moves over the ground. The black line is the ground vector. The ground vector is conventionally marked by two arrowheads and, as already defined, indicates the track of the aircraft over the ground, and the aircraft's groundspeed.

The triangle of velocities is, in fact, an illustration of what is known as vector addition.

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The wind vector is superimposed upon, or added to, the air vector in order to give the resultant ground vector, which is the vector which indicates how the aircraft actually moves relative to the ground over which it is flying.

When the triangle of velocities has been constructed to scale, we are able to measure the magnitude of the aircraft's drift angle and the aircraft's groundspeed.

The Drift Angle and Groundspeed.

Let us now look at a couple of practical examples of the triangle of velocities as applied to an aircraft flying at different speeds in a given wind.

The three sides of the triangle of velocities are:

- *Heading / True Airspeed*
- *Track / Groundspeed*
- *Wind Velocity*

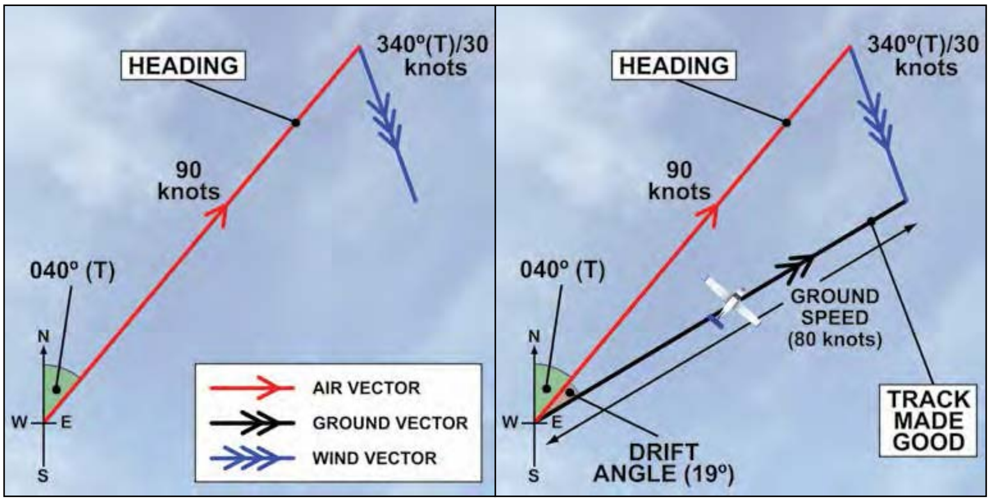

Figure 9.5a *Figure 9.5b.*

Constructing a triangle of velocities.

In *Figure 9.5* the true airspeed of the aircraft is assumed to be 90 knots. The aircraft is flying on a heading of 040° (T), while the speed of the wind is taken to be 30 knots, 340° (T). We construct the triangle of velocities to scale, and so angles represent directions and the lengths of the vectors represent speeds. The length of the air vector is three times the length of the wind vector, because the aircraft's true airspeed is three times the speed of the wind. We construct the air vector and wind vector from the known bearings and speeds *(Figure 9.5a)* and, then, joining the open ends of the wind and air vectors, we draw a line to give us the resultant ground vector, as illustrated by *Figure 9.5b*. The angle between the air vector and the resulting ground vector gives us the angle of drift, and the length of the ground vector, gives the groundspeed.

Both graphically and mathematically, it is straightforward to calculate, for the above example, that the drift angle is 19° and the groundspeed is about 80 knots. Consequently, the aircraft is making good a track over the ground of 059° (T) at a groundspeed which is 10 knots slower than its true airspeed. You will learn how to carry out these calculations in Chapter 11, and from the CD-ROM on the navigation computer which accompanies this volume.

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The higher an aircraft's airspeed, the less drift it will experience on any heading.

In *Figure 9.6* the true airspeed of the aircraft is assumed to be 120 knots, on an identical heading to the first aircraft, of 040° (T), while the speed of the wind is still 30 knots, and still blowing from 340° (T). The length of the air vector must now be four times as long as the length of the wind vector, to represent the higher true airspeed of 120 knots, at which this aircraft is flying.

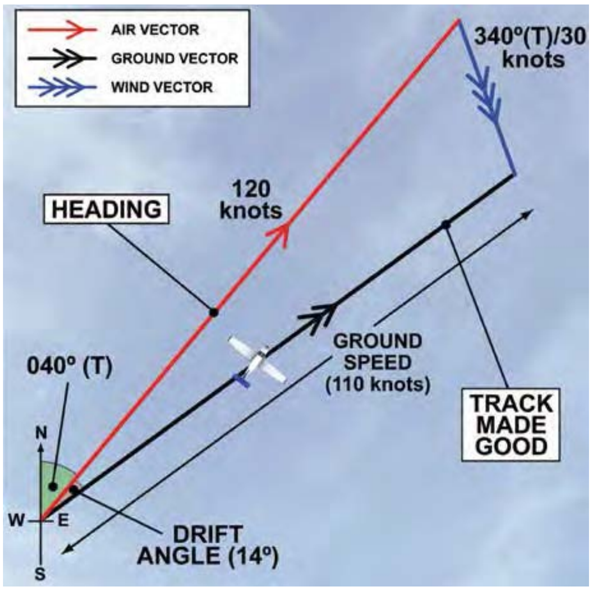

Figure 9.6 The higher the airspeed, the smaller the drift angle.

The Effect of True Airspeed on Drift Angle and Groundspeed.

The amount of drift experienced by an aircraft in flight is a function of the aircraft's true airspeed, its desired track and the speed and direction of the wind.

You will see immediately from the triangle of velocities that, at the greater true airspeed, the angle of drift between the air vector and the ground vector is smaller than in *Figure 9.5*, while the length of the ground vector, representative of the groundspeed, is greater. By calculation, the drift angle is now only 14°, while the groundspeed is 110 knots. So this faster aircraft is making good a track of 054° (T) over the ground, at a groundspeed which is 10 knots slower than its true airspeed. The drift angle of the faster aircraft is smaller than that of the slower aircraft, because, in flying faster, it is deflected from its track by the wind by a smaller amount. However, because the wind is of the same strength (speed) and from the same direction in both cases, it has the same headwind component in both cases, and slows down both aircraft by the same margin of 10 knots.

We may conclude, then, that, for a given desired track, and for a given speed and direction of wind blowing across the aircraft's desired track, an aircraft flying at a higher true airspeed will have a smaller angle of drift and a higher groundspeed.

If the crosswind has a headwind component as in *Figures 9.5* and *9.6*, the aircraft's groundspeed will always be less than its true airspeed. Conversely, as depicted in *Figure 9.7*, if the crosswind has a tailwind component, the aircraft's groundspeed will always be greater than its true airspeed.

In *Figure 9.7*, the aircraft is flying a heading of 240° (T) at a true airspeed of 90 knots. The wind is from 030° (T) with a strength of 15 knots. The aircraft is experiencing 5° of port drift and, therefore, making good a track over the ground of 235° (T).

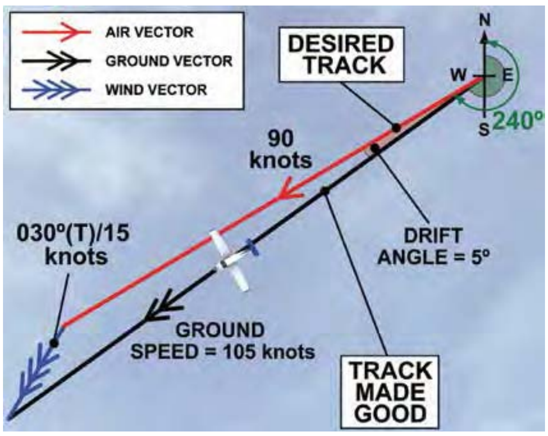

Figure 9.7 With a tailwind component, groundspeed is always greater than true airspeed.

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And because there is a tailwind component on the heading it is flying, the aircraft's groundspeed is almost 105 knots.

The Concept of Maximum Drift.

Following on from the situations analysed above, we should be able to deduce fairly easily, that a pilot can fly from **A** to **B** by pointing his aircraft along the direct track from **A** to **B** only if one of three conditions prevails during the planned flight: that there is absolutely no wind at all, or if the wind is a perfect headwind or tailwind.

If there is any crosswind element to the wind, the pilot must make allowance for wind when he sets his heading. The greater the crosswind element and the greater the windspeed, the greater will be with wind correction angle that the pilot needs to apply to make good his desired track.

At any given true airspeed, an aircraft will experience maximum drift when flying a track which puts the prevailing wind at 90° to that track. When the wind is directly on the nose or on the tail of his aircraft, there will be no drift, the effect of the wind being confined to modifying the aircraft's achieved speed over the ground by a value equal to the windspeed. When blowing from intermediate quarters, the wind will cause the aircraft to drift at an angle which lies between 0° and the maximum drift angle.

Consequently, it is of practical interest to the pilot, to know what will be the maximum drift he is likely to experience when flying on different tracks at different true airspeeds.

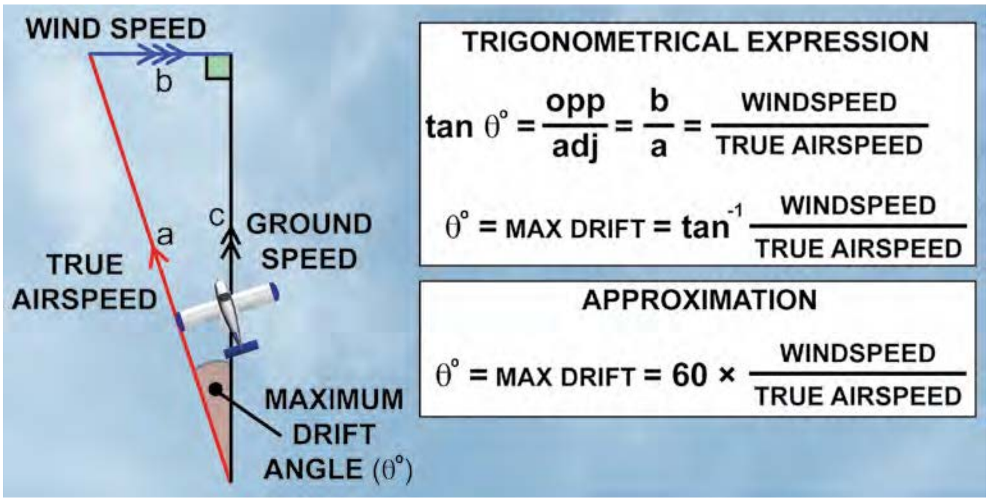

Figure 9.8 Calculating Maximum Drift when the wind is blowing at 90° to the aircraft's track.

It can be shown that that for a given windspeed and aircraft true airspeed (TAS), approximate maximum drift in degrees is given by the following formula:

$$\textbf{Approximate Maximum drift (°)} = 60 \times \frac{\textbf{Windspeed (knots)}}{\textbf{TAS (knots)}}$$

In practice, in order to find maximum drift, it is easier for a pilot to divide 60 by his planned TAS and multiply by the wind speed.

Max Drift ° = 60 × $\frac{\textit{Windspeed}}{\textit{True Airspeed}}$

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So, on a day when the windspeed is 30 knots at your cruising altitude, if you have elected to fly at a TAS of 90 knots, the maximum drift your aircraft will experience is:

Maximum drift (°) = $\frac{60}{90}$ **x 30 = 20° (or two thirds of the windspeed)**

If, on the same day, you were able to fly at a TAS of 120 knots, the maximum drift you would experience would be:

Maximum drift (°) = $\frac{60}{120}$ **x 30 = 15° (or half the windspeed)**

Using Maximum Drift in Mental Dead Reckoning Navigation When Airborne.

If you have to revise headings while airborne, it is worth knowing that you can estimate drift quite accurately using mental dead reckoning (MDR) techniques, by applying a "clock code" to the angle between the wind and track.

If, by pointing your aircraft's nose along the new track, the wind will be blowing at an angle greater than 60° measured from the aircraft's nose or tail, you will be experiencing, for all practical purposes, full maximum drift. At 30°, the wind will cause your aircraft to experience ½ maximum drift, and at 45° you will experience ¾ of the maximum drift. Similarly, 20º and 40º give 1/3 and 2/3 max drift

You will notice that the proportion of **maximum drift** that you experience for a wind blowing at a given angle to your desired track, is the same proportion that the value of the angle, expressed as minutes (time) instead of degrees, would have to one hour. *(See Figure 9.9.)*

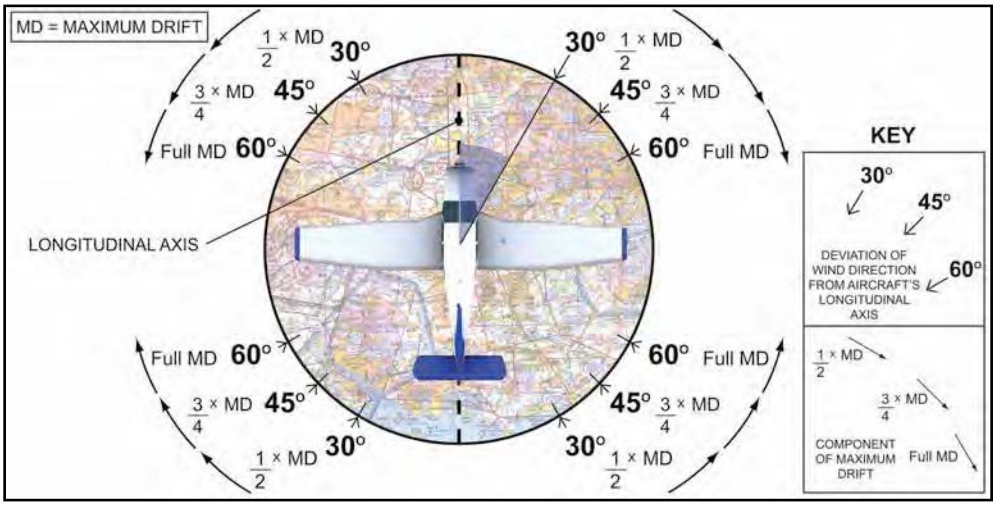

Figure 9.9 Calculating component of maximum drift acting on an aircraft.

Note that this rule is an approximation only, but is good enough for visual navigation flights.

Let us assume that your aircraft is flying at a TAS of 90 knots on a day when the wind speed is 30 knots. As we have already calculated, the maximum drift you will experience in these conditions is 20°. The MDR "clock code" principle depicted in Figure 9.9 tells us that because 60 minutes is a complete hour, a wind blowing at

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60° to the desired track will cause the aircraft to be subjected to the full maximum drift of 20°. If the wind blows at 30° to the desired track the aircraft will experience ½ maximum drift, that is, 10°, by the reasoning that 30 minutes is half an hour. A wind at 15° to the desired track would cause the aircraft to drift at ¼ maximum drift, 5°, because 15 minutes is ¼ hour, and so on. The accurate calculation of the variation of the proportion of maximum drift with angle is again trigonometrical, based on the sine of the wind angle, but, again, our MDR "clock code" method gives results which are close enough for practical MDR navigation purposes.

This method of estimating drift is extremely useful to the pilot-navigator.

Calculating the Heading to Steer.

Now that we have covered the concept of the triangle of velocities, it is a fairly straightforward step to determine what heading we must steer, in a given wind, if we wish to fly along a desired track from **A** to **B** at a predetermined true airspeed.

Let us look at a few fundamental principles of how a pilot achieves his desired track, based on what we have learned so far.

- In order to follow a desired track, the pilot must steer a heading which will compensate for the wind. (Unless the wind is a perfect headwind or tailwind.)

- If the pilot points the nose of his aircraft along the desired track, any cross wind will always blow the aircraft from its desired track.

- The nose of the aircraft must, consequently, always be orientated into wind, by a greater or lesser extent. The wind will then blow the aircraft from its heading onto the desired track.

- **The heading <u>correction</u> that a pilot applies to the aircraft's heading in order to make good the desired track is equal to the value of the drift angle that the aircraft would experience if the pilot attempted to point its nose along the desired track.**

We will examine this last point a little more closely, because it is fundamental to our pre-flight calculations when we plan to fly cross country.

From our study of the triangle of velocities, we have already seen that if a pilot attempts to head the aircraft directly along a desired track, with respect to which the wind has a crosswind component, his aircraft will drift from the desired track. **The stronger the crosswind component and the slower the aircraft, the greater will be the drift angle**.

Wind blows an aircraft from Heading to Track.

As we have just stated, in order to set out along a desired track on a heading which will allow the aircraft to follow, or make good, that desired track, the pilot must modify the aircraft's heading by pointing the nose of the aircraft into wind by a number of degrees equal to the drift the aircraft would experience if the pilot had set a heading directly along the desired track.

The magnitude of the heading correction that a pilot has to make will depend on the wind speed and direction and the true airspeed of the aircraft.

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The theory of how the required heading correction is calculated is fairly straightforward and may easily be appreciated by looking again at the triangle of velocities.

Constructing a Triangle of Velocities to Determine the Heading to Fly.

We will construct a triangle of velocities similar to the ones earlier in this chapter which explained the phenomenon of drift. But, this time, in constructing the triangle of velocities, we will approach the task from the point of view of the pilot who, knowing the track he wishes to follow, the true airspeed at which he will fly, and the forecast wind, wishes to compensate for expected drift and calculate a heading to fly in order to make good the desired track.

Let us assume that we are calculating a heading to fly for the first leg of a cross-country flight from Oxford Kidlington to Wellesbourne Mountford, via Ledbury, for which we measured tracks and distances in Chapter 7. *(See Figure 9.10.)*

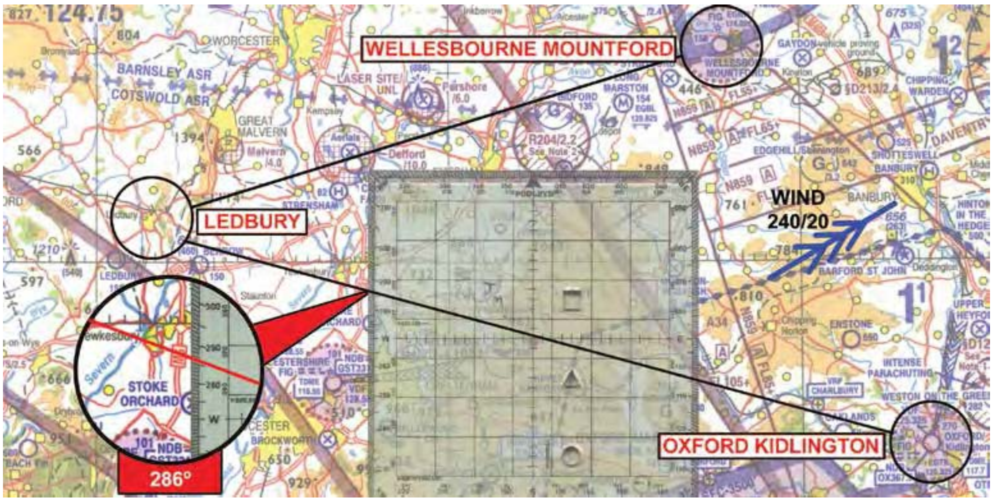

Figure 9.10 The first step in calculating the heading to fly for the leg Oxford Kidlington to Ledbury. True Track is 286° (T), True Airspeed will be 105 knots and the Forecast Wind is from 240° (T) at 20 knots.

When preparing a navigation flight, always carry out gross error checks to ensure that you have not misaligned the protractor or applied drift corrections in the wrong direction.

We will further assume that our true airspeed from Oxford Kidlington to Ledbury will be 105 knots and that the forecast wind for that leg is from 240° (True) at 20 knots.

During the flight planning stage, the pilot should draw the forecast wind on his chart near the middle of his planned route so that he is able to retain a mental picture of the wind with respect to the desired track, throughout the flight. We already know that the heading we calculate will orientate our aircraft into wind, so if the true track we require is 286° (T) and the wind is from 240° (T), we can already see from the chart that the true heading we require is going to be less than 286° (T).

This type of initial mental calculation is a useful gross error check.

Let us now look at the triangle of velocities that we need to construct for the first leg of the route, in order to appreciate the theory of calculating the heading we need to fly to make good the desired track.

When you come to actually prepare a route for yourself, you will not have to construct a triangle of velocities, (though you could choose to do so if you wished). You will almost certainly be calculating the heading to fly using a navigation computer. (See Chapter 11).

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Figures 9.11a, 9.11b and *9.11c* depict the three stages in the construction of the **triangle of velocities**.

Drawing in the Ground Vector.

In *Figure 9.11a*, we have simply drawn a line in the direction of the true track. This line is to be our ground vector; it is the track we must make good so we already know its direction: 286° (T). When the triangle of velocities is complete, the length of the ground vector will give us our ground speed, but we do not yet know how long the line will be. However, as this line is the ground vector, we may already mark it with two arrowheads.

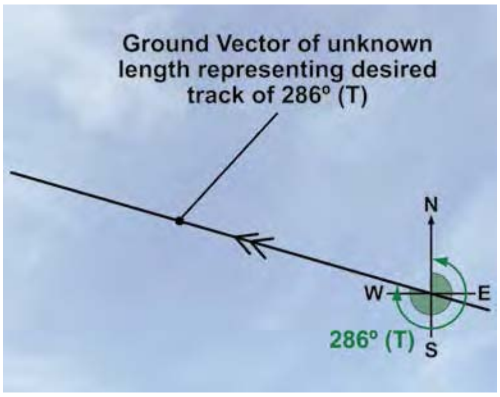

Figure 9.11a We wish to calculate the heading to fly for the leg Oxford, Kidlington, to Ledbury True Track is 286° (T), True Airspeed will be 105 knots and the Forecast Wind is from 240° (T) at 20 knots.

Drawing in the Wind Vector.

In *Figure 9.11b*, we have added the wind vector to the triangle of velocities that we are constructing. For the wind vector, we have information on both direction and speed which we have obtained from the forecaster or from documentation such as Met Office Form 214, the Spot Wind Chart. The wind is blowing from 240° (T) at 20 knots, so for the wind vector we can draw in a line of known direction and known length.

We must take care at this point, though, to make a sensible choice of scale with which we can represent speed by length. We decide to use the scale 1cm = 10 knots. We can choose any scale we wish but we have to think of practical lengths, and when we mark off our true airspeed of 105 knots, we will need to draw a line of 10.5 cm using the scale we have chosen. So 1 cm to 10 knots seems about right, in order that we can keep our lines on the paper that we have at our disposal.

Remember that the wind will always blow the aircraft from the heading we are going to calculate onto the desired track. (That is why to achieve the desired track we always have to point the nose of the aircraft into wind.) Consequently, in the triangle of velocities, the wind vector points towards the ground vector. We draw in the wind vector at <u>any point along the ground vector</u> with a direction of 240°(T) and 2 cm long to represent 20 knots.

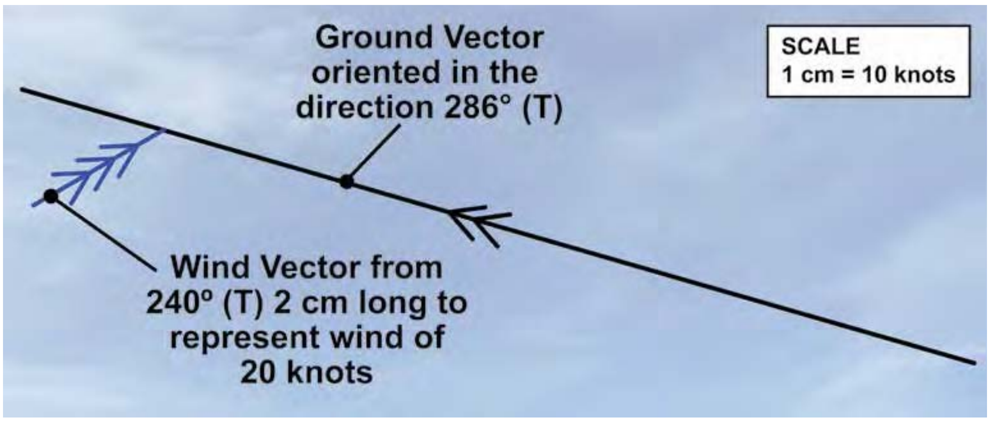

Figure 9.11b Drawing in the Wind Vector.

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Completing the Triangle of Velocities: The Air Vector and Ground Vector.

In *Figure 9.11c*, we complete the triangle of velocities to obtain the heading to steer and the groundspeed, by drawing in the air vector. We do not know the direction of the air vector; that will be the heading that we are trying to find. But we do know that its length must represent our planned true airspeed of 105 knots.

On the scale we have chosen, this length will be 10.5 cm. We, therefore, take a pair of compasses and set the point and pencil tip 10.5 cm apart. Placing the point of the compasses at the end of the wind vector, 2 cm from its origin, we inscribe a short arc to intersect the ground vector. The point at which the arc intersects the ground vector allows us to complete our triangle of velocities, so we draw in the air vector to join the end of the wind vector and the point at which the arc intersects the ground vector, at 10.5 cm distance.

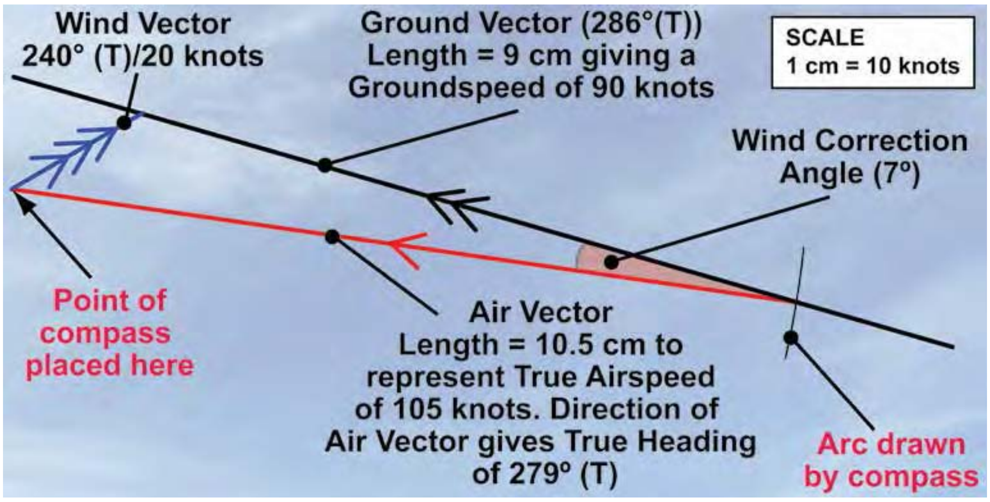

Figure 9.11c Constructing the Air Vector to determine True Heading, and establishing the length of the Ground Vector to obtain Groundspeed.

The direction of the air vector now gives us the true heading that we must steer, at 105 knots true airspeed, to make good our desired track of 286° (T).

The angle between the air vector and the ground vector (which represents the direction of our desired track) is the wind correction angle that we must apply to the desired track angle in order to obtain the true heading.

If we wish, we can measure the wind correction angle directly from the triangle of velocities, as the triangle has been drawn to scale, or we can calculate the heading using trigonometry. Whichever method we use, we will find that the wind correction angle is 7° and the heading to steer is 279° (T).

We also now have a length for the ground vector. This is 9 cm which tells us that our groundspeed along our desired track will be 90 knots. We, of course, expect our groundspeed to be less than the airspeed because the wind on this leg has a headwind component.

That completes the theory of how a heading is calculated to make good a desired track at a planned true airspeed, and for a given wind strength and direction. Everything we need to calculate may be worked out by considering velocities; that is, speeds and directions.

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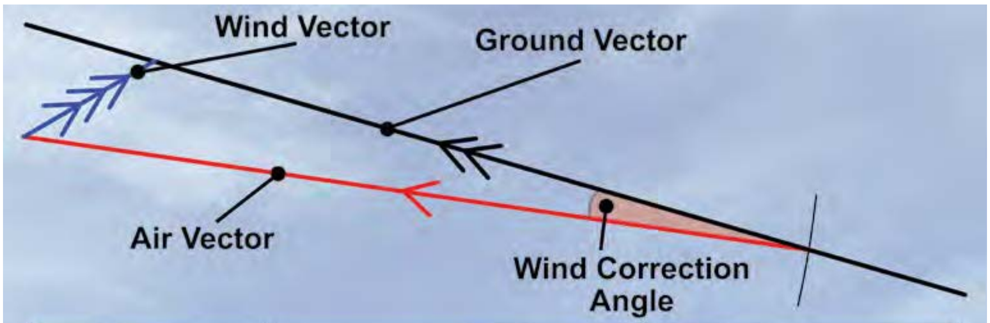
Figure 9.12 below sums up what you need to recall from the triangle of velocities, together with a table which sums up the information given by each of the three vectors.



NAME OF VECTOR	DIRECTION OF VECTOR	MAGNITUDE OF VECTOR
Ground Vector	Desired true track over ground	Groundspeed
Wind Vector	True direction from which wind is blowing	Wind speed
Air Vector	True heading	True Airspeed

Figure 9.12.

With a bearing for our desired track, a known true airspeed and a known wind direction and speed, the triangle of velocities enables us to calculate two further parameters in which the pilot is interested: true heading, and speed achieved over the ground. This latter value, the groundspeed, will enable us to work out estimated times of arrival (ETAs) at checkpoints, turning points and destination.

In the example that we have been using, we have seen that, in order to make good a desired track of 286° (True) at a planned true airspeed of 105 knots, with a wind from 240° (True), at 20 knots, a pilot will need to fly a heading of 279° (True), and will achieve a groundspeed of 90 knots. At this groundspeed, the distance of 42 nautical miles from Oxford Kidlington to Ledbury, would take just about 28 minutes to cover. *(See Figure 9.13.)*

Figure 9.13 Flying from Oxford Kidlington to Ledbury on track and on speed for a given wind.

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Note that a separate triangle of velocities would need to be constructed for the leg from Ledbury to Wellesbourne Mountford, because that has a different true track angle, and the wind will be orientated differently with respect to that leg. The wind on the second leg would be a following wind for the aircraft, and so the aircraft's groundspeed will be greater than its airspeed.

Practical Calculations of Heading and Groundspeed.

In practice, the calculations of heading to fly and groundspeed achieved can be carried out easily on the navigation computer. You will learn how to carry out these calculations in Chapter 11, and from the CD-ROM whichaccompanies this volume *(See Figure 9.14.)*

Figure 9.14 The Navigation Computer and CD-ROM.

Using the navigation computer, headings and groundspeeds can be calculated for any desired track you may wish to fly.

Knowing groundspeeds, a pilot can of course calculate not only times to cover whole routes, but also times to checkpoints and turning points. Chapter 4 taught you how to do this, using the equation:

$$\textbf{time} = \frac{\textbf{distance}}{\textbf{speed}}$$

As we discussed in Chapter 8, checkpoints along a route should be chosen at time intervals of every 10 minutes or so. Inevitably, therefore, you will be required to work out the time taken in minutes from a groundspeed in knots, and distances in nautical miles. In this case, the above equation becomes:

$$\textbf{time (mins)} = \frac{\textbf{distance (nm)}}{\textbf{groundspeed (kts)}} \times 60$$

As we have said, all the above calculations may be carried out on the navigation computer. The navigation computer also enables you to carry out calculations for fuel consumption rates, which will be of prime concern to you during a cross country flight, as well as other calculations of importance to the pilot-navigator, such as endurance, track errors, etc. (See Chapter 11.)

The Flight Log – True Headings and Magnetic Headings.

Heading and groundspeed information for any flight must be entered in the flight log that you are preparing for the flight.

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We have included representative information for the flight from Oxford Kidlington to Wellesbourne Mountford, via Ledbury, in *Figure 9.15*.

VFR FLIGHT LOG

DATE:		T/O:		LDG:				FLT TIME:					
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LEDBURY			240/20	105	286	279	3°	282	90	42 nm	28	
LEDBURY	WELLESBOURNE MOUNTFORD			240/20	105	072	074	3°	077	125	32 nm	15½	
ALTERNATE													

FUEL	
TO DESTINATION	
TO ALTERNATE	
10% CONTINGENCY	
45 MIN HOLDING	
TOTAL REQUIRED	
TOTAL ON BOARD	
ENDURANCE	

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

Figure 9.15 A partially completed VFR flight log.

The calculated True Heading to steer must be converted to Magnetic Heading by applying the local Magnetic Variation.

All calculations that we have made so far, have involved true bearings and headings. In measuring the bearing of our desired track, we measure that bearing with respect to the meridians of longitude on our chart; so the desired track will be in degrees True.

Once in the aircraft, the pilot must note any Magnetic Deviation Corrections for the heading he is to steer, in order to convert Magnetic Heading to Compass Heading.

Wind forecasts for route flying are also always given in degrees True.

Consequently, when we calculate a heading to fly from this information, that heading will likewise be in degrees True.

We will then need to convert the calculated heading to fly into a magnetic heading, and then into a compass heading, before setting off en-route.

The flight log reminds you that the pilot needs to take into consideration the local magnetic variation in order that he may convert the true heading to steer into a magnetic heading to steer. When he enters the aircraft, he must then convert the calculated magnetic heading into a compass heading, by applying any magnetic deviation corrections from the compass deviation card.

The Route: Kidlington – Ledbury – Wellesbourne Mountford.

Before, we leave the cross country route from Oxford Kidlington to Wellesbourne Mountford via Ledbury, let us look at the basic visual navigation considerations concerning the route that you have learned so far.

Figure 9.16 overleaf depicts the route Oxford Kidlington to Wellesbourne Mounteford via Ledbury marked on a 1:500 000 chart at the beginning of the flight planning stage of a pilot's preparation for this cross country flight. The partially completed flight log is at *Figure 9.15*. Conditions are as before, with a prevailing wind from 240° (T) at 20 knots. The calculations for heading, groundspeed and leg times have been carried out and entered into the flight log. There are more calculations to be done that you will learn about later, but for the moment we are just going to concentrate on headings, timings and checkpoints.

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Figure 9.16.

Oxford Kidlington to Ledbury.

We calculated, above, the true heading of 279° (T) required to make good the true track of 286° (True) from Oxford Kidlington to Ledbury, at a true airspeed of 105 knots. The groundspeed, you will remember, came out to be 90 knots, based on which we calculated that the time required to cover the first leg distance of 42 nautical miles (nm) will be 28 minutes. You will notice from the flight log that we have entered a magnetic heading of 282° (M) because the local magnetic variation (in 2007) is 3° West. Obviously, once in the aircraft, we would check the compass deviation card to check whether a further deviation correction is necessary to obtain the final compass course.

You have learnt that at light aircraft speeds, it is a good idea to chose evenly spaced checkpoints every 5 to 10 minutes, so on the leg from Oxford Kidlington to Ledbury, two checkpoints should suffice. Examining the chart, a pilot would probably conclude that the airfield at Little Rissington, 14 nm from Oxford Kidlington is an excellent first check point, while the M5 junction and parallel railway line on the south-east outskirts of Tewkesbury, 32 nm from Oxford Kidlington, is a good second checkpoint.

Crossing the line feature of the M5 near the junction to the right of track will give us an exact en-route time check. We can get a good time check as we pass abeam Little Rissington, too, though we must take care that our wind correction angle of 7° (the difference between the track bearing and our heading) does not lead us to misjudge when we are passing abeam the airfield. Remember, we will be orientated into wind, so when the middle of Little Rissington airfield is on our port wing tip, we will be a short distance beyond this check point. However, 7° is not a large wind correction angle, so we should not have that problem on this flight.

In any case, having calculated that our groundspeed will be 90 knots, we can write on our chart, in china graph or water soluble marker pen, next to Little Rissington, the elapsed time of 9½ minutes for the 14 nm from Oxford Kidlington. (This assumes that you set your heading and start your stop watch, overhead Oxford Airport, on speed and on track).

Remember:

$$\textbf{time (mins)} = \frac{\textbf{distance (nm)}}{\textbf{groundspeed (kts)}} \times \textbf{60}$$

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We calculate that the elapsed time from Oxford Kidlington to the second checkpoint of the M5, at 32 nm distance, will be 21 minutes. This elapsed time can also be entered on the chart. We have already calculated that the elapsed time to the turning point will be 28 minutes.

Ledbury to Wellesbourne Mountford.

The length of the second leg of the flight from Ledbury to Wellesbourne Mountford, is 32 nm, and its true bearing is 072° (T). If the forecast wind is correct, we calculate that the true heading to fly for this leg (see Chapter 11), at our planned true airspeed of 105 knots, will be 074° (T), (note that the wind is from almost directly behind us so the wind correction angle is only 2°). Adding the magnetic variation of 3° West will give us a magnetic heading of 077° (M) and our groundspeed will be 125 knots, (again, showing that we are under the influence of the strength of an almost perfect tailwind). Our groundspeed of 125 knots is high, so we will cover the 32 nm leg in about 15 ½ minutes.

On this second leg, then, one check point about mid track should be enough. The airfield at Pershore which lies just to the left of track at 16 nm from Ledbury will be a good checkpoint. We calculate that we will pass abeam Pershore, and also over a loop in the River Severn, 7 ½ minutes after setting our new heading from Ledbury. We note that it is important to remember that at Ledbury, our turning point, we must restart our stopwatch.

Stratford upon Avon which lies to left of track 27 nm along the route will be a good marker for you, as Wellesbourne Mountford lies just beyond the town, 3 ½ nm to the East. You will reach Stratford 13 minutes after setting heading from Ledbury, and just 2 ½ minutes before you are due to arrive overhead Wellesbourne Mountford. (Bear in mind that ground is covered rapidly at 125 knots!) Having consulted the Aerodromes Section of the UK AIP, you should have all the information you need concerning Wellesbourne Mountford. You may also have consulted one of the popular Flight Guides such as those produced by Pooley's and Airplan Flight Equipment, which also give useful information about joining procedures.

Here, we have mentioned only the mental dead reckoning aspects of navigation on the route Oxford Kidlington to Wellesbourne Mounteford via Ledbury. Other important aspects of visual navigation, such as safety altitude and restricted airspace will be covered in Chapter 12, 'Flight Planning'. For instance, on the leg from Ledbury to Wellesbourne Mountford, you would have to plan to overfly the High Intensity Radio Transmission Station of Defford at a safe altitude and also be careful to not to overfly the unlimited laser site and the HIRTA at Pershore (above the upper limit of 3000ft) or divert around it. Check the notes on the 1:500 000 scale chart, yourself, to find out why.

THE IMPORTANCE OF USING TRUE AIRSPEED IN NAVIGATIONAL CALCULATIONS.

In the 'Aeroplanes' and 'Principles of Flight' volumes in this series of books, you will learn that the indicated airspeed that a pilot reads from the Airspeed Indicator (ASI) in the cockpit is not the same as true airspeed.

It is important that you note, that true airspeed (TAS) is the speed of the aircraft relative to the air mass in which it flying, and that, in all navigation calculations, it is TAS than you must use, not indicated airspeed.

In your navigational calculations, use True Airspeed, not Indicated Airspeed.

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The Difference Between True Airspeed and Indicated Airspeed.

Indicated airspeed is a function of the dynamic pressure sensed by the ASI mechanism and transmitted to a scale on the ASI, graduated in knots.

As you learn in other books in this series:

Dynamic pressure (Q) = ½ ρ v² where **ρ** is the **density of the air** and **v** is **true airspeed**.

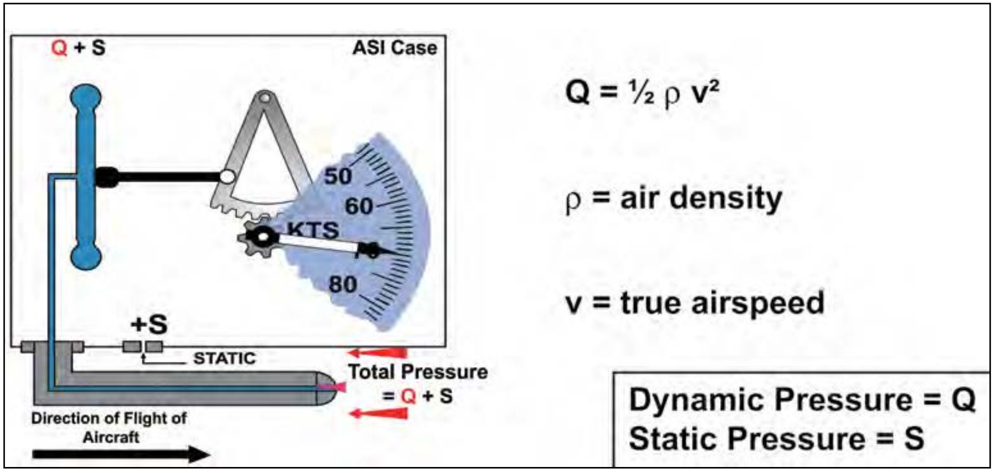

Figure 9.17 Indicated airspeed is a function of dynamic pressure Q.

IAS will be different from TAS at all times, unless the air in which the aircraft is flying corresponds exactly to ISA sea-level conditions.

The ASI will, therefore, measure the aircraft's true airspeed only if the local density of the air in which the aircraft is flying is equal to the value of **ρ** assumed by the manufacture of the ASI when the ASI was calibrated. All ASIs are calibrated assuming that the air density, **ρ**, has its ICAO Standard Atmosphere (ISA) sea-level value of 1.225 kg per cubic metre.

It follows, therefore, that the indicated airspeed that a pilot reads from his ASI will be different from his aircraft's true airspeed at all times, unless the air in which the aircraft is flying corresponds exactly to ISA sea-level conditions.

At altitude, an aircraft's TAS will invariably be higher than its IAS.

The higher an aircraft flies, the lower the density, **ρ**, will become. From the equation for dynamic pressure which gives us the reading on the ASI, Q = ½ **ρ** v², we can see that, for any given value of Q (i.e. for any given indicated airspeed), if **ρ** decreases, v, the true airspeed must increase to maintain the value of Q. Consequently, at altitude, an aircraft's true airspeed will be higher than its indicated airspeed.

As an example, on a day when atmospheric conditions are (fortuitously) close to ISA conditions, with 15°C surface temperature and a sea-level pressure 1013 millibars, an aircraft cruising at 5000 feet, an indicated airspeed of 105 knots would be making a true airspeed of about 111 knots.

It is important, therefore, that it is not the planned indicated airspeed that you use in your navigation calculations, but the appropriate true airspeed.

In correcting indicated airspeed to obtain true airspeed (TAS) there are, in fact, other ASI errors to take into account, apart from the density error that we have just mentioned. The two that are pertinent to light aircraft; instrument error and pressure error (sometimes called position error). We will not concern ourselves overmuch with instrument error and position error because the errors tend to be small. You may, however, find that the Pilot's Operating Manual for your aircraft refers to them so we will make brief mention of them here.

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Indicated airspeed corrected for instrument error is known as rectified or calibrated airspeed. To be absolutely accurate, true airspeed should be calculated from rectified or calibrated airspeed. In practice, ASIs are tested extensively, on the bench and in flight, by the manufacturer, and, in light aircraft, instrument error, including temperature errors, is largely compensated for within the ASI before it is released for service. Consequently, a light aircraft pilot flying at typical light aircraft cruising levels may make a reasonable assumption that the indicated airspeed (IAS) he reads from his ASI, the indicated airspeed, approximates very closely to the rectified or calibrated airspeed.

Calculations to convert indicated airspeed to true airspeed are simple to carry out using the navigation computer. The CD-ROM which accompanies this volume teaches how to carry out these calculations.

Calculations to convert Indicated Airspeed to True Airspeed are simple to carry out using the navigation computer.

Never omit to calculate the true airspeed equivalent of the indicated airspeed at which you plan to fly a cross country route, whatever type of navigation computer that you use.

ESTIMATING HEADING AND GROUNDSPEED IN THE AIR.

Estimating Heading to Steer.

You may be able to deduce from our study of the triangle of velocities that the wind correction angle that must be applied to our desired track angle to give us heading to fly is, in fact, equal to the angle of drift off-track that we would experience if we were to try to fly our route by pointing the nose of our aircraft along the desired track.

Always use True Airspeed for your Navigation Calculations during Pre-Flight Planning.

Consequently, it is extremely useful for a pilot to be able to estimate drift angle, when following an unplanned track, for example, during an unexpected diversion. If he does have to divert, he will have to apply drift to his new track in order to obtain a heading to steer.

Drift along a given track may be estimated using the mental dead reckoning (MDR) "clock code" that we mentioned earlier. We reproduce the MDR clock code diagram at *Figure 9.18*.

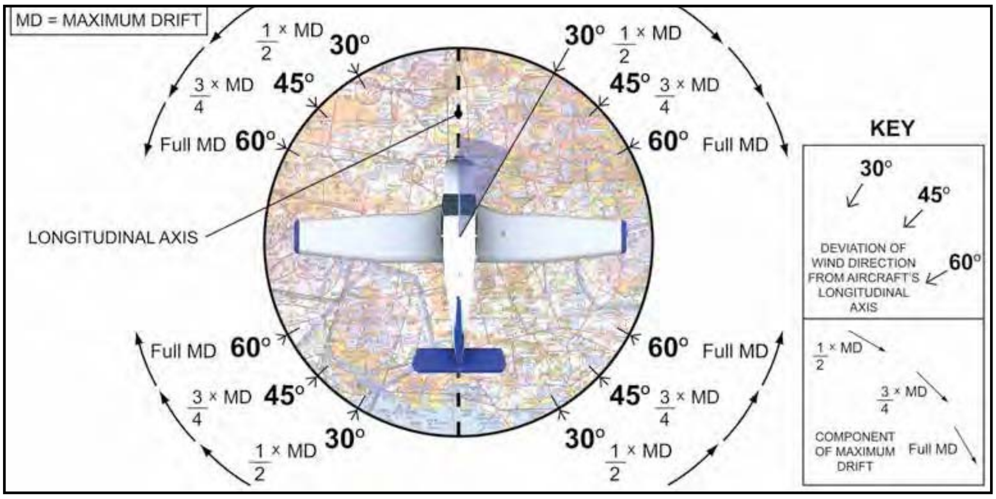

Figure 9.18 Calculating drift depending on the angle of wind direction with respect to the aircraft's heading.

Remember that, by applying the MDR clock code to maximum drift, you can calculate the drift that you will experience in any given wind for your planned true airspeed.

Wind correction angle is equal to drift angle.

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By using the MDR clock code, you can make a good estimation of the proportion of maximum drift that your aircraft will experience on any track when the wind is blowing at a known angle to that track. The estimated drift may then be applied to the track angle in order to determine the heading you must fly to maintain your new desired track.

Let us assume that, on the cross country flight we have been considering, shortly after leaving Oxford Kidlington for the first turning point at Ledbury, you elect to revise your flight plan and fly directly to Wellesbourne Mountford. You decide to set heading to Wellesbourne Mountford from the Visual Reference Point for Kidlington, located at Charlbury, about 4 nm from the Kidlington ATZ, along your first leg.

You have already calculated during the flight planning stage that, at your true airspeed of 105 knots, and with a wind from 240° (T) at 20 knots, the maximum drift experienced by your aircraft will be 12°.

$$\left(\textbf{Max drift (°)} = 20 \times \frac{60}{105} = 12° \textbf{ approximately} \right)$$

By laying a straight edge from Charlbury to Wellesbourne Mountford, you estimate the true track angle for your diversion to be 345° (True).

You see then that, with the wind coming from 240° (T), it will meet your diversion track of 345° (True), from behind and from the left.

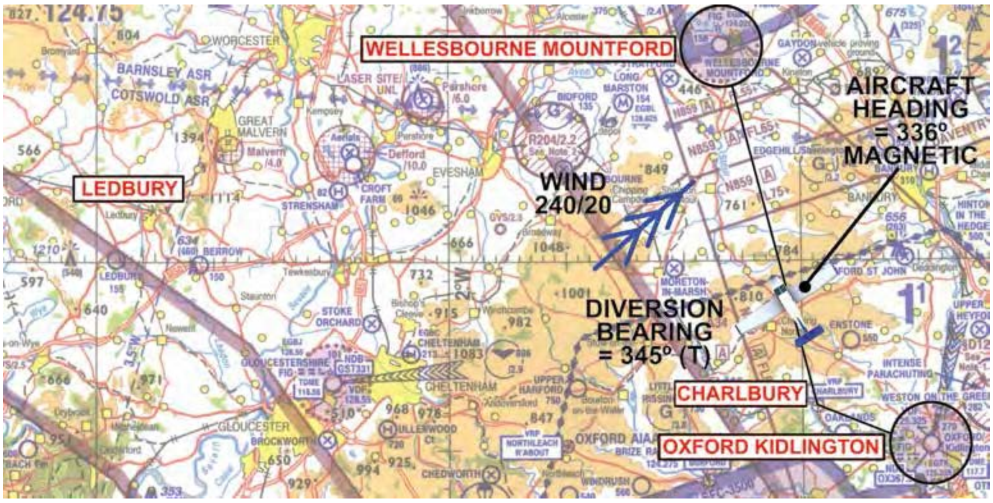

Figure 9.19 Estimate a heading to fly to make good the diversionary track.

The MDR clock code shows that when the angle between the wind and the longitudinal axis of an aircraft, which is heading along a desired track, is 60° or greater, the aircraft will experience the whole maximum drift. In this case, therefore, on your diversionary track, you will experience a drift of 12°. The drift, as you see from examining the wind arrow that you drew on your chart before take-off, will be to starboard. **Consequently, as you know that in order to make good a track in a cross wind, you must orientate the nose of your aircraft <u>towards</u> the wind by an appropriate angle, you deduce that you must head 12° to port of the 345° (T) track heading and steer 333° (T)**. And because the magnetic variation in your area is about 3° West, you take on a heading of 336° Magnetic. You would, of course, consult the compass deviation card to see if there was a further deviation correction to make on that heading.

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Estimating Groundspeed.

Having set your diversion heading of 336° (M), you decide to obtain a ground fix as soon as possible to confirm whether or not your estimated heading is good. Seeing Chipping Norton pass about one nautical mile to the left of your track, you decide that you are indeed on track, and, therefore, elect to maintain your heading of 336° (M).

Being happy with your track, and seeing that your chart does not reveal any good intermediate checkpoints between Chipping Norton and your destination of Wellesbourne Mountford, you realise that you should try to estimate your groundspeed in order to calculate an approximate estimated time of arrival (ETA) at Wellesbourne Mountford.

You can estimate your groundspeed using a version of the MDR clock code. If the wind were a perfect tailwind you would simply add the whole of the wind speed to your true airspeed to obtain your groundspeed. If the wind were directly on your nose, you would subtract the whole wind speed from your true airspeed to obtain your groundspeed. On the other hand, if the wind were blowing at 90° to your track, it would have little effect on your aircraft's speed and your groundspeed would be equal to your airspeed. But, if the wind is meeting the track at an intermediate angle, a proportion of the wind speed needs to be added or subtracted to your true airspeed to obtain the aircraft's ground speed. In order to calculate what proportion of wind speed should be added or subtracted, we use a version of the MDR clock code.

For groundspeed calculations, however, we must measure the wind angle from a line cutting the track at 90°. **(In actual fact, we should be measuring the wind relative to the aircraft's lateral axis, but for small wind correction angles and light winds we can take track as our reference line.)**

Figure 9.20 shows how the MDR clock code works for ground speed. If the wind meets the line passing at 90° through the track line at an angle of 60° or greater, then the whole of the wind speed can be added or subtracted from the true airspeed to obtain the groundspeed. If the angle is 30°, then half the wind speed is applied; for 45°, ¾ of the wind speed is applied; for 10°, 1/6 of the wind speed is applied, and so on.

The number of degrees is treated as a number of minutes, and that number is compared to a fraction of an hour, just as you learned earlier. *Figure 9.20 below.* gives the detail.

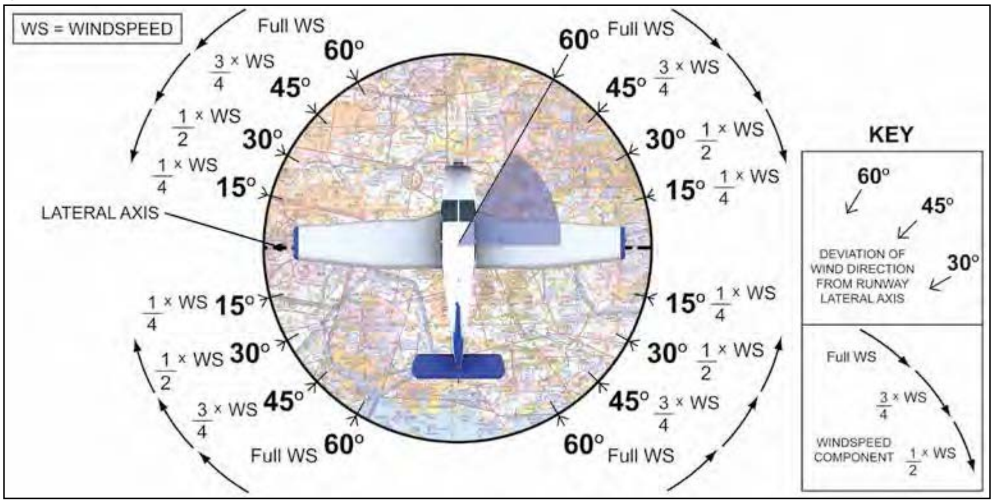

Figure 9.20 Calculating the proportion of windspeed affecting groundspeed.

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For your track of 345° (T) and a wind blowing from 240° (T), the angle between the wind and a line passing at 90° through the desired track line is 15°, from behind. *(See Figure 9.21.)*

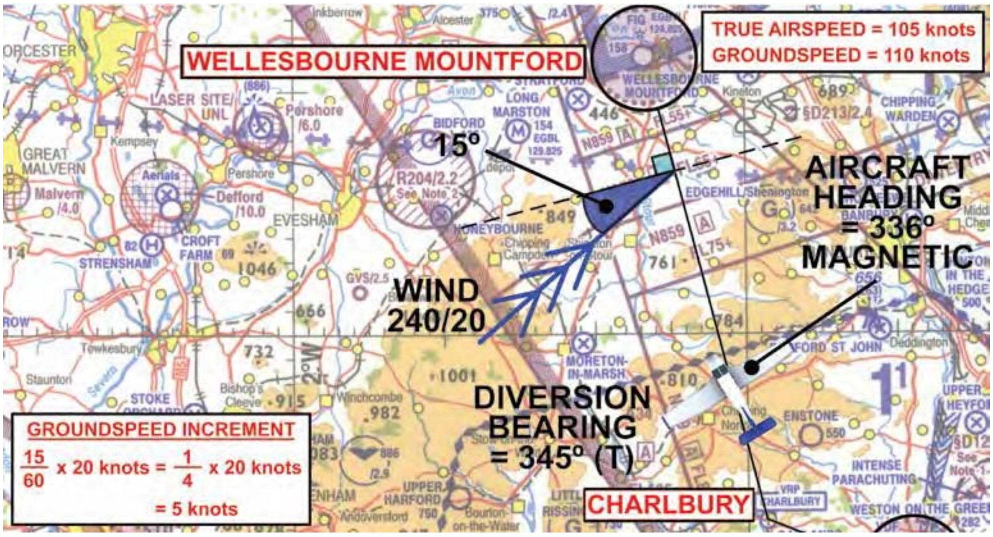

Figure 9.21 Estimating groundspeed along the diversionary track. With the wind meeting track at 15° from behind, add ¼ of windspeed to airspeed to obtain groundspeed.

At this angle, the MDR clock code tells us that you would apply ¼ of the windspeed to your true airspeed to obtain the groundspeed. One quarter of 20 knots is 5 knots. As the wind is behind you, add the 5 knots to your true airspeed of 105 knots to obtain your groundspeed of 110 knots.

110 knots is just under 2 nautical miles (nm) per minute, so estimating that you have 16 nm to run from Chipping Norton to Wellesbourne Mountford, you calculate that you should arrive overhead Wellesbourne Mountford in about 9 minutes time. You decide, then, to begin looking for Wellesbourne Mountford after 7 minutes have elapsed. (The example above illustrates the principle of the technique, but with the drift angle of 12deg, the lateral axis of the aircraft on a heading of 333(T) is aligned on 243/063deg, only 3deg different from the wind, giving a tailwind of 1 knot. However, over short distances, the difference in calculated groundspeed would not significantly affect timings. See third last paragraph on p.145)

CONCLUSION.

The key to successful visual navigation, using the mental dead reckoning calculations and methods that we have studied in this chapter, is to make your flight planning as thorough as possible, to double check your heading and groundspeed figures and then, in the air, to concentrate on flying accurate headings and airspeeds. If you fly accurately, and the wind forecast is also accurate, you should arrive over your checkpoints after the expected elapsed time. Consult your chart about 2 minutes before each checkpoint is due to be reached. The checkpoint should be visible by then. Once you have reached the checkpoint and confirmed the time, put your chart away and continue to concentrate on flying accurately.

Even if the wind forecast is inaccurate, with checkpoints marked on your chart at regular intervals of 5 to 10 minutes flying time, you will not be far off track and you will be in a position to correct any track error from observing where your ground position lies with respect to the checkpoint, after the calculated elapsed time. You will learn how to correct for track errors in a later chapter.

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When updating estimated elapsed times and estimated times of arrival, it is convenient to do so at checkpoints which lie halfway or a third, and two thirds, of the way along track.

If you are, say, one minute behind time at the half-track point, you will complete the leg two minutes behind time.

If you are two minutes early at a checkpoint, one third of the way along track, you will be four minutes early at a checkpoint two thirds of the way along track and 6 minutes early at your destination or turning point.

So, fly accurately, consult your chart at appropriate times, and maintain a good look out for other traffic.

Above all, you should be aware that, in visual navigation, most of the navigation is done before you even get airborne. If you carry out your flight planning thoroughly, and study your route closely, the navigational task in the air should be straightforward.

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Representative PPL - type questions to test your theoretical knowledge of Principles of Dead Reckoning Visual Air Navigation.

1. You plan to fly a cross-country flight at 2 500 feet at a true airspeed of 90 knots. The forecast wind is 165°(T) / 30 knots. What will be the maximum drift your aircraft will experience?

   a. 30º
   b. 20º
   c. 45º
   d. 25º

2. You plan to fly a cross-country flight at 3 000 feet at a true airspeed of 120 knots. The forecast wind is 280°(T) / 20 knots. What will be the maximum drift your aircraft will experience?

   a. 10º
   b. 40º
   c. 20º
   d. 30º

3. You plan to fly a cross country flight at 2 000 feet at a true airspeed of 120 knots. Your track is 270° (True) and the wind is from 225° (True) at 24 knots. Using the Mental Dead Reckoning Clock Code, what true heading would you steer, and what would be your magnetic heading if the local magnetic variation is 4° West?

   a. 258° (True) 262° (Magnetic)
   b. 261° (True) 265° (Magnetic)
   c. 261° (True) 257° (Magnetic)
   d. 279° (True) 283° (Magnetic)

4. You plan a flight to another airfield, for which the true track angle is 050° (T), at a true airspeed of 120 knots, and at a cruising altitude for which the wind forecast is 020° (True) / 20 knots. Use the Mental Dead Reckoning Clock Code to estimate the required true heading and groundspeed.

   a. 045° (True) 100 kts
   b. 055° (True) 100 kts
   c. 045° (True) 80 kts
   d. 040° (True) 110 kts

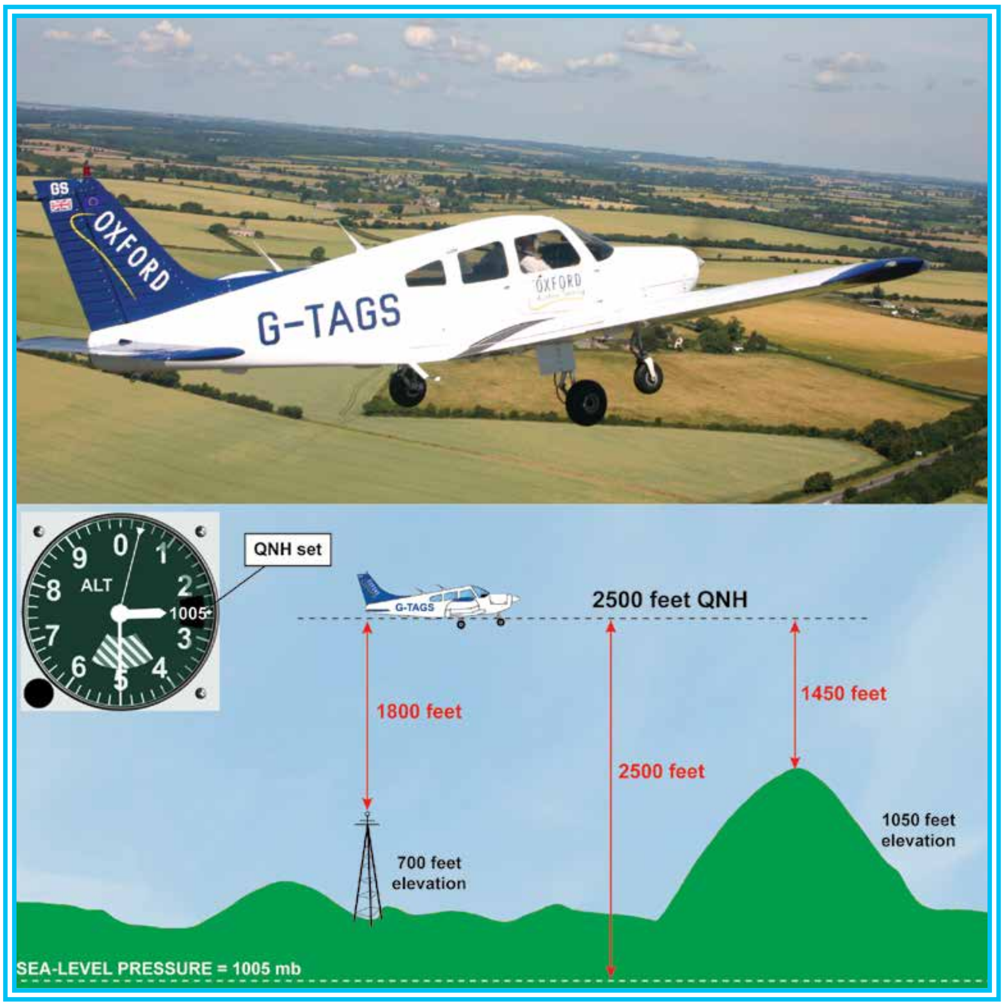
5. You plan to fly a cross country flight at 2 500 feet at a true airspeed of 90 knots. Your track is 160° (True) and the wind is from 010° (True) at 15 knots. Using the Mental Dead Reckoning Clock Code, estimate your magnetic heading and groundspeed. Assume that Magnetic Variation is 3° West.

   a. 168° (Magnetic) 105 kts
   b. 162° (Magnetic) 98 kts
   c. 152° (Magnetic) 98 kts
   d. 158° (Magnetic) 105 kts

Question	1	2	3	4	5
Answer					

The answers to these questions can be found at the end of this book.

CHAPTER 10
ALTIMETER SETTINGS



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INTRODUCTION.

This Chapter deals with the subject of altimeter interpretation and altimeter settings. It is reproduced from the 'Air Law' volume of this series.

When flying cross country on a visual navigation route, you will be flying in accordance with the Visual Flight Rules (VFR). Therefore, you must at all times maintain Visual Meteorological Conditions (VMC).

The definition of VMC varies according to the airspace you are flying in, the altitude or Flight Level at which you are operating, and, in certain circumstances, your airspeed. VMC and VFR are dealt with fully in Volume 1, 'Air Law'.

The visual navigation routes we have considered for the purposes of this book do not involve entry into or transit of controlled airspace. However, when flying cross country, you may need to request entry into, or transit of, a control zone (CTR). You will also often find that you fly beneath controlled airspace of which you wish to remain clear. Sometimes, that controlled airspace will be an airway which, in the United Kingdom, is Class A airspace, and which, as a VFR pilot, you are not permitted to enter.

VMC criteria are also different outside controlled airspace depending on whether you are flying above or below an altitude of 3000 feet, and, if you are above 3 000 feet, whether or not you are above or below Flight Level 100.

When you fly, you are able to move in three dimensions. Pilots, therefore, must be able to navigate in three dimensions, too. Monitoring and controlling your vertical distance above terrain or above sea-level requires you to have a sound understanding of altimetry. At the very least, as you have learned in this book, pilots have to decide the minimum altitude at which each leg of a cross country route can be safely flown, and to be able to calculate a safety altitude for each leg.

THE ALTIMETER AND ALTIMETER SUBSCALES.

This chapter deals with the subject of altimetry from the point of the pilot interpreting the altimeter in the cockpit and selecting the appropriate altimeter setting on the instrument's subscale. The mechanical and meteorological aspects of altimetry are dealt with in other volumes in this series.

Basically, the aircraft's altimeter is an instrument which measures atmospheric pressure and is calibrated so as to indicate the vertical separation of the aircraft from a defined pressure datum level.

The altimeter indicates the vertical separation of the instrument from a defined pressure datum level.

In the regions of the atmosphere in which most aircraft fly (certainly all light aircraft), atmospheric pressure decreases with increasing distance from the Earth's surface at a linear rate of approximately 1 millibar every 30 feet. So it is fairly straightforward to calibrate the altimeter to indicate to the pilot his vertical distance in feet - the standard unit of altitude in aviation - from a selected pressure datum. This pressure datum is set in the altimeter when the pilot selects what is known as an altimeter subscale setting. In analogue altimeters, the altimeter subscale setting is invariably displayed in a small rectangular window on the face of the instrument. The figures displayed in this window usually express the pressure datum in millibars or hectopascals.

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Figure 10.1 The altimeter subscale set to the Standard Pressure Setting of 1013 mb.

In the ICAO Standard Atmosphere (ISA), the sea-level pressure is 1013.2 millibars (hectopascal). This pressure setting is known as the Standard Pressure Setting (SPS) which pilots select on their altimeters when flying above the transition altitude by reference to Flight Level. You should note that in Europe, outside the United Kingdom, the unit of pressure used in aviation is the hectopascal. Fortunately, 1 hectopascal (hPa) = 1 millibar (mb), so the figures representing pressure in these two units are identical. In the USA and Canada, altimeter subscale pressures are give in inches (in) of Mercury (Hg), the SPS being 29.92 in Hg. You may find altimeters with two subscale windows, showing both mb and in Hg.

From day to day, of course, pressure at sea-level in the real atmosphere varies, so if a pilot wished to read his vertical separation above mean sea-level (defined as altitude) on any given day, he would have to set the mean sea-level pressure in his altimeter subscale.

Atmospheric pressure changes rapidly. Therefore, in order to have accurate information on terrain clearance, pilots must obtain frequent updates of mean sea-level pressure, either QNH or Regional Pressure Setting.

Sea-level pressure has been known to vary from about 975 millibars to 1065 millibars in the United Kingdom. In fact, atmospheric pressure changes rapidly, and we cannot even assume that it will remain constant from one hour to the next. Consequently, pilots who are flying near the Earth's surface, and for whom a primary concern is to maintain terrain clearance, will regularly need to obtain actual pressure values corrected to msl (known generally as QNH) from appropriately equipped Air Traffic Service Units. A current pressure setting is of course, of particular importance when flying over hilly or mountainous terrain. An alternative to QNH when not in the vicinity of an airfield is the Regional Pressure Setting (see pages 155 and 157). If the subscale setting is not reset periodically during a flight of more than short duration, the altimeter may give a false indication of the altitude and hence the vertical separation between an aircraft and the terrain.

A primary purpose of altimeter subscale settings, then, is to enable pilots to ensure proper and adequate clearance from the ground. Another important function of the altimeter is to ensure that an aircraft maintains safe vertical separation from other traffic.

In order to achieve the above-mentioned aims, pressure settings are disseminated by Air Traffic Service Units to aircraft for flight below what is known as the transition altitude (explained later in this chapter).

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When flying under IFR above the transition altitude, by reference to Flight Levels, pilots set the Standard Pressure Setting (SPS) of 1013.2 mb (hPa) on their altimeters.

For the United Kingdom, altimeter setting procedures are defined in the UK AIP En-route Section (ENR) Chapter 1-7.

CHANGING ATMOSPHERIC PRESSURES.

As we have established, pressure at sea-level and throughout the atmosphere will vary with time and with changing weather systems. Consequently, any flight of more than a very short duration, especially a cross-country flight, will inevitably require the altimeter subscale to be reset periodically.

If the sub scale is not reset periodically, the altimeter is likely to give false indications of the vertical distance of the aircraft above the ground or water.

The two altimeter subscale settings which vary with location and time and which need to be frequently updated by the pilot are known as QFE and QNH. (These two codes are part of what is known as the "Q" code which dates back to the days when the Morse Code was the main method of communicating between aircraft and ground stations.)

QFE AND QNH.

QFE.

QFE is defined as the pressure setting for aerodrome elevation. This will normally be the pressure setting at the aerodrome reference point, usually the highest point on the landing area. Aerodrome elevation is defined as the vertical distance of the aerodrome above sea-level. So, if an aircraft is on the ground at the highest point on the landing area of an aerodrome with the aerodrome QFE set on the altimeter subscale, the altimeter will indicate zero feet.

The QFE is the pressure setting at the aerodrome reference point.

Figure 10.2 QFE set on the altimeter subscale.

In general, with aerodrome QFE set on the altimeter, the altimeter will read zero when the aircraft is on the ground at the aerodrome.

You should note that at many aerodromes the aprons are at a different elevaton from the aerodrome elevation. Thus, if a pilot asks ATC for the QFE while on the apron, the altimeter may not read precisely zero feet. For example, the apron at Oxford/ Kidlington is 240 feet above mean sea-level (amsl), whereas the general aerodrome elevation is 270 feet amsl. Therefore, if a pilot sets the QFE given to him by the Tower, while on the apron, his altimeter would read minus 30 feet.

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With QFE set on the altimeter subscale, the altimeter of an aircraft in flight will read height above the aerodrome.

When an aircraft with QFE set on the altimeter subscale is in the air, its altimeter will read height above the aerodrome. You should note that the word height is, by definition, the vertical distance of an aircraft, in flight, above the pressure datum level defined by the QFE set on the altimeter subscale.

QNH.

QNH is the pressure measured at any point, corrected for temperature error and then reduced to mean sea-level under standard ISA conditions.

So, if an aircraft is on the ground at an aerodrome with the QNH set on its altimeter subscale, the altimeter will read the elevation of the ground on which it is standing.

When we speak of the elevation of ground, we are referring to its vertical distance from mean sea-level.

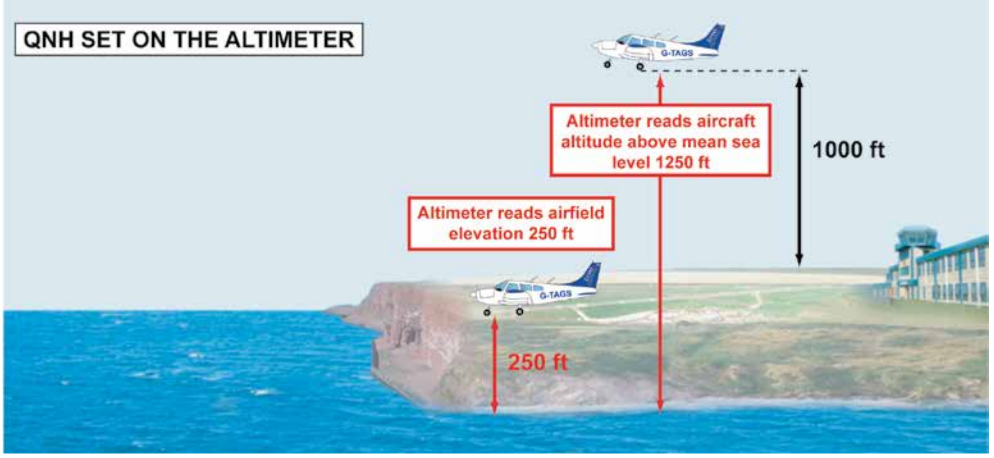

Figure 10.3 QNH set on the altimeter subscale gives vertical distance above sea-level.

With QNH set on the altimeter subscale, the altimeter of an aircraft in flight will read altitude - that is, the vertical distance of the aircraft above sea-level.

When airborne, the altimeter, with QNH set, will read the altitude of the aircraft; that is, its vertical distance above mean sea-level.

RT Phraseology.

In order to confirm that the pilot has correctly understood the QFE or QNH passed to him by a ground station, he is required to "read back" the QFE or QNH. Note that, in the UK, when the QFE or QNH is 1000 millibars or below, the word "millibars" is included in the radio transmission, whereas for pressure settings above 1000 millibars, it is customary to omit the word "millibars".

Aircraft request:	**"Oxford Tower, G-ABCD, request QFE"**
ATC reply:	**"G-CD, QFE 996 millibars"**
Aircraft read-back:	"**QFE 996 millibars, G-CD"**
	or
Aircraft request:	**"Oxford Tower, G-ABCD, request QNH"**
ATC reply:	**"G-CD, QNH 1003"**
Aircraft read-back:	**"QNH 1003, G-CD"**

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Should I set QFE or QNH?

If a pilot remains in the circuit at the aerodrome, it is appropriate to use QFE so that the pilot has the height information he needs to fly the circuit pattern correctly. Be aware, though, that some aerodromes may give circuit information in QNH.

When flying locally, outside the circuit, QNH should generally be used so that a pilot has the altitude information he needs in order to compute the vertical separation between his aircraft at the terrain beneath him.

CROSS-COUNTRY FLYING AND ALTIMETER SUBSCALE SETTINGS.

General.

When flying cross-country, it is essential that the pilot should remain aware of the vertical separation between his aircraft and the terrain and obstacles over which he is flying. When flying in the vicinity of an aerodrome, it is useful to have that aerodrome's QNH set on the altimeter subscale. However, in the United Kingdom, when on an extended cross-country flight more than 25 nm from an airfield, it is more usual for the pilot to request the Regional Pressure Setting for the region of the country he is flying over. Regional Pressure Settings are the lowest forecast value of msl pressure for a given Altimeter Setting Region. Regional Pressure Settings are covered in detail later in this chapter.

On charts, the top of all obstacles (high ground, tall buildings, radio masts etc.) is relative to mean sea-level, so, with QNH set, obstacle clearance can be assured with the help of simple arithmetic.

By subtracting the elevation of an obstacle from the altimeter reading, the pilot will know his approximate height above the obstacle.

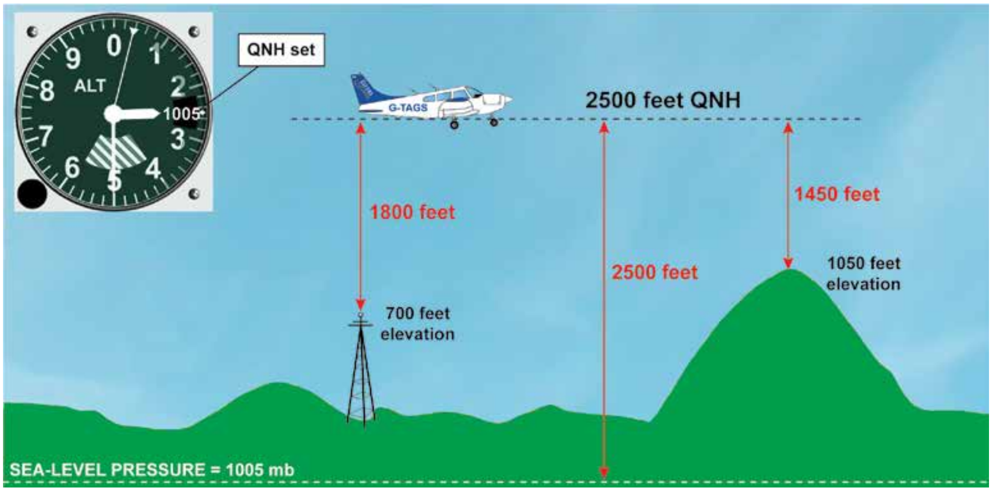

Figure 10.4 Flying cross-country at 2500 feet with QNH set.

However, although flying on a cross-country route with QNH set will enable a pilot to compute his vertical separation from terrain and obstacles, this is not the whole story in terms of maintaining a safe altitude.

Remember, the altimeter is indicating an aircraft's vertical separation from a pressure level; that is, the level at which the pressure prevails which is set on the altimeter

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subscale. With QNH set, the pressure datum level is mean sea-level. If the pressure at sea-level changes while the aeroplane maintains level flight, the altimeter reading will change. But if the pressure changes and the aircraft flies in such a manner as to maintain a constant altimeter reading, the aircraft will either climb or descend. Let us look at an example of this latter situation.

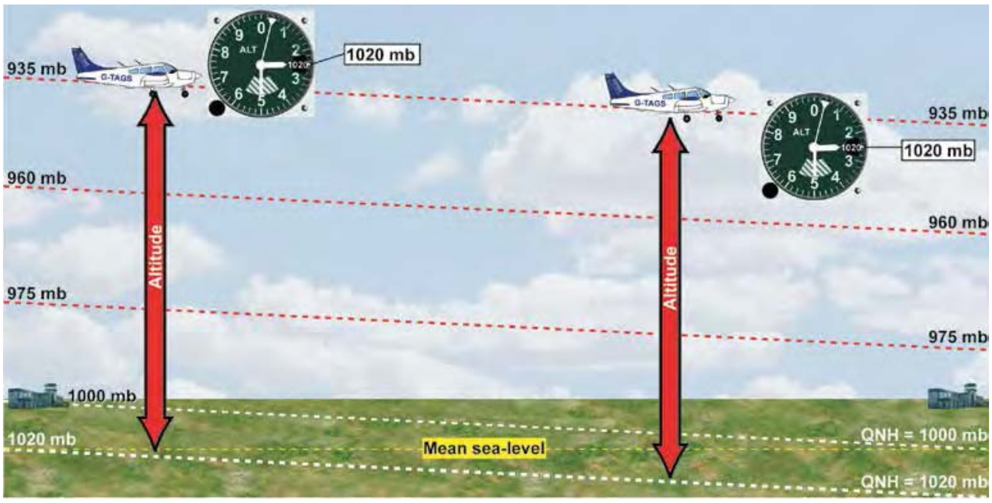

Figure 10.5 When flying into a region of falling atmospheric pressure while maintaining a constant altimeter subscale setting, the aircraft descends.

The aircraft in *Figure 10.5* is leaving its departure aerodrome on a cross-country flight that the pilot intends to carry out at an altitude of 2 500 feet. The pilot has set the departure aerodrome QNH of 1020 millibars on his altimeter and elects, unwisely, to remain on that QNH for the duration of the flight. Let us assume that, unbeknown to the pilot, as he flies towards his destination aerodrome he is flying into an area of falling pressure. As we have established, because the pilot elects not to update the altimeter setting and maintains 2 500 feet as indicated by the altimeter, the changing pressure situation means that he will either climb or descend. But why should this be?

For the departure aerodrome, we know that the calculated sea-level pressure is 1020 millibars, and the pilot has set this on his altimeter subscale as the QNH. As he leaves the aerodrome at his cruising altitude of 2 500 feet indicated, the aircraft is actually flying along an invisible pressure datum line of about 935 millibars. (We can calculate the pressure at 2 500 feet fairly easily, as pressure falls at an approximate rate of 1 millibar for every 30 feet gain of height. The actual rate is 27ft/mb, but for ease of calculation, (particularly if airborne), it is easier to use 30).

If we assume that the pressure reduced to sea-level at the destination airfield is 1000 mb (this will be the destination aerodrome's QNH), you can see from *Figure 10.5* that the isobars are sloping downwards. The aircraft that we are considering, then, as it is following the 935 millibar pressure surface, will be descending along its route, even though the pilot is unaware of this because of his poor flight planning and because he is maintaining a constant altimeter reading of 2 500 feet. It is not difficult to work out that, if the destination QNH is 1000 millibars, by following the 935 millibar pressure surface, the aircraft will be only 1950 feet above sea-level when it arrives at its destination, even though the altimeter still indicates 2 500 feet. Of course, had the pilot reset the QNH to 1000 mb, the indicated 2 500 feet altitude would have reflected his true altitude. So, in the situation we have described, the aircraft's

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true altitude is reducing while its indicated altitude remains the same. This is a potentially hazardous situation, especially in poor visibility. However, the situation is hazardous in good visibility, too, because an ATZ, Control Zone, or Danger Area could be penetrated when a pilot thinks he is passing above the Zone or Area.

Therefore, a pilot must exercise particular caution when flying into an area of falling atmospheric pressure.

In the opposite situation, flying towards a high pressure area, an aircraft which maintained a constant indicated altitude, without the pilot updating the QNH, would actually be climbing. Though this situation is not hazardous from the terrain clearance point of view, a pilot may unwittingly enter an airway and cause danger to himself and others as a result.

Consequently, it is of the utmost importance that the pilot should update the QNH regularly. This updating of QNH along a cross-country route may be effected by requesting QNH from aerodromes along the route, or, if in the United Kingdom, by requesting the Regional Pressure Setting.

Update aerodrome QNH at appropriate intervals and, when on a cross-country flight, make sure that you have the correct Regional Pressure Setting on your altimeter.

Regional Pressure Setting.

The United Kingdom is divided into a number of **Altimeter Setting Regions** (*See Figure 10.6*) for each of which the Met Office calculates the lowest forecast pressure, for the next two hours. These pressure settings are known as Regional Pressure Settings. Regional Pressure Settings are updated every hour.

The Regional Pressure Setting (RPS) may be obtained from all aerodromes providing an Air Traffic Service, or on the London, Manchester or Scottish Flight Information Service frequencies. The purpose of RPS is to enable pilots to maintain safe terrain clearance when a local aerodrome QNH is not available. Because of the nature of the RPS, and its purpose, an altimeter with RPS set on it will always indicate lower than the actual altitude. RPS must not be used as the vertical reference in the vicinity of controlled airspace.

When approaching the destination airfield, the pilot will be given the QNH of the aerodrome, and possibly also its QFE.

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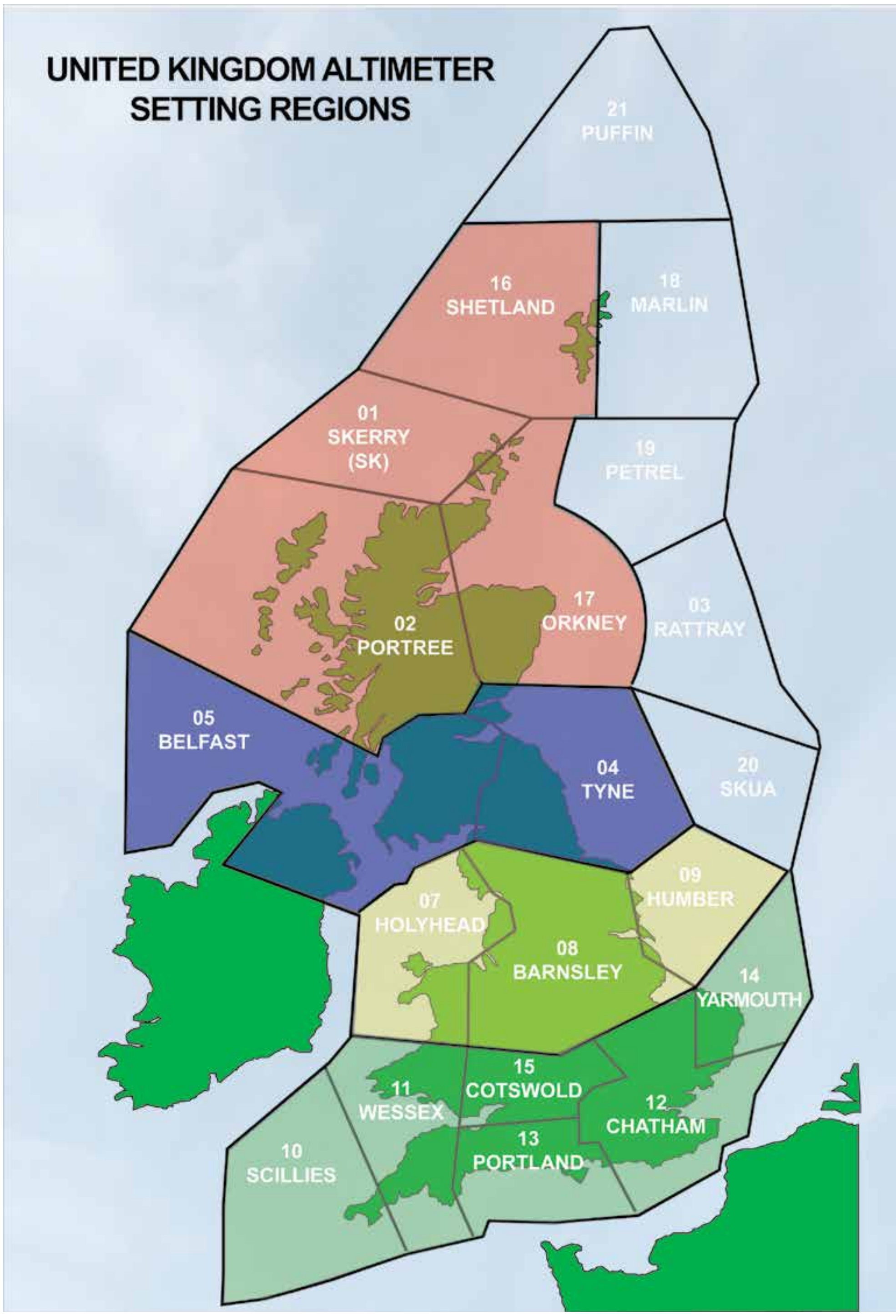

Figure 10.6 United Kingdom Altimeter Setting Regions.

Remaining Clear of the Base of Controlled Airspace.

Control Zones (CTRs) and Control Areas (CTAs), with certain exceptions, are not part of the Altimeter Setting Region network. Therefore, when flying near to the base of a CTA (or TMA), pilots must obtain a QNH from a nearby aerodrome in order that they may avoid, unwittingly, entering the CTA/TMA from beneath. When flying beneath

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an airway whose base is expressed as an altitude, pilots are likewise recommended to obtain a QNH from an adjacent aerodrome, in order to avoid entering the base of the airway.

THE STANDARD PRESSURE SETTING OF 1013.2 MILLIBARS.

During flights well above terrain, changes in atmospheric pressure along a route, and over time, are not so critical to terrain clearance considerations. At these higher altitudes, the fact that a pilot may fly over long distances without updating the altimeter subscale pressure setting will not endanger the aircraft. In fact, having all aircraft use the same altimeter subscale setting, above a defined altitude, will actually help an Air Traffic Control Unit (ATCU) maintain vertical separation between the aircraft that the ATCU is controlling or in communication with.

So, by international agreement, above a certain defined altitude, called the transition altitude, which varies from country to country and even, in some cases, from aerodrome to aerodrome, the Standard Pressure Setting (SPS) of 1013.2 mb (or hPa) is used. The use of the SPS is obligatory in controlled airspace above the transition altitude, and strongly recommended for VFR flights conducted above the transition altitude, outside controlled airspace. For IFR flights, the use of the SPS is obligatory above the transition altitude, both inside and outside controlled airspace.

THE TRANSITION ALTITUDE.

Transition altitudes are established by national aviation authorities to meet the air traffic and flight safety requirements of local conditions. Obviously, over countries with lots of mountainous areas, the transition altitude will be higher than over lowlands. The transition altitude in the United Kingdom is 3000 feet over most of the country and at all aerodromes, unless otherwise notified. There are exceptions, however. For example, the London TMA, Cardiff and Bristol have a transition altitude of 6000 feet; Manchester has a transition altitude of 5000 feet, and East Midlands and Birmingham 4000 feet. Wherever possible, there is a common transition altitude for all aerodromes within a Control Zone.

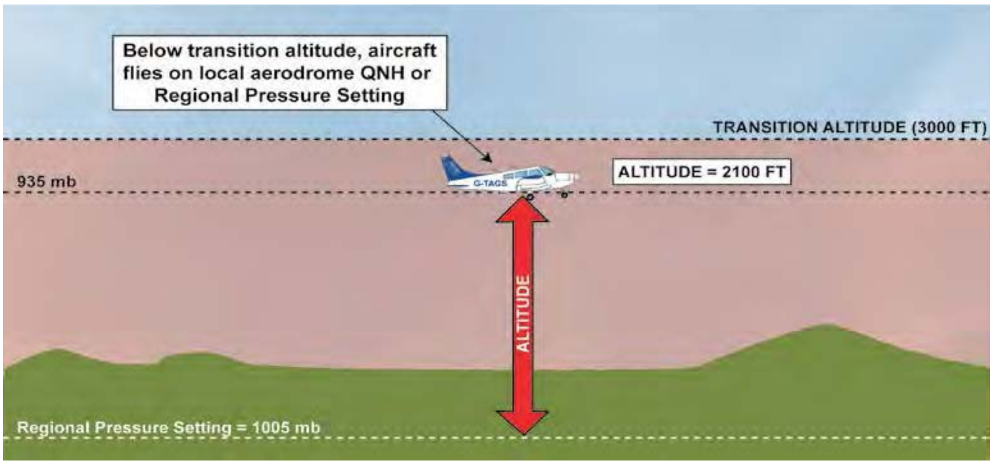

Figure 10.7 Cruising below a transition altitude of 3000 feet with Regional Pressure Setting or local Aerodrome QNH set on the altimeter subscale.

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In the United States, the transition altitude over the whole country is 18 000 feet. In New Zealand, the transition altitude is generally 13 000 feet.

When flying below the transition altitude, pilots set an aerodrome QNH or the Regional Pressure Setting (RPS) on the altimeter in order that they can maintain separation with terrain and obstacles. (*See Figure 10.7.*)

Typically, on a cross-country flight, a VFR pilot will have studied the ICAO 1:500 000 topographical chart closely. The elevation of all high ground and obstacles will be given on the chart so the pilot will know the vertical distance of hill tops and obstacle summits from sea-level. By subtracting known elevations from his altimeter reading, with QNH or RPS set, he will know how high he is above the terrain.

Maximum Elevation Figures are not Safety Altitudes.

1:500 000 charts also show Maximum Elevation Figures (MEF) in quadrants marked on the chart. The MEFs, as the name suggests, show the elevation of the highest known features in each quadrant, expressed in thousands and hundreds of feet above mean sea-level. Natural obstacles (hills, etc.), will have 300ft added to allow for possible undeclared small structures such as masts. Elevations are rounded UP to the next whole hundred feet. *Figure 10.8* highlights an MEF of 1 300 feet for the Isle of Wight which indicates a tower whose actual elevation is 1297 feet above mean sea-level. **Note that an MEF is not a Safety Altitude.**

Figure 10.8 Maximum Elevation Figures on the Isle of Wight. With the altimeter set to QNH or RPS, the pilot can compute the vertical separation between his aircraft and terrain or obstacles.

Above the transition altitude, with the SPS of 1013 mb set on the altimeter, altimeter indications are referred to as Flight Levels.

Above the transition altitude the SPS of 1013 mb is set. When an aircraft is equipped with two or more altimeters, it is standard practice when flying above the transition altitude, that one altimeter should remain set to QNH so that the pilot may still know his clearance from terrain. Above the transition altitude, with 1013.2 mb (hPa) set on the altimeter subscale (the pilot can only dial up the digits 1013, of course), the indications on the altimeter are referred to as Flight Levels.

When air traffic controllers and pilots transmit Flight Levels over the radio, or when Flight Levels are written down, the last two zeros of the altimeter reading are omitted. So, when flying by reference to Flight Levels above the transition altitude, with 1013 mb (hPa) on the altimeter, an altimeter indication of 5000 feet would be referred to as

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Flight Level 50; an indicated 6500 feet would be referred to as Flight Level 65, and an altimeter reading of 15 000 feet would be referred to as Flight Level 150.

Under IFR, Flight Levels are not established for every altimeter reading with the SPS set on the subscale. Flight Levels (FL) are given for intervals of 500 feet between transition altitude and FL 250 and at intervals of 1000 feet above FL 250; e.g. FL 35, FL 40, FL 45 and so on up to FL 245; then FL 250, FL 260, FL 270 and so on. Under VFR, any FL can be flown.

Flight Levels are used principally to maintain adequate separation between aircraft flying in accordance with Instrument Flight Rules (IFR). Under VFR, any FL can be flown. But pilots flying in accordance with the Visual Flight Rules (VFR) in controlled airspace must also use SPS and fly by reference to Flight Levels when instructed to do so by the ATCU.

With all aircraft flying at Flight Levels, invariably during the en-route phase of flight, Air Traffic Controllers know that all aircraft are flying at vertical distances from the same pressure datum level of 1013.2 mb (hPa). In these circumstances, with altimeter indications referenced to the same standard pressure datum level, Air Traffic Controllers can safely allocate Flight Levels to the aircraft under their control and be confident that vertical separation will be maintained if pilots keep to their assigned levels.

At this point, it is pertinent to give a formal definition of the transition altitude.

The 'transition altitude' is the altitude at or below which the vertical position of an aircraft is normally monitored by reference to altitude.

The transition altitude is the altitude at or below which the vertical position of an aircraft is normally monitored by reference to altitude.

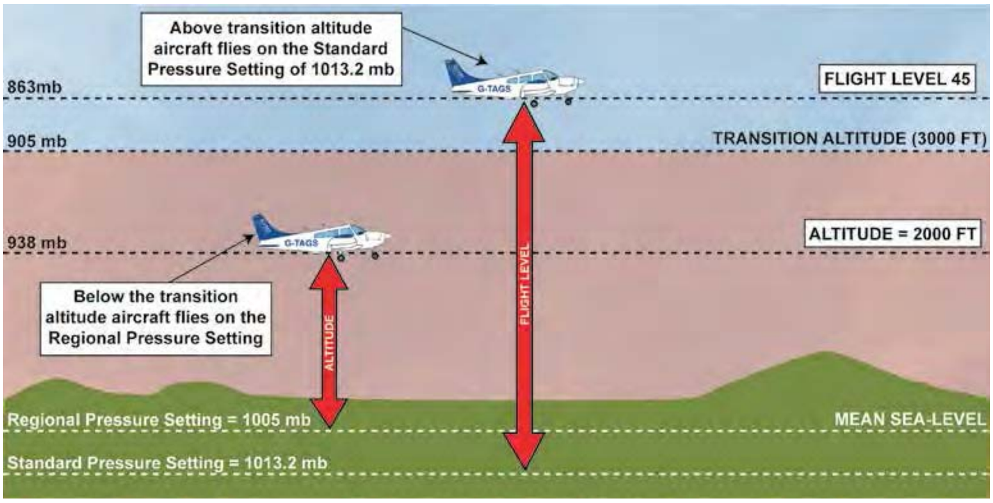

Fig 10.9 Cruising above and below the Transition Altitude.

The transition level is always above the transition altitude.

Below the transition altitude, an aircraft flying cross-country, in the United Kingdom, will normally have the Regional Pressure Setting (RPS) on the subscale of its altimeter (though it <u>may</u> have a local aerodrome QNH set), and will refer to its vertical position as altitude. Above the transition altitude, the aircraft will normally have the SPS of 1013.2 mb set on the altimeter, and will refer to its vertical position as a Flight Level.

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For example, in *Figure 10.9 previous page*, the RPS is 1005 mb, and the transition altitude is 3000 feet, as is standard outside controlled airspace in the United Kingdom. For an RPS of 1005 mb, 3000 feet represents a pressure level of about 905 mb. (Remember, atmospheric pressure falls by 1 mb for every 30 feet gain of height. So, 3000 feet represents approximately 1005 mb – (3000/30) mb = 1005 mb – 100 mb = 905 mb.) The lower aircraft, cruising below the transition altitude, is at an altitude of 2000 feet. In other words, the aircraft is flying at 2000 feet above mean sea-level, along the 938 mb isobar.

The higher aircraft, flying above the transition altitude, and so has 1013 mb set on its altimeter subscale. The pilot has elected to fly at 4500 feet indicated, and will report his vertical position as Flight Level 45. The aircraft is, of course, flying at 4500 feet above the pressure datum of 1013.2 mb, and will be flying along the 863 mb pressure surface.

NB: The above pressure calculations are for illustration purposes only; you do not need to know the actual pressure at your cruising level, only the required altimeter subscale setting (QNH/RPS/SPS).

THE TRANSITION LEVEL.

The lowest Flight Level above the transition altitude which is available for use is called the transition level (TL). The airspace between the transition level and the transition altitude is called the transition layer. *(See Figure 10.10.)*

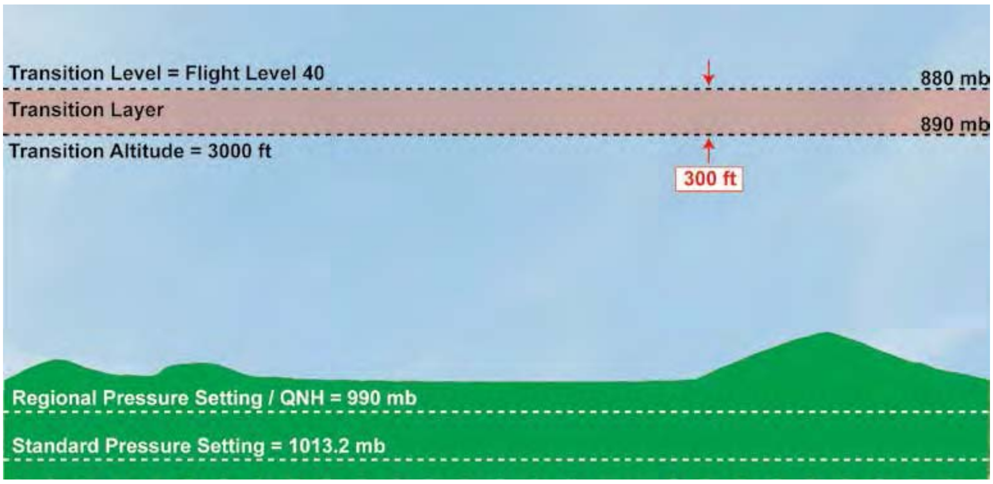

Fig 10.10 The Transition Level is the lowest available Flight Level above the Transition Altitude. Here, the Transition Level is FL 40, and the Transition Layer is 300 feet deep.

The transition altitude is, as you have learnt, an altimeter indication established by the national aviation authority. Above the United Kingdom it is 3000 feet, unless otherwise notified. The transition altitude, like any other altitude, is measured against a constantly changing value of sea-level pressure which is passed to the pilot as an aerodrome QNH or Regional Pressure Setting (RPS).

The transition level always lies above the transition altitude.

The transition level, however, is not set at a level identified by a given altimeter indication, but is measured against the constant pressure datum for Flight Levels of 1013 mb (hPa). So the Flight Level which identifies the transition level (i.e. the lowest useable Flight Level above the transition altitude) will change with changing QNH or RPS , but TL cannot be physically below TA.

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This is not an easy concept to grasp, so let us examine the issue using an actual example.

Take a look again at *Figure 10.10*. In the diagram, the QNH (or RPS) is 990 millibars. The transition altitude is shown as being 3000 feet above that pressure datum. The Standard Pressure Setting (SPS), of 1013.2 mb will, in this situation, lie below the QNH datum.

A Flight Level is, as you have learnt, measured as a vertical position measured with reference to the SPS. Furthermore, the transition level, which is the lowest useable Flight Level on any given day, must lie above the transition altitude.

So what Flight Level represents the transition level in the circumstances depicted in *Figure 10.10*?

We know that the transition altitude of 3000 feet is 3000 feet above the RPS of 990 mb, so it will, necessarily, be at a greater vertical distance above the 1013.2 mb. This SPS datum is, in fact, 23.2 mb "lower" than the RPS datum. At 30 feet per millibar, that makes the SPS datum almost 700 feet lower (696 feet, to be exact), and puts the transition altitude of 3000 feet at 3700 feet above the SPS datum. Consequently, the lowest available Flight Level above the transition altitude is Flight Level 40; i.e., 4000 feet above the SPS datum of 1013.2 mb at a pressure level of 880 mb. Naturally, in these conditions, the transition layer will be 300 feet in depth. Note, too, that at Flight Level 40, in the prevailing conditions illustrated in *Figure 10.10*, an aircraft will be only 3 300 feet above sea-level, not the 4 000 feet indicated on the altimeter.

By a similar calculation process, if the QNH/RPS were 950 mb, the lowest available Flight Level, the transition level would be Flight Level 50. *(See Figure 10.11.)*

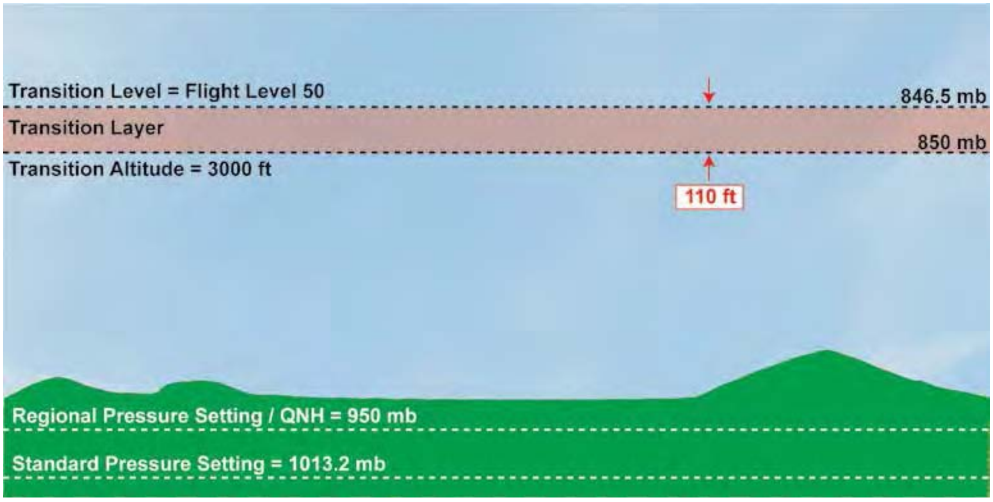

Fig 10.11 In the atmospheric pressure conditions depicted here, the Transition Level is FL 50, and the Transition Layer is 110 feet deep.

The SPS datum level would be 63 mb or approximately 1890 feet (63 x 30) lower than the RPS datum, making the transition altitude of 3000 feet, 4890 feet above the SPS datum, and giving a lowest available Flight Level of Flight Level 50. An aircraft would, of course, have to climb 110 feet to get from the transition altitude to the transition level of Flight Level 50. The transition layer would be, in this case,

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therefore, about 110 feet deep, and at Flight Level 50, the aircraft is only 3110 feet above sea level.

Looking at this situation from a slightly different perspective, let us imagine that, with a QNH of 950 mb set, a pilot has just approached the transition altitude of 3000 feet. He now resets 1013 mb on his altimeter subscale, winding on 63 mb to change the subscale setting from 950 to 1013. At 30 feet per millibar, the pilot sees his altimeter indication rise from 3000 feet to 4890 feet. The pilot knows, therefore, that he must climb a further 110 feet to give an altimeter reading of 5000 feet. As he now has the SPS in his altimeter subscale, that puts him at Flight level 50. But the aircraft remains only 3110 feet above sea-level. Hence the importance of flying with QNH or RPS in the altimeter subscale when descending below the transition level.

Care should be taken in conditions of abnormally low atmospheric pressure when an altimeter set to SPS may indicate an apparently safe altitude while the actual altitude is much lower. Note that,if ambient pressure is sufficiently above Standard, (by about 20mb), the Transition Level may be numerically lower than TA (e.g. FL25), but can never be physically below it.

FLIGHT AT OR ABOVE THE TRANSITION LEVEL.

Inside Controlled Airspace.

If a pilot is flying inside controlled airspace, above the transition altitude, he must set the Standard Pressure Setting (SPS), 1013 mb (hPa), on his altimeter, and report his level to the responsible Air Traffic Control Unit (ATCU) as a Flight Level. If a second altimeter if fitted to the aircraft, the pilot should set the Regional Pressure Setting (RPS) or appropriate aerodrome QNH on that altimeter in order that he may compute his vertical distance from terrain and obstacles. When descending below the transition level in controlled airspace, the ATCU will pass the appropriate RPS/ QNH to the pilot.

Outside Controlled Airspace.

Outside controlled airspace, when flying above the transition level, IFR traffic must, and VFR traffic should, follow the Quadrantal Rule

Outside controlled airspace, when above the transition altitude, in level flight, an aircraft flying in accordance with the Instrument Flight Rules (IFR) must set the SPS on his altimeter (1013 mb) and, if below Flight Level 195, fly at a Flight Level determined by the aircraft's magnetic track, as stipulated by the Quadrantal Rule. The Quadrantal Rule is based on magnetic track, and effectively, divides all possible magnetic tracks into four sectors, confining aircraft to specific Flight Levels within each sector. Magnetic tracks are used as the reference instead of magnetic heading because slow moving aircraft are affected much more by drift than high-speed aircraft. Consequently, aircraft may well be on converging tracks even when steering the same compass heading. The Quadrantal Rule is summarized in *Figure 10.12*.

The simple procedure for flying in accordance with the Quadrantal Rule is:

1. The pilot determines the magnetic track he needs. This is normally done on the ground during the flight planning stage.

2. The pilot chooses a cruising level appropriate to his magnetic track and compliant with the Quadrantal Rule.

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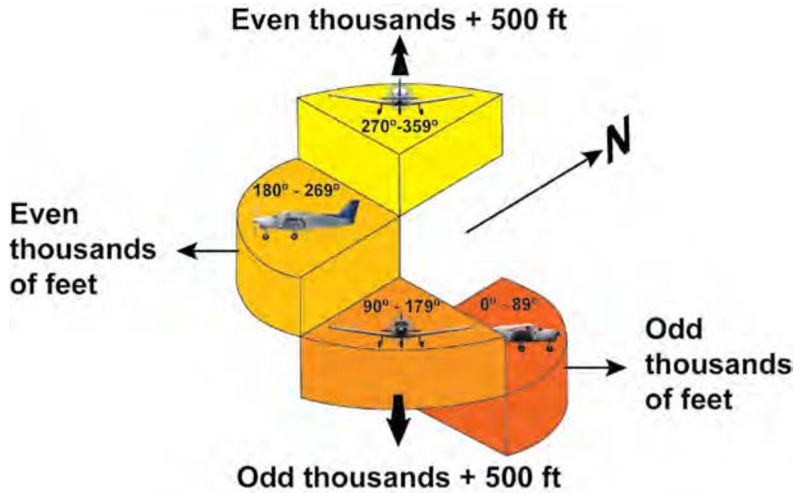

Fig 10.12 The Quadrantal Rule - to be followed when flying IFR or VFR outside controlled airspace, above the transition altitude but below FL 195.

The Quadrantal Rule is based on an aircraft's magnetic track.

Pilots flying in accordance with the Visual Flight Rules (VFR) above TA, while not obliged to fly Flight Levels, are strongly advised to set their altimeters to the SPS and to fly at a Flight Level compliant with the Quadrantal Rule.

Following the Quadrantal Rule may often be the only systematic way to ensure separation from other aircraft when flying VFR in marginal visual conditions above the transition level.

ALTIMETER SETTING PROCEDURES.

The following general altimeter setting procedures should be used by VFR flights.

Take-off, Climb and Cruise.

Outside controlled airspace, there is no stipulated altimeter subscale setting. However, the following considerations should be borne in mind:

- If departing on a cross-country flight, aerodrome QNH will be an appropriate altimeter setting for the take-off, climb out and cruise within 25nm of the aerodrome (being more accurate than an RPS, which is a lowest forecast value). At the selected cruising level, if below the transition altitude, obtain the RPS through a Flight Information Service or Lower Airspace Radar Service and set as required, adjusting altitude to the chosen cruising level.

- If passing below a Control Area (CTA) or Terminal Control Area (TMA), the QNH of an aerodrome situated beneath the CTA/TMA should be used.

- Above the transition altitude, VFR pilots are strongly advised to set the Standard Pressure Setting (SPS) of 1013 mb on their altimeter and to fly at a Flight Level appropriate to their magnetic track in accordance with the Quadrantal Rule.

When Flying beneath a CTA or TMA, the QNH of an aerodrome located beneath the CTA/TMA should be set on the altimeter subscale.

At a controlled airfield, a VFR pilot will often be given both the aerodrome QNH and QFE from the Air Traffic Control Unit (ATCU), before take-off. Within a Military Aerodrome Traffic Zone (MATZ), pilots will normally be given the airfield QFE.

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- On leaving the CTR, Aerodrome Traffic Zone (ATZ) or MATZ, the ATCU controller will normally pass the Regional Pressure Setting to the pilot. If the pilot remains underneath a CTA or TMA on leaving the CTR, ATZ or MATZ, he should remain on aerodrome QNH.

- At and above the transition altitude, if the pilot remains in controlled airspace, he should set the SPS of 1013 mb on his altimeter and report all levels as Flight Levels.

- If, in controlled airspace, the aircraft is below the transition altitude, the pilot will be passed the appropriate QNH, or QFE from a military airfield, by the responsible ATCU.

Approach and Landing.

Approaching an aerodrome with a **CTR** or **ATZ**.

- When descending from above the transition level, where the aircraft will have been flying at a Flight Level, the aerodrome QNH will be passed by the CTR controller or Aerodrome Flight information Service Officer (AFISO). On vacating his Flight Level to commence the descent, the pilot will replace the SPS on his altimeter by the aerodrome QNH, unless a CTR controller wishes him to continue reporting Flight Levels in the descent.

- When descending from below the transition altitude with the RPS set, the CTR controller or AFISO will pass the aerodrome QNH to the pilot, who should select it immediately, in place of the RPS. If the aircraft has been cruising below a TMA or CTA immediately prior to the descent, it will have the aerodrome QNH set on the altimeter already.

- A clearance will be required to enter a CTR around a destination aerodrome.

- Normally the aerodrome QNH will be kept on the altimeter for the circuit and approach to land. If a circuit altitude is not published, add the airfield elevation to the circuit height (standard is 1 000 ft) to obtain circuit altitude. However, the pilot may be passed the QFE. He may also, of course, request the QFE.

Approaching an aerodrome with only an Air-Ground Radio Service.

- When descending from a Flight Level above the transition altitude, obtain the RPS from an Air Traffic Service Unit providing a Flight Information Service or Lower Airspace Radar Service. On making contact with the air-ground radar service, an advisory QNH or QFE may be given. If not, the pilot will have to retain the RPS on his altimeter for the circuit and approach to land, making sure to add the aerodrome elevation to all altimeter readings in the circuit in order to maintain the correct height above airfield level at all times.

- When descending from below the transition altitude the RPS or an aerodrome QNH from a nearby ATSU will normally already be set. On making contact with the air-ground radar service, the pilot may have to retain the RPS or QNH on his altimeter for the circuit and approach to land. If so, the pilot must

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be sure to add the aerodrome elevation to all altimeter readings in the circuit in order to maintain the correct height above airfield level, at all times.

The air-ground radio operator may be able to pass an advisory QFE to the pilot. Pilots should, however, exercise caution when setting advisory QFE. The instruments from which air-ground radio operators obtain the QFE are often not regularly calibrated or otherwise checked. Of course, the VFR pilot should always be able to assess visually his separation from the ground.

ALTIMETER SETTING SUMMARY.

The table, below, is a summary of the altimeter subscale settings covered in this chapter, as they may apply to a VFR flight in a light aeroplane. The table contains details of the type of pressure datum set in the altimeter subscale, the term used to refer to the vertical distance associated with subscale setting, and when each setting is used.

ALTIMETER SUBSCALE SETTING (PRESSURE DATUM)	VERTICAL DISTANCE FROM PRESSURE DATUM REFERRED TO AS	WHEN USED
Standard Pressure Setting, 1013.2 mb (hPa)	Flight Level	• At or above the **transition altitude**, the lowest useable **Flight Level** being known as the **transition level**.
Aerodrome QNH	Altitude	• At or below the **transition altitude**. • When descending from a **Flight Level** unless **ATC** require further level reports. • At the pilot's discretion, on final approach.
QFE	Height	• Normally, in the circuit and on final approach.
Regional Pressure Setting	Altitude	• At or below the **transition altitude**, when not in the vicinity of a major aerodrome or under a **CTA** or **TMA**.

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Representative PPL - type questions to test your theoretical knowledge of Altimeter Settings.

1. You are flying above the Transition Altitude with 1013 mb (hPa) set on the altimeter which is reading 6 000 feet. What is your Flight Level (FL)?

    a. FL6
    b. FL006
    c. FL60
    d. FL600

2. You are on the apron of an aerodrome and ask ATC for the aerodrome QFE which you then set on the altimeter. Would your altimeter then read zero feet?

    a. Yes
    b. Not necessarily, since QFE is measured from a standard pressure setting
    c. Not necessarily, since QFE is measured from the Aerodrome Reference Point which may not be coincident with the apron
    d. There is no location on the aerodrome, where the altimeter would read zero

3. You are on the apron of an aerodrome and ask ATC for the aerodrome QNH which you then set on the altimeter. Which of the following should your altimeter reading indicate?

    a. Height
    b. Vertical distance above the SPS
    c. Zero feet
    d. The apron elevation

4. What is the Standard Pressure Setting?

    a. QNH
    b. QFE
    c. Zero feet
    d. 1013.2 millibars or 1013.2 hectopascals

5. You fly from an aerodrome of a given atmospheric pressure to a destination aerodrome where the atmospheric pressure is significantly lower than at your point of departure. If you fly the route at a constant altimeter reading, what would be the path of your aircraft in terms of its vertical separation from the ground?

    a. It would climb as you approach your destination
    b. It would descend as you approach your destination
    c. It would remain at the same height above the ground
    d. It would remain at the same vertical distance above mean sea-level

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6. What is QFE?

   a. The pressure setting at the aerodrome reference point, normally the highest point on the landing area
   b. The pressure setting at the aerodrome reference point, reduced to sea level
   c. The pressure setting of the altimeter in the ATC Tower
   d. The pressure setting at the lowest point on the aerodrome

7. What is the Transition Altitude at most aerodromes in the United Kingdom?

   a. 2 000 feet
   b. 3 000 feet
   c. 5 000 feet
   d. 18 000 feet

8. If a pilot is to carry out circuit practice at an aerodrome, what is the most practical and appropriate pressure setting for the altimeter?

   a. QFE
   b. 1013 mb (hPa)
   c. The Standard Pressure Setting
   d. The Regional Pressure Setting

9. If you are to fly a cross-country route below the transition altitude, what is the most appropriate pressure setting for your altimeter when you have left the immediate vicinity of your departure aerodrome?

   a. QFE
   b. Regional Pressure Setting provided you are not still beneath a CTA or TMA
   c. Standard Pressure Setting
   d. 1013 mb (hPa)

10. You are flying en-route below the Transition Altitude. How must you report your aircraft's vertical position to an Air Traffic Service Unit?

   a. As a Flight Level
   b. As a height
   c. As an altitude
   d. As an elevation

11. What is defined as the "first available Flight Level above the Transition Altitude"?

   a. Transition Layer
   b. Transition Elevation
   c. Transition Level
   d. Transition Height

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12. What is the Transition Layer?

    a. The vertical distance between a given Flight Level and the Transition Level
    b. The vertical distance between the Transition Altitude and the Transition Level
    c. The vertical distance from the ground to the Transition Altitude
    d. The vertical distance from the Aerodrome Reference Point (ARP) to the Transition Altitude

13. An altimeter reading from an aircraft in the air, based on aerodrome QFE is reported as:

    a. Elevation
    b. Altitude
    c. Height
    d. Flight Level

14. The reading of an altimeter, in flight, with QNH set on its subscale is known as:

    a. Flight Level
    b. Altitude
    c. Height
    d. Elevation

15. Which of the four options below gives the most accurate definition of “transition altitude”?

    a. The altitude at or above which the vertical position of an aircraft is monitored by reference to altitude
    b. The altitude at or below which the vertical position of an aircraft is monitored by reference to altitude
    c. The altitude at or above which the vertical position of an aircraft is monitored by reference to height
    d. The altitude at or below which the vertical position of an aircraft is monitored by reference to height

16. What pressure setting should be entered on the altimeter subscale of an aircraft which is descending to below the transition level prior to commencing a visual approach to a non-military aerodrome?

    a. The Regional Pressure Setting
    b. The Standard Pressure Setting
    c. The Aerodrome QFE
    d. The Aerodrome QNH

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17. Complete the following sentence. While passing through the transition layer, vertical separation from the appropriate pressure datum level should be expressed as ______ when climbing and ______ when descending.

a.	Flight Level	Altitude
b.	Height	Altitude
c.	Flight Level	Height
d.	Height	Flight Level

18. A VFR pilot is cruising, en-route, in level flight, above the transition level of FL35. His magnetic heading is 355º, and he sees that by having allowed for 8º of starboard drift he is exactly on track. What would be an appropriate Flight Level for the pilot to choose in accordance with the Quadrantal Rule?

a. FL40
b. FL45
c. FL50
d. FL55

19. A pilot setting off on a cross-country route in a cruise climb over a part of the country where the transition altitude is 3000 feet, has just been given a Regional Pressure Setting of 970 mb (hPa), from a local ATSU. His magnetic track is 260º. What will be the transition level and what will be lowest available Flight Level that the pilot can use, in accordance with the Quadrantal Rule? (Note: assume that pressure falls with increasing height by 1 mb every 30 feet)

a.	FL 45	FL 60
b.	FL 40	FL 55
c.	FL 30	FL 30
d.	FL 45	FL 55

20. A pilot, who has just left the ATZ of the departure aerodrome and has set off on a cross-country route, is flying beneath a Terminal Control Area (TMA). What pressure setting should he have on his altimeter subscale?

a. The destination aerodromes QFE
b. The Regional Pressure Setting
c. The departure aerodrome's QFE
d. The QNH of an aerodrome beneath the TMA

21. You are flying above the transition level, on a VFR cross-country flight in a light aircraft, following a magnetic track of 180º. You refer to the Quadrantal Rule to decide what Flight Level to cruise at. With your altimeter subscale set at 1013 mb (hPa), you should choose:

a. Odd thousands of feet
b. Even thousands of feet
c. Even thousands of feet plus 500
d. Odd thousands of feet plus 500

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22. The transition altitude for civil aerodromes in the United Kingdom is:

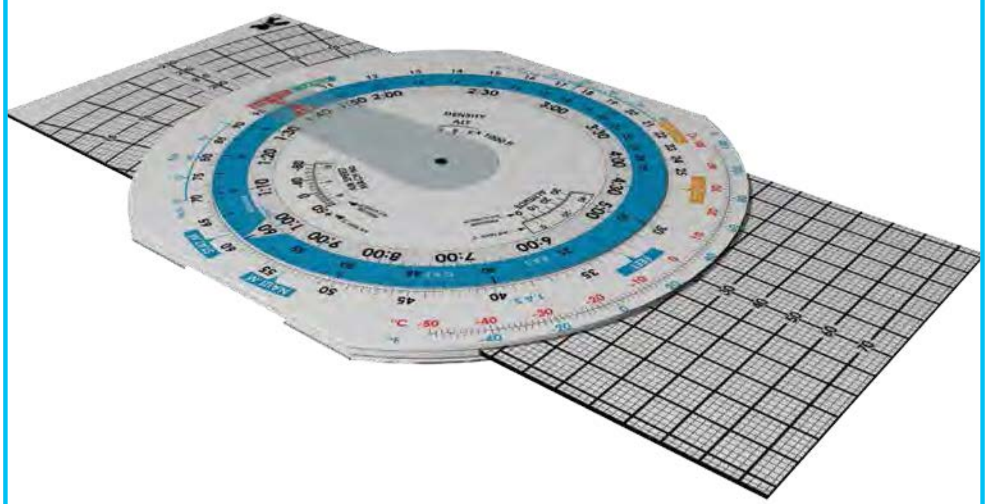
a. 5 000 feet amsl
b. 3 000 feet amsl unless otherwise notified, for example for the Scottish, Manchester and London TMAs
c. 4 500 feet amsl
d. 3 000 feet amsl

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer												

Question	13	14	15	16	17	18	19	20	21	22
Answer										

The answers to these questions can be found at the end of this book.

CHAPTER 11
THE NAVIGATION COMPUTER



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CONVERSION TABLE FOR VOLUMES, WEIGHT & DISTANCES.

FLUIDS.

1 Imperial gallon	=	4.55 litres	=	1.2 US gallons
1 litre	=	0.22 Imperial gallons	=	0.264 US gallons
1 US gallon	=	0.83 Imperial gallons	=	3.8 litres

WEIGHTS.

1 Imperial gallon of water weighs 10 pounds (lb)
1 litre of water weighs 1 kilogram (kg)
1 US gallon of water weighs 8.3 lb

1 kg	=	2.2 lb
1 lb	=	0.454 kg

Specific gravity of AVGAS = 0.72

DISTANCES.

1 metre	=	3.28 feet	=	1.1 yards		
1 inch	=	2.54 centimetres				
1 nautical mile	=	1.15 statute miles	=	1.85 kilometres	=	6080 feet
1 kilometre	=	0.54 nautical miles	=	0.62 statute miles	=	3280 feet
1 statute mile	=	0.87 nautical miles	=	1.61 kilometres	=	5280 feet
1 metre/second	=	1.94 knots	=	197 feet per minute		

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INTRODUCTION.

In Chapter 9, you learnt the theory of how drift angle, heading to fly and groundspeed are calculated from first principles through the construction of a triangle of velocities. We could, if we wished, construct a triangle of velocities for every navigation leg we planned to fly, provided that we have measured the true bearing of the route, decided on an indicated airspeed at which to fly the route, converted that indicated airspeed to a true airspeed, and obtained an accurate wind forecast.

To carry out our navigation calculations in such a way would, however, be impractical and time consuming. It is fortunate therefore that modern pilots have a choice of computers to help them with their pre-flight planning. Computers are nowadays invariably electronic digital machines, but older analogue computers, based on the principle of the slide-rule, still have their use. A computer is literally any device which can perform calculations, and one of the most reliable navigation computers is the circular/slide-type computer, sometimes known as the “whiz wheel,” that all student pilots preparing for ground examinations must still be able to use fluently.

There are numerous types of the circular/slide-type navigation computer on the market, produced by companies such as Pooley’s, Airplan Flight Equipment, Transair, Jeppesen, etc. All of them work on the same principle, and all of them allow pilots to carry out, quickly and accurately, navigation problems, involving the triangle of velocities, the calculation of true airspeed, fuel consumption, endurance, track error, and so on. All whiz-wheel navigation computers derive ultimately from the Dalton Computer developed by Philip Dalton of the United States Navy, in the late 1930s.

Oxford Aviation Academy has produced a training CD-ROM for this type of navigation computer which aims to teach you every one of the computer’s functions, and which incorporates a fully-functional, virtual Dalton-type computer. The CD-ROM is included with this book. (*See Figure 11.1.*)

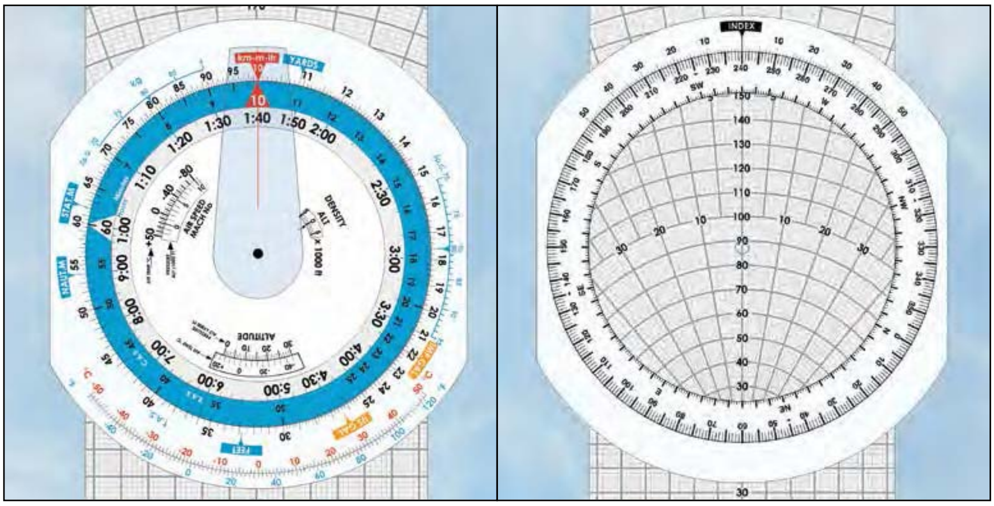

Figure 11.1 The Dalton-type navigation computer.

For the mental dead reckoning method of visual navigation that a student is required to learn in order to gain a private pilot’s licence, the Dalton-type analogue navigation computer is an excellent teaching device, as well as a calculator.

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By mastering this type of instrument, in order to calculate drift and headings, pilots learn how to visualise what dead reckoning navigation is all about.

In fact, skill in the use of the Dalton-type navigation computer is thought to be so important to the training of the modern pilot-navigator that it is still (in 2007) the only navigation computer that may be used in the formal examinations set by the majority of national aviation authorities.

Thus, every student pilot must become proficient in the use of the Dalton-type computer. The CD-ROM will introduce you to the computer and teach you all that you need to know about its functions; but for quick reference purposes, the main operations that a pilot is required to work out on the computer are covered in this chapter.

THE CONSTRUCTION AND APPEARANCE OF THE COMPUTER.

Actual, branded Dalton-type computers vary slightly in the detail of their layout compared to the one shown in our illustrations, but their main features are very similar and their principle of operation is the same in all cases. You will probably find that the computer you are using looks very much like the instrument depicted in this chapter.

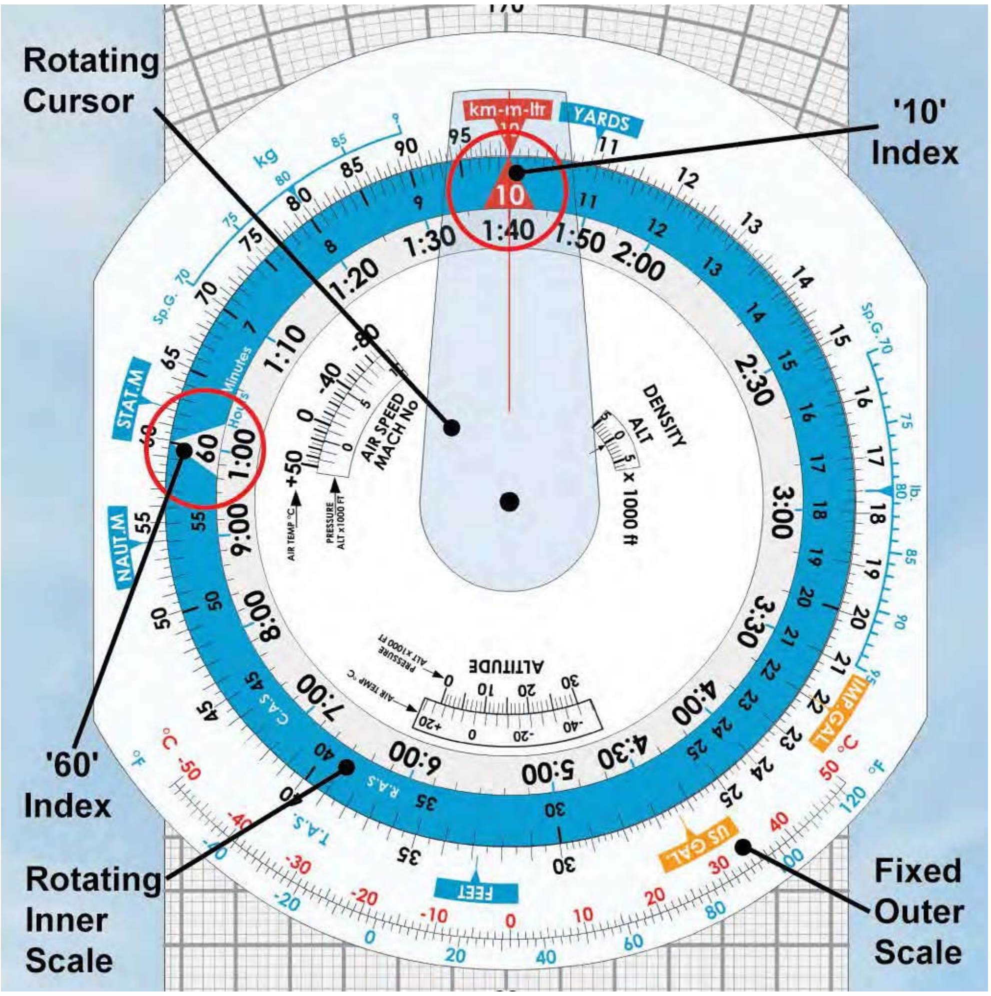

Figure 11.2 The Circular Slide Rule Face of the Dalton-type navigation computer, featured in Oxford Aviation Training's CD-ROM.

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The Circular Slide Rule Face.

The Dalton-type navigation computer has two faces. One face is the circular slide rule face, depicted in *Figure 11.2,* which has inner and outer scales. While the outer scale is fixed, the inner scale is free to rotate.

There are two index marks on the inner scale.

The red triangle with the Number 10 inside, is the index which is used when manipulating the computer as a rotary slide-rule to make general calculations; for example, multiplication and division. We will refer to this as the “10 index”. The white triangle with the Number 60 inside is the index we use when carrying out calculations concerning time, distance and speed. We will refer to this index as the “60 index”.

The circular slide rule face is used primarily to carry out calculations involving multiplication, division, conversions, speed, distance, time, fuel consumption, and track error corrections.

If you examine the outer scale closely, you will see that there is no number smaller than 10 or larger than 99. Consequently, when carrying out calculations, you must insert decimal points and zeros for yourself, in your mind’s eye. For instance, the number 12, on either scale, may also represent 0.12, 1.2, 120, 1200 etc. Decimal points and zeros also have to be inserted by the user, when a calculation has been completed.

Consequently, when using any brand of Dalton-type navigation computer, it is essential to carry out a rough calculation in your head in order to deduce the order of magnitude of the value calculated on the computer.

The Wind Face.

The other face of the computer is called the wind face. The wind face comprises a slide, marked with speed line arcs and drift lines, and a rotating window. The wind face is used to mostly to calculate heading and groundspeed from track and wind information. Effectively, the wind face constructs a triangle of velocities when the user inserts the appropriate data.

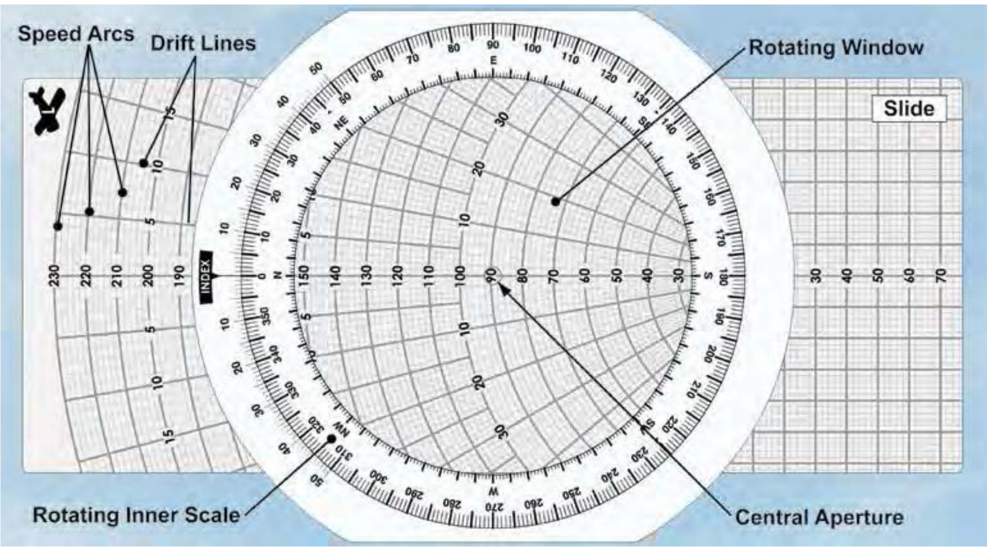

Figure 11.3 The Wind Face of the Dalton-type Navigation Computer.

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CALCULATING HEADING AND GROUND SPEED.

Calculating heading and groundspeed is by far the most frequent operation carried out by pilots when planning a cross-country flight using mental dead reckoning techniques. For our first calculation, we will work out a heading to fly to make good a desired track, and our groundspeed along that track. This is the type of calculation that we studied from first principles in Chapter 9, by constructing a triangle of velocities. As we pointed out then, this type of calculation is easy using the navigation computer.

In order to illustrate how heading and groundspeed are calculated on the navigation computer, we will stay with our route from Oxford Kidlington to Wellesbourne Mountford, via Ledbury.

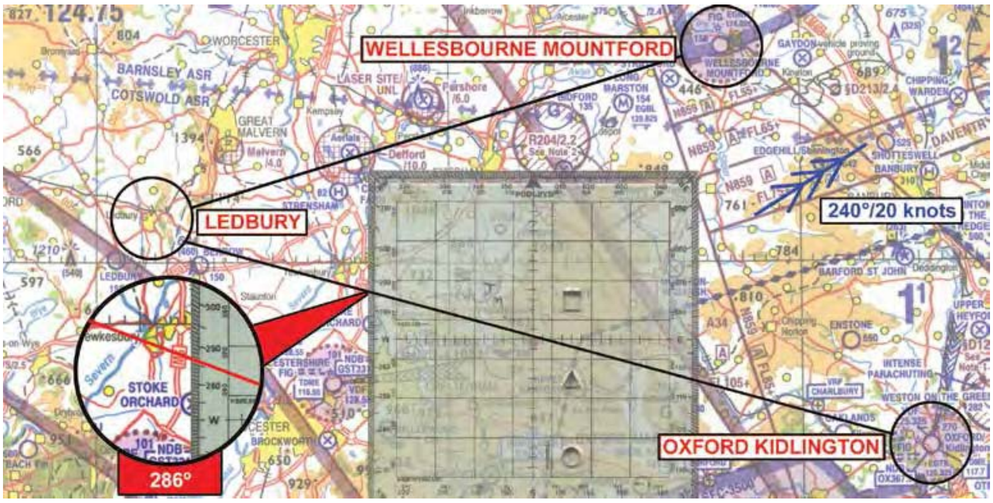

Figure 11.4 The route from Kidlington to Ledbury. The route is to be flown at 105 knots, True Airspeed. What will be the True Heading and Groundspeed?

In Chapter 9, we worked out, using the triangle of velocities method, the heading that we need to fly from Oxford Kidlington to Ledbury, in order to make good the true track of 286°(T), at a true airspeed of 105 knots, in a wind from 240°(True), at 20 knots. You will remember that the heading and groundspeed were 279° (True), and 90 knots, respectively. (*See Figure 11.5.*)

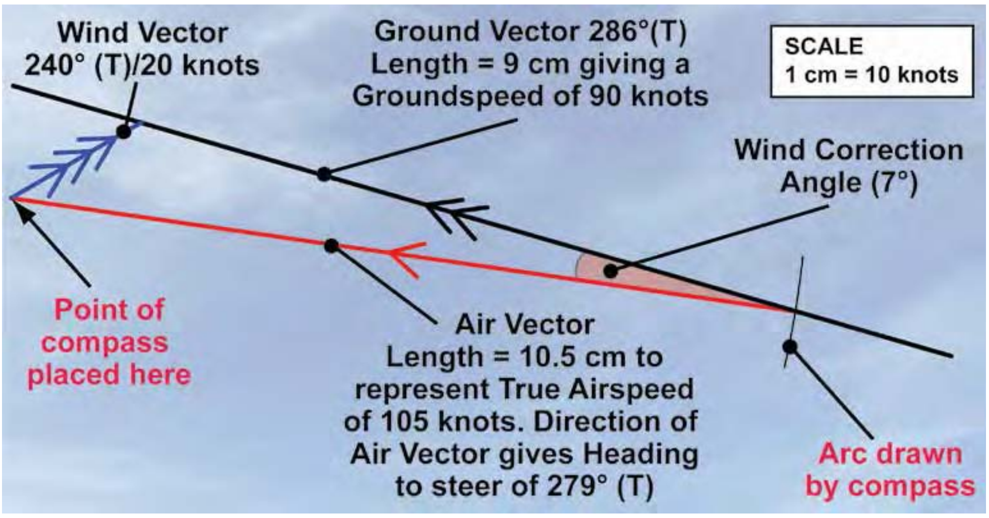

Figure 11.5 The Triangle of Velocities constructed to determine True Heading and Groundspeed on the route from Kidlington to Ledbury.

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You will now learn how you carry out the same calculations for heading and groundspeed, but, this time, on the navigation computer.

There are, in fact, two ways of carrying out this calculation on the navigation computer. Both methods are taught on the CD-ROM. Here, we shall use the more straightforward of the two methods, known as the “wind-up method”. You should follow through the method we are about to teach you on your own navigation computer.

It is vitally important to be minutely accurate in your movement of the scales and your pencil marking.

On the wind face of your navigation computer rotate the inner scale in order to set the wind direction of 240° against the index mark at the top of the outer fixed scale. Position any of the speed arcs on the slide, centrally, in the blue aperture in the middle of the rotating part of the wind face. We have used the 100 knots speed arc, but any arc will do. Following the vertical centre line of the slide, mark a point, with a sharp, soft pencil or chinagraph, 20 knots up from the arc under the blue aperture. You mark the point on the 120 knots speed arc, on the slide centre line. This point represents the 20 knots wind speed. You just need to mark the point, but we have drawn a wind vector line in our diagram, because the wind vector is what you have just marked on the computer. (*See Figure 11.6.*)

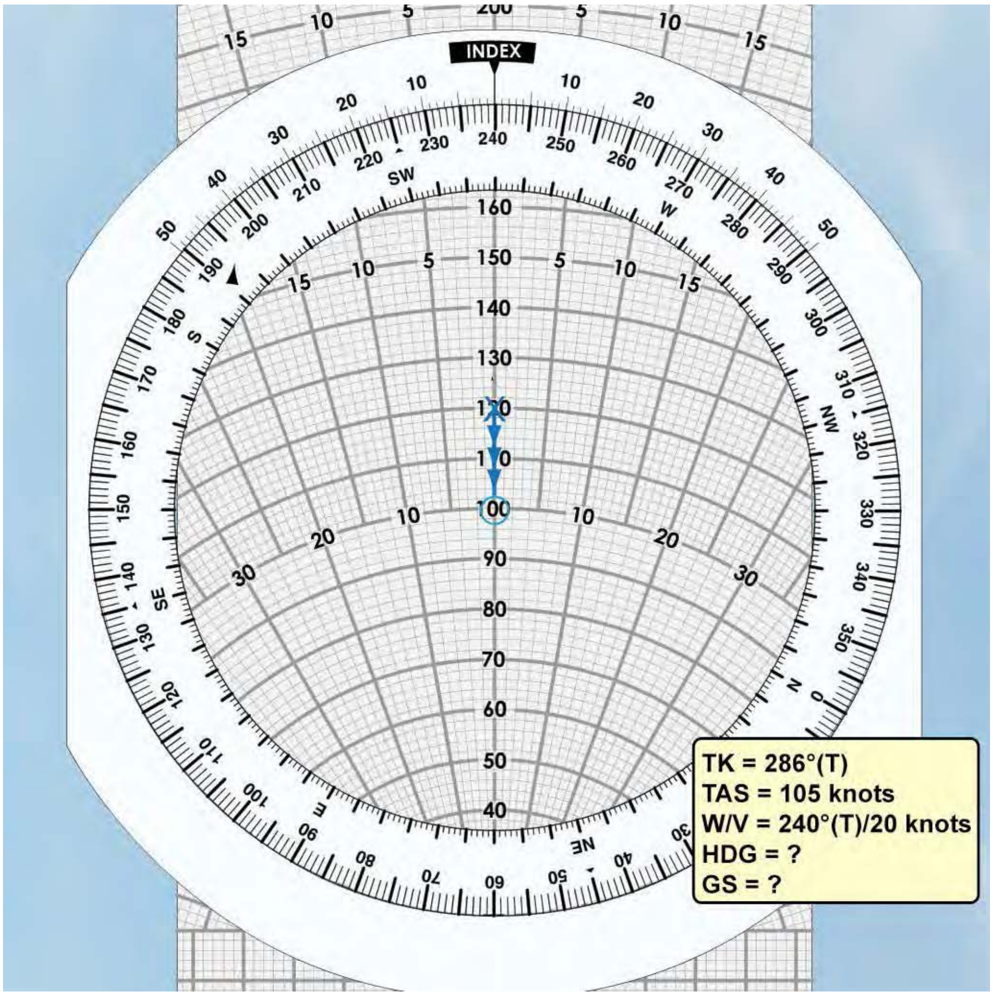

Figure 11.6 Marking the wind vector.

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The method we are using is called the "wind up method" simply because we have marked the wind speed "up" from the blue aperture.

Now rotate the inner scale to set the desired track of 286°(T) against the index mark. The slide centre line now gives you the orientation of the ground vector, of the triangle of velocities.

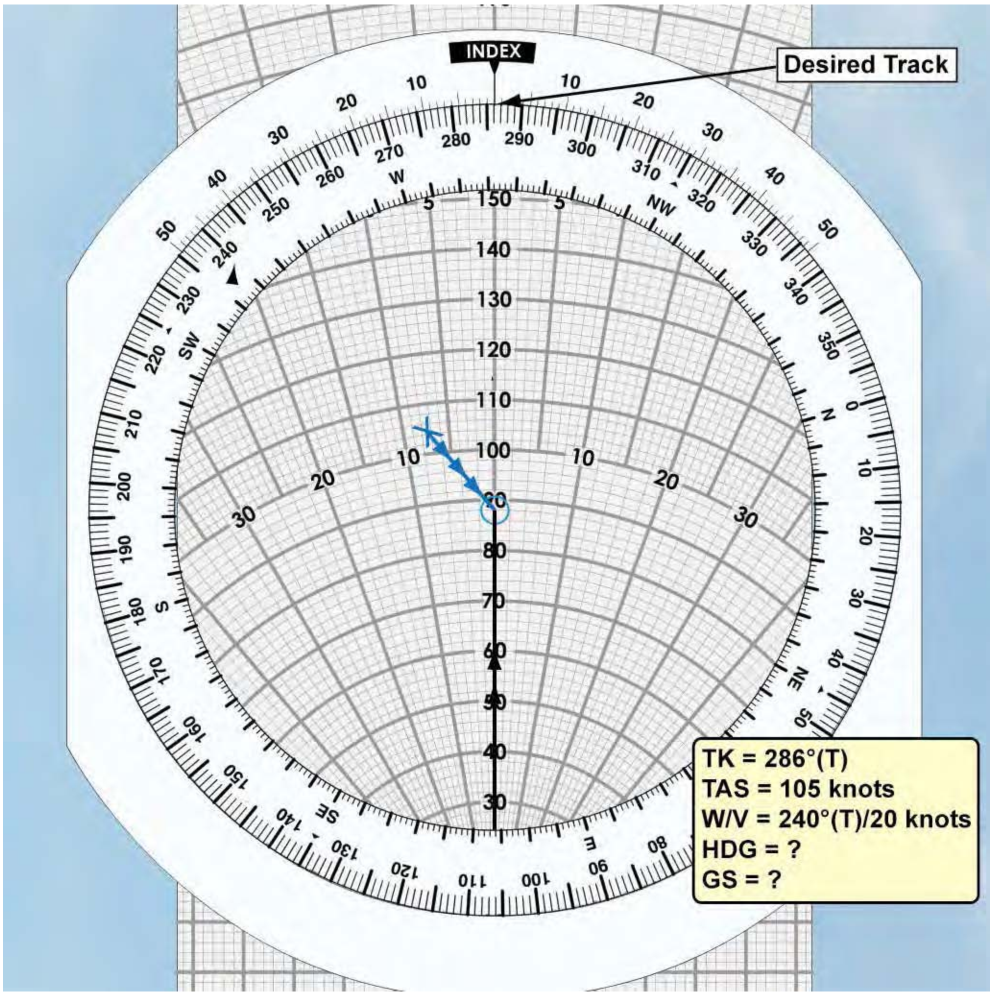

Figure 11.7 Position the Desired Track against the Index Mark and adjust the slide to place the True Airspeed under the Wind Mark.

We have marked the ground vector on the wind face, but you do not need to do so. You should now be able to see the triangle of velocities taking shape with the wind vector pointing towards the ground vector, just as in real life, the wind will effectively blow the aircraft from its heading onto its track.

Now adjust the slide so that the speed arc representing the planned true airspeed of 105 knots is coincident with the wind mark. *(See Figure 11.7.)*

Note that the wind mark is now over the 7 degree drift line to the left of the centre line. (*See Figure 11.8.*) Using the "wind up method", the drift lines indicate the direction in which we have to head our aircraft in order to compensate for drift. So, in this case, with the wind mark to the left of the centre line, we need to head left by 7°. Therefore,

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we subtract 7° from the desired track of 286º(T) to obtain a true heading to steer of 279°(T). If the wind mark were to the right of the centre line, we would add drift to our track to obtain our heading.

From *Figure 11.8*, you can see that the navigation computer has now completed the construction of the triangle of velocities. Though you can not see the whole triangle, it is indeed complete, the drift line of 7° to port representing the air vector; that is the vector which gives us the heading to steer, based on our true airspeed.

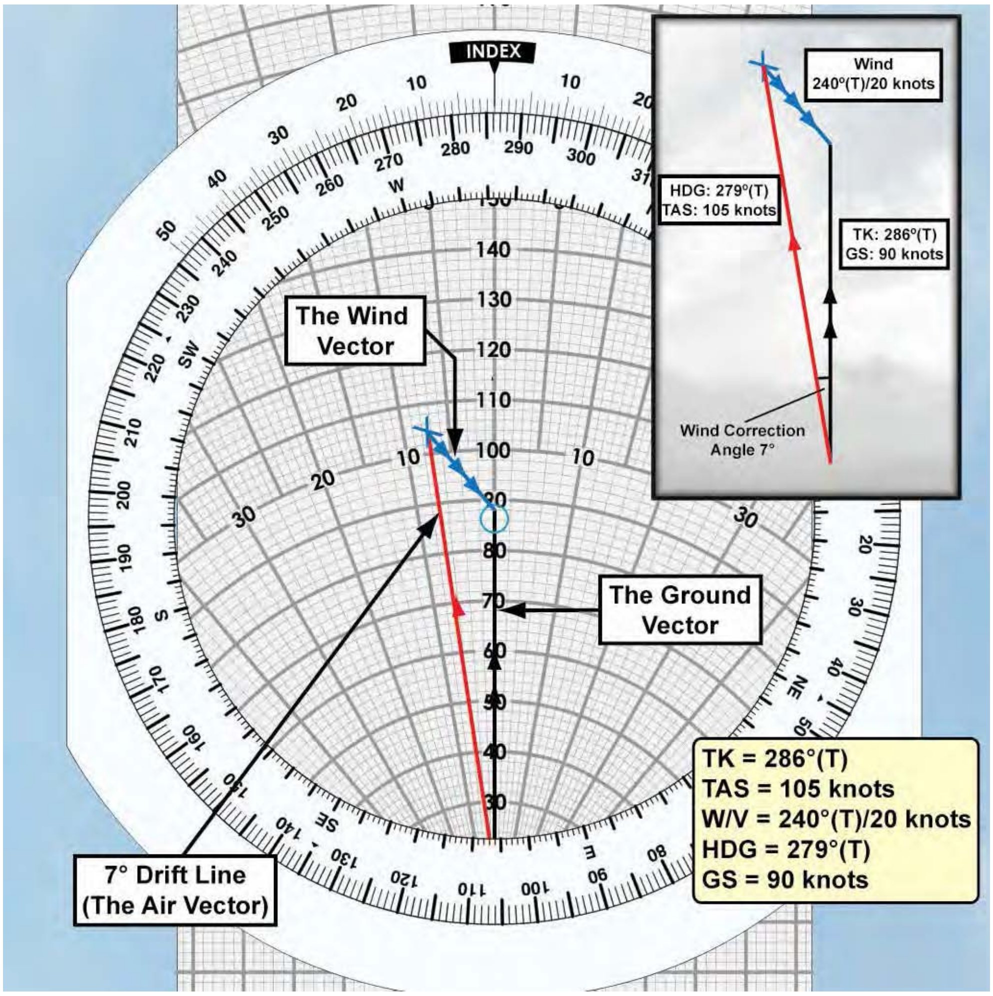

Figure 11.8 The calculation of heading and groundspeed is complete.

The length of the ground vector is now represented by the speed arc which lies under the blue aperture. That speed arc gives us our groundspeed of 90 knots.

We have calculated, then, that at a true airspeed of 105 knots, with a wind from 240° (True) at 20 knots, we need to fly a heading of 279° (True) to maintain a track of 286° (True).

In order to find the heading to steer on your compass, do not forget to apply the local magnetic variation, and then to make any required deviation correction by consulting the compass deviation card. You will see that the values for heading to steer and groundspeed are identical to those that we obtained from the geometrically constructed triangle of velocities in Chapter 9.

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Now try, yourself, to work out the heading to and groundspeed for the cross country leg from Ledbury to Wellesbourne Mountford. Our solution is printed in the partially completed flight log at *Figure 9.15*, in Chapter 9.

You will find numerous test calculations on heading and groundspeed on the CD-ROM.

TRUE AIR SPEED.

As you learnt in Chapter 9, the value for airspeed which must be used for all navigational calculations is the aircraft's true airspeed. The crucial consideration in navigational calculations is that airspeed should refer to the actual speed with which the aircraft is moving relative to the air mass in which it is flying. This is what we mean by true airspeed.

You learn in Chapter 9, and in the 'Principles of Flight' and 'Aeroplanes' volumes in this series of books, that when atmospheric conditions differ from ICAO Standard Atmosphere (ISA) sea-level conditions, there is a significant difference between the indicated airspeed that the pilot reads from the Airspeed Indicator (ASI) and the aircraft's true airspeed. All ASIs are calibrated with respect to ISA sea-level conditions.

Indicated airspeed is proportional to the dynamic pressure (Q), sensed by the ASI. The equation for **dynamic pressure** is $\mathbf{Q = \frac{1}{2} \rho v^2}$. In this equation, v represents true airspeed and ρ represents air density. Therefore, for any given value of true airspeed, if ρ decreases, the indicated airspeed, as a function of Q, will also decrease. Consequently, as density decreases with increasing altitude, indicated airspeed, at altitude, will inevitably be lower than true airspeed. This error in the ASI reading is known as density error.

As you learn elsewhere, the atmospheric parameters which govern the value of density are pressure and temperature. Both pressure and temperature decrease with altitude. The navigation computer allows you to calculate true airspeed for any indicated airspeed, by entering values for the altitude at which you plan to fly, the temperature at that altitude and your planned indicated airspeed. (Note that the altitude for which you wish to calculate the true airspeed equivalent of any indicated airspeed must be pressure altitude; that is, altitude measured with respect to a pressure datum of 1013.2 millibars (hectopascals).)

The ASIs fitted to many aircraft may suffer from position and instrument errors. Indicated airspeed corrected for these errors is known as calibrated airspeed or rectified airspeed. The Pilot's Operating Manual will contain calibration tables to convert indicated airspeed readings into calibrated or rectified airspeed. For accurate conversions of the ASI reading to true airspeed, pilots should ideally use the calibrated or rectified airspeed. However, instrument and position errors on ASIs are often very small, so, for PPL light aircraft flying the indicated airspeed can usually be used as the basis for calculating true airspeed. This is the practice we shall adopt in this chapter. You learn more about indicated airspeed, calibrated or rectified airspeed and true airspeed in 'Principles of Flight' and 'Aeroplanes'.

Calculating True Airspeed Using the Navigation Computer.

There follows an example of how true airspeed calculations are carried out using the navigation computer. There are more examples, as well as numerous test questions, on the CD-ROM.

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Let us assume that we are planning to fly a route at 3000 feet on a fine day in January in the United Kingdom, when the Regional Pressure Setting (RPS) for our area is given as 1003 millibars, and the temperature at 3000 feet is forecast to be +2° Celsius (C). We plan to fly the route at an indicated airspeed of 110 knots. What will be the true airspeed that we need to use in order to calculate our heading and groundspeed for the route?

First of all we must express our chosen cruising altitude as a pressure altitude. As the atmospheric pressure at sea-level for our region (the RPS) is given as 1003 millibars, the datum of 1013.2 millibars, which we need for our true airspeed calculation, will lie lower than the RPS, and the pressure altitude will, therefore, be higher than 3000 feet. As pressure changes by about 1 millibar for every 30 feet of altitude, and the difference between 1003 millibars and 1013.2 millibars is, for all practical purposes, 10 millibars, we deduce that the pressure altitude equivalent of 3000 feet, on the day of our flight, will be 3000 + (30 x 10) = 3300 feet.

Now, on the circular slide-rule face of the navigation computer, identify the window marked Airspeed. The Airspeed window is depicted in *Figure 11.9*.

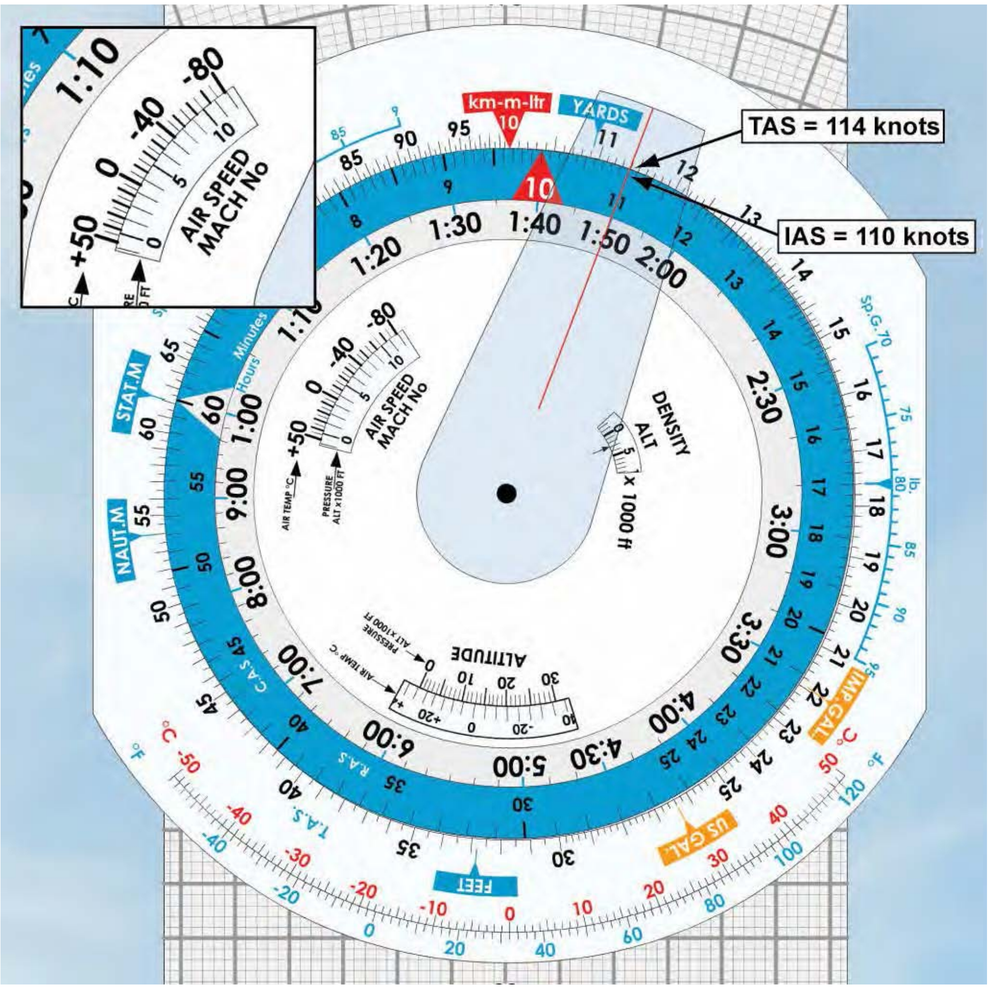

Figure 11.9 At 3300 ft pressure altitude with a temperature of +2°C, 110 knots indicated airspeed is the equivalent of 114 knots true airspeed.

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The top moveable scale of the Airspeed window is the temperature in °C; the fixed scale inside the window is the pressure altitude in 1000s of feet. We, therefore, set the pressure altitude of 3300 feet against the forecast temperature at that altitude of 2°C, as depicted in *Figure 11.9*. Setting up these figures requires a bit of estimation between scale gradations, so use the computer's cursor to help you. Set the cursor line over your best estimate for 3300 feet and then line up +2°C with the cursor, too. With the circular slide rule set up in this way, true airspeed can be read off on the slide rule's outer scale against the indicated airspeed on the inner scale. Against our planned indicated airspeed of 110 knots on the inner scale, we read off, on the outer scale, the equivalent true airspeed of 114 knots.

As a rough approximation, true airspeed is about 8% more than indicated airspeed at 5000 feet, and 17% greater at 10 000 feet, so 114 knots seems a reasonable figure for 3300 feet, being 4% greater than 110 knots.

114 knots true airspeed will be the airspeed figure that we use in our navigation calculations for our planned flight.

If you wish to practise more true airspeed conversions, there are many more on the CD-ROM.

SPEED, DISTANCE & TIME CALCULATIONS.

Introduction.

In Chapter 4, you learnt about the importance of speed, distance & time calculations to the pilot-navigator. You learnt, too, that in carrying out these calculations it is of crucial importance that the units match one another, otherwise you will obtain nonsense answers. Revise Chapter 4 now, if you feel it to be necessary.

In this section on the navigation computer, you will learn how to use the computer to carry out speed, distance and time calculations much more quickly and easily than is possible when working them out "long-hand", or in your head.

Practise mental calculations of Speed, Distance and Time regularly. Skill at mental arithmetic is essential for the pilot-navigator.

You should, nevertheless, get used to working out estimates of speed, distance & time calculations mentally, and practise mental calculation regularly, as a means of checking the order of magnitude of the solutions obtained from the navigation computer. It cannot be over-emphasised how important it is for you to know where to place the decimal point in the figures that you read off from the various scales on the computer. For instance, if you were to read off, as a solution to a particular problem, the figures 185, you will know where to place the decimal point in these figures only if you have calculated mentally the order of magnitude of the answer. Are you expecting an answer of 185, 18.5, 1.85, 0.185, 0.0185?

Calculating Time.

During the flight planning stage of a cross country trip, after calculating your heading to steer and groundspeed for each leg, you will need to work out the time required for each leg, as well as the time required for the whole trip, in order that you can work out your fuel requirements.

Timings are entered in the flight log, along with the fuel requirements for the whole trip, as well as the fuel required to complete the flight from nominated turning points and checkpoints, based on your aircraft's fuel consumption rate.

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As an example of carrying out time calculations on the navigation computer, let us calculate the time required to fly from Oxford Kidlington to Wellesbourne Mountford, via, Ledbury, based on the groundspeed for the two legs of that flight, that we worked out earlier. We have, in fact, already worked out the times, long hand, and entered them in the flight log, in *Figure 9.15*, but we will now show you how to work out those times on the navigation computer.

Time Required for the Leg from Oxford Kidlington to Ledbury.

We have already measured the distance and calculated the groundspeed for the leg from Oxford Kidlington to Ledbury. The distance is 42 nautical miles (nm), and the groundspeed worked out to be 90 knots.

We know that **time** $= \dfrac{\textbf{distance}}{\textbf{groundspeed}}$

Distance is in nm, and groundspeed is in knots (i.e. nm per hour), so the units match. The navigation computer permits you to read off the time in minutes or hours and minutes.

On the navigation computer, the index mark we use for speed, distance, time calculations is the 60 index, on the inner scale. (With speed, distance & time, we are working in hours, minutes and seconds, so we are working to base 60, not base 10.)

In order to calculate the time required to cover a given distance at a given groundspeed, simply position the 60 index on the inner scale against groundspeed on the outer scale. For the first leg of the flight from Oxford Kidlington to Ledbury, the calculated groundspeed is 90 knots, so we set the 60 index against 90 on the outer scale.

With the 60 index on the inner scale against the value of 90 on the outer scale, any distance you require can be identified on the outer scale and the resulting time required, in minutes, or in hours and minutes, to cover that distance at the selected groundspeed may be read from the two inner scales. Note that the blue inner scale has numbers only; these are read off as minutes. The white inner scale, inside the blue scale, indicates hours and minutes. It is essential, therefore, that you carry out an approximate mental calculation of the time that you are expecting, so that you know whether to expect a time in minutes, or in hours and minutes.

In this case, you position the cursor over 42 (for 42 nm) on the outer scale and as illustrated in *Figure 11.10*, you see that the corresponding value on the inner scale is almost exactly 28.

Now you will see the importance of carrying out approximate mental calculations. You need to have worked out mentally that at 90 knots (90 nm per hour) it will take less than an hour to cover 42 nm. In fact, it is fairly easy to work out in your head that at a groundspeed of 90 knots, an aircraft will cover 42 nautical miles in just less than ½ an hour. Therefore, you should easily deduce that the value 28 represents 28 minutes. You, therefore, enter a time of 28 minutes in the flight log for the leg from Oxford Kidlington to Ledbury. You will see that this is exactly the same time as that which we calculated earlier, with pencil and paper. All calculations are as straightforward as that, really.

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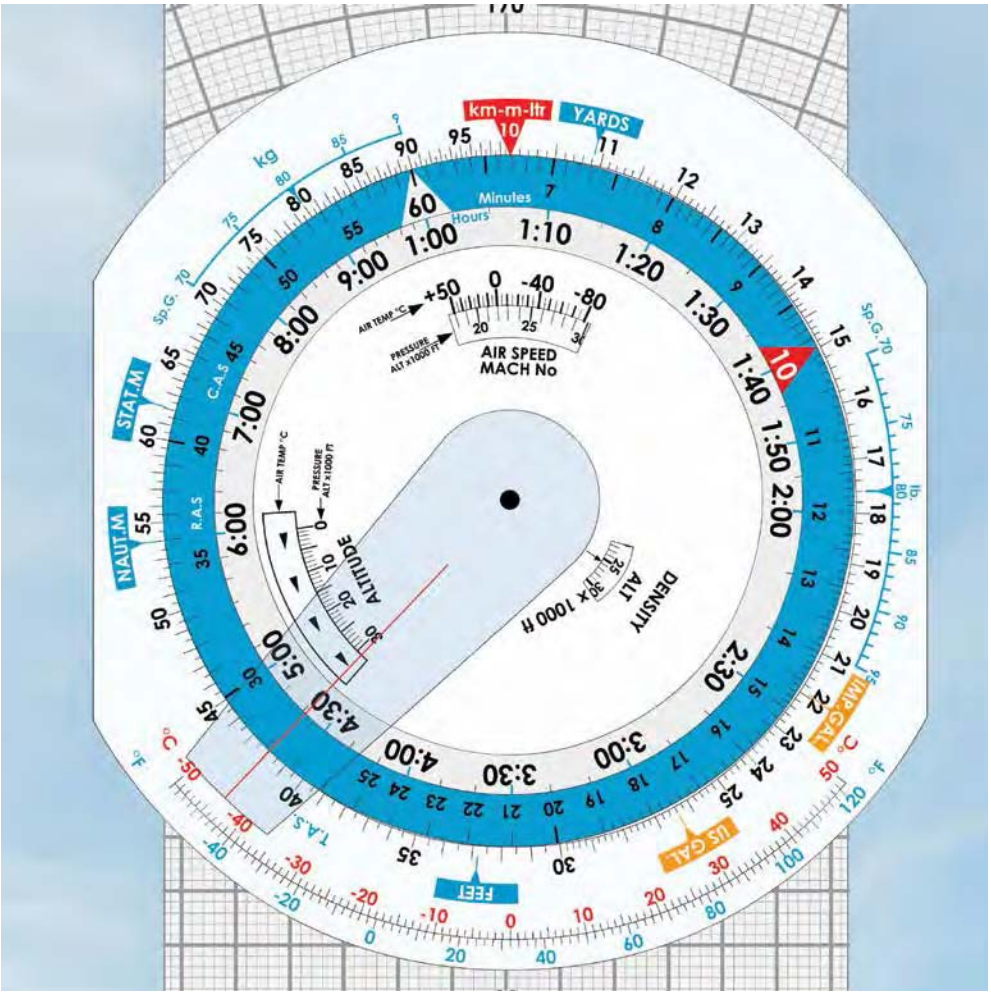

Figure 11.10 Calculating the time taken to fly 42 nm at a groundspeed of 90 knots.

Remember, you are using the 60 index, so any time indicated by the blue inner scale will be in minutes. The white inner scale gives answers in hours and minutes, if the solution is greater than one hour.

Without moving the 60 index from its position against 90 knots, you can now read off the expected elapsed time from Oxford Kidlington to your first checkpoint at Little Rissington, 14 nm along the route. That will be 9½ minutes.

Similarly, the elapsed time from Oxford Kidlington to the second checkpoint of the M5, at 32 nm distance, can be read off the inner scale of the navigation computer as 21 minutes, to the nearest minute.

Time Required for the Leg from Ledbury to Wellesbourne Mountford.

We measured the leg from Ledbury to Wellesbourne Mountford to be 32 nm and calculated that in the prevailing wind we would make a groundspeed of 125 knots. In order, then, to calculate the time required for the leg, we position the 60 index against 125 on the outer scale, identify the value 32 (for the distance of 32 nm) on the outer scale, and read off the value 153 from the divisions on the blue inner scale, as illustrated in *Figure 11.11.*

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Again, you need to have worked out mentally that at 125 knots, it will take about ¼ hour to cover 32 nm. Therefore, the value 153 represents 15.3 minutes. You decide to round up to 15½ minutes and to enter that time in the flight log. This is exactly the same time as we calculated earlier, on paper. (*See* Chapter 9 *Figure 9.15.*)

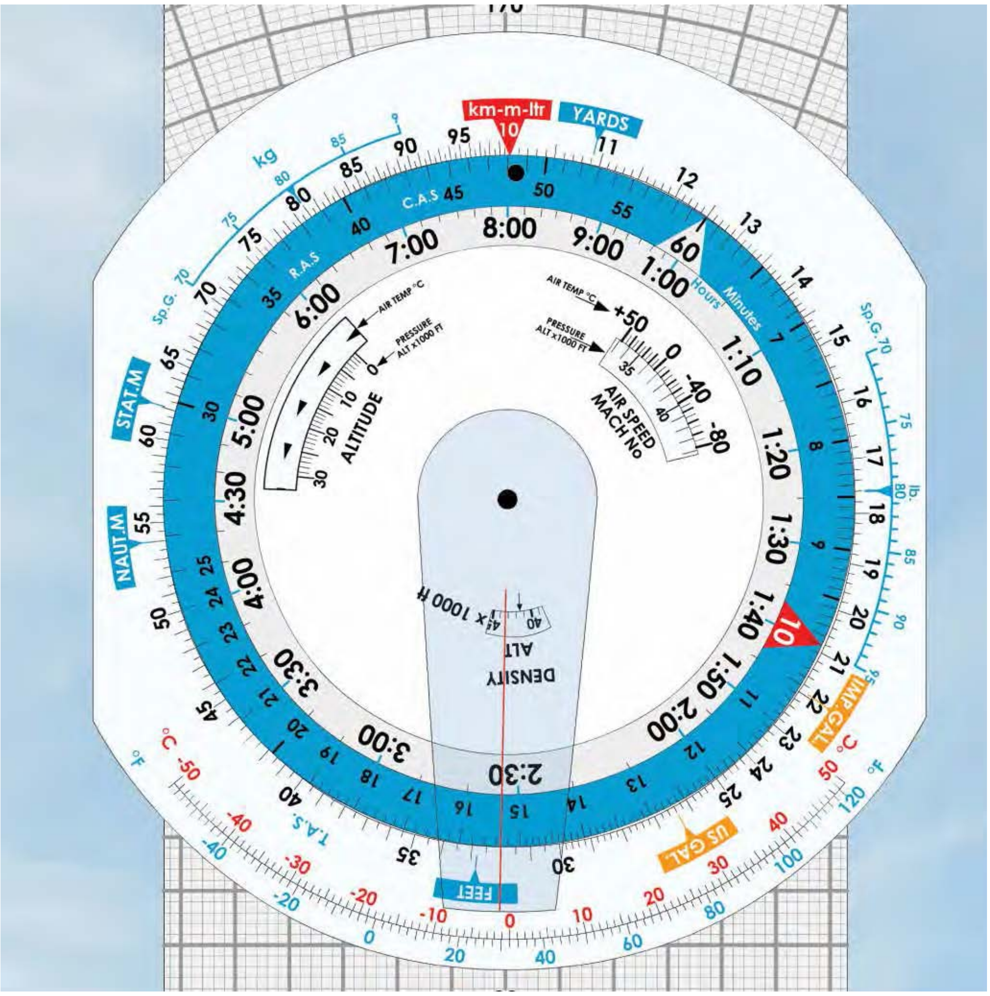

Figure 11.11 Calculating the time taken to fly 32 nm at a Groundspeed of 125 knots.

With the 60 index still against the groundspeed of 125 knots, read off on the inner scale the expected elapsed time of 7 ½ minutes to your mid-track checkpoint of Pershore Airfield, which lies at 16 nm from Ledbury.

You may practise as many time calculations as you wish using the CD-ROM which accompanies this book.

Calculating and Updating Groundspeed.

When you actually get airborne and are flying a cross country leg, you may observe that you do not arrive at a checkpoint after the expected elapsed time. If you have been flying accurately, at your elected airspeed (an essential navigation skill), any timing error will be because the forecast wind velocity was inaccurate or that the wind velocity has changed. If this is the case, you will need to correct the groundspeed calculated at the flight planning stage and calculate your actual achieved groundspeed.

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This is easy to do using the navigation computer. Let us assume that during the actual flight from Ledbury to Wellesbourne Mountford, you arrive at your checkpoint of Pershore Airfield after 8½ minutes instead of the expected 7½ minutes. In such a case, the wind speed has either fallen, or has less of a tailwind component than expected. As you are exactly on track, you conclude that the wind must have weakened.

You must now calculate your actual achieved groundspeed in order to update the estimated time of arrival (ETA) at Wellesbourne Mountford. It is essential that you carry out these revisions if you are to continue to navigate accurately, and, remember, if you are to succeed in the navigation part of the PPL skills test, you must arrive at a turning point and/or destination within 3 minutes of your declared ETA.

In order to calculate a revised groundspeed on the navigation computer, you adapt the time calculation method that you have just learned. In this case, you have observed the time yourself; you have taken 8½ minutes to cover a known distance of 16 nm, from Ledbury to Pershore. So. identifying the value 16 on the outer scale, you position the centre line of the cursor on that value, and line up under the cursor the value 8½ (i.e. 8.5, half way between 8 and 9) on the inner scale. You now see that, with the circular slide rule face lined up in this way, the 60 index indicates your actual groundspeed of 113 knots.

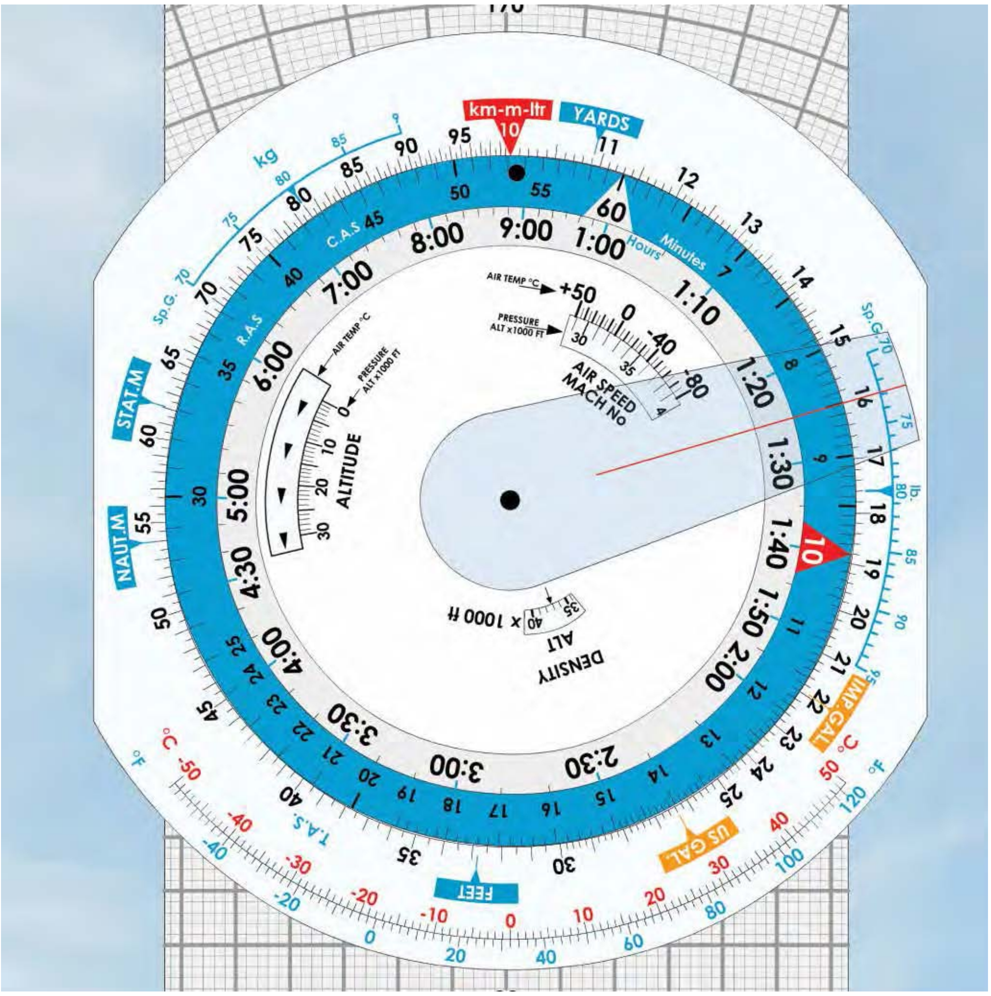

Figure 11.12 Updating timings from a revised groundspeed.

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At that new groundspeed you can immediately see, using the method that you learned above, that you will cover the 32 nm from Ledbury to Wellesbourne Mountford in 17 minutes instead of the planned 15 ½ minutes.

Of course, you could have calculated mentally that if you are one minute late at the mid-track position, you will be two minutes late at you destination. This mental calculation would have led you to estimate your arrival at Wellesbourne Mountford as being 17½ minutes after setting heading from Ledbury. That calculation is also accurate enough for visual navigation.

If you are on track at the mid-track point, but are one minute behind your calculated time, you will be two minutes late at your turning point or destination. Whatever time error you record at the ½ track point, double the error for the completion of the leg.

You will be able to practise calculating speeds using the numerous examples available on the CD-ROM.

Calculating Distance Flown.

If, while flying a cross country leg, you do not positively identify an expected checkpoint at the planned time, you should continue to fly on your planned heading, at your planned airspeed. If you are on track, it could be that the headwind component is stronger than forecast and that the checkpoint is still ahead of you, or that your groundspeed is higher than calculated and that you have already over-flown the checkpoint without seeing it. If you suspect this latter scenario to be the case, you should consider maintaining heading and look out for the following checkpoint to appear, earlier than planned.

If checkpoints still fail to appear, you may decide to note the time elapsed since your last confirmed position and calculate the distance flown since that position, using the value for groundspeed previously calculated. This action will give you a dead reckoning position which will prove useful in attempting to identify a positive ground fix.

In order to calculate distance flown on the navigation computer, we make a further small modification to the method used earlier to calculate time and groundspeed.

You have a calculated groundspeed of 90 knots, so set the 60 index against the value of that speed on the outer scale.

Let us assume that you have not identified either of the two checkpoints on the Oxford Kidlington to Ledbury leg of the cross country flight, nor have you spotted Ledbury, itself, though 32 minutes have elapsed since you set heading from Oxford Kidlington.

With the 60 index against 90 on the outer scale of the circular slide rule face of the navigation computer (this position is already illustrated in *Figure 11.10*), identify the value 32, to represent the observed elapsed time of 32 minutes, on the inner scale. Now read off, against the 32 mark, the distance covered of 48 nm, on the outer scale.

Using your navigation rule, you see that 48 nm from Oxford Kidlington gives you a dead reckoning (DR) position of half way between Ledbury and Hereford. If you are still on track, then, Hereford should be about 4 nm ahead of you. There should be a railway line running parallel to track on your starboard side, and you should soon be crossing the River Wye. This DR position should give you enough indications to be able to identify a positive ground feature and establish a fix which will enable you to return to Ledbury and continue your planned flight to Wellesbourne Mountford. If this

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is not the case, you should admit that you are unsure of your position, and follow the advice given in Chapter 14 on the Lost Procedure.

The CD-ROM contains numerous practice test questions on calculating distance.

FUEL CALCULATIONS.

When planning to carry out a cross country flight, the most common fuel planning considerations for the general aviation pilot are:

- calculating the quantity of fuel required to fly the whole route, including the fuel contingency requirements for taxying, holding at destination, diversions etc, and assuming a minimum amount of reserve fuel on landing.

- calculating the fuel required to complete the route from pre-defined turning points or checkpoints.

- calculating the expected fuel remaining at pre-defined turning points and checkpoints.

- calculating your aircraft's endurance with the fuel you are planning to carry.

The calculations mentioned above must be based on a known fuel consumption rate for the aircraft. Fuel consumption is expressed in litres or gallons per hour.

When you have worked out the groundspeed for each leg of the flight, you can calculate the time required to fly each leg, and, then, knowing your aircraft's fuel consumption rate, calculate the fuel required to complete the flight.

Fuel planning figures are then entered in the flight log.

On your aeronautical chart, you can enter figures for each leg of the flight, to include fuel required to complete the flight from selected checkpoints or turning points. But for the purpose of this short study of the use of the navigation computer, we will concern ourselves only with the overall figures required to complete a fuel log of the type depicted in *Figure 11.13* below. Fuel planning considerations will be covered in more detail in the next chapter.

VFR FLIGHT LOG

DATE:		T/O:		LDG:			FLT TIME:						
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LEDBURY	2500	2700	240/20	105	286	279	3°	282	90	43 nm	29	
LEDBURY	WELLESBOURNE MOUNTFORD	2500	2700	240/20	105	072	074	3°	077	125	32 nm	15½	
ALTERNATE													

FUEL	
TO DESTINATION	
TO ALTERNATE	
10% CONTINGENCY	
45 MIN HOLDING	
TOTAL REQUIRED	
TOTAL ON BOARD	
ENDURANCE	

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

Figure 11.13 A partially completed VFR flight log.

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Calculating Fuel Required.

Let us calculate the expected fuel required for the cross country navigational exercise from Oxford Kidlington to Wellesbourne Mountford, via Ledbury, that we have been considering. We will assume that, at the airspeed and power setting at which we have elected to fly, the fuel consumption rate given in the Pilot's Operating Handbook is 8½ US gallons per hour.

We will work in US gallons for now, and make any conversions we wish into litres or Imperial gallons at convenient points in our calculations. As you will learn, we can use the navigation computer to carry out these conversions.

Given the forecast wind, we have already calculated expected groundspeed and times for both legs. At a groundspeed of 90 knots, the first leg from Oxford Kidlington to Ledbury, a distance of 42 nm, should take 28 minutes. What quantity of fuel do we require, then, to fly this first leg? A quick mental calculation tells that, at very nearly ½ hour, 28 minutes of flying time at a fuel consumption rate of 8½ US gallons per hour will require about 4 gallons.

Because we are working in hours and minutes, in order to carry out fuel calculations, we once again use the 60 index on the navigation computer.

Firstly, we place the 60 index against the numerical value for fuel consumption rate, 8½, on the outer scale. 8½ is identified by the value 85 (for 8.5) on the outer scale. We now identify flying time on the inner scale and read off fuel required from the outer scale. We have already carried out an approximate calculation mentally, so we will know the order of magnitude of our answer. Against 28 on the inner scale representing 28 minutes, we read off 40 on the outer scale, to the nearest whole number. Use the cursor to help you read off the figures, if that makes things easier. Our mental calculation confirms for us that the value 40 indicates that 4.0 US gallons will be consumed on the first leg of our flight. (*See Figure 11.14.*)

If the fuel gauges in your aircraft are graduated in US gallons, you may choose to record fuel requirements in the flight log in US gallons. Otherwise you may convert to litres or Imperial gallons, as required.

For the second leg of the flight, from Ledbury to Wellesbourne Mountford, we have calculated that the flying time will be 15½ minutes. With the 60 index still against 85, representing 8½ US gallons per hour, we identify 155 on the inner scale (representing 15.5 minutes), and read off 22 on the outer scale. 15½ minutes is very nearly ¼ hour, so we expect fuel consumed on this second leg to be about one quarter of 8½ US gallons, which will be just over 2 US gallons. 22 on the outer scale, then, evidently represents 2.2 US gallons.

While we are looking at fuel calculations *on the navigation computer, note that the white scale inside the blue inner scale is graduated in hours and minutes. This latter scale is also used in calculations of time and fuel consumption, or fuel required. For instance, if an aircraft's fuel consumption rate were 8.5 US gallons per hour and the aircraft was to cover a route requiring 2 ½ hours flying time, we could calculate the fuel required for the flight using the white hours and minutes scale. With the 60 index set against 8.5 on the outer scale, we could locate 2:30 on the inside white scale, representing 2 hours 30 minutes and read off the figures 213 on the outer scale. (See Figure 11.14.) A quick mental calculation would tell us that the value 213 represented an amount of fuel consumed on the 2 ½ hour flight of 21.3 US gallons.*

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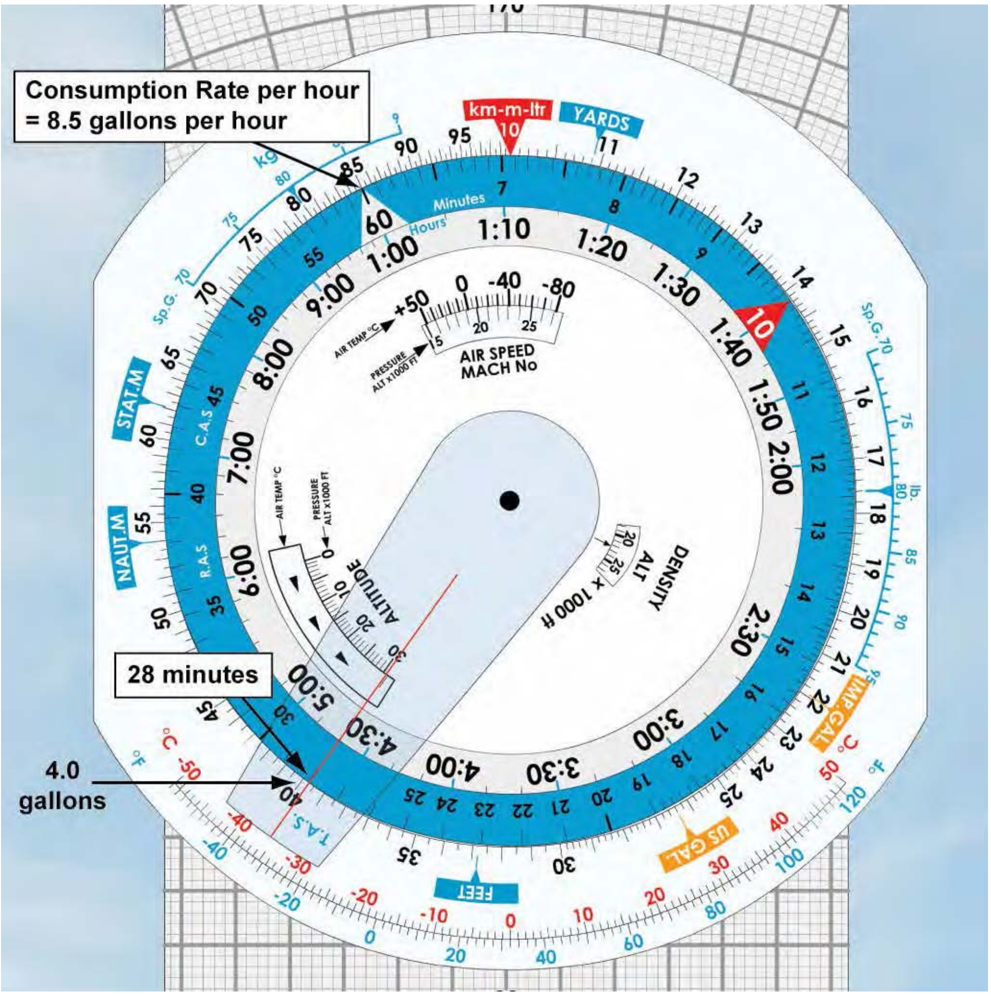

Figure 11.14 Calculating fuel consumed in 28 minutes at a fuel consumption rate of 8.5 US gallons per hour.

But to return to the Oxford Kidlington – Ledbury – Wellesbourne Mountford flight, the fuel required for the whole flight will be (4.0 + 2.2) US gallons. That makes 6.2 US gallons. We can round that figure up to 7 US gallons.

We now enter our fuel calculations in our flight log.

Completing the Fuel Log.

Although we have not specified an alternate airfield for this example of a cross country, we would, of course, do so for an actual planned flight, and will discuss this requirement in the next chapter, which deals with Flight Planning. In the fuel log at *Figure 11.15*, we have assumed a fuel requirement of 1 US gallon in case a diversion to an alternate aerodrome is necessary.

The fuel log also includes a fuel contingency requirement of 10% of the fuel required for the primary route and diversionary route to an alternate airfield, as well as fuel for 45 minutes holding time at destination.

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VFR FLIGHT LOG

DATE:	T/O:			LDG:				FLT TIME:					
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LEDBURY	2500	2700	240/20	105	286	279	3°	282	90	42 nm	28	
LEDBURY	WELLESBOURNE MOUNTFORD	2500	2700	240/20	105	072	074	3°	077	125	32 nm	15½	
ALTERNATE													

FUEL	
TO DESTINATION	7
TO ALTERNATE	1
10% CONTINGENCY	1
45 MIN HOLDING	7
MINIMUM RESERVE	5
TOTAL REQUIRED	21
TOTAL ON BOARD	35
ENDURANCE	3h 56min

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

Figure 11.15 A Fuel Planning Log from a VFR Flight Log.

Contingency Fuel.

8 US gallons are required to complete the primary route and to divert to an alternate airfield. The contingency field requirement of 10% is, therefore, 0.8 US gallons. You would round that up to 1 gallon.

Holding Fuel.

We read off from the navigation computer that, at a fuel consumption rate of 8½ US gallons per hour, 45 minutes holding time will require 6.4 US gallons. It would be prudent to round this quantity up to 7 gallons, too.

Minimum Reserve Fuel.

We should also plan to land with a pre-determined minimum fuel quantity in the aircraft's tanks, because not all of the fuel in the tanks will be useable fuel. Let us put the minimum fuel quantity at 5 US gallons.

Total Fuel Requirement.

We see, then, that the fuel we require to carry in the aircraft, in order to complete our planned flight safely is (7 + 1 + 0.8 + 7 + 5) US gallons; that is, 21 US gallons, rounded up to the nearest gallon.

The next figure we enter into the fuel log is the total fuel on board. Obviously, it is your responsibility as the pilot to upload sufficient fuel for the flight. But, you will, of course, have to consider your overall mass and balance calculations before deciding on the amount of fuel to carry. In the flight log, above, we assume that the result of your mass and balance calculation (see Volume 5 'Aeroplanes') leads you to decide to carry 35 US gallons of fuel. As this quantity of fuel is well above the 21 US gallons just calculated, it is a safe margin of fuel for the planned flight.

Having chosen the quantity of fuel to carry, you sensibly decide to conclude your fuel calculations by calculating on the navigation computer your aircraft's endurance on the 35 US gallons it is carrying.

Calculating Endurance.

In order to calculate endurance, we just have to make a simple modification to the method that you learnt above for calculating fuel required.

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Leave the 60 index set against the aircraft's fuel consumption rate of 8.5 US gallons per hour. Now, it is simply a question of identifying the fuel quantity carried, on the outer scale, and reading off the time your aircraft can remain airborne on that fuel (i.e. the aircraft's endurance) on the inner scales. Remember, the blue scale indicates the endurance in minutes and the inside white scale indicates the endurance in hours and minutes.

Before carrying out this calculation, be sure to look up in the Pilot's Operating Handbook for your aircraft the amount of fuel in your aircraft's tanks which is unusable. Let us assume that this amount is 1.5 US gallons. Therefore, if you are going to carry 35 US gallons of fuel, only 33.5 gallons will be usable.

With the 60 index against 8.5 on the outer scale, locate the figure 335 (for 33.5 US gallons), also on the outer scale. You read off 236 on the inner scale. (Use the cursor, if you need to.) You have already calculated mentally that 33.5 US gallons is going to give you an endurance of about 4 hours, at a fuel consumption rate of 8.5 US gallons per hour, so you conclude that 236 is 236 minutes, giving a result for your endurance of 3 hours 56 minutes. A glance at the inside white scale confirms you conclusion.

You can test yourself on numerous calculations of this kind, using the CD-ROM.

Calculating the Weight of Fuel.

It is most important that pilots include the weight of the fuel that their aircraft is carrying in the pre-flight mass & balance calculations.

Whether converting from gallons (gal) or litres (ltr) to pounds (lb) or kilograms (kg), the weight of fuel can be computed from its volume using the two blue specific gravity scales on the outer rim of the circular slide rule face of the navigation computer, as depicted in *Figure 11.16*. One of the specific gravity scales is used for converting fuel quantities to lb and the other to kg, each scale being annotated with the letters lb or kg, respectively. The two scales are marked Sp.G., representing the words specific gravity.

The Significance of Specific Gravity.

The specific gravity of any fuel denotes the relationship between the weight of the fuel compared to the weight of an equivalent volume of water.

The **specific gravity of water**, the standard, is regarded as **1.0**. One Imperial gallon of water weighs 10 lbs, one US gallon weighs 8 lbs and one litre of water weighs 1 kg. The specific gravity of fuel varies with a number of factors, such as temperature, and refining processes used in the production of the fuel. Pilots, though, are unlikely to have data available to them, when refuelling, that will enable them to calculate the exact specific gravity of the AVGAS that they are putting in to their aircraft.

But it is reasonably accurate to assume a **specific gravity** of **0.72** for **AVGAS**.

Notice that specific gravity has no units because it expresses a ratio of the weight of the AVGAS to the weight of an equivalent volume of water. If you wish to have a good approximate figure for actual weights, you can reasonably assume that AVGAS weighs 7.2 lb per imperial gallon, 6 lb per US gallon, or 0.72 kg per litre. As we have said, for our calculations on the navigation computer, we will work from the specific gravity figure for AVGAS of 0.72.

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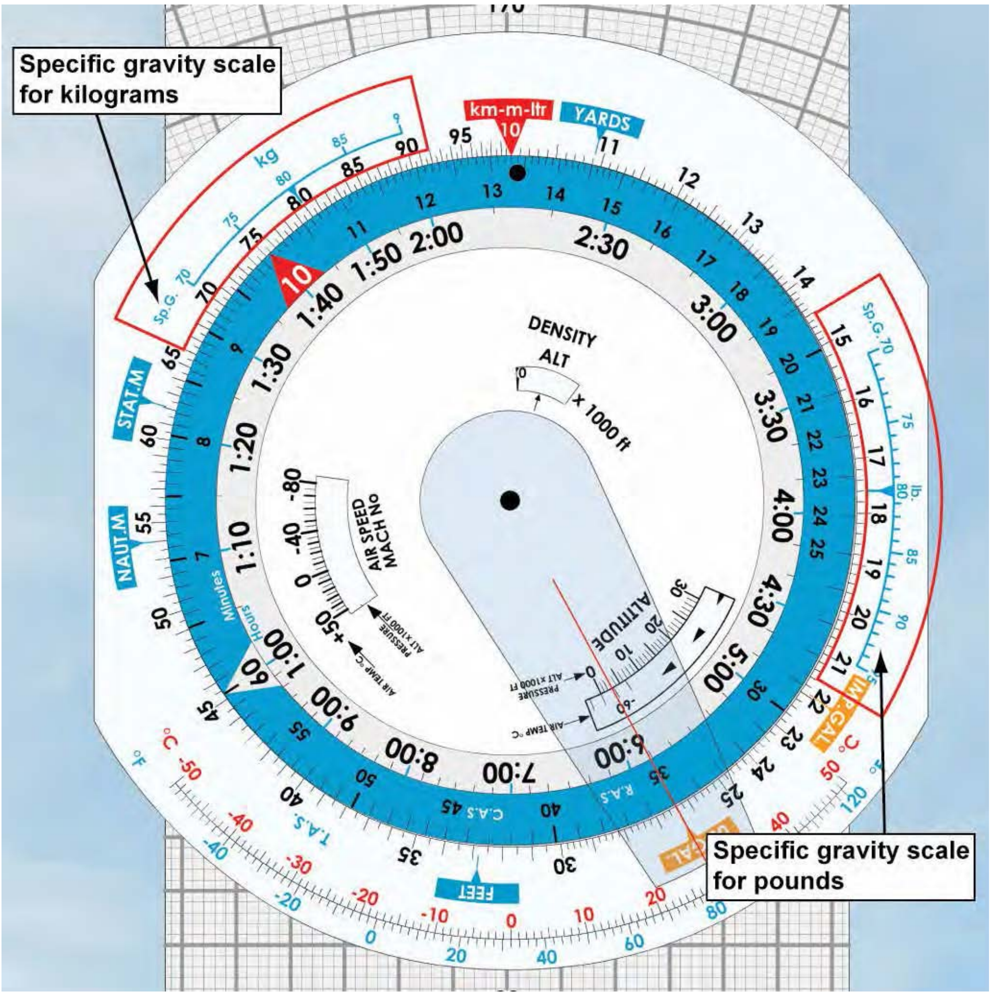

Figure 11.16 The two Specific Gravity Scales on the circular slide-rule face of the navigation computer. The Sp.G. scales are used for converting fuel volume to fuel weight, and vice versa.

Converting Fuel Volume to Fuel Weight.

Let us assume that you wish to know the weight, both in lb and kg, of the 35 US gallons that you plan to carry in your aircraft for the Oxford Kidlington-Ledbury-Wellesbourne Mountford trip.

Position the centre line of the cursor over the yellow US GAL indicator on the outer rim of the navigation computer, as illustrated in *Figure 11.17.*

Now rotate the inner part of the computer so that the figures 35 (representing 35 US gallons) is underneath the centre line of the cursor and, thus, against the US GAL pointer. With the computer set up in this way, now position the cursor over the value of 72 on the lb specific gravity scale.

From the blue inner scale, read off the value 21. From our knowledge that one US gallon weighs about 6 lb, we can deduce that, for 35 US gallons, the value 21 represents a weight of 210 lb.

To obtain the weight of 35 US gallons of fuel in kg, now reposition the centre line of the cursor over the value 72 on the kg Sp.G. scale, and read off the value 96. As a kg is about 2.2 lb, we deduce that 96 represents 96 kg.

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If you wished to work out the weight, in lb and kg, of 80 ltr of AVGAS, you would position 8 on the blue inner scale, representing 80 ltr, against the red km-m-ltr index mark on the outer scale, and then:

- read off on the lb Sp.G. scale, under the value 72, the weight in lb; that is 126 lb. Naturally, you would carry out a mental calculation to ensure that you obtain the correct order of magnitude from the figures 126. (One litre of fuel weighs about 1.6 lb.)

- read off on the kg SP.G. scale, under the value 72, the weight in kg; that is 57.5 kg. Again, you would carry out a mental calculation to ensure that you obtain the correct order of magnitude from the figures 575. (One litre of fuel weighs about 0.72 kg.)

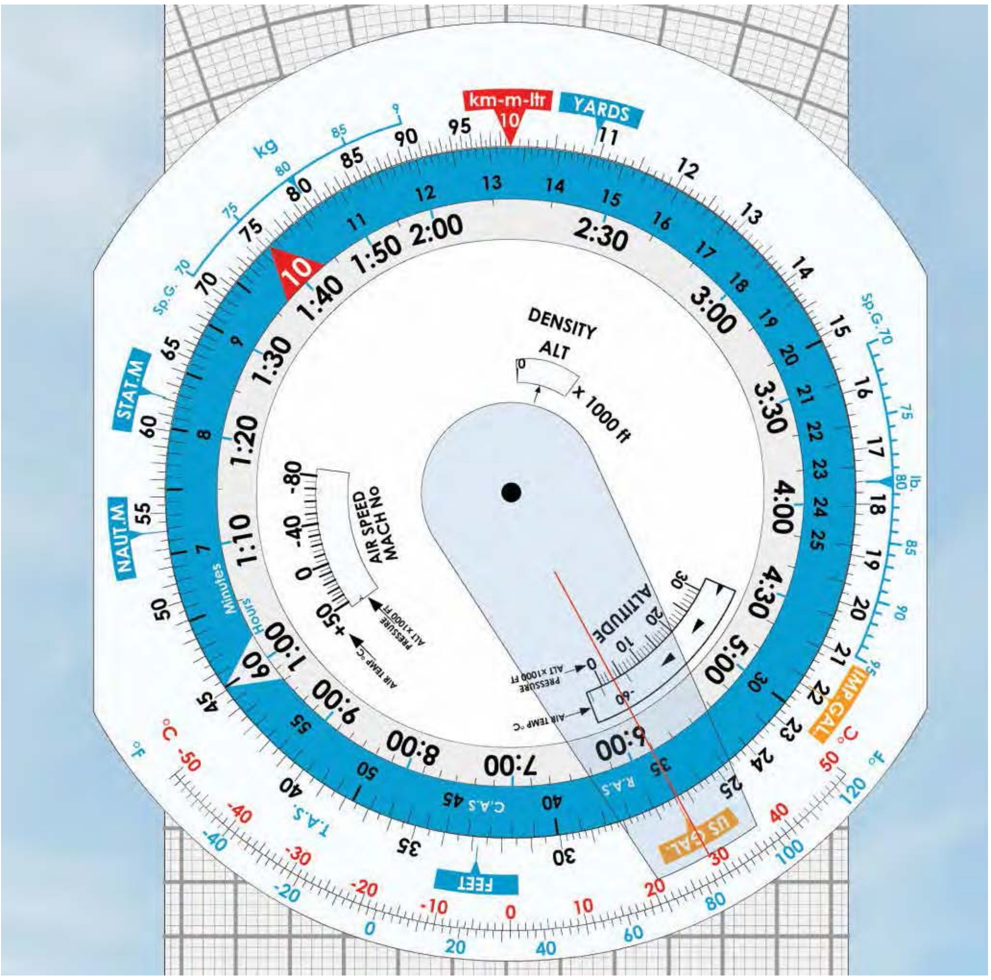

Figure 11.17 Align 35 on the blue inner scale with the US GAL flag on the outer rim of the navigation computer.

Converting Fuel Weight to Fuel Volume.

Another way of considering the conversion of fuel weights and volumes is to calculate the volume of fuel you may safely carry in your aircraft when a specified passenger and baggage payload is to be transported on a given flight.

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Let us assume that, following pre-flight mass & balance calculations, you discover that the weight of fuel in the aircraft's tanks may amount to 150 lb without overloading the aircraft or putting the aircraft's centre of gravity outside limits. You wish to know, therefore, what volume of fuel 150 lb represents in US gallons and litres, so that you can carry the maximum amount of fuel permitted by the mass & balance calculations.

You can use your navigation computer to carry out this calculation. You just have to adapt slightly the method that you have just learnt for calculating weight from volume.

This time, you place 15 on the inner scale of the computer, representing 150 lb of AVGAS, against 72 on the lb Sp.G. scale, using the cursor to assist you. (*See Figure 11.18.*)

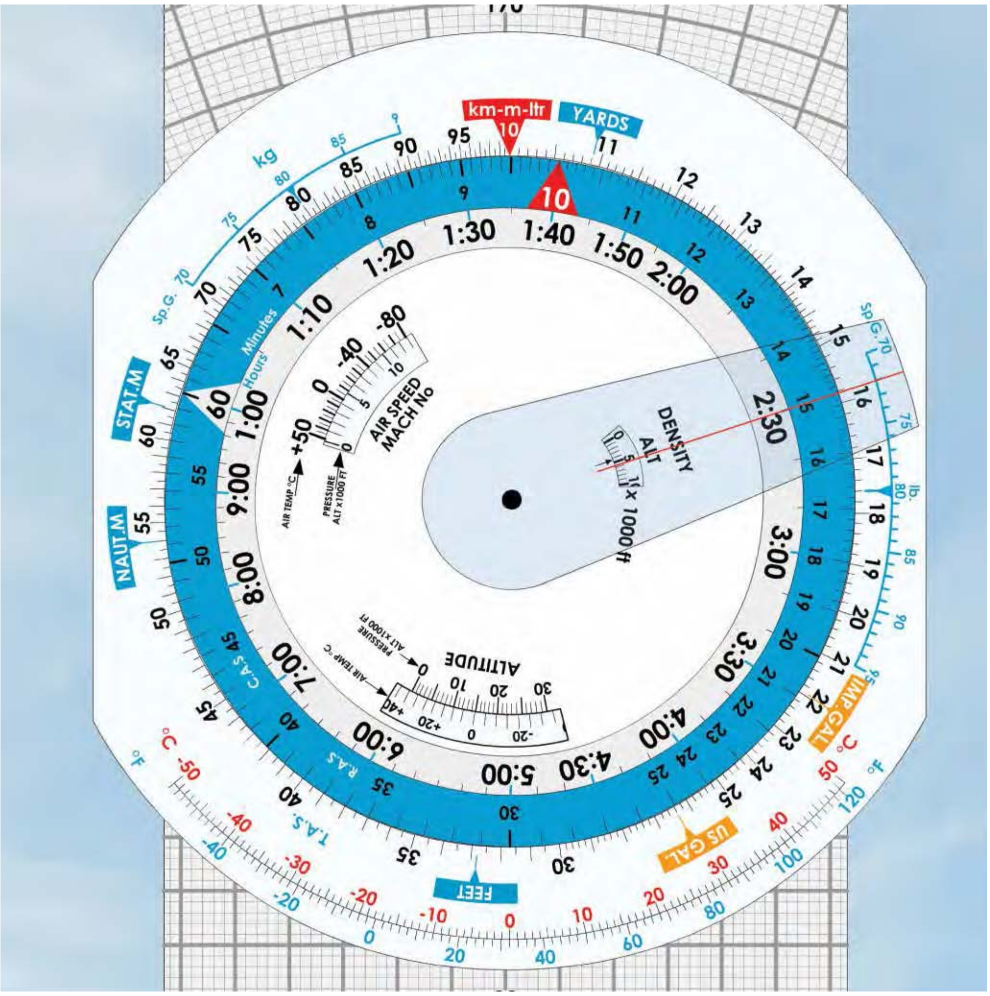

Figure 11.18 Calculating what volume in US gallons or litres may be carried for an allowable fuel load of 150 lb.

Now rotate the cursor to line up with the US GAL index and read off, on the inner scale, the equivalent volume of fuel: 25 US gallons. (Your mental calculation based on AVGAS weighing about 6 lb per US gallon confirms the magnitude of the value represented by the figures 25.)

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Finally rotate the cursor to line up with the km-m-ltr index and read off 95 litres. (Your mental calculation based on AVGAS weighing about 1.6 lb per litre confirms the magnitude of the value represented by the figures 95.)

You may use the CD-ROM to practise further volume to weight and weight to volume conversions.

CONVERSIONS OF UNITS OF VOLUME.

We will finish this introductory chapter on the use of the navigation computer, by carrying out simple conversions of units of volume. As we have just been carrying out fuel calculations, we will convert between US gallons, Imperial gallons and litres. These calculations may well be necessary to a pilot flying in Britain or Europe, if he is operating an aircraft built in the United States of America. US aircraft inevitably have fuel gauges graduated in US gallons, whereas, in Britain and Europe, fuel may be uploaded in litres, Imperial gallons or US gallons.

We will, therefore, convert the total fuel quantity required for the Oxford Kidlington-Ledbury - Wellesbourne Mountford flight, from US gallons to litres. Having decided to carry 35 US gallons of fuel, you see from the aircraft's fuel gauges that there are already 20 US gallons in the tanks. Consequently you need to take on a further 15

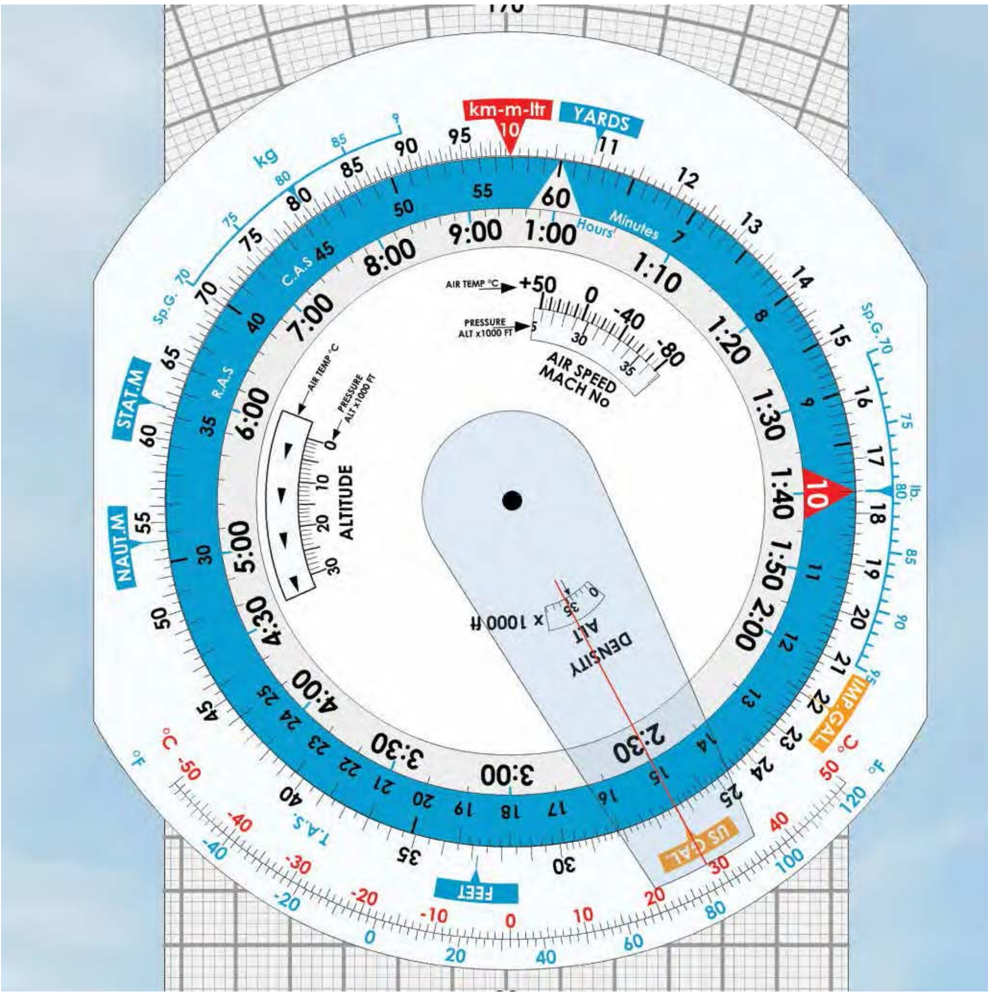

Figure 11.19 Converting 15 US gallons to litres.

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US gallons. The fuel bowser from which you plan to refuel delivers fuel in litres so, using your navigation computer, you calculate how many litres are the equivalent of 15 US gallons.

The operation is simple. Locate the yellow indicator annotated US GAL on the outer rim of the circular slide rule face of the navigation computer, and position the centre line of the cursor over the point of the US GAL indicator, as illustrated in *Figure 11.19.*

You now adjust the moveable inner scale so that 15, on the inner blue scale, representing 15 US gallons, is positioned under the centre line of the cursor. Now simply move your cursor to line up with the pointer of the red flag marked km-m-ltr, as illustrated in *Figure 11.20.*

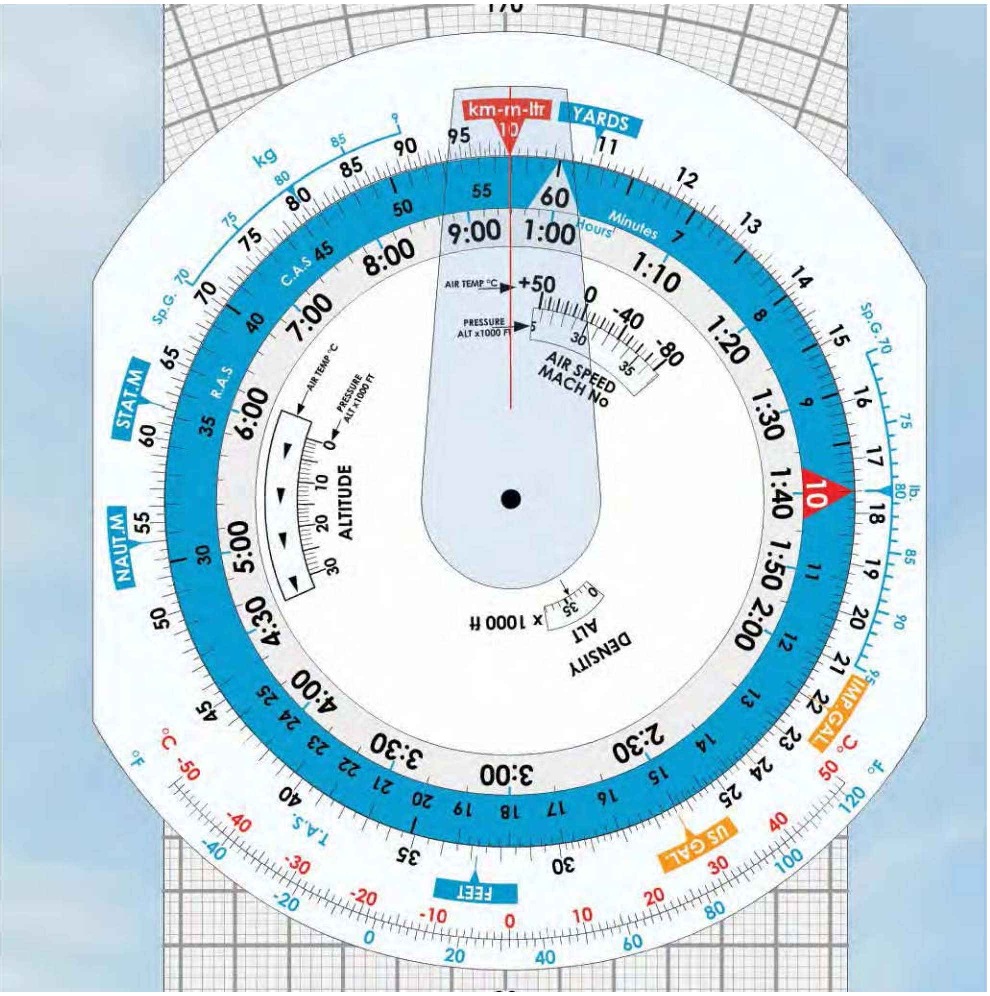

Figure 11.20 15 US gallons is equal to about 57 litres.

The symbols km-m-ltr stands for kilometres-metres-litres; this flag is used for all conversion operations involving those three units. At present, of course, you are interested in litres.

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Underneath the cursor's centre line, read off the value 573. Knowing that there are about 4 litres in a US gallon, a quick mental calculation confirms that 573 is to be read as 57.3 litres. This, then, is the amount of fuel that you need to upload from the bowser.

All conversion calculations between units are carried out in this way. The CD-ROM will teach you how to make all types of conversions, and will give you practice in as many test questions as you wish.

CONCLUSION.

The aim of this chapter has been to teach you the use of the Dalton-type dead reckoning computer in carrying out the principal calculations that concern the pilot-navigator when preparing a cross country flight.

There are many other types of calculation which may be made on the navigation computer that we do not mention here.

However, all functions of the navigation computer are taught on the navigation computer training CD-ROM which accompanies this book. Please study the CD-ROM carefully before taking your navigation examination.

Bear in mind, too, that despite this being the age of the digital computer, the traditional Dalton-type analogue computer will give you all the accuracy you require for the navigation calculations you will perform during flight planning. The Dalton-type navigation computer does not, of course, need any kind of power source other than yourself, so it will rarely, if ever, let you down.

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Representative PPL - type questions to test your theoretical knowledge of The Navigation Computer.

1. If magnetic variation in a certain part of the world is given as so many degrees East, then:

   a. True North is East of Magnetic North
   b. Compass North is West of Magnetic North
   c. True North is West of Magnetic North
   d. Magnetic North is West of Compass North

2. Select the correct option to fill out the blanks of the table below:

TRUE	VARN	MAG	DEVN	COMP
270°	?	274°	-3°	?

   a. 4°E, 277°
   b. 4°W, 271°
   c. 4°W, 277°
   d. 4°E, 271°

3. Using the wind face of your flight computer, complete the table shown below:

HDG°(T)	W/V	TRACK°(T)	TAS	GS
?	040/20	005	110	?

   a. 011 90
   b. 011 93
   c. 015 90
   d. 015 97

4. Using the wind face of your flight computer, complete the table shown below:

HDG°(T)	W/V	TRACK°(T)	TAS	GS
?	125/35	045	196	?

   a. 057 195
   b. 035 187
   c. 057 190
   d. 055 188

5. Using the wind face of your flight computer, complete the table shown below:

HDG°(T)	W/V	TRACK°(T)	TAS	Groundspeed (knots)
?	170/23	113	105	?

   a. 129º 90 knots
   b. 123º 120 knots
   c. 102º 90 knots
   d. 124º 92 knots

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6. Using the wind face of your flight computer, complete the table shown below:

HDG°(T)	W/V	TRACK°(T)	TAS	GS
?	145/20	021	80	?

a. 033 89
b. 033 93
c. 030 85
d. 030 87

7. Using the wind face of your flight computer, complete the table shown below:

HDG°(T)	W/V	TRACK°(T)	TAS	GS (knots)
?	170/15	287	100	?

a. 285º 100 knots
b. 275º 100 knots
c. 270º 95 knots
d. 279º 105 knots

8. Using the circular slide rule on your flight computer for distance, speed, time and conversion calculations, complete the table shown below:

Fuel Flow	Flying Time	Fuel Consumed
9 US gallons/hr	1h 20min	?

a. 18 gallons
b. 10 gallons
c. 12 gallons
d. 12 litres

9. Using the circular slide rule on your flight computer for true airspeed (TAS) and altitude conversions complete the table shown below. Assume that indicated airspeed (IAS) is the same as rectified airspeed.

IAS (kt)	Pressure Altitude (ft)	Temp (°C)	TAS (kt)
115	5 000	-10	?

a. 115
b. 150
c. 193
d. 120

10. You are planning a cross-country flight on which your desired track is 340º True. Your planned TAS is 89 knots and the forecast wind speed is 130/14. What true heading must be flown to maintain this track, and what will be your groundspeed?

a. 335º True 101 knots
b. 345º True 76 knots
c. 335º True 76 knots
d. 345º True 101 knots

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11. Using the circular slide rule on your flight computer for true airspeed (TAS) and altitude conversions complete the table shown below. Assume that indicated airspeed (IAS) is the same as rectified airspeed.

IAS (kt)	Pressure Altitude (ft)	Temp (°C)	TAS (kt)
100	3 000	+10	?

a. 105
b. 101
c. 124
d. 81

12. Using the circular slide rule on your flight computer for distance, speed, time and conversion calculations, complete the table shown below:

Ground Speed (kt)	Distance (nm)	Time (min)
130	?	23

a. 50
b. 116
c. 55
d. 48

13. Using the circular slide rule on your flight computer for distance, speed, time and conversion calculations, complete the table shown below:

Ground Speed (kt)	Distance (nm)	Time (min)
?	41	26

a. 100
b. 95
c. 65
d. 158

14. Using the circular slide rule on your flight computer for distance, speed, time and conversion calculations, complete the table shown below:

Ground Speed (kt)	Distance (nm)	Time (min)
110	24	?

a. 22
b. 44
c. 13
d. 26.5

FOR THE REMAINING QUESTIONS, ASSUME THAT AVGAS HAS A SPECIFIC GRAVITY OF 0.72.

15. What is the weight in lb of your fuel load if your aircraft's tanks hold 25 US gallons?

a. 149 lb
b. 68 lb
c. 25 lb
d. 180 lb

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16. What quantity of fuel can you carry in US gallons if you calculate that your aircraft may carry 230 lb of fuel?

    a. 69 gallons
    b. 41.5 gallons
    c. 32 gallons
    d. 38 gallons

17. What is the weight in lb of your fuel load if your aircraft's tanks hold 75 litres?

    a. 54 lb
    b. 68 lb
    c. 25 lb
    d. 118 lb

18. What quantity of fuel can you carry in litres if you calculate that your aircraft may carry 150 lb fuel?

    a. 69 litres
    b. 21 litres
    c. 95 litres
    d. 63 litres

Question	1	2	3	4	5	6	7	8	9	10	11
Answer											

Question	12	13	14	15	16	17	18
Answer							

The answers to these questions can be found at the end of this book.

CHAPTER 12
FLIGHT PLANNING

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INTRODUCTION.

What is Flight Planning?

Whenever you fly, you must flight plan. Even a short local area flight requires the pilot to obtain a reliable weather forecast and to observe the actual weather situation in the vicinity of the airfield to see if it is suitable for the intended flight. Furthermore, the pilot must also make sure that the aircraft is serviceable and carries sufficient fuel and oil. Additionally, the pilot should set an aim for the flight, and must always carry a suitable up-to-date aeronautical chart of the area in which the flight is to take place. All these activities constitute what is termed flight planning.

However, the expression flight planning normally refers to the activities associated with planning for a cross-country navigational flight, which is to be conducted either visually or on instruments. In this chapter we will assume that you are planning to carry out a visual navigational flight.

Good flight planning for a cross country flight will help ensure that the flight proceeds efficiently and in safety. As you will have learnt from earlier chapters, sound navigational preparation will make navigation, once airborne, as undemanding as possible, leaving the pilot with maximum mental and physical capacity to fly the aircraft, deal with radiotelephony requirements, and cope with any revisions of his flight plan that prove necessary. Successful flight planning will normally consist of the following activities:

- Planning the route.
- Checking Airspace Restrictions
- Obtaining a weather forecast.
- Chart preparation.
- Completing the flight log.
- Fuel calculations.
- Weight and balance calculations.
- Aeroplane performance calculations.
- Submitting a flight plan.

Personal Equipment.

Before starting your flight planning, you should make sure that you have the appropriate items of personal equipment. The following list is a guide.

- Relevant charts covering your intended route.
- Navigation computer, ruler and protractor.
- A reliable watch or stopwatch.
- A Torch.
- Pencils and pens.
- Clipboard or kneepad for the flight log.
- Sunglasses.
- Aircraft checklists.
- Headsets for yourself and passengers.

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PLANNING THE ROUTE.

The starting point for flight planning is invariably your choosing a destination to which you wish to fly. In this chapter, we will assume that you wish to fly from Oxford Kidlington to Hawarden, an aerodrome situated about 10 miles South of Liverpool. *(See Figure 12.1.)* You should have your own **1:500 000 chart** of Southern England at hand while working through this chapter. By referring to your own chart regularly, you will draw maximum benefit from your study of the chapter.

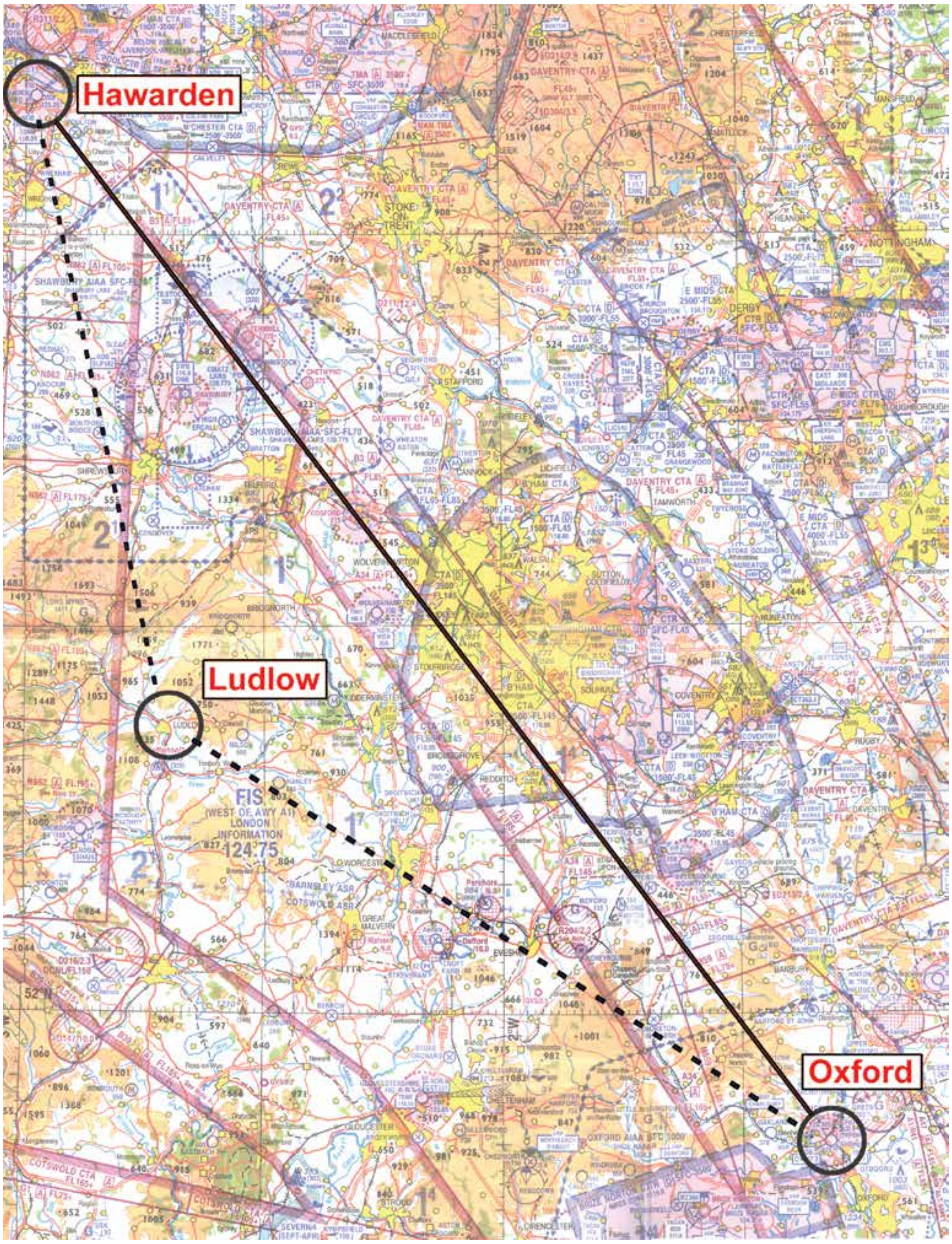

Figure 12.1 Alternative routes from Oxford to Hawarden. The route via Ludlow will keep you clear of controlled airspace

Having chosen your destination, there are several factors which may influence your choice of route to that destination.

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The Weather.

A primary factor influencing your choice of route will be the weather. If your intention were simply to plan a cross country route for training purposes only, you would probably plan to go where the weather is most favourable. On the other hand, if you wish to fly to a particular destination, in this case, to Hawarden, then you will have to accept the weather as it is, or decide that the weather is not good enough for the flight to take place. You may also be able to pick a route which will keep your aircraft in acceptable weather conditions. Whatever the case may be, you must not take-off on any flight without obtaining a weather forecast.

Routing Considerations.

In order to fly from A to B as quickly as possible, the direct straight line route will be the fastest route but not always the best route. For example, the direct route to Hawarden from Oxford would take you under the Birmingham Control Area (CTA). There would be nothing illegal about this, but if you strayed slightly right of track you would be under a part of the CTA with a lower limit of 2 500 feet. Consequently, while in the vicinity of the Birmingham CTA, it would be unwise to plan on flying higher than an altitude of 2 000 feet. This altitude is rather low for flight over a major conurbation and, furthermore, you would be unable to climb if you needed to.

The direct route from Oxford to Hawarden would also take you through the Combined Military Air Traffic Zones (CMATZ) at Ternhill and Shawbury. There is no reason why you should not fly through the CMATZ; it would be good practice at using a MATZ Penetration Service, but, if you were to be asked by the MATZ controller to divert around the CMATZ, that would be a major inconvenience.

You can avoid all the potential difficulties of the direct route by routing via Ludlow. In electing to fly a dog-leg route via Ludlow, you will add only 9 miles to the distance from Oxford Kidlington to Hawarden. Note, however, that the dog-leg route does take you over some high ground North of Ludlow, so you would need to check the weather in that area carefully.

Obtaining a Weather Forecast.

A comprehensive weather briefing may currently be obtained from the Met Office website, http://www.metoffice.gov.uk/aviation/ga.html.

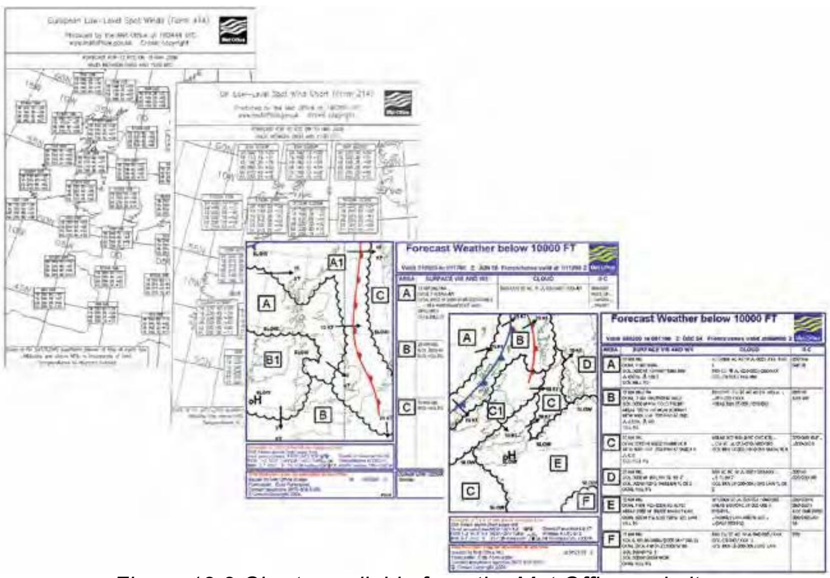

Figure 12.2 Charts available from the Met Office website.

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There are several weather briefing (forecast) charts to choose from *(see Figure 12.2)* so you can select the type of forecast which most suits you. Terminal Aerodrome Forecasts (TAFs) and Routine Aviation Aerodrome Weather Reports (METARS) are also available on the Met Office website. All these charts, forecasts and reports may also be available in hard copy, at the airfield from which you fly. Form F215, the UK Low-Level Weather Chart, and Form F214, the UK Spot Wind Chart, are two very useful charts. Their interpretation is explained in detail in Volume 4 of this series of manuals: Meteorology.

In whatever format you access the weather briefing, you will need to study the information on the weather and the winds that you can expect to meet en route to Hawarden.

Figure 12.3 depicts a typical UK Low-Level Forecast Chart (Form 215) which we will assume is current for the day of your flight to Hawarden.

The two commonly used Met Office charts in flight planning are:

***214** - UK Spot Wind Chart which gives wind velocity for different altitudes.*

***215** - UK Low-Level Forecast Chart.*

The weather depicted on **Form 215** is divided into areas. The weather in each area is summarised in the boxes to the right of the chart. Note, however, that the **Form 215** does not give information about wind. You will need **Form 214** for the wind.

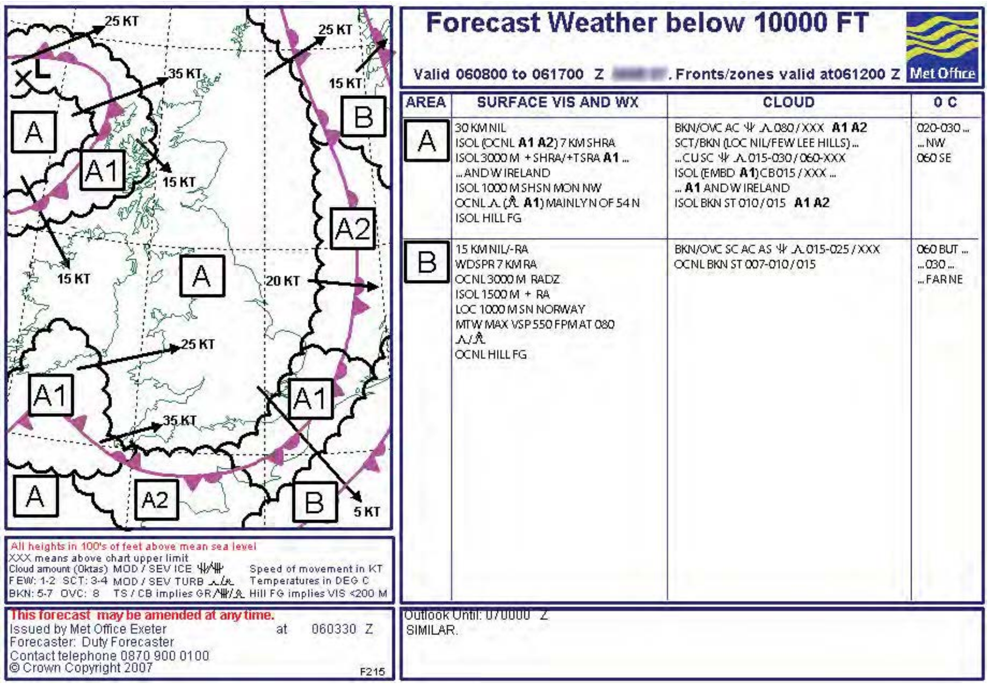

Figure 12.3 Form 215 - The UK Low-Level Forecast Chart.

The forecast shows that the route from Oxford to Hawarden will be entirely within **Area A** and that visibility will be 30 km with nil weather. Visibility will decrease in isolated showers, but you should be able to see these isolated showers from a long way off.

With a forecast of nil weather and good visibility, you decide that a cruising altitude of 2 500 feet would be appropriate, allow you to maintain Visual Meteorological Conditions and keep you an adequate height above obstacles all along your intended route. After examining the chart, you also make a mental note that the approach to Hawarden will pass under Class A airspace with a base of 3 000 feet. (Calculation of Safety Altitude is covered in more detail later in this chapter).

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With the Maximum Elevation Figure on both legs of your route being 2 100 feet, you note that your Safety Altitude will be 3 100 feet, should conditions deteriorate.

For information on the wind that you can expect along your route, you need to consult a current Met **Form 214**, the UK Low-Level Spot Wind Chart. *(See Figure 12.4.)* In **Form 214**, wind direction and speed are given at the latitude and longitude shown in each box. **Altitudes are pressure altitudes, in thousands of feet above mean sea-level and temperatures are in degrees Celsius.**

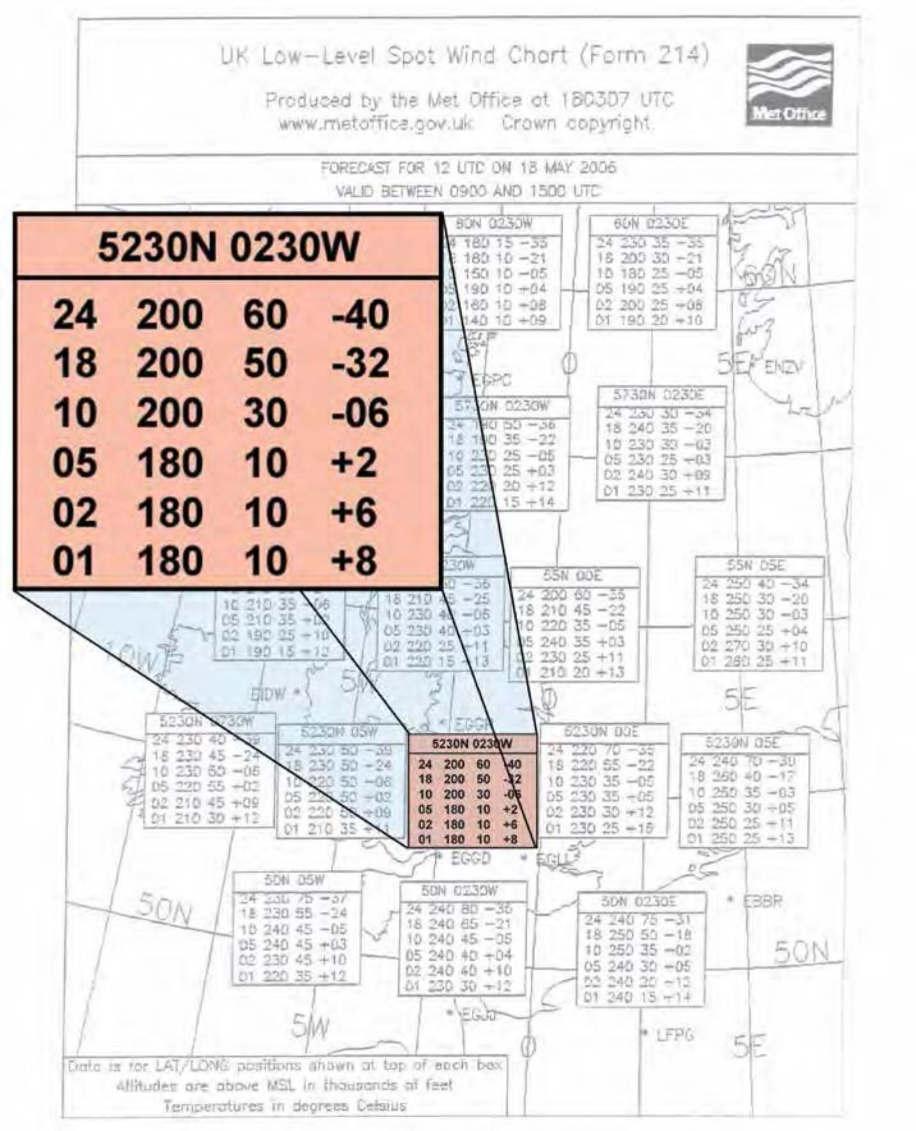

Figure 12.4 Met Form 214 - The UK Low-Level Spot Wind Chart.

To select the wind for your route, you look for the box nearest your intended route and take the wind nearest your intended cruising altitude. You may need to interpolate, if your cruising altitude lies between the published altitudes.

For example the 5230N, 0230W box lies about mid-way along your track from Oxford to Hawarden. As you have decided to cruise at 2 500 feet, you decide to examine the wind at 2 000 feet and 5 000 feet. The figure on the left hand side of the box is the

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altitude, expressed as a pressure altitude, followed by the wind direction, the wind speed and, finally, the temperature.

You see that the wind at 2 000 feet is from 180º at 10 knots with a temperature at 2000 feet of +6ºC, while the wind at 5 000 feet is likewise from 180º at 10 knots but with a temperature of +2ºC. Based on this information, with the wind at 2 000 feet and 5 000 feet being the same, it is easy to conclude that the wind you will use for your navigation calculations and flight log will be 180º/10 knots. (Note, that wind direction is given in degrees True.)

Now that you have your en route weather, you decide to check what the weather will be at your departure and destination airfields.

(TAFs) and (METARs) can be obtained for many UK aerodromes via the TAF and METAR bulletins on the Met Office website. TAFs are updated every 3 hours and METARs every 30 minutes. However, you should bear in mind that many aerodromes are not included, and this applies to Oxford Kidlington. TAF and METAR information for Hawarden can be found on Met Office website under 'TAF and METAR search'.

Consequently, in order to obtain a general indication of the weather at both locations you should select, from the nearest aerodromes for which TAFs and METARs are published. For example, Brize Norton (EGVN) is the nearest aerodrome to Oxford. To obtain a more detailed forecast for your arrival time at Hawarden you could, of course, telephone the aerodrome. The phone number can be found in the various published Flight Guides.

After consulting the METAR and TAF, you see that the weather and visibility at the two aerodromes will be good throughout the day.

AIRSPACE RESTRICTIONS.

An important part of the flight planning process is to check whether there are any temporary or longer term airspace restrictions, or navigation warnings, which might affect the safe and expeditious progress of your flight. It is also a good idea to check the serviceability of the aerodrome you plan to use (including your diversion aerodrome) and whether there have been any recent changes in radio frequencies along your route.

The United Kingdom Aeronautical Information Publication (AIP) contains information on long-standing and permanent operational matters. More recent changes and amendments are issued as AIP Supplements.

In addition Aeronautical Information Circulars (AICs) contain information of a more administrative nature, although they are also used to give advanced warning of impending operational changes. Most of this information, including pre-flight route and aerodrome information bulletins, should be available at your flying school or club.

The information is also available on the National Air Traffic Services (NATS) website (**www.ais.org.uk**).

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Among the services offered on the NATS website are a series of briefings listed here:

UK Aerodrome Briefing

UK Area Briefing

UK Route Brief

UK Narrow Route Briefing

To obtain information on current NOTAMs, and all other warnings or restrictions pertaining to a particular route, click on UK Route Briefing. A form will appear which, when completed, saves you a lot of time because the system selects only those NOTAMs which apply to your route, giving you a Pre-Flight Information Bulletin which summarises all the relevant information for your flight.

We will assume that you have noted the pre-flight bulletin information from the NATS website and that there are no operational reasons why you should not continue with your planned route.

DESTINATION AND ALTERNATE AERODROMES.

An essential part of flight planning is obtaining information about destination and alternate aerodromes.

Aerodrome information is available from several sources, including commercially published flight guides, such as Pooley's and Airplan Flight Equipment guides, and the United Kingdom Air Information Publication (AIP). Information from the AIP can also be obtained from the NATS website.

Figure 12.5, overleaf, is an example of an aerodrome map for Hawarden from Pooley's Flight Guide for the United Kingdom. The map contains information such as circuit height and direction, radio frequencies, navigation aids, telephone numbers, etc.

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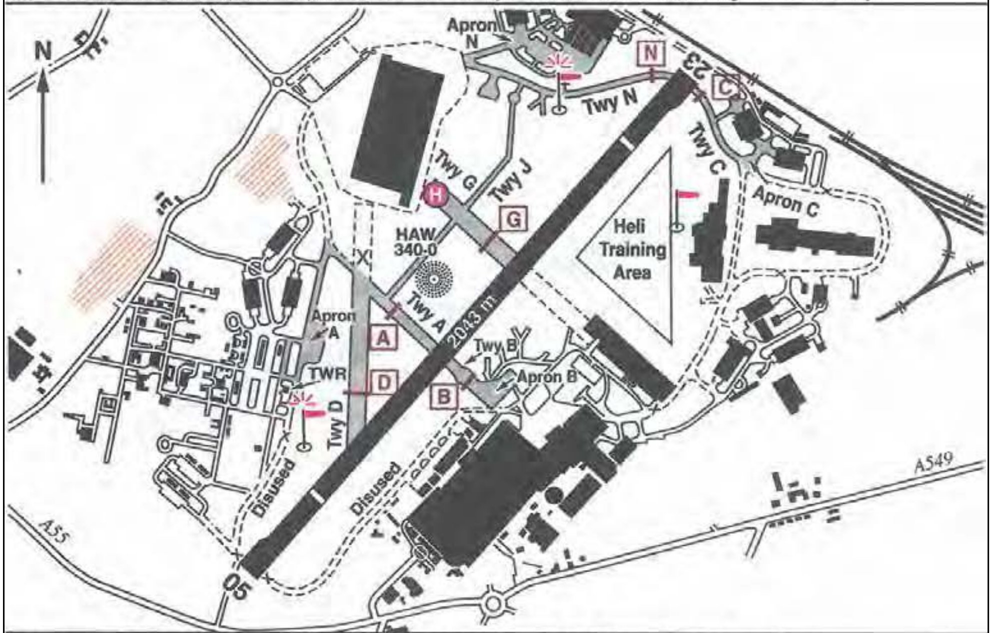
EGNR 2006

N53 10·68 W002 58·67 **HAWARDEN** 35 ft AMSL

3·5 nm WSW of Chester. **WAL 114·10 163 14**

c/s Hawarden. APP 123·35. TWR 124·95. RAD 130·25. VDF 123·35, 130·25. NDB 'HAW' 340·0 (On A/D). ILS/DME Rwy 23 (225°M) I-HDN 110·35 ILS/DME Rwy 05 (042°M) I-HWD 110·35 (LLZ offset 2·6°, Rwy QFU 045°).



Rwy	Dim(m)	Surface	TORA(m)	LDA(m)	Lighting
05/23	2043x45	Asphalt/ Concrete	05-1962 23-2043	05-1663 23-1743	Ap Thr Rwy PAPI 3·5° RH Ap Thr Rwy PAPI 3° ABn Gn.

Op hrs: Mon-Fri 0800-1900, Sat & Sun 0930-1600.

Landing Fee: Less than 1500 kg £16.80 Mon-Fri; £21 Sat & Sun; all incl VAT.

Hangarage: Hawarden Air Services 01244-538568. **Maintenance:** Available. **Customs:** 24 hrs PNR

Remarks: Operated by Airbus UK, Hawarden Airport, Broughton, Chester, N Wales CH4 0DR. Strictly PPR. Non-radio aircraft prohibited. Test flying outside A/D hours.
Circuits at 1000' QFE, RH on Rwy 05, LH on Rwy 23.
Aircraft over 3000 kg mandatory handling, contact Chester Handling Services, Apron 'N', Tel: 01244-536853, Fax: 01244-537268.
High visibility clothing to be worn on all aprons.

Noise: Departing aircraft Rwy 23 climb straight ahead to 1·5 DME before turning onto track. Jet/Turbo Prop aircraft must join final not less than 1000 ft QFE.

Warnings: Reinforcing steel within the concrete pavement of Rwy 05/23 may cause Compass deviation on stationary aircraft.
Possible turbulence from buildings when westerly or easterly wind above 15 kt.
Glider flying at weekends, up to 3000' QFE at RAF Sealand, 3 nm NNW of A/D.
Chimney 561' aal 596' amsl 241°/3·4 nm.
High ground rising to 1848' amsl between 5 nm and 10 nm SW of aerodrome.

Fuel: 100LL (Apron N), Jet A1 By arrangement with Hawarden Air Serv.

Tel: 01244-522012 ATC; 522013 PPR. **Fax:** 01244-523035.

Figure 12.5.
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The section of the UK AIP which contains aerodrome information is annotated AD (Aerodromes). From that section you can obtain a detailed map of the aerodrome layout and find out such things as hours of operation, radio and navigation aid frequencies, local flying restrictions, warnings and obstacles, and a variety of administrative details.

From time to time, information contained in the AIP will be amended by NOTAM. Make sure to read any NOTAMs which affect your route. Once you have collected the information you need for en-route and airfield weather, airspace restrictions and your departure and destination airfields, you can start preparing your charts and flight log.

CHART AND FLIGHT LOG PREPARATION.

Chart preparation is usually done in conjunction with the compiling of your flight log, so we will look at both these activities together.

You must always carry the appropriate current chart or charts for your proposed flight. For instance the UK CAA 1:500 000 chart is renewed every 12 months.

You may confirm that your charts are the latest edition by consulting the green **Aeronautical Information Circulars (AICs)**. The date showing the validity of the 1:500 000 aeronautical chart is displayed in the legend in the bottom left hand corner of the chart. Make sure the chart includes your alternate aerodrome and that it covers at least 50 nautical miles either side of your intended track. This should ensure that you do not fly off the edge of the chart!

It is a legal requirement to carry, on every flight, a current and up-to-date chart for the area in which you are to operate.

VFR FLIGHT LOG

DATE:		T/O:				LDG:				FLT TIME:			
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
ALTERNATE													

FUEL	
TO DESTINATION	
TO ALTERNATE	
10%CONTINGENCY	
45 MIN HOLDING	
MINIMUM RESERVE	
TOTAL REQUIRED	
TOTAL ON BOARD	
ENDURANCE	

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

Figure 12.6 A VFR Flight Log.

Flight logs come in a wide variety of formats. The log shown in *Figure 12.6* is the format which we will use in this and the next chapter. There is a full-size, blank Flight Log at the end of this chapter, should you wish to make copies of it.

Drawing Tracks.

In preparing your chart, the first thing to do is to draw the tracks for your intended route. If the chart is plastic covered, you will find that fine-tipped permanent marker pens, in various colours, are best for marking tracks and other information as they cannot be inadvertently smudged or erased, but can be removed after flight with methylated spirit, or by overwriting with a white board marker. Chinagraph can be used, but gives thicker lines and is not smudge-proof.

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The colour of the **track line** is a personal choice but it must stand out clearly on the chart. (Note that if you fly at night, red lines will not be easily discernible on your chart.)

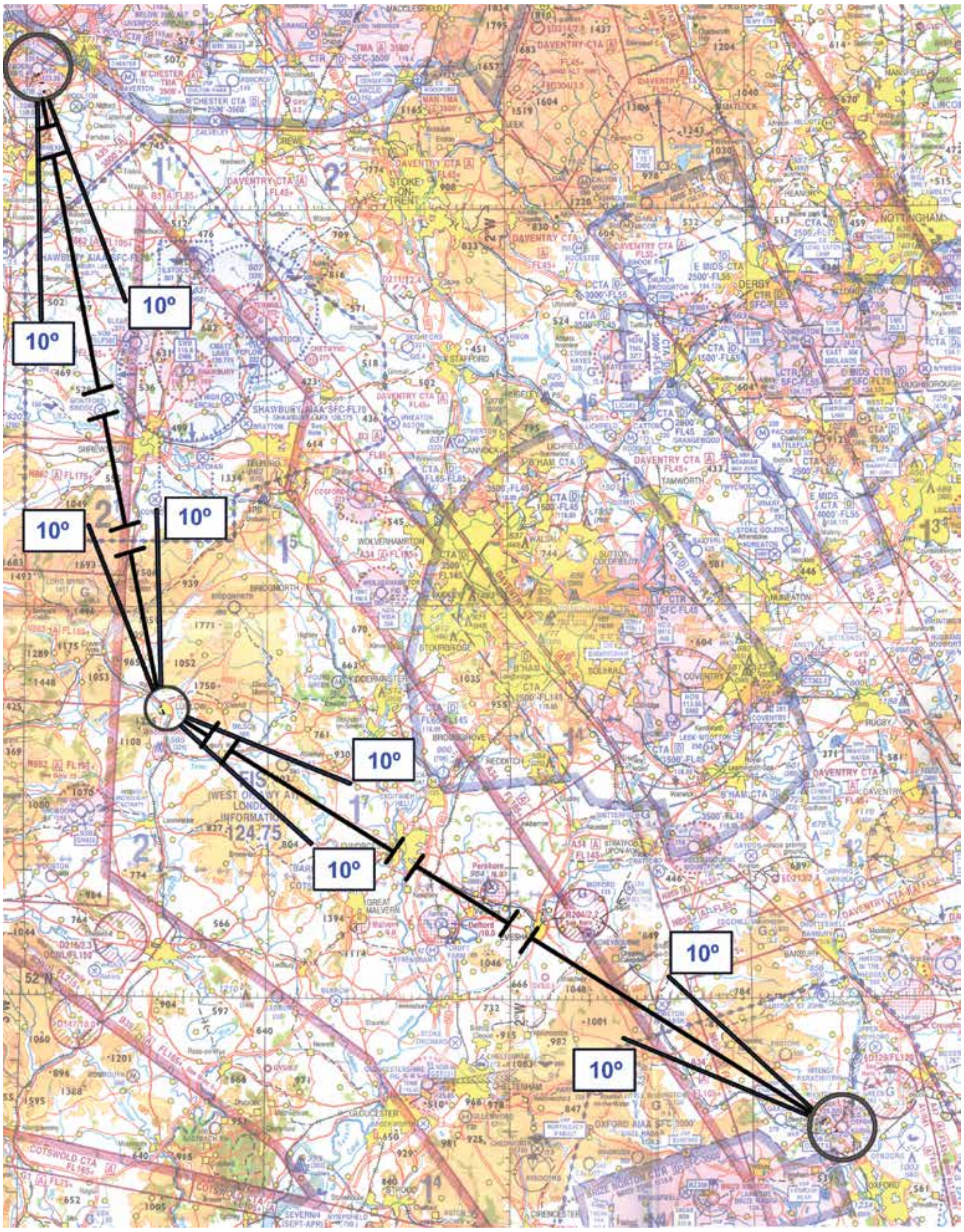

Figure 12.7 Drawing the planned track on the chart.

It is a good idea to draw small circles around your destination and departure aerodromes and any turning points as shown in *Figure 12.7.* This will ensure that these features are not obscured by the tracks. Do not make the track lines too thick as they may hide vital information on the chart. As you learnt in earlier chapters, it is a good idea, too, to “break” the track lines at checkpoints along the track that you plan to use as fixes. We will return to the subject of checkpoints and fixes shortly.

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It is convenient, at this stage in your chart preparation, to draw in track error (from departure/turning point) and closing angle (to turning point/destination) guide lines, as depicted in *Figure 12.7*. Remember to measure the true bearing half way along the track, as shown by *Figure 9.10.* We have drawn the track guides at 10º either side of the track, in order to help you determine any track error with respect to your starting point, turning point or destination. Guide lines can be drawn on one side only, and, for longer tracks, at 5 deg as preferred, but marked with the angle to avoid errors (and perhaps in a colour different from the track).

Having drawn the track lines on the chart for your intended route, you are now ready to carry out all the preliminary measurements and dead-reckoning navigation calculations that you have learnt about in the earlier chapters of this book.

It is of crucial importance that you understand that by planning your navigational flight thoroughly and carrying out the dead reckoning calculations of **heading** and **groundspeed** accurately, you will greatly simplify the airborne navigational task.

You proceed to measure the true bearings (or true track angles) of the two track lines that you have drawn, and enter this information into the flight log. The true track from Oxford Kidlington to Ludlow is 302° (T) and that from Ludlow to Hawarden is 349° (T). Then you measure the distances of each leg; Oxford Kidlington to Ludlow is 60 nautical miles (nm) and Ludlow to Harwarden is 49 nm.

In order to calculate your true heading for each leg, you need to think about what your true airspeed will be. You have already elected to fly the route at an altitude of 2 500 feet, and now decide that your indicated airspeed will be 100 knots. Referring again to the wind information on the currently valid UK Spot Wind Chart, you note that the temperature at 2 000 feet is +6°C and at 5 000 feet it is +2°C. Working from this information, you estimate that the temperature at your cruising altitude will be +5°C. With that estimated temperature and the cruising pressure altitude, you work out on your navigation computer that your true airspeed at 100 knots indicated will be 103 knots. Bear in mind that although the difference between indicated airspeed and true airspeed, is small in these present calculations, it is essential that you follow the correct technical process in order to work out true airspeed. In other circumstances, especially if you are, one day, to pilot an aircraft which flies much higher and faster, the difference might be significant. We enter the true airspeed in our flight log.

On the day of your flight the forecast wind is 180°(True)/10 knots. Using this wind, you calculate the true heading and groundspeed for both legs of the flight on your navigation computer. Given the forecast wind, and a true airspeed of 103 knots, the true heading from Oxford Kidlington to Ludlow will be 297°(T) with a groundspeed of 108 knots, and the true heading from Ludlow to Hawarden will be 348° (T), at a groundspeed of 112 knots. Next, you calculate the expected times to complete each leg of the flight. You work out that the first leg should take you 33 minutes to complete, and the second leg 26 minutes.

Noting the magnetic variation for your area, you now apply that variation to convert the true headings to magnetic headings. We have assumed that the magnetic variation for the area in which we are flying is 4° West, so that makes our magnetic headings 301° (M) from Oxford Kidlington to Ludlow, and 352° (M) from Ludlow to Harwarden.

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Route forecasts for wind are in degrees True. Use the True Wind Direction and True Track Angle to calculate True Heading. Then apply the Magnetic Variation to obtain Magnetic Heading.

It is essential that you calculate true heading before applying magnetic variation to obtain the magnetic heading. Route forecasts for wind are in degrees true. So you must use the true wind direction and the true track angle to calculate true heading before converting to magnetic heading.

You now enter all the information from your calculations in the flight log.

The partially completed flight log is at *Figure 12.8*. Make sure that you check our calculations yourself using the methods you have learned in previous chapters.

VFR FLIGHT LOG

DATE:		T/O:		LDG:				FLT TIME:					
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LUDLOW	2500	3100	180/10	103	302	297	4W	301	108	60	33	
LUDLOW	HAWARDEN	2500	3100	180/10	103	349	348	4W	352	112	49	26	
ALTERNATE													
HAWARDEN	LIVERPOOL	2000		180/10	103	026	028	4W	032	112	10	5½	

FUEL	
TO DESTINATION	
TO ALTERNATE	
10%CONTINGENCY	
45 MIN HOLDING	
MINIMUM RESERVE	
TOTAL REQUIRED	
TOTAL ON BOARD	
ENDURANCE	

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

Figure 12.8 The partially completed VFR Flight Log.

Alternate Aerodrome.

While you are carrying out your navigation calculations, you realize that you have to choose an alternate aerodrome. The forecast is good for the whole route so we do not expect any weather problems. It would seem logical, then, to take Liverpool as the alternate aerodrome, in case you are not able to land at Hawarden for some operational reason. You, therefore, calculate track, groundspeed and time for the short leg from Hawarden to Liverpool, and enter those in your flight log. Carry out your own calculations for the diversionary leg, too, in order to check our figures in the flight log.

Make sure you look at the aerodrome plate for Liverpool and check the joining requirements.

SAFETY ALTITUDE.

Although you have already chosen a safety altitude of 3 100 feet for your intended route, we will here examine the concept of safety altitude in a little more depth.

Calculation of Minimum Safe Altitude is mandatory for all flights under IFR, but is not for VFR flights. The reason why the concept of safety altitude exists for flights conducted in accordance with the Visual Flight Rules (VFR) is that, if you lose sight of the ground or visibility worsens markedly, climbing to the safety altitude will keep you safely clear of any terrain or obstacles within a given distance of your track. **Of course, if you are navigating VFR you must, in any case, remain in sight of the ground and in VMC.** Nevertheless, it is common sense and sound airmanship to calculate your safety altitude and enter it in your flight log.

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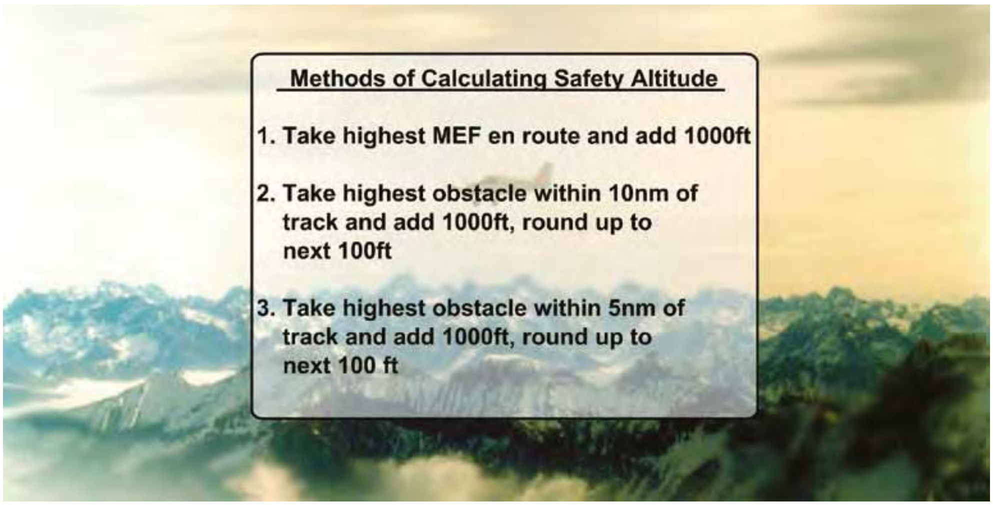

Figure 12.9 Optional Methods of calculating Safety Altitude.

There are a number of ways of calculating Safety Altitude, three of which are listed at *Figure 12.9*. The method we have used is to take the highest Maximum Elevation Figure (MEF) and add 1 000 feet. On the first leg from Oxford Kidlington to Ludlow, the highest MEF is 2 100 feet, so our Safety Altitude is 3 100 feet. On the second leg, the highest MEF is still 2 100 feet so the Safety Altitude also remains the same. Safety Altitude must be recorded in the appropriate column of your flight log.

Methods 2 and 3 are similar, but 3 uses the narrower band of terrain required under IFR, and thus the lowest possible Safety Altitude, hence a better chance of getting below cloud safely in the event of inadvertent cloud penetration. A 10nm band is more practical for VFR navigation, where tracking errors are possibly greater than in IFR navigation following radio aids. The MEF method covers a much wider area, likely to be well outside 10nm, and is suitable for rapid flight planning and in-flight diversions.

CHART PREPARATION.

Before turning to the detail of the visual navigation task, itself, and the preparation of your chart to make this task as undemanding as possible, you decide to examine the route to see if there are any controlled airspace or navigational hazards which might concern you. You had satisfied yourself that there were no major issues with the route before drawing your track lines, and have already checked that there is no NOTAMed information to affect you, or navigation warnings on the day. You have also examined the terrain you will be overflying and chosen a safety altitude.

On the first leg, you note that your track passes to the South West of Restricted Area R204, which lies East of Evesham. As long as you keep Evesham to starboard, you will not infringe the area. You note, too, that you will be flying at 2 500 feet altitude, so you would, in any case, be above the Restricted Area, whose upper limit is 2 200 feet above mean sea level. Furthermore, Note 2 to R204 on your 1:500 000 chart informs you that this particular Restricted Area applies only to helicopters. You will also pass just to the South West of the disused airfield at Pershore where there is Laser Site with an unlimited ceiling and a High Intensity Radio Transmission Area reaching up to an altitude of 6000 feet above mean sea level. You note that you must be careful not to stray into those areas. The track from Oxford Kidlington to Ludlow also passes to the North East of the Defford High Intensity Radio Transmission Area, but you should pass well clear of that.

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On the second leg of the flight from Ludlow to Harwarden, you will pass through the Shawbury Area of Intense Aerial Activity (AIAA). You note this fact and that you must maintain a good look out in this area. The Combined Military Aerodrome Traffic Zones (CMATZ) of Shawbury and Ternhill lie to the right of track on the second leg. You do not envisage having to enter the CMATZ, but you note that you will be able to get a Radar Information Service from Shawbury, if you need one.

Finally, if you had to fly to your declared alternate aerodrome of Liverpool, you note that you would need to get a clearance from Liverpool to enter its Class D Control Zone (CTR).

Having noted the above navigational issues, and studied again the lie of the high terrain, you turn your attention to the track in order to set timings and identify suitable checkpoints.

Timing Marks.

You have worked out your aircraft's ground speed for each leg, so you can put *timing marks* on your chart. You learnt about the importance of this in Chapter 8.

There are several ways of choosing the position of timing marks. The simplest is to place marks at a quarter, half and three quarters, or one third and two thirds of the way along the track, and then work out the time you will take to reach each mark. This system works satisfactorily provided that there is a reasonably prominent ground feature at or near each mark. If there is no such feature that you can use as a fix, the timing mark is of little use. This system is therefore not very precise, and, thus, unsuitable for visual navigation flights.

In Chapter 8, on Map Reading, you were advised to select easily recognisable ground features as visual checkpoints along track, at between 5 and 10 minute intervals. By using suitable ground features as a possible fix, and setting your timing marks to coincide with those features, you will increase the accuracy of your timing, and make the navigation task easier. Note that time is normally measured to the nearest half minute.

On the first leg, with a ground speed of 108 knots, checkpoints need to be between 9 and 18 miles apart. Over a distance of 60 miles, no more than 4 checkpoints will be required. Suggested ones are in *Figure 12.11.*

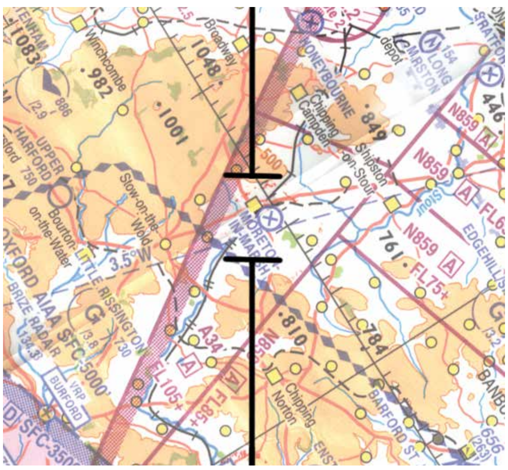

Figure 12.10 A disused airfield can make an excellent visual checkpoint.

The town of Moreton-in-Marsh has a railway line running through it and a disused airfield to the North East. *(See Figure 12.10.)* A feature like the airfield, not exactly on track and with adjacent features to confirm correct identification, makes an excellent checkpoint. It is 16 nautical miles (nm) along track so, at 108 knots, will take you 9 minutes to get there. You decide, therefore, to chose Moreton-in-Marsh airfield as your first checkpoint and mark your map as shown in *Figure 12.11* so that the timing mark and the time are clearly legible.

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The next significant feature along the route is the town of Evesham through which flows the River Avon. Crossed by a railway line, Evesham is 11 miles beyond Moreton-in-Marsh, 15 minutes flying time from Oxford Kidlington. You decide to put this timing mark on your map, too.

The town and disused airfield of Pershore is some 5 miles further along track. However, for your next ground fix you choose the motorway junction on the M5, to the South East of Worcester. The M5 passes over a railway line just South of the junction, so that checkpoint should be unmistakeable. You put a timing mark at this checkpoint, too, 20 ½ minutes from Oxford Kidlington.

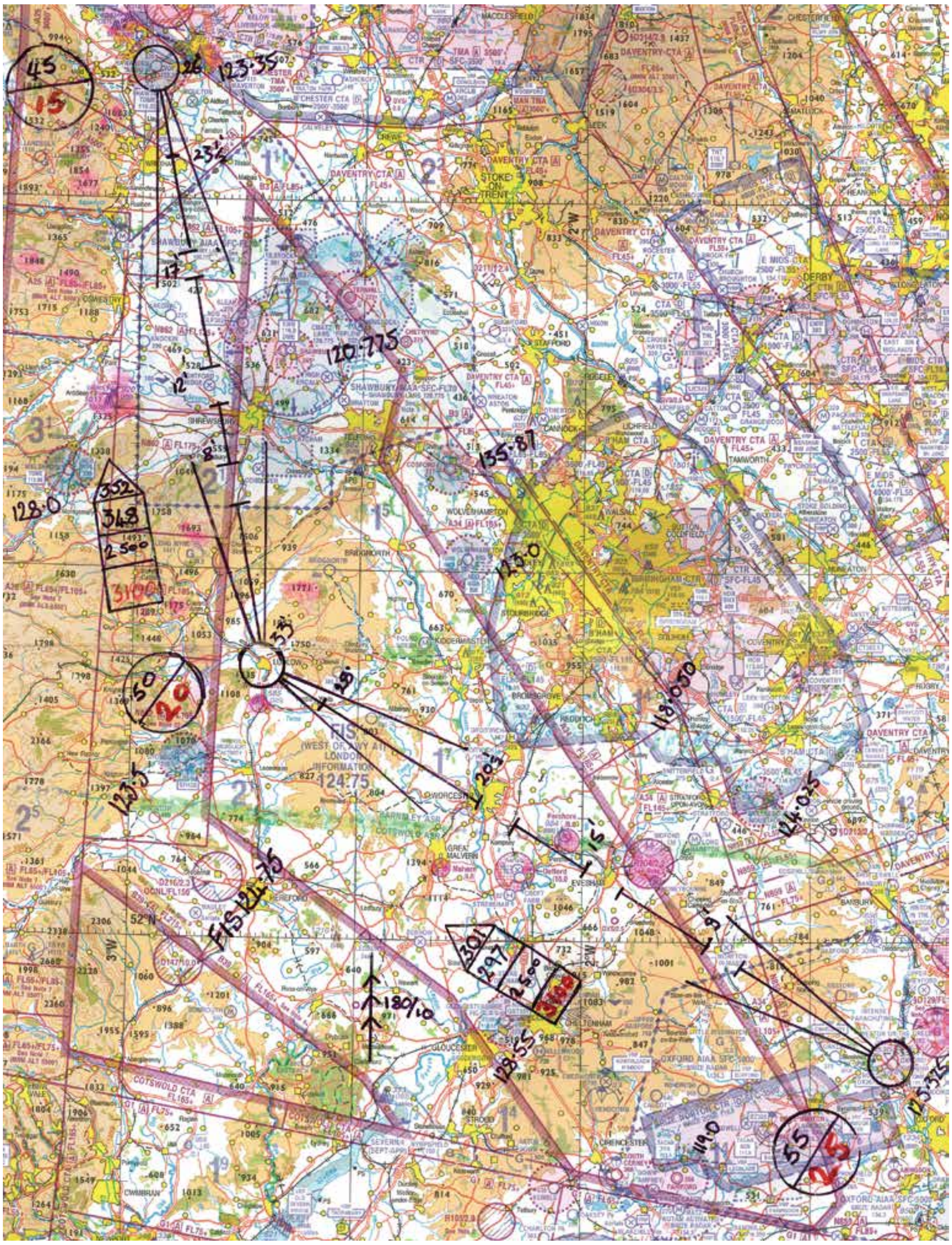

Figure 12.11 A suggested method of marking up your chart, to aid navigation and situational awareness.

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The other feature to look for at Worcester is the racetrack beside the river, to the right of track.

The motorway junction at Worcester is 20½ minutes flying time from Oxford Kidlington.

After Worcester, there are no major features to use as checkpoints before reaching Ludlow, with the possible exception of the town of Tenbury Wells. However, as Tenbury Wells is only 5 miles from Ludlow it is not particularly useful as a timing point; but you could certainly use it as a checkpoint.

Now examine the second leg of the route, from Ludlow to Hawarden, on your own chart and select two or three visual checkpoints that you judge to be most suitable as fixes. Then compare your choice with the checkpoints on our chart at *Figure 12.11*. You should also check the timings that we have written on our chart, using your navigation computer, noting that the groundspeed on the second leg is 112 knots.

When you have finished the above exercise, spend a little time studying the marked-up chart at *Figure 12.11*.

Having prepared your flight log, you should mark up your chart in order to make the task of navigating in the air as easy as possible. The chart should not, of course, have so many markings on it that it becomes cluttered, but the idea is that enough pertinent information is on the chart to minimise cockpit activity If you can navigate by only having to consult your chart, you will be cutting down cockpit paperwork to a minimum and be able to concentrate on flying, navigating and communicating without any unnecessary distraction. However, care must be taken when transferring numbers from the log during flight planning; also remember that the log must be filled in during flight with ETAs and other relevant information. Ultimately, whether you use this method of marking the chart or not is a matter of personal preference.

You will see that we have marked up our chart in the following way:

- With start point, turning points and destination circled.

- With track lines broken at the selected visual check points along the route, so as not to hide significant chart information. As discussed earlier, visual checkpoints may be chosen at $^1/_4$, $^1/_2$, $^3/_4$, $^1/_3$ and $^2/_3$ track positions to make the revision of ETAs easier, if timing updates are required. But the most important factor in choosing visual checkpoints is that they should be easily identifiable as fixes.

- With track error lines from departure and turning points, and closing angle lines to turning points and destination.

- With timing marks next to the visual checkpoints, turning points and destination.

- With the wind at your selected cruising altitude marked in a convenient position on the chart. It is also useful to mark the max drift near the wind symbol, e.g. MD7

- With the radio frequencies of all the airfields that you might wish to communicate with, and for any other airfields in the vicinity of your route, in case you need to make an unplanned diversion. Write the frequencies next to the airfield symbols on your chart.

- With a "box" for each leg, as shown in *Figure 12.12*, in which is displayed the following information:

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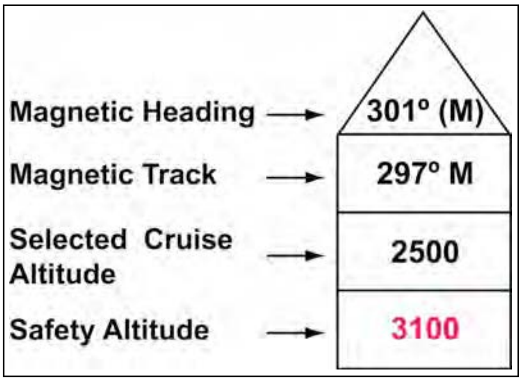

Figure 12.12 A track box, completed for the leg from Oxford Kidlington to Ludlow.

- In the top section at the box apex: the magnetic heading to be flown.
- In the second box: The magnetic track angle (magnetic bearing of the track).
- In the third box: the altitude at which you have elected to fly the leg.
- In the bottom box: the safety altitude. We have marked the safety altitude in red.

- With a fuel planning circle, as depicted in *Figure 12.13*. The top half of the circle contains your planned fuel remaining at turning points. The bottom half of the box is the fuel required to complete the route, at turning points, and must include all contingency, diversion and holding fuel. (See below.) *Note: These fuel circles should be marked on the chart if there are no appropriate columns on your VFR Nav log.*

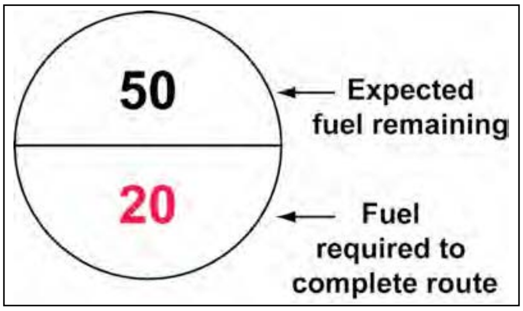

Figure 12.13 Fuel Planning Circle for the turning point at Ludlow.

The Fuel Plan.

You must carry sufficient fuel to complete your flight and to cater for contingencies such as the need to hold in the air if, for some reason, you are not able to land at the destination aerodrome, and sufficient fuel to fly to a diversion aerodrome, if necessary.

The fuel you should carry should be based on the following considerations:

- Fuel required to complete the route, including taxi and initial climb.
- Holding fuel.
- Contingency fuel to allow for stronger than expected headwinds, increased fuel consumption rate, navigational errors.
- Diversion fuel.
- A minimum fuel reserve.

The above considerations have already been discussed in Chapter 11.

For the flight to Hawarden, we will assume that your aircraft's fuel consumption rate is 10 US gallons per hour. Your total flight time to Hawarden is 59 minutes, so the amount of fuel required for the flight is 10 US gallons.

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The flight time from Hawarden to Liverpool, your elected diversion airfield, is 6 minutes which equates to 1 gallon.

It is standard practice to allow a 10% margin for contingency fuel, so that is a further 1.1 gallons.

VFR FLIGHT LOG

DATE:	T/O:		LDG:				FLT TIME:						
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LUDLOW	2500	3100	180/10	103	302	297	4W	301	108	60	33	
LUDLOW	HAWARDEN	2500	3100	180/10	103	349	348	4W	352	112	49	26	
ALTERNATE													
HAWARDEN	LIVERPOOL	2000		180/10	103	026	028	4W	032	112	10	5½	

FUEL (U.S. GALLS)	
TO DESTINATION	10
TO ALTERNATE	1
10%CONTINGENCY	1.1
45 MIN HOLDING	7.5
MINIMUM RESERVE	5
TOTAL REQUIRED	25
TOTAL ON BOARD	55
ENDURANCE	5½ hrs

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ
OX TWR	125.325	OX	367.5		
BZN RAD	124.275	HAW	340.0		
SHOB	123.50	WPL	323		
WPL	128.0				
SHB RAD	120.775				
HWD TWR	123.35				
LVP TWR	119.85				

Figure 12.14 VFR Flight Log including Fuel Planning.

The 45 minutes holding reserve will require a further 7.5 gallons. You decide that the minimum fuel reserve for landing should be 5 gallons. The total fuel required for the flight, then, is 25 gallons, so this is the very minimum fuel with which you must take off. The mass and balance calculations will guide you as to what extra fuel you may carry, over and above the useful payload of passengers and baggage.

In your flight log, always record total fuel on board and your aircraft's endurance.

Whatever fuel load you carry, it is sound airmanship to record what this represents in terms of endurance so that you know just how long you can stay in the air.

Figure 12.14 shows what the completed fuel plan should look like.

Communications Plan.

For a VFR cross-country flight, your radio communications plan should be fairly simple. Make a note in the flight log of the frequencies you are likely to use, and, also, mark the frequencies on the chart.

Radio frequencies for aerodromes can be found in the UK AIP, AD Section, under the appropriate aerodrome name. *Figure 12.15* shows the information for Hawarden. En-route, you may wish to obtain a Basic Service from London Information, and perhaps a Traffic Service from RAF Shawbury.

EGNR AD 2.18 – ATS COMMUNICATION FACILITIES

Service Designation	Callsign	Frequency (MHz)	Hours of Operation	Remarks
1	2	3	4	5
APP	Hawarden Approach	123.350	Mon-Fri 0800-1900 (Winter). Mon-Fri 0700-1800 (Summer).	ATZ hours coincident with APP hours. On request Sat, Sun.
TWR	Hawarden Tower	124.950	Mon-Fri 0800-1900; Sat, Sun 0930-1600 (Winter). Mon-Fri 0700-1800; Sat, Sun 0830-1500 (Summer).	ATZ hours coincident with TWR Sat, Sun hours.
RAD	Hawarden Radar	130.250	As above.	On request Sat, Sun.

Figure 12.15 Hawarden Airfield Information.

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There is also a list of aerodrome and airfield frequencies in one of the information boxes on the 1:500 000 chart. This box also indicates whether the air traffic service at an aerodrome is full air traffic control, an airfield flight information service or simply an air-ground radio service. On recent editions of the chart, airfield frequencies have also been included on a separate card.

You should enter in your flight log, and mark on your chart, all the radio frequencies that you think you may need. Note that the radio frequency of your alternate aerodrome, Liverpool, should also be included. You may, of course, also wish to use the NDB at Hawarden to help you with your visual navigation on the second leg, so note that frequency, too.

Radio and radio-navigation frequencies relevant to the planned flight from Oxford to Hawarden are shown in the flight log at *Figure 12.14*.

Mass & Balance and Aircraft Performance Calculations.

It is a requirement in law, as well as being good airmanship, always to complete mass and balance calculations to ensure that you are not exceeding weight limitations, and that the aircraft's Centre of Gravity is within the prescribed limits. If you are unsure how to do this, refer to the section on Mass and Balance in Volume 5 of this series, entitled 'Aeroplanes'.

You must also confirm by calculation that your aircraft is able safely to take-off and land at your start and destination aerodromes. If you are unsure how to do this, refer to the section on **Aircraft Performance**, in **Volume 6** of this series, entitled **Principles of Flight**.

The VFR Flight Plan.

The subject of VFR flight plans is covered in detail in the Air Law volume of this series of training manuals. Here we will confine ourselves to summarising the topic very briefly. The flight plan is an air traffic message in a set format which is transmitted to the appropriate Air Traffic Service Units (ATSU) which may be concerned with the flight in question. A pilot may file a flight plan for any flight, though for visual navigation flights, outside controlled airspace, flight plans are not usually required.

If you do not submit a flight plan, you must contact the ATSU or operations agency at your departure aerodrome before commencing your flight. This action is called "booking out".

For flights made in accordance with VFR in the United Kingdom, flight plans <u>must</u> be submitted on the following occasions:

- For a flight from, or back to, the United Kingdom which will cross the United Kingdom FIR boundary. (NB: A flight plan need not be filed for a flight which crosses the London/Scottish FIR Boundary.)

- For all flights in controlled airspace of Classes B, C and D.

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Notes on ***Classes A, B, C, and D controlled airspace****:*

1. *VFR flight is not permitted in Class A airspace.*
2. *There is currently no Class B airspace in the UK.*
3. *All airspace at and above Flight Level 195 is Class C airspace.*
4. *The class of controlled airspace which will mostly concern VFR pilots is Class D airspace. Most Control Zones and Control Areas in the UK are Class D airspace. The requirement to submit a flight plan for flights within or across Class D airspace may be satisfied by passing flight details by radio to the responsible ATCU, in order to obtain a clearance to enter the airspace.*

- any flight from an aerodrome in the United Kingdom, being a flight whose destination is more than 40 km from the aerodrome of departure, and where the aircraft Maximum Total Weight Authorised exceeds 5700 kg.

- any flight in Class F Airspace, wishing to participate in the Air Traffic Advisory Service.

It is advisable to file a VFR flight plan when:

- intending to fly out to sea more than 10 nautical miles from the UK coastline.

- Intending to fly over sparsely populated areas where Search and Rescue operations might be difficult.

Remember, however, that a VFR flight plan may be filed for any flight, if the pilot-in-command so wishes.

An example of a completed flight plan is shown at *Figure 12.16 (overleaf)*. Instructions on how to complete and submit a flight plan are contained in the appropriate Aeronautical Information Circular, and in Chapter 15 of Volume 1, Air Law.

Remember, that when wishing to enter or transit certain control zones (CTRs), an abbreviated flight plan may be submitted over the radio, whilst airborne. (See Volume 1, Air Law, Chapter 15, and Volume 7, RT Communications.)

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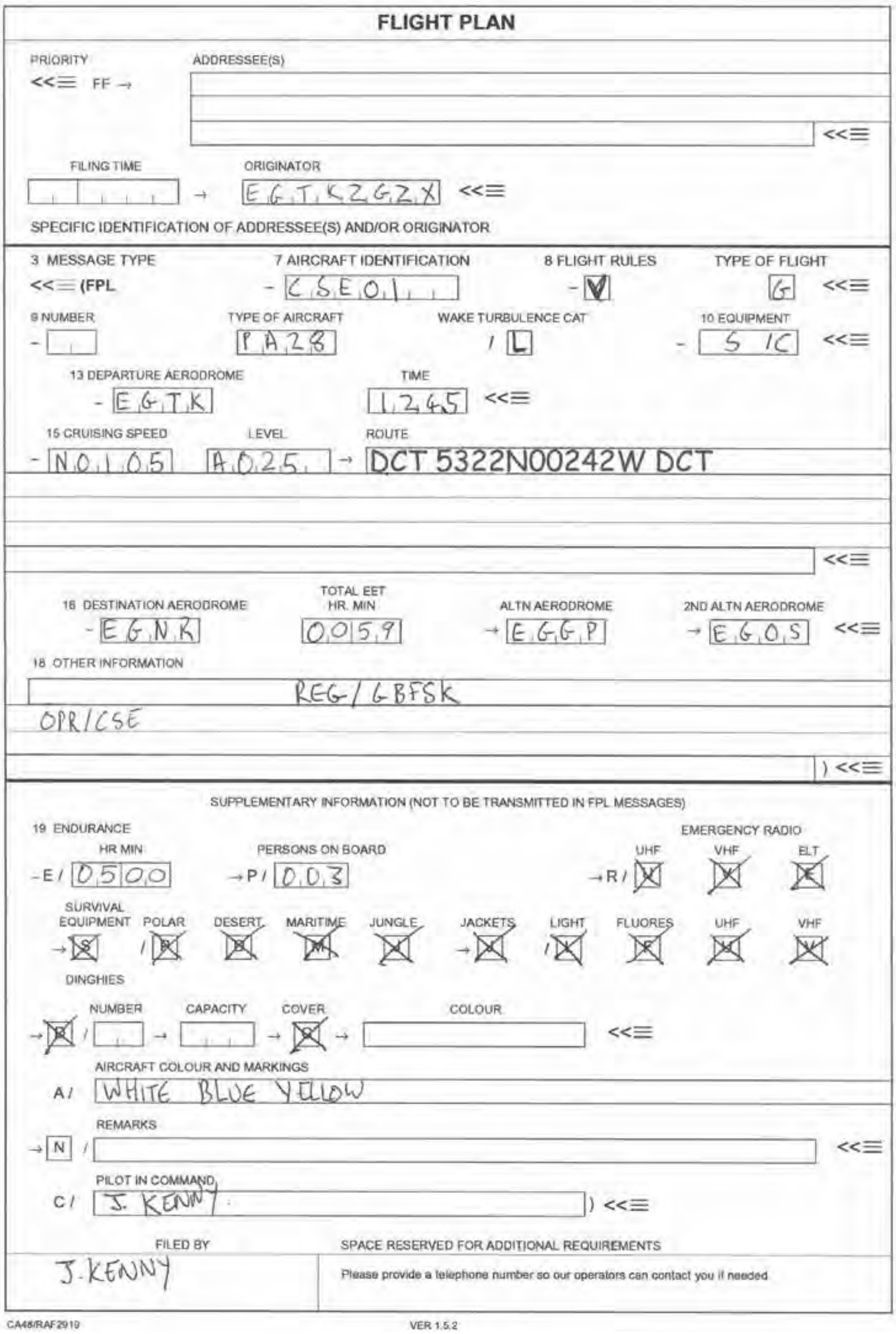
FLIGHT PLAN

PRIORITY <<≡ FF → ADDRESSEE(S) <<≡

FILING TIME → ORIGINATOR EGTKZGZX <<≡

SPECIFIC IDENTIFICATION OF ADDRESSEE(S) AND/OR ORIGINATOR

3 MESSAGE TYPE <<≡ (FPL — 7 AIRCRAFT IDENTIFICATION - CSEO1 — 8 FLIGHT RULES - V — TYPE OF FLIGHT G <<≡

9 NUMBER - — TYPE OF AIRCRAFT PA28 — WAKE TURBULENCE CAT / L — 10 EQUIPMENT - S / C <<≡

13 DEPARTURE AERODROME - EGTK — TIME 1245 <<≡

15 CRUISING SPEED - N0105 — LEVEL A025 — ROUTE → DCT 5322N00242W DCT

<<≡

16 DESTINATION AERODROME - EGNK — TOTAL EET HR. MIN 0059 — ALTN AERODROME → EGGP — 2ND ALTN AERODROME → EGOS <<≡

18 OTHER INFORMATION REG/GBFSK
OPR/CSE
) <<≡

SUPPLEMENTARY INFORMATION (NOT TO BE TRANSMITTED IN FPL MESSAGES)

19 ENDURANCE HR MIN -E/ 0500 — PERSONS ON BOARD →P/ 003 — EMERGENCY RADIO →R/ UHF VHF ELT

SURVIVAL EQUIPMENT → S / POLAR P DESERT D MARITIME M JUNGLE J — JACKETS → J / LIGHT L FLUORES F UHF U VHF V

DINGHIES → D / NUMBER → CAPACITY → COVER C → COLOUR <<≡

AIRCRAFT COLOUR AND MARKINGS A/ WHITE BLUE YELLOW

REMARKS → N / <<≡

PILOT IN COMMAND C/ J. KENNY) <<≡

FILED BY J. KENNY — SPACE RESERVED FOR ADDITIONAL REQUIREMENTS: Please provide a telephone number so our operators can contact you if needed

CA48/RAF2919 — VER 1.5.2

Figure 12.16 A completed Flight Plan.

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Representative PPL - type questions to test your theoretical knowledge of Flight Planning.

The following task is based on a visual navigation flight that you are planning to make from Welshpool (EGCW) to Hawarden (EGNR) and return. You plan to make Shawbury your en-route alternate.

Carry out the necessary planning for the intended flight, based on the tasks listed below, and check your answers against the completed Flight Log on Page 230.

You plan to fly at 3000 feet. You obtain wind information by accessing Met Office Form 214, (The Spot Wind Chart), on the Met Office web site. The box relevant to the area in which your flight will take place is reproduced below

5230N 0230W			
24	340	35	-28
18	335	35	-15
10	335	30	-10
05	275	20	00
02	260	05	+06
01	255	05	+09

The Regional Pressure Setting for the area of your planned flight is 1013 millibars

You have elected to fly the route at an Indicated Airspeed of 100kts

Your aircraft consumes fuel at a rate of 10 US gallons per hour

Draw your planned route on your own ICAO 1:500 000 chart of Southern England and Wales, choosing suitable en-route visual check points; then carry on with your flight planning, to include a diversion route from Hawarden to Shawbury, for the return leg.

1. Interpolate the data from the Spot Wind Chart box, in order to extract the wind speed and direction, and outside air temperature, for 3000 feet, and use that information to complete your Flight Log. Compare the values with the solution, given on Page 230, in order to calculate your headings and true airspeed.

2. Measure the true track angle of your desired tracks.

3. Measure the distance of each leg.

4. Identify a suitable visual check point along your desired track.

5. Choose a safety altitude.

6. Identify appropriate frequencies of aerodromes adjacent to your route, including the most relevant radio navigation aids.

7. Calculate your True Airspeed at 3000 feet.

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8. Calculate the True Heading for each leg.

9. Calculate the Magnetic Heading for each leg. (Assume a local Magnetic Variation of 4° West.)

10. Calculate the groundspeed for each leg.

11. Calculate the leg times.

12. Calculate times at your visual check point, from both Welshpool and Hawarden.

13. Calculate the fuel required for each leg and consider Contingency Fuel, Holding Fuel and Minimum (landing) Reserve Fuel requirements. (All fuel requirements should be rounded up to the nearest whole US gallon.)

The solutions to these tasks are on Page 230.

FLIGHT LOG FOR THE ROUTE FROM WELSHPOOL TO HAWARDEN AND RETURN

DATE:	T/O:			LDG:				FLT TIME:					
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
WELSHPOOL	HAWARDEN	3000	4100	265/10	103	011	006	4W	010	106	33 ½	19	
HAWARDEN	WELSHPOOL	3000	4100	265/10	103	191	196	4W	200	100	33 ½	20	
ALTERNATE													
HAWARDEN	SHAWBURY	3000	3100	265/10	103	154	159	4W	163	107	25	14	

FUEL	
TO DESTINATION	7
TO ALTERNATE	3
10%CONTINGENCY	1
45 MIN HOLDING	8
MINIMUM RESERVE	5
TOTAL REQUIRED	24
TOTAL ON BOARD	40
ENDURANCE	4 HRS

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ
WELSHPOOL	128.0				
		WPL NDB	323	WELSHPOOL DME	115.95
HAWARDEN	123.35				
		HAWARDEN VDF	123.35	HAWARDEN DME	110.35
SHAWBURY	120.775				
		HAW NDB	340	SHAWBURY VOR/DME	116.8
L'POOL	119.85				

Answer to Task 1: Wind at 3 000 feet: 265º/10 knots; Outside Air Temperature at 3 000 feet: +4ºC.

Answer to Task 3: **Identify suitable visual check points along your desired track**. As, at the calculated groundspeed of 103 knots, you will require no more than 20 minutes to fly each leg, you need only one visual check point, close to the mid track position. The railway line passing through the small town of Chirk would serve this purpose. Chirk is 19 miles from Welshpool which is just over midway, on the northerly route. The town is 14½ miles from Hawarden. There is also a Roman aqueduct in Chirk which would be a unique ground feature, and, therefore, excellent for a ground fix.

Answer to Task 11: On the northerly leg, at a calculated ground speed of 106 knots, you should reach Chirk 11 minutes after leaving overhead Welshpool. On the return leg, at a calculated groundspeed of 100 knots, you would reach Chirk just under 9 minutes after setting course from Hawarden.

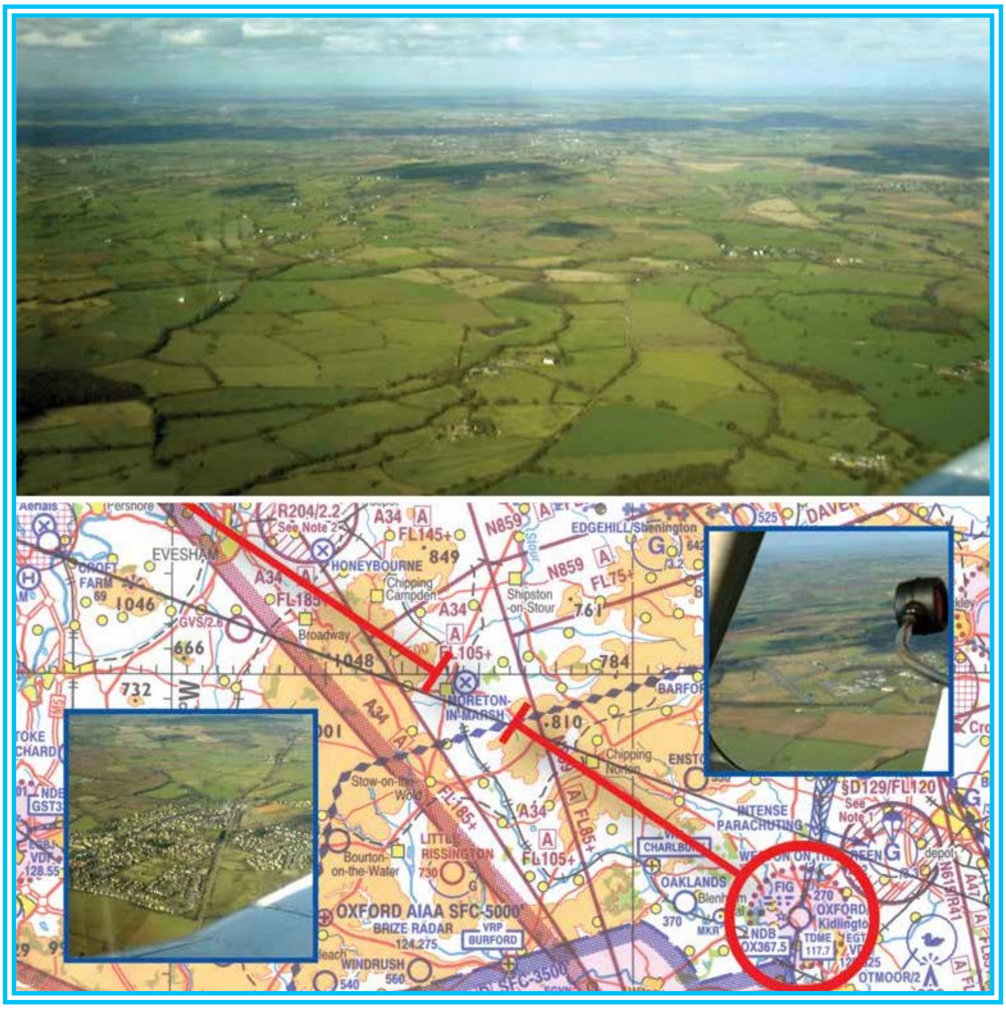
VFR FLIGHT LOG

DATE:	T/O:			LDG:			FLT TIME:							
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA	

FUEL	
TO DESTINATION	
TO ALTERNATE	
10%CONTINGENCY	
45 MIN HOLDING	
MINIMUM RESERVE	
TOTAL REQUIRED	
TOTAL ON BOARD	
ENDURANCE	

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ

CHAPTER 13
PRACTICAL NAVIGATION



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NAVIGATION AROUND THE ROUTE.

In this chapter, we examine how you would navigate around the route for which you have just completed the flight planning. If you have not done so already, mark up your own 1:500 000 chart for the route along the lines of the teaching given in the previous chapter, and consult it when appropriate as you work your way through the chapter.

Before going out to your aircraft, you should check that you have all the navigation and personal equipment that you require for the flight:

- Your marked-up chart and relevant airfield maps.
- The flight log.
- Pen/pencil or chinagraph, protractor, ruler and navigation computer.
- Stopwatch and chronometer displaying accurate time.
- Checklists for your aircraft.
- Headset for yourself and any passengers.
- Any other personal items you may require.

In the aircraft, check the compass deviation card to see if there are any corrections to be applied to your planned magnetic headings in order to obtain a compass heading.

DEPARTURE PROCEDURES.

After take-off, there are two commonly used departure procedures for setting heading. You should decide which of these departure procedures you are going to use, during the flight planning stage.

Overhead Departure.

The overhead departure is a sound and reliable procedure to use, especially on your early cross country flights. The overhead departure technique involves climbing to the planned altitude and then setting heading from directly overhead the airfield, as shown in *Figure 13.1a*.

When using this procedure, you must ensure that when you arrive overhead the airfield you are at your planned altitude, on the correct heading and at the correct speed. You should start your stopwatch as you pass overhead the airfield.

You should already be on heading as you make your run-in to the airfield overhead, and choose a lead out feature on track to confirm that your heading is correct. By ensuring that you are tracking to the lead out feature, any inaccuracy in the forecast wind and, as a consequence of that, in your calculated compass heading can be established at the very beginning of the first leg.

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Using the overhead departure procedure, ensure that as you arrive overhead the airfield, you are on speed, on heading and at the correct altitude.

If possible, choose a lead-out feature which is prominently visible and on your planned track. The lead-out feature can reveal, at the very beginning of the first leg, whether the forecast wind and your calculated compass heading are correct.

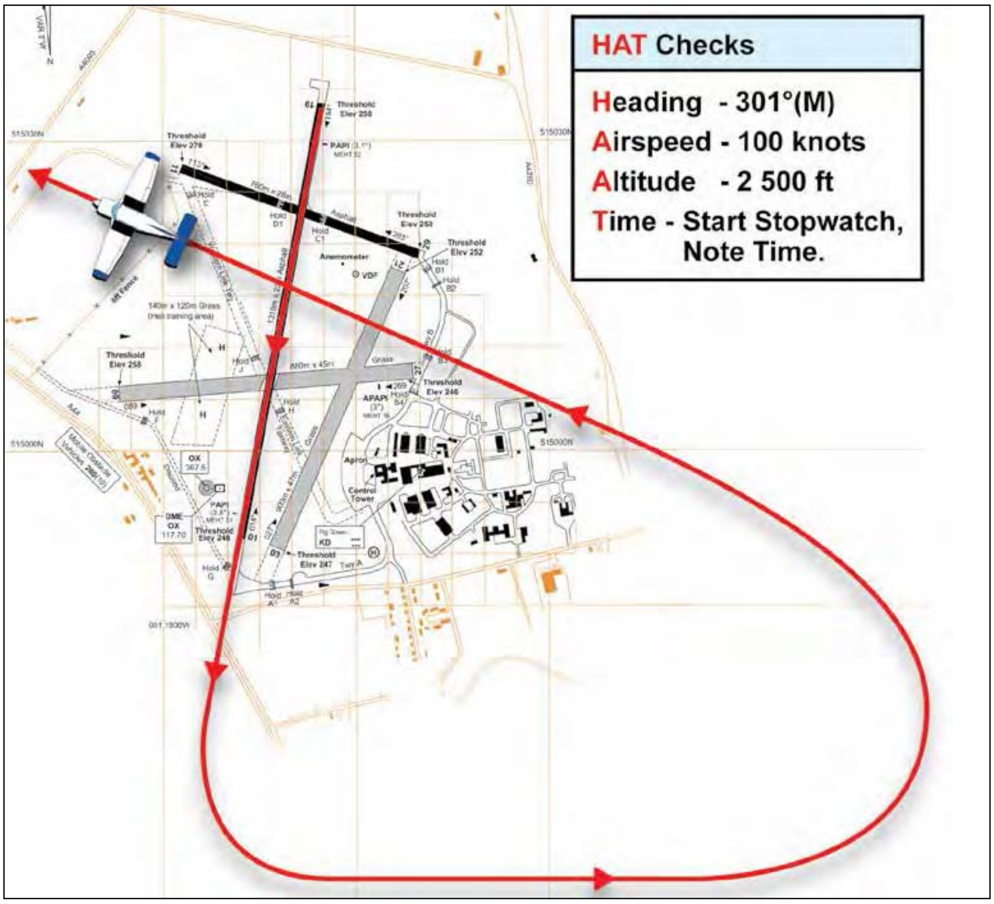

Figure 13.1a Overhead Departure.

A good check to follow before you set off on track is a check frequently used in the Royal Air Force called the HAT check.

H **HEADING** to fly, and that compass and DI are synchronised.
A **AIRSPEED** - **ALTITUDE** - Check that you are at your planned airspeed, and at your planned altitude on the correct **altimeter** setting.
T **TIME** - Zero your stopwatch; when overhead the start or turning point, turn onto heading and start the timer.

When steady on heading, repeat HAT, this time checking:

H Check **heading** correct as per log, and check feature(s) in correct relative positions (gross error check).
A Check **altitude and airspeed** correct.
T Check **timer** is running, work back to find leg start time and log it. Note time for next event.

Always carry out your HAT checks at the start of your route, at each turning point, and regularly throughout the flight.

The overhead departure technique may also be adopted with respect to a remote starting point from above a prominent ground feature, in the vicinity of your aerodrome. If you use a remote starting point, the track line on your chart will, of course, have to originate from that point.

En-Route Departure.

The en-route departure is slightly more complicated than the overhead departure but it gets you on track and clear of the airfield more quickly. *(See Figure 13.1b.)*

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Using the en-route departure technique, the angle at which you intercept the outbound track should not be too great; an angle of between 30º and 45º is normally appropriate. Intercept the outbound track visually by looking back to your departure airfield, carry out first HAT check and then turn on to your first heading when you estimate you are on track. After turning on track, carry out your second HAT check. Your stopwatch will need to be started at an appropriate position, as you leave the aerodrome circuit. If your cruise altitude is more than a few thousand feet AGL, it might be worth a cruise climb to ensure your speed is more closely matched with your cruise speed.

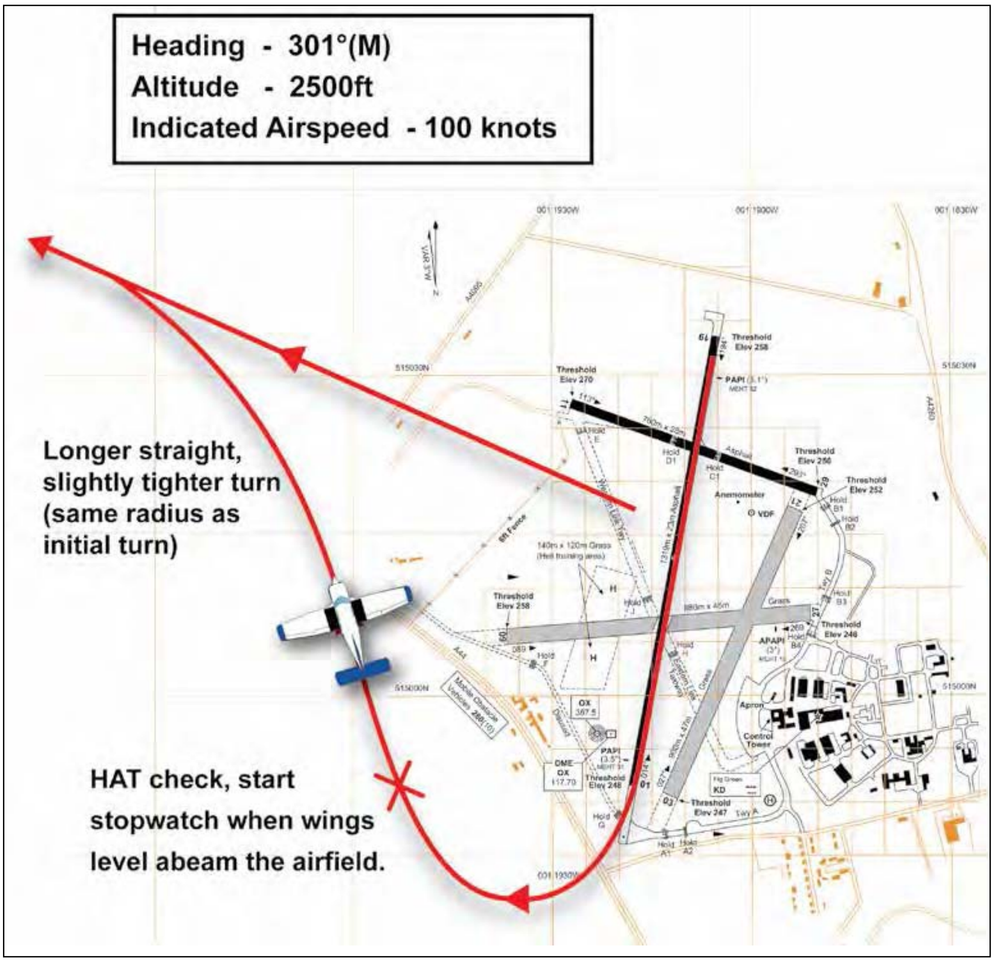

Figure 13.1b En Route Departure.

EN-ROUTE.

Once en-route, and on-track, it is vitally important that you fly your pre-planned heading, altitude and speed as accurately as you can.

By flying an accurate heading and airspeed, you will stand a very good chance of arriving at your next checkpoint, turning point, or destination, on time and on track, provided the wind forecast is accurate.

If your heading and airspeed are not accurately maintained, no matter how carefully you have planned, you will soon get off track, your timing will become inaccurate and you may well end up getting lost. Your priorities on your flight must be: Aviate, Navigate, Communicate, in that order.

The key to accurate navigation is holding your heading and airspeed accurately.

Carry out airborne taskswith the following priorities

1. AVIATE
2. NAVIGATE
3. COMMUNICATE

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The normal work cycle in all phases of flight is:

L - Lookout
A - Attitude
I - Instruments

Regular en-route checks.

F - Fuel
R - Radio
E - Engine
D - DI
A - Altimeter Setting

Once you have settled down on track, look at your chart to remind yourself of the next event en-route, such as radio frequency change, radio calls, time at next checkpoint, then put your chart away and concentrate on flying accurately.

While continuing to fly accurately, the normal work cycle is given by the acronym **LAI - Lookout - Attitude - Instruments**. During the instrument scan, include the aircraft's clock or stopwatch so that you are aware of when the next checkpoint is due. You will need to look at your chart again about 2 minutes before the checkpoint is due to appear. Another thing to consider while maintaining your heading, speed and altitude is the necessity to carry out regular **FREDA checks**. **FREDA checks** are covered in **Chapter 3.**

The **R** part of the **FREDA check** reminds you to confirm that you have the correct radio frequency. Once established en-route, you should consider changing to the London Information frequency, or perhaps to the Birmingham frequency, to request a Basic Service. Either of these stations will give you the Regional Pressure Setting which you will select on the altimeter sub-scale. That should take care of the **A** part of the **FREDA** check, too.

Other actions to carry out at this early stage on the first leg are:

- Having noted the time of departure from overhead Oxford Kidlington, enter your ETA at Ludlow in the flight log.

- Carry out a gross error check to confirm that you are on track. There should be a railway line lying to port, and you might expect to see the airfield at Enstone, to starboard. *(See Figure 13.2.)*

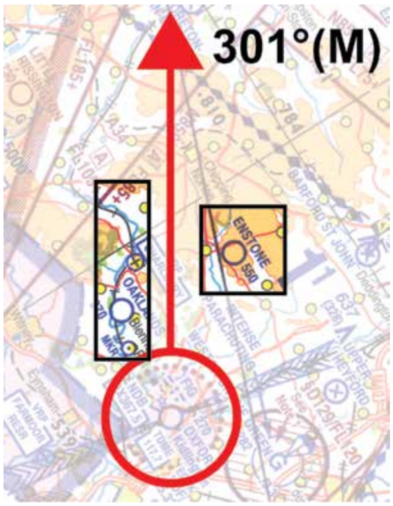

Figure 13.2. Check that you are on track.

Your chart should be put away at this point. You will be aware of the positions of the railway line and Enstone Airfield, from the study of the route that you made, during flight planning:

First Check Point.

According to your plan, it should take you 9 minutes to get to your first check point at Moreton-in-Marsh, so, after 7 minutes, take out your chart and look for the checkpoint. Map read from chart to ground and from "big picture" to "little picture". From the chart, you can see that there are two major features to look for – the disused airfield to the North East of the town, and the railway line running roughly North to South *(See Figure 13.3)*. These two features together will positively confirm the checkpoint.

If On Or Nearly On Track.

If you see the town of Moreton-in-Marsh directly ahead of you, then you are on track, the calculated heading is good and the wind forecast will have been fairly accurate. However, you must note the elapsed time at which you over-fly Moreton, and if the elapsed time is not as calculated, you will need to update your estimated time of arrival (ETA) at the next checkpoint at Worcester, and at Ludlow, the turning point.

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Figure 13.3. The first checkpoint: the disused airfield at Moreton-in-Marsh, and the railway line passing through the town.

If Moreton-in-Marsh is ahead but very slightly to the left or right of your track made good, then there is a small track error which could have been caused either by inaccurate flying or because of a slightly different wind than that forecast. If you suspect that your flying has not been as accurate as it could have been, fly towards the fix and, when over it, note the time, revise ETAs, and resume the originally calculated heading of 301° Magnetic. If, however, you feel that your flying has been accurate, estimate from your drift lines the drift which must have caused the small track error, fly towards Moreton and, when over the town, adjust your heading appropriately. If your estimated drift is, say, 2° to port, when overhead Moreton, you would adjust heading 2° starboard to 303°(M) and continue en-route. Of course, when overhead Moreton-in-Marsh you would check the elapsed time and, if necessary, revise your ETAs.

As you continue en-route, do not forget your FREDA checks at the appropriate intervals. The Direction Indicator (DI) needs resynchronising with the compass every 15 minutes or so. You should note well that, in visual navigation, headings are not maintained by sole reference to the DI or compass. Having confirmed that you have the desired heading, and are on track, look well ahead and select an appropriately prominent feature towards the horizon as a heading reference point and fly towards that feature.

If there is Significant Track Error.

If, when you get to Moreton-in-Marsh, you find that there is a significant track error, it would not be sensible to make a large change in heading to overfly the town. Such an action would compound the timing errors. If this situation arises, there are two methods of determining a new heading in order to regain track or to fly directly to your turning point or destination: These standard track-correction methods are known as the double track error method and the closing angle method. The double track error method is a suitable method to use when you are still less than half way along the leg, so we will look at the double track error method first. Let us assume that when you positively identify Moreton-in-Marsh, you see that you are to the North of the disused airfield. *(See Figure 13.4.)*

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Figure 13.4 Use the Drift Lines to determine Track Error. Here the Track Error is about 5°.

You observe that the calculated elapsed time is correct and that, therefore, there is no need at present to revise your ETA for Ludlow. Having decided that you will use the double track error method to regain track, you set about estimating your track error. There are two ways of doing this. You can either refer to the drift lines on your chart or use the 1 in 60 Rule which is taught on the CD-ROM.

- **Use of Drift Lines.** The drift lines which you drew on your map during flight planning will help you estimate your track error. This has the advantage of not requiring any mental arithmetic; you estimate the angle by observation. In this case the drift lines indicate that you are 5° right of track.

- **The 1-in-60 Rule.** The 1-in-60 Rule is taught on the CD-ROM. This rule provides you with a simple mental arithmetic method of estimating angles in order to correct your heading. As *Figure 13.5* shows, for a distance of 60 miles, each mile off track subtends an angle of 1º. For example, if you are one mile off track after travelling 15 miles this is the same as being 4 miles off, at 60 miles, so the track error is 4º.

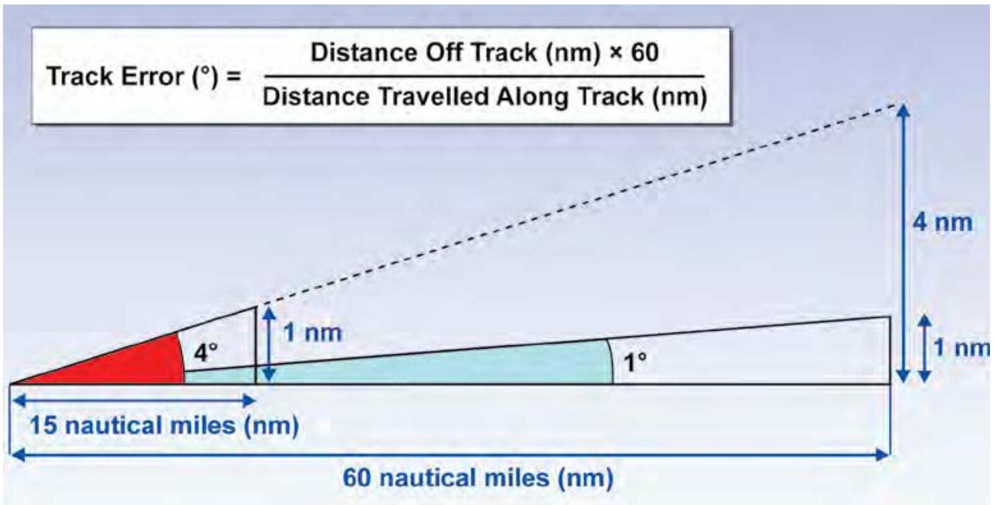

Figure 13.5 The 1-in-60 Rule.

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Looking again at the chart, we will assume that you estimate your position as 1½ miles right of track and that you have flown 17 miles. The 1-in-60 Rule, taught on the CD-ROM and summarised in *Figure 13.5*, indicates that you are about 5º off track.

$$\textbf{Track Error} = \frac{1\frac{1}{2} \times 60}{17} = 5^\circ \textbf{ approximately}$$

Double Track Error Method.

Having estimated your track error, you now have to determine by how much and for how long you need to alter heading, to regain track. If you were to alter your heading by 5°, you would be flying parallel to your desired track. However, doubling the track error and turning left by 10° will take you back towards your desired track. Let us examine how this works out.

The double track error method is suitable for regaining track up to the half way point on a route or leg.

Alter heading left from 301º to 291º, Note the time at which you make the heading change. You notice from your stopwatch that 10 minutes have elapsed since you set heading from overhead Oxford Kidlington.

Maintain the new heading of 291º for a further 10 minutes. Doing this will bring you back onto your desired track. Assuming that the original track error was the result of an innacurate wind forecast, you will not wish simply to resume your original heading of 301°(M). If the drift at your current airspeed is 5° to starboard, your original track error, you must lay off this drift, now that you are back on track, by altering your original heading 5° to port. Consequently, once back on your desired track, you steer 296°(M) in order to stay on track.

When back on track, adjust your original heading to offset the drift which caused the track error, in order to stay on track.

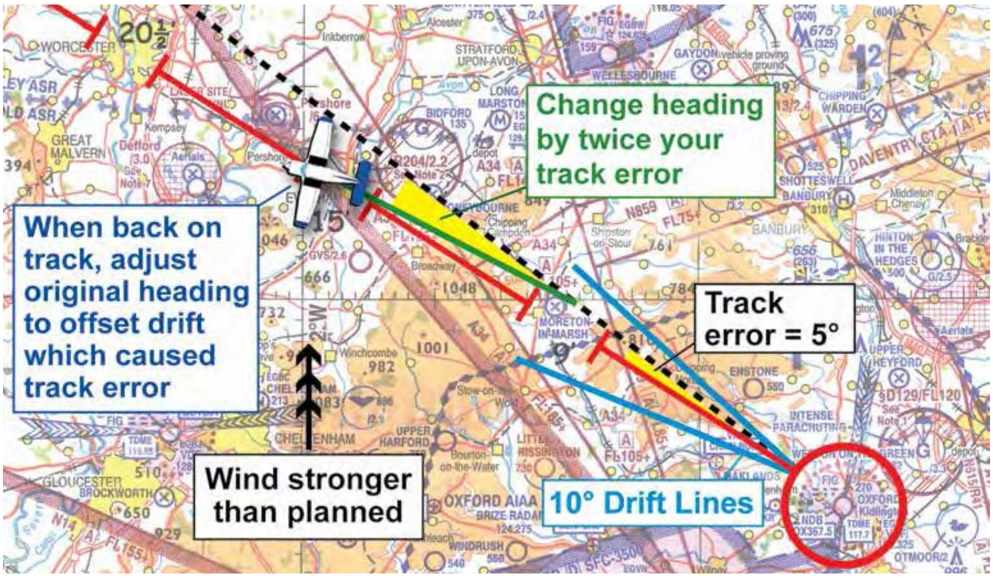

Figure 13.6 Using the Double Track Error Method to Regain Track. Change heading by twice the value of the track error and fly that heading for a time equal to the time lapse at which the error was discovered.

The double track error method of regaining track is a suitable method to use to regain track up to the halfway point. Beyond that point, you should use an adaption of the double track method which we will examine shortly.

It should be easy to see that if a track-error correction using the double track error method were made exactly at the halfway point on a cross-country leg, the double-track error correction should take you directly to your turning point or destination.

Revision of ETA.

If the actual wind is different from the forecast wind, it is reasonable to assume that your achieved groundspeed will be different from your calculated groundspeed. Therefore, you should pay particular attention to the elapsed time at the next checkpoint to see if this is so.

We will continue to assume that you may have ended up 5° right of track at Moreton-in-Marsh because the wind velocity was greater than forecast. If the wind was stronger, but its direction of 180°(T) was as forecast, you will also have a greater tailwind component than the one you have calculated, making your groundspeed higher than calculated, too.

We will assume then that instead of arriving at Evesham (your second checkpoint) after 15 min, as planned, you arrive there after an elapsed time of 14 minutes. Now, Evesham is 28 miles along a track of 60 miles which is close to half way to your turning point at Ludlow. Therefore, if you are 1 minute early at the halfway point you will be 2 mins early at Ludlow.

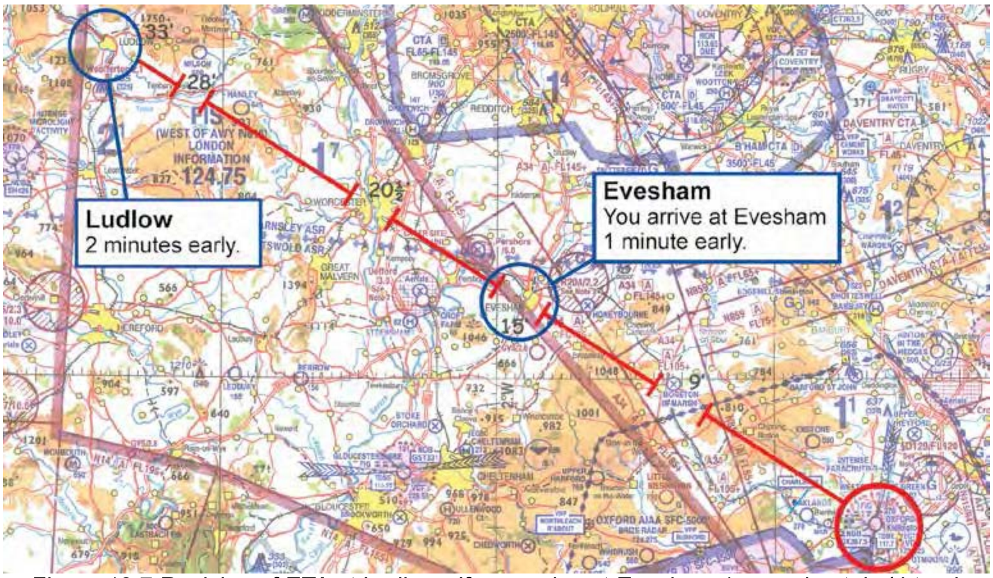

Figure 13.7 Revision of ETA at Ludlow. If you arrive at Evesham (approximately ½ track length) one minute early, you will be two minutes early at Ludlow.

Track Error Correction after Halfway Point.

We will now examine how you would calculate an appropriate heading alteration if you were to find yourself off-track after the halfway point on your leg to Ludlow, assuming no corrections have been made since departure.

Let us assume that as you approach Worcester you find that you pass over the motorway junction to the North-East of the city rather than the junction to the South-East which lies on your planned track. *(See Figure 13.8.)* The two motorway junctions look very similar from the air so you take particular care to confirm that you are in fact approaching the junction to the North-East of Worcester.

Being only 12nm from your turning point at Ludlow, you are well beyond half way on your first leg. You cannot sensibly, therefore, use the double track error method to regain track. You need a method of track error correction which will take you directly to Ludlow. In your current situation, then, you need to estimate your track

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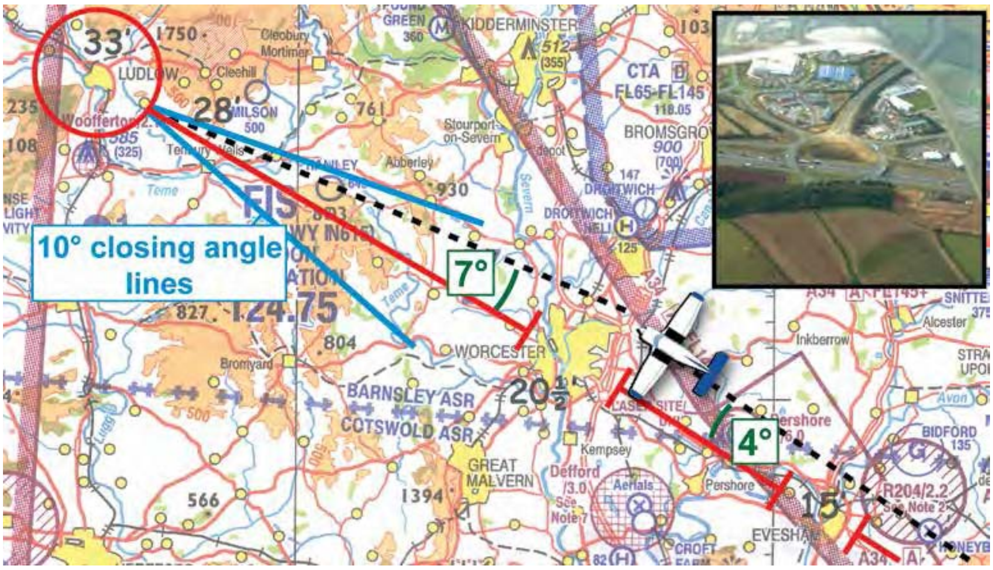

Figure 13.8 Calculating Track Error and Heading Correction to fly directly to Ludlow from a position North of track, at Worcester.

error with respect both to your starting point at Oxford Kidlington and to your turning point at Ludlow, and add both errors together in order to obtain the required heading correction.

This is how you proceed:

- From your chart and by direct observation you estimate your distance off-track to be 3 nautical miles(nm).
- From your chart, with the help of the drift lines originating from Ludlow, you estimate the track error with respect to Ludlow to be 7°.
- From the 1 in 60 rule (See CD-ROM), either using your navigation computer or carrying out a mental calculation, you estimate your track error with respect to Oxford Kidlington to be 4°.

  You know that Worcester is about 40 nm from Oxford Kidlington, so if you are 3 miles off track after 40 miles:

$$\textbf{Track Error} = 3 \times \frac{60}{40} = \textbf{4.5°, which we will call 4°.}$$

Changing heading by 4° to port would cause you to parallel your original planned track. Changing heading by a further 7° to port will take you direct to Ludlow.

You elect, therefore, to change heading 11° to port and to head directly to Ludlow. If you were still on your original heading of 301°(M), your revised heading for Ludlow would be 290°(M).

Do not forget to check the actual elapsed time at Worcester and, if it is different from the calculated elapsed time, update your ETA at Ludlow.

Carry out **HAT** and **FREDA** checks.

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Approaching Ludlow.

For the approach to your turning point at Ludlow, we will assume that there have been no track or timing errors and that you are approaching the turning point on track and on time. At 28 minutes, then, over Tenbury Wells, you take out your chart. Remember, you map read from chart to ground, and from big picture to little picture.

When map reading, read from chart to ground, and from "big picture" to "little picture".

Ludlow should be easy to spot as it is a sizeable town, on its own, surrounded by high ground. That is the big picture.

The chart shows a ring road to the East of Ludlow which looks quite distinctive. Also there is a spot height of 1750 feet to the North-East and a 585 foot mast to the South. However, masts are notoriously difficult to see even in good visibility. A river skirts the town around its South-West edge and a railway line passes through the town. These latter features constitute the little picture.

At the start of each leg, and at checkpoints, carry out the HAT checks.

H - On Heading?

A - On Airspeed?
- At Altitude?

T - On Time?

Arriving at the turning point, Ludlow.

When you are overhead the town, the curve of the ring road, the path of the river and the general layout of the town should confirm that it is Ludlow.

Now, carry out the pre-HAT checks, turn and start the stopwatch, and carry out the post-HAT checks as described earlier.

Note on the flight log the actual time of arrival (ATA) at Ludlow, and work out the ETA at Hawarden.

COMMUNICATIONS.

Radio communications on a visual navigation flight which remains outside controlled airspace are normally straightforward and uncomplicated.

For this particular route, you would probably stay on the Oxford approach frequency until you were, say, 10 miles from Oxford, then change to the London Information Frequency of 124.75 MHz for a Basic Service. Note that the London Information Frequency is printed on your chart in various positions, one of which is just to the South-East of Ludlow.

Basic information on the Basic Service is at Annex 1 to this book . You will learn about the Traffic Service in Chapter 19.

You might choose to continue receiving a Basic Service from London Information until you were established on the second leg, when it might be prudent to call Shawbury for a Traffic Service or a Basic Service.

Finally, when you are about 15 nm from Hawarden, you would change to the Hawarden approach frequency to advise them of your arrival and to obtain the relevant airfield information.

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THE SECOND LEG: LUDLOW TO HAWARDEN.

Once established on the second leg of the flight to Hawarden, with HAT checks complete, and having also carried out a further, regular FREDA check, you concentrate on flying an accurate heading and airspeed. Having carefully studied your route during the flight planning stage, and just having put your chart away following your arrival at Ludlow, you do not need to consult your chart to confirm that you have high ground around the Long Mynd on your port side *(see Figure 13.9)*, and that you will soon be approaching the town of Church Stretton, also on your left. These observations constitute the big picture confirmation, or gross error check, that you should make as you begin each new leg. You should arrive at Church Stretton about 2 minutes before your first checkpoint at the road-bridge over the railway line, South-West of the disused airfield at Condover.

At the start of each new leg, carry out a gross error (big picture) check to confirm that you are heading in the planned direction.

Figure 13.9. Early on the second leg, you note the high ground around the Long Mynd to the left of track.

A Missed Checkpoint.

You realise that the road bridge over the railway line is going to be a difficult ground feature to spot, and you suspect that, for that reason, you may have been mistaken in choosing it. Nevertheless, you are expecting to over-fly it, 8 minutes out from Ludlow. So, after 6 minutes you take out your chart to remind yourself of the ground features running up to the checkpoint, and begin looking for it.

Figure 13.10. Checkpoints which are not distinctive or prominent enough may be very difficult to spot.

Do not choose as checkpoints ground features which are not distinctive enough to spot easily.

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If you fail to spot a checkpoint but have no reason to doubt your flying accuracy, maintain heading, speed and altitude, and note the time at which the next checkpoint is due to appear.

The 8 minutes elapsed time interval approaches and passes, but there is no sign of the bridge. You feel sure it is there somewhere, but you just cannot see it. Perhaps you are slightly to the right of track and it is underneath you. You look out to the right to try to spot Condover airfield but you do not see that either.

You have no reason to doubt your flying accuracy, or the forecast wind, and so, quite correctly, you decide to ignore that checkpoint and continue to fly the aircraft accurately towards the next checkpoint, maintaining heading and airspeed. For the time being you must assume that you are on track.

Re-establishing Your Position.

Almost immediately, you see Shrewsbury in front of you just to the right of the track you are making, so you know that you are very close to your planned track. With your next checkpoint of the disused airfield at Montford Bridge only 3 minutes away, you continue concentrating on accurate flying and, after a further minute, take out your chart and begin looking ahead for Montford Bridge airfield which, you see, lies just beyond a loop in a river.

After a very short period of looking, you see the distinctive runway pattern of the disused airfield of Montford Bridge ahead of you, beyond a river. *(See Figure 13.11.)*

Figure 13.11. The runway pattern of the disused airfield of Montford Bridge, ahead of you, beyond a river, confirms that you are exactly on track.

So, despite having missed a checkpoint, you have continued to hold your heading and airspeed and have been able to confirm that you are, in fact, exactly on track.

To be able accurately to maintain heading and airspeed is an essential skill of the pilot-navigator.

To be able accurately to maintain heading and airspeed is an essential skill of the pilot-navigator. If you can master that skill, and if your pre-flight planning is thorough and comprehensive, following the teaching of the previous chapters, you will find that mental dead reckoning (MDR) visual navigation techniques can be very accurate. Using MDR techniques you should, given a good wind forecast, be able to maintain track, or be able quickly to determine your track error and take appropriate remedial action to put yourself back on track, or to fly directly to your next turning point, or your destination.

If you were early or late at Montford Bridge, you could easily revise your ETA at Hawarden. At 23 nautical miles from Ludlow, Montford Bridge is just about half way to Hawarden, so any elapsed time error at Montford Bridge merely needs to be doubled to obtain a revised ETA for Hawarden. If you were one minute late at Montford Bridge, you would be 2 minutes late at Hawarden. If you were 2 minutes early at Montford Bridge, you would be 4 minutes early at Hawarden, and so on.

Furthermore, because Montford Bridge is half way between Ludlow and Hawarden, any track error you observe at Montford Bridge just needs to be doubled to obtain a heading which should take you directly to Hawarden. For Instance, if you were 2 miles to the left of track at Montford Bridge airfield, you can easily estimate your track error using the 1 in 60 rule.

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Track Error (°) = $\dfrac{\textbf{Distance Off Track (nm)} \times 60}{\textbf{Distance Along Track (nm)}}$

Track Error (°) = $\dfrac{2 \times 60}{23}$ **= 5° (by approximate mental arithmetic)**

So, changing heading by 10° to starboard, from 348° (M) onto 358° (M) should take you directly to Hawarden.

The Closing Angle Method of Correcting Track Error.

If the wind forecast has been inaccurate, while you have accurately held your planned heading, there is a further method of heading correction you may use, if you find yourself off track. You can, if you wish, use a method which assesses corrections relative to your destination only. This method of heading or track error correction is called the Closing Angle Method.

In the Closing Angle Method, an assessment of the amount of correction to be applied is based on the proportion of the total leg distance already flown, and the closing angle to the destination, as illustrated in *Figure 13.12.*

If, during a flight from **A** to **B**, a pilot pinpoints himself off track at a position **X**, he must establish two things.

- **The closing angle with the destination (or next turning point).**
- **The proportion of the total leg distance already covered.**

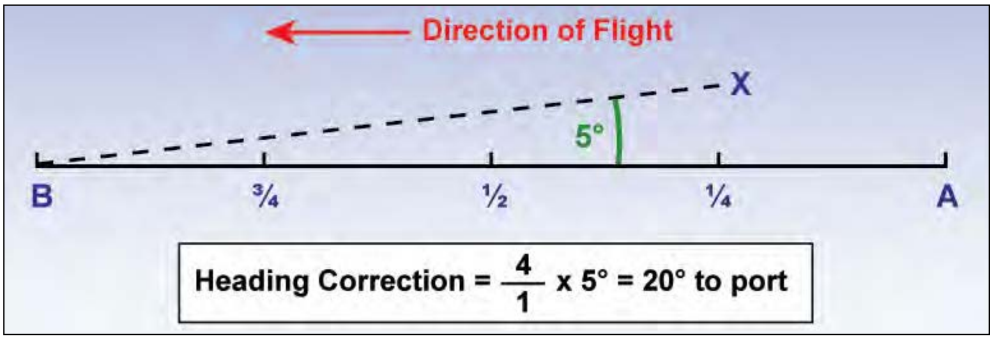

Figure 13.12. The Closing Angle Method of Track Error or Heading Correction.

In *Figure 13.12*, the pilot has estimated (using drift lines or the **1 in 60 Rule**) that the closing angle with his destination, **B**, is **5°**. He has established, too, that he has flown ¼ of the total leg distance.

Using the Closing Angle Method of heading correction, the pilot simply inverts the fraction of the leg-distance already flown (so ¼ becomes 4), and multiplies the inverted fraction by the closing angle. Therefore, in *Figure 13.12*, the heading correction to arrive at B from X is 4 × 5° = 20° to port. For subsequent track checks, figures used must be relative to the previous fix - see page 248.

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Let us try a practical example of using the Closing Angle Method of track-error and heading correction.

If, after spotting your third checkpoint, the lake at Ellesmere, you pinpoint your position as being 2 miles to the left of your desired track, what would be the heading to steer to fly directly to Hawarden?

Figure 13.13. Two miles to the left of track at Ellesmere.

You know from your flight planning that the lake at Ellesmere is 33 nautical miles (nm) along the total leg distance of 49 nm from Ludlow to Hawarden. That is ⅔ of the leg distance, as near as makes no difference.

Being 16 nm from Hawarden, and using the 1 in 60 Rule, you estimate your track error with respect to Hawarden (in other words, your closing angle to get to Hawarden) as being 8°.

Track Error (°) = $\frac{2 \times 60}{16}$ = 8° (by approximate mental arithmetic)

As with drift angle lines, a closing angle line originating from the turning point/destination makes finding the closing angle quicker and easier. In accordance with the closing angle method, you multiply 8° by the inverse of the fraction ⅔ in order to obtain the heading correction that you need to make, to track directly to Hawarden.

Heading Correction (°) = $\frac{8° \times 3}{2}$ = 12°

Consequently, you alter heading by 12° to starboard and, if you had been steering 348° (M) up to that point, you would steer 360°(M).

This technique is also called the New Track Reference technique, as it puts the aircraft on a new track (hopefully fairly close to the original) to the turning point. If subsequent heading checks are carried out on the same leg, the calculation is slightly modified: the change in closing angle since the previous fix is multiplied by the inverse of the proportion of track flown since the previous fix. You should note that all the methods of making heading correction that you have learned in this chapter are approximations, but that for VFR mental dead reckoning, over relatively short

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legs, say, less than 100 nm, the methods are accurate enough for successful visual navigation.

Revision of ETA.

It has been mentioned several times that any elapsed time errors that are noted at the half way point along a leg are doubled in order to obtain the error at the next turning point or destination. For instance, if you are 2 minutes early at the mid-way point, you will arrive at destination 4 minutes early.

In order, however, to revise ETA based on an elapsed time error that you might record at any point along the leg of a navigational flight, you can use the inverse fraction operation from the closing angle method that you have just learned. For instance, if you observe that you are 2 minutes late at a checkpoint, $^{2}/_{3}$ of the way along a leg, you multiply the elapsed time error by the inverse of $^{2}/_{3}$, that is, $^{3}/_{2}$, which tells you that you will be 3 minutes late on completion of the leg. Likewise if you are $1\,^{1}/_{2}$ minutes early at the $^{1}/_{4}$ leg point, you will $^{4}/_{1} \times 1\,^{1}/_{2} =$ 6 minutes early when the leg is completed.

Any elapsed time error at the half-way point along a leg is doubled to obtain the time error on completion of the leg.

ARRIVAL AT HAWARDEN.

After making the heading correction at Ellesmere Lake, and with the visibility being excellent, you soon pick out the town of Wrexham, in front of you in the distance. Being happy with your track and timings, and knowing that with a tail wind component, you should arrive at Hawarden in about 9 minutes, you inform whatever station you have been speaking to, that you are changing frequency to the Hawarden frequency which is entered in your flight log. You have studied the Hawarden airfield plan during the flight planning stage (See Page 214) and have a copy of it on your knee pad, so you already have the basic information about the airfield, such as runway orientation, landing distances available, circuit height, noise restrictions etc. You are also aware from your pre-flight study of the 1:500 000 chart that Hawarden provides a full air traffic control service and will, therefore, provide you with information and instructions for the approach to land. The aerodrome even has a VHF Direction Finding facility, if you should need to use it.

Hawarden ATC will tell you how they wish you to join the circuit; but if you were joining an airfield without full air traffic control, you might wish to consider joining the circuit pattern by adopting the standard overhead joining method described in the Civil Aviation Authority's Safety Sense Leaflet No 6: 'Aerodrome Sense', and in Volume 1, Air Law, in this series of manuals.

Before setting up your approach to Hawarden, assure yourself beyond doubt that you have identified the correct aerodrome, and do not put your chart away until you are absolutely sure that it is indeed Hawarden that you are approaching.

Figure 13.14. Arrival at Hawarden.

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AFTER THE FLIGHT.

In visual navigation, most of the navigating should be done on the ground before the flight.

After your flight, when you are back at home or in the club house, do not fail to analyse the flight in detail. You can learn an awful lot from considering how the flight went: what worked well and what was not so good. Did you fly the headings and airspeeds accurately enough? Did you hold your altitude well? Did you carry out the HAT and FREDA checks at the right time, and regularly enough? Were your RT exchanges timely, proficient and effective? Did you monitor the drift and wind speed effectively at the start of each leg? Did you react correctly and effectively to any track or timing errors? And so on.

You will almost certainly conclude that most of the navigating needs to be done on the ground before you even take off.

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Representative PPL - type questions to test your theoretical knowledge of Practical Navigation.

The following questions are based on a visual cross-country flight that you are planning to make from Cambridge aerodrome (EGSC) (N5212 E00019) to Fenland aerodrome (EGCL) (N5244 W00002), via the village of Elmswell (N5214 E00054) and the railway junction at Reedham (N5233 E00133). You plan to use Peterborough Sibson (EGSP) (N5233 W00023) as your destination alternate.

First of all, draw your route on your own ICAO 1:500 000 of Southern England and Wales, choosing suitable visual checkpoints. Draw 10° drift lines from your airfield of departure, destination airfield and turning points, as you think fit. When you have drawn your route, compare it with the route at Appendix 1, at the end of the book, then answer the following questions.

The answers to these navigation questions are given in Appendix 2, at the end of the book, either within the completed Flight Log, or beneath the Flight Log.

Having confirmed from the Met Report that the weather will be good for the whole flight, with a cloud base of 4000 feet, you begin your flight planning. The magnetic variation in the region of your flight is 2° West. After obtaining the Regional Pressure Setting (RPS) of 1011 millibars, you elect to fly the whole route at Flight Level 35 as, at that level, you will not pass through any of the Military Aerodrome Traffic Zones or Aerodrome Traffic Zones which lie on or near your route, and calculate that, at your planned Indicated Airspeed, your True Airspeed at Flight Level 35 will be 100 knots. The wind at that level is forecast to be 230° (T) at 15 knots.

1. Measure the True Track and distance, and calculate the Magnetic Heading and Ground Speed for the first leg from Cambridge to Elmswell, and enter the values in your Flight Log.

2. Measure the True Track and distance, and calculate the Magnetic Heading and Ground Speed for the second leg from Elmswell to Reedham, and enter the values in your Flight Log.

3. Measure the True Track and distance, and calculate the Magnetic Heading and Ground Speed for the third leg from Reedham to Fenland, and enter the values in your Flight Log.

4. Choose an appropriate Safety Altitude for each leg and enter them in your Flight Log.

5. How long will it take you to fly from overhead Cambridge (EGSC) to your first turning point at Elmswell?

6. How long will it take you to fly from overhead Elmswell to your second turning point at Reedham?

7. How long will it take you to fly from overhead Reedham to your destination at Fenland (EGCL)?

8. How long, after passing overhead Elmswell, and turning onto your new heading for the second leg, will you reach your visual checkpoint at the disused airfield of Thorpe Abbots?

9. On the third leg, after turning at Reedham, what will be the time lapse before crossing the railway line running from Kings Lynn to Ely?

10. How much fuel will your aircraft consume to complete the whole route, if its fuel consumption rate is 10 US gallons per hour? (Round up your calculations to the nearest whole gallon.)

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11. You bear in mind the following considerations concerning fuel consumption: **a**. Time to complete route: ? **b**. Planned diversion time from destination to alternate: 12 mins. **c**. 10% Contingency: ? **d**. Holding Fuel: 8 US gallons. **e**. Minimum Reserve (Landing) Fuel: 5 US gallons. **f**. Fuel Consumption Rate: 10 US gallons per hour.

What, then, is the minimum fuel you must carry for the planned flight? Round up each element of the calculation to the nearest gallon.

12. On the second leg, after 17 nm, you fix your position over the centre of a town you identify as Harleston. Assuming you have flown your planned compass heading from Elmswell and have made no obvious errors in your navigational calculations, what should be your heading correction to reach the next turning point at Reedham?

13. If, on the third leg, you were thee minutes late on crossing the Kings Lynn – Ely railway line, what would be your approximate timing error on arrival at Fenland, if you maintained your planned airspeed?

14. At Shipdham, maintaining Flight Level 35, you contact the Marham MATZ controller to inform him that you will be passing above the MATZ. He gives you the Marham aerodrome QFE of 1008 which you decide to set on your altimeter while you overfly the MATZ. How will you altimeter reading change as you set the QFE?

15. If, on the third leg, from a position where your planned track crosses the Kings Lynn to Ely railway line, you were to elect to divert to Peterborough Sibson (EGSB), what would be your new Magnetic Heading, your Ground Speed and time taken to arrive at your alternate?

16. Deciding, however, to fly straight on to Fenland, you are informed, when you make your joining call, that Fenland are using Runway 18 and that the surface wind is 210/15. What will be the cross wind component on Runway 18?

17. On the third leg, where your planned track crosses the Kings Lynn to Ely railway line, you find yourself 2 nm to the right of track, on the Southern edge of Kings Lynn. You see from the drift lines from Fenland aerodrome, that you drew on your map during flight planning, that your track error with respect to your destination of Fenland is 10°. You have held a constant, accurate heading since leaving Reedham so you deduce that the wind must have backed and become more of a Southerly wind. Quickly assessing that you have flown about ¾ of the leg distance from Reedham to Fenland, you use the Closing Angle Method of track error correction to calculate the heading correction you need to make to fly direct to Fenland. What heading correction would you make?

18. If your aircraft were fitted with a VOR, ADF, and DME, as well as a standard VHF voice communications radio, which radio navigation aid might you elect to use to help you track towards Fenland?

19. What is the circuit direction for Runways 26 and 18, at Fenland? Consult the airfield information for Fenland, at Appendix 3.

20. On the third leg, as you approach the Marham MATZ, you decide to comply with the Quadrantal Rule, even though your are flying VFR. You elect, therefore, to use a Flight Level which corresponds to your magnetic track, in accordance with the Quadrantal Rule. What is the lowest Flight Level you can use?

21. When might you expect an Aerodrome Flight Information Service to be available from Fenland? Consult the airfield information for Fenland, at Appendix 3.

22. If you had diverted to Peterborough/Sibson, and received AFIS information that the surface wind there was 210/08, which runway would you expect to be in use, what would be the circuit height and direction, and what would you have to be particularly aware of, on the approach? Consult the airfield information for Peterborough/Sibson, at Appendix 3.

CHAPTER 14
THE LOST PROCEDURE

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INTRODUCTION.

There is a long standing aviation joke that pilots are never lost, just temporarily uncertain of position. But being lost is quite different from being temporarily uncertain of position. If a pilot has missed a checkpoint but manages to determine his position again, relatively quickly, he is not lost. But not being able to discover where one is, when airborne, and realising that one is lost, can be quite a frightening experience. Consequently a pilot needs to have a plan of action in case he one day gets lost.

In the lesson on practical navigation, you "flew" an example route from Oxford to Hawarden via Ludlow. You will remember that, on the second leg, one of the checkpoints, the road/railway bridge, South West of the disused airfield at Condover, was not seen, because the feature was not distinguishable enough, and the aircraft flew right over the top of it. The advice we gave, in that case, was to maintain the planned heading and speed and look for the next checkpoint, at the planned time. In those circumstances, until the next feature was seen, the pilot could be said to be temporarily uncertain of position, because he had not had a position fix for 8 minutes. If the next feature, the disused airfield at Montford Bridge, had not been seen, then the pilot would have missed two, planned visual fixes and would be lost.

If you practise diligently the flight planning and navigation skills that you will learn during your pilot training, it is improbable that you will get lost on such a short leg as the leg from Ludlow to Harwarden, unless the visibility is very poor. If, however, you are forced to the conclusion that you are lost, you must have in mind a logical plan of action to take, in order to re-establish your position. This chapter covers the essentials of the action to take when lost. We will call it the lost procedure.

Above all, having come to the conclusion that you are lost, do not fly on aimlessly; put into action the lost procedure.

If you realise that you are lost, do not fly around aimlessly. Carry out the lost procedure.

REASONS FOR GETTING LOST.

Inaccurate Flying.

The most common reason why a pilot gets lost in a light aircraft is inattention to flying accurate headings, speeds and levels. In VMC, if the correct heading is flown, at the planned airspeed and altitude, and correct allowances are made for forecast wind, magnetic variation and compass deviation, there should be no reason why the aircraft should deviate from track far enough to become lost. So, the chances are that the reason for getting lost will be an error in one of the aforementioned parameters.

You should, therefore, make the following checks of flying accuracy:

- Check your heading. Is it the planned heading? Pilots have been known to select a figure group from the wrong column of their flight log when setting course from a turning point, or to steer the true track, instead of the magnetic track, or even to take the groundspeed figures as their heading to fly. You should, therefore, consider highlighting with marker pen or coloured pencils the correct magnetic heading, or even better, compass heading, on your Flight Plan. (*See Figure 14.1.)*

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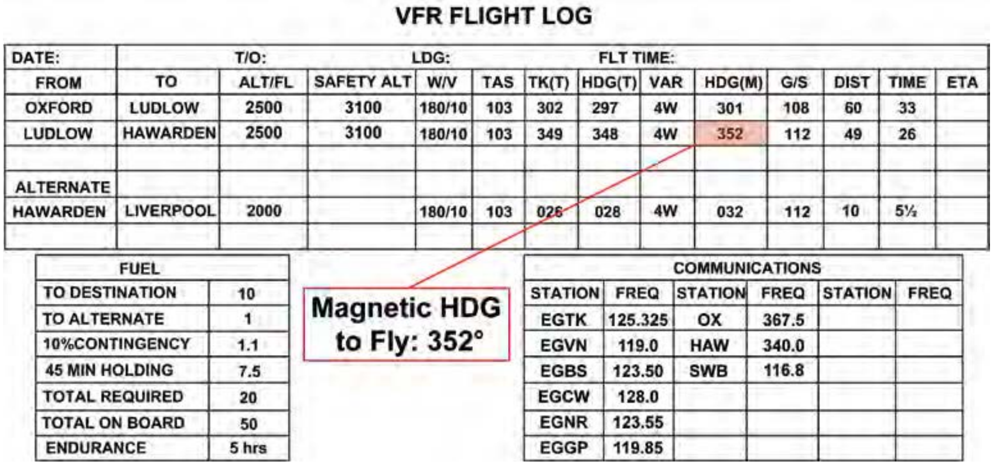
Check the synchronisation of your DI with the magnetic compass, when you are flying in straight, steady, unaccelerated flight.

- Check the synchronisation of the Direction Indicator (DI) with the magnetic compass and ensure that no metal objects (such as bulldog clips, cameras or torches) are stowed adjacent to the compass where they could affect the heading indication. If your compass is giving erroneous indications, you will not be able to synchronise your DI correctly.

- Check that variation, deviation and wind correction angle have been applied in the correct sense in your flight planning calculations, and entered correctly in your flight log.

- Check that the airspeed is as planned.

- Check your stopwatch or clock. It may have stopped. Timing is very important in navigation. If your watch has stopped, you will have lost the most important reference for knowing when to look for planned checkpoints and fixes.



VFR FLIGHT LOG

DATE:	T/O:			LDG:				FLT TIME:					
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
OXFORD	LUDLOW	2500	3100	180/10	103	302	297	4W	301	108	60	33	
LUDLOW	HAWARDEN	2500	3100	180/10	103	349	348	4W	352	112	49	26	
ALTERNATE													
HAWARDEN	LIVERPOOL	2000		180/10	103	026	028	4W	032	112	10	5½	

FUEL	
TO DESTINATION	10
TO ALTERNATE	1
10%CONTINGENCY	1.1
45 MIN HOLDING	7.5
TOTAL REQUIRED	20
TOTAL ON BOARD	50
ENDURANCE	5 hrs

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ
EGTK	125.325	OX	367.5		
EGVN	119.0	HAW	340.0		
EGBS	123.50	SWB	116.8		
EGCW	128.0				
EGNR	123.55				
EGGP	119.85				

Figure 14.1 Make sure that you are steering the correct Magnetic Heading, or even better Compass Heading..

If you discover an error in any of the above parameters early enough, you should be able to estimate your position using the mental dead reckoning methods that you have learnt in this book and estimate a heading and time required to regain your planned track, or to arrive at a planned destination or turning point.

Inaccurate Wind Forecast.

Even if your pre-flight navigation calculations were good, and though you have been flying accurate, planned headings and airspeeds, you may still be off-track and uncertain of position if the forecast wind direction and speed were significantly different from the actual wind velocity. However, if you have chosen good visual check points at appropriate intervals along track, and marked them on your chart, you should be able to identify any drift from your planned track well before you become uncertain of your position. Once drift has been recognised, your planned track may be regained and a new heading chosen, using the methods taught in Chapter 13 on Practical Navigation.

THE LOST PROCEDURE.

The advice that follows is just that: advice. There are several ways of attempting to re-establish your position, if you are unsure of where you are. The method we suggest in the following paragraphs is not the only valid method but it is logical and effective.

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Altitude.

Check that you are flying at a safe altitude, clear of cloud and that you are in visual contact with the ground. Ensure that you are not in danger of collision with high ground or man-made obstructions, such as television and radio masts, captive balloons etc. The quickest way to establish that you are at a safe altitude is to climb to 1 000 feet above the altitude indicated by the Maximum Elevation Figure (MEF) on your chart. *(See Figure 14.2.)* Be sure to maintain your planned heading as you climb.

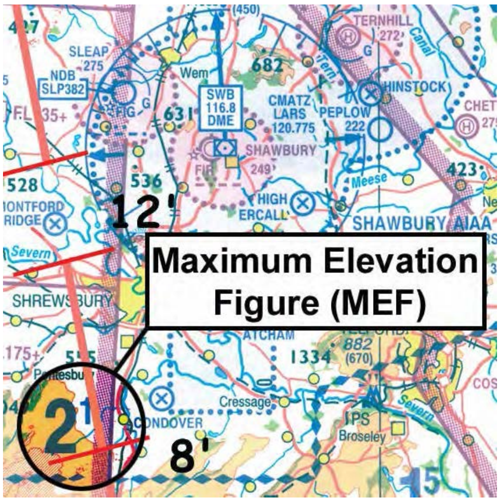

Figure 14.2 When lost, climb to a safe altitude, 1 000 feet above above the relevant MEF, and remain in visual contact with the ground.

When lost in poor visibility, fly at the Safety Altitude: 1 000 feet above the appropriate MEF.

Even if you are lost, you should have an idea of which graticule of the chart you are in; but if there is any doubt, base your safety altitude on the highest MEF in the region.

Maintain VMC and visual contact with the ground.

Maintain Visual Meteorological Conditions (VMC), and remain in visual contact with the ground. Take care that you do not climb into controlled airspace, and continue to fly your planned heading.

In most circumstances, the higher you fly, the greater will be your field of vision, and the greater the chance of seeing a recognisable ground feature or group of features. However, in hazy or misty conditions, there is a danger that visibility will decrease as height is gained. But, if the visibility is good, you will be able to map-read better, at height.

Cruising Speed.

In conditions of bad visibility, consider adopting the slow safe cruise configuration for your aircraft, but weigh this decision against the need to fly at an economical cruising speed.

Endurance Considerations.

Check the amount of fuel remaining and estimate your aircraft's endurance. Then, set an economical cruise power setting, with mixture appropriately leaned. From now on, check the fuel contents regularly and update the endurance as required.

Continue on Heading and on Speed.

Continue at your planned airspeed and on your planned heading beyond your estimated arrival time at the second missed checkpoint for 10% of the time for the whole leg. This will allow for flying at an airspeed lower than planned, or for an unexpectedly strong headwind. It also gives you time to carry out the checks listed above under 'Inaccurate Flying'.

Finding Your Probable Position.

Having arrived at the most probable reason for your track error, draw a line from your last positive ground fix in the direction of the track that you estimate you have been making. The length of the line must represent the distance you estimate having flown. Sketch in fan lines 30º either side of the probable track line.

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For example, if you suspected that there had been a 10° discrepancy in the synchronisation of the Direction Indicator so that your planned heading of 352º had actually been 342º, then you might assume that your track made good was 10° to the left of the required track.

Having estimated the distance flown along your probable track made good, mark this point as the dead reckoning position; then draw a circle around this point, with a radius of 10% of the estimated distance, as shown in *Figure 14.3*.

In *Figure 14.3,* you see the planned track from Ludlow to Hawarden that you studied in the chapter on “Practical Navigation”. You can also see the check feature South West of Condover, which was the first checkpoint to be missed, and also the second checkpoint at Montford Bridge which we are now assuming does not appear on time, either.

The pilot, uncertain of his position, has drawn his probable track made good from the last identified fix, which was the turning point at Ludlow. At a groundspeed of 113 knots, the pilot estimates that he has flown 23 miles along that track. This gives him his mental dead reckoning position. From this position, the pilot draws a “circle of uncertainty” of radius 3 nautical miles, about 10% of distance flown.

*The normal method of map reading is map to ground. But, when putting into action the **lost procedure**, read from ground to map.*

Attempting to Establish Position Within the Circle of Uncertainty.

When map reading during visual navigation flights, the correct method is to read from chart to ground to confirm that the feature you are expecting to see is in the position it ought to be. But when you are lost, the process is reversed. Look within the circle of uncertainty for features that stand out on the ground, and then try to identify one or more of those features, on your chart. In other words, read from ground to chart.

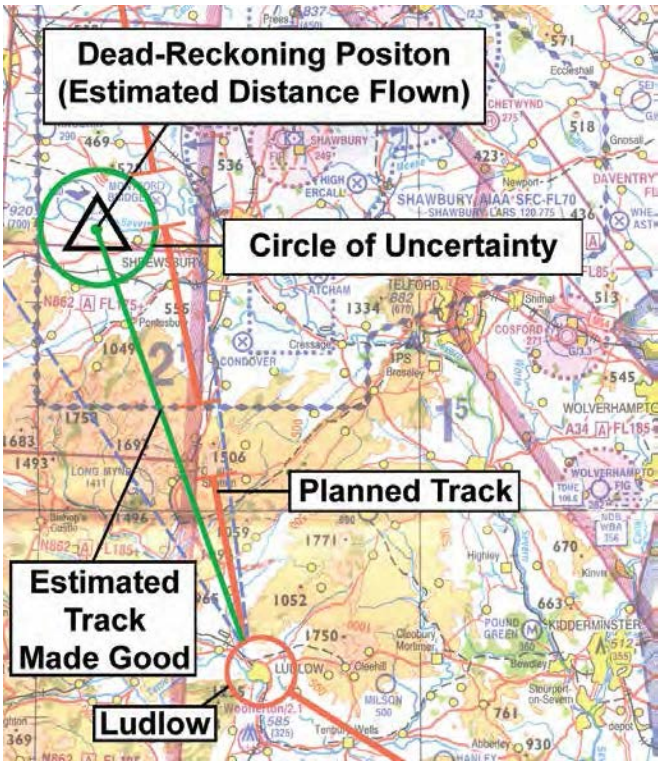

Figure 14.3 Uncertain of Position - Probable Track and Circle of Uncertainty.

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If you obtain a position fix, work out a new heading and ETA for your destination, in this case Hawarden, taking into account your revised assessment of wind strengths and directions. Chapter 9 teaches you how to do this calculation.

Identifying a Line Feature.

If you have not picked out a prominent ground feature, from which you can fix your position, after a reasonable time, say 5 minutes, or if there are no such features in the circle of uncertainty, as is the case in *Figure 14.3*, consider turning towards a line feature such as a coastline, motorway, railway line or river. But check that you will not be flying into controlled airspace.

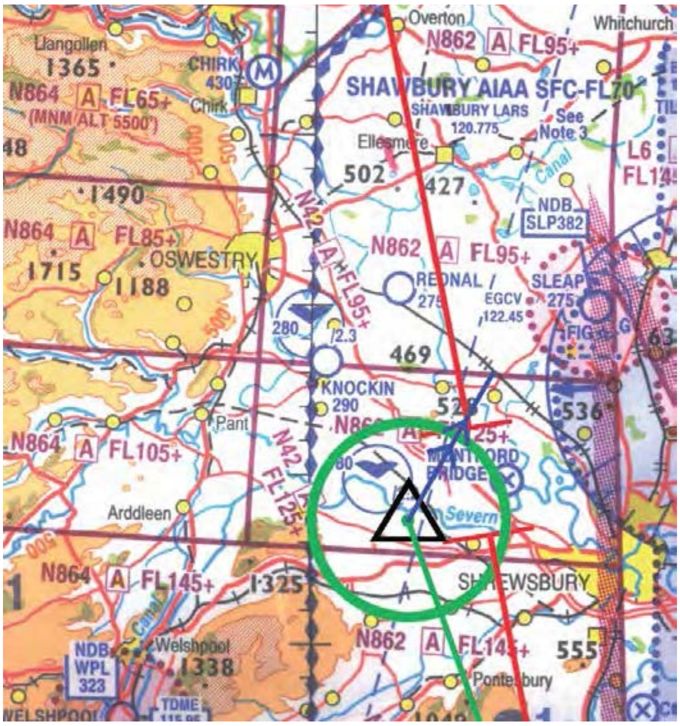

Figure 14.4 Turn towards a line feature: intercepting the railway-line from Shrewsbury to Chirk.

This line feature should be outside the circle of uncertainty. *Figure 14.4* shows that the pilot has chosen to alter course to the right in order to try to find the double track railway-line that runs from Shrewsbury to Chirk.

Flying towards a line feature is a sound method of re-establishing position. But check that the feature is not in controlled airspace

If the pilot is indeed to the left of his planned track and near his mental dead reckoning position, steering a heading of about 045° (M) for about 5-6 minutes would lead the pilot to intercept the Shrewsbury - Chirk railway line.

Having found the railway line, the pilot might reasonably elect to turn left and follow the railway line to the small airfield at Rednal. At Rednal, the drift lines from Hawarden (see Chapter 13) indicate that the pilot, having readopted the original, planned heading of 348° (M), would have a closing angle of about 8° with Hawarden. Recognising this closing angle, and seeing that he has flown about $^2/_3$ the distance of the leg, the pilot could apply the closing angle method to calculate a new heading to Hawarden (See Chapter 13). So, multiplying 8° by $^3/_2$ gives a heading correction of 12° to apply to 348° (M). As he now knows that he is to the left of his planned track, the pilot adds the 12° to 348° (M) and steers 360° (M), due North, towards Hawarden.

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AFTER HAVING RE-ESTABLISHED POSITION.

Having re-established his position from a positive fix, the pilot would set heading accurately from overhead Rednal, recording the new heading in his flight log, and establish radiotelephony contact with Hawarden, without delay.

In our imagined scenario, then, the pilot has re-established his position without too much delay and set a new heading for his destination. There would be no danger of running short of fuel in this scenario but always bear that possibility in mind.

Under no circumstances must you run out of fuel. If fuel is short, plan to land in a suitable field before fuel is exhausted.

Fuel Considerations.

Under no circumstances must you run out of fuel. Learn well the principles and techniques of the field landing when power is available (See **OAAmedia's CD-ROM, 'Practical Flying Training'**), and ensure that you have a safe margin of fuel and daylight. If you do have to land in a field, secure the aircraft against possible damage from livestock or wind, and telephone your home airfield as soon as possible.

USE OF RADIO AIDS WHEN LOST OR UNSURE OF POSITION.

If you become lost on a visual navigation flight that you have planned and are flying using mental dead reckoning navigation techniques, you will probably judge it logical and practical to attempt to re-establish your position, at least initially, using a mental dead reckoning procedure along the lines of the lost procedure discussed in this chapter.

You may, however, elect to use radio-navigation position fixes and headings.

During the navigation part of the flying skills test, sometime after the first leg of the navigation test route, or during the practice diversion leg, you may be required to fix your position using radio aids and to intercept and briefly track a beacon radial using a radio aid nominated by the examiner; therefore, you will learn how to do this during your flying training.

Part Two of this book teaches you the basic theory of position-fixing and tracking, using VHF Direction Finding, Automatic Direction Finding, VHF Omni-Directional Range, Distance Measuring Equipment and radar services.

Do not allow a situation where you are unsure of position, or lost, to develop into an emergency situation. Seek help from an ATSU, in good time.

Whatever method you use to re-establish your position and to determine a new heading to your destination aerodrome, or to some other, nearby aerodrome, if you do not succeed in finding out where you are after a reasonable time, you should seek navigation assistance from an Air Traffic Service Unit (ATSU). Do this sooner rather than later; you must not allow your situation to develop into an emergency, where you are flying on into the unknown, running short of fuel and/or daylight, or about to stray, unannounced and unauthorised, into controlled airspace. You may also elect, in the United Kingdom, to seek a position fix and a heading to steer from one of the country's two Distress and Diversion Cells on the international emergency frequency of 121.5 MHz.

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THE USE OF PILOT-INTERPRETED RADIO-NAVIGATION AIDS TO OBTAIN A POSITION FIX.

Pilot-interpreted radio-navigation aids are fitted to many general aviation aircraft. Those most commonly found in light aircraft are Automatic Direction Finding (ADF) (formerly referred to as the radio compass), VHF Omni Directional Radio Range (VOR), and Distance Measuring Equipment (DME). You will learn the principle of operation of these radio-navigation aids, and their use in position fixing and, in the case of ADF and VOR, obtaining headings to steer to arrive at the beacon, in the chapters which follow.

A pilot who had become lost on a visual navigation flight from Ludlow to Hawarden in the circumstances that we have just been considering, and whose aircraft was fitted with the necessary pilot-interpreted radio-navigation aids, would have a number of immediate options for determining his position or obtaining a heading to steer. These options are presented below. The order of presentation does not constitute a recommendation to use one method in preference to another; seek your flying instructor's advice on that matter.

Refer to your 1:500 000 aeronautical chart of Southern England and Wales while reading through the next few paragraphs.

Option 1.

Hawarden, the destination aerodrome, is equipped with a Non Directional Beacon (NDB) and with a DME beacon. As you will learn in Chapter 16, an NDB is the ground element of an ADF system; so if the pilot has ADF fitted to his aircraft, he can get an immediate indication of the magnetic heading to steer to reach his destination. If he has DME, too, the pilot will also have range information to give him a constant read-out of his distance to run to Hawarden. The pilot should, however, continue to attempt to fix his position visually. This should be achieved as soon as possible; he is on a visual navigation flight in accordance with the Visual Flight Rules (VFR), so he should confirm visually his track over the ground as well as make early visual contact with Hawarden.

When uncertain of position or lost under Visual Flight Rules, and tracking to an aerodrome using radio-navigation aids, you should nevertheless fix your positon visually as soon as possible.

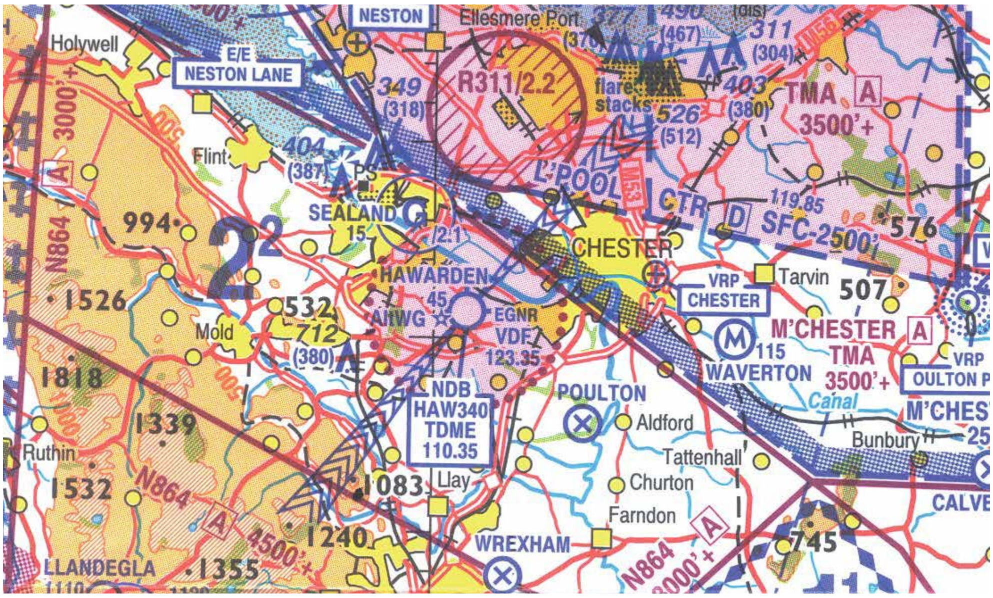

Figure 14.5 Hawarden is equipped with an NDB and a DME beacon.

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When using a pilot-interpreted radio-navigation aid, ensure that the beacon is the correct one by confirming the Morse identification code.

As with all radio navigation aids, the pilot must confirm that he is tuned into the correct beacon by listening to the beacon's Morse Identification Code (or 'ident'). The Hawarden NDB operates on the frequency of 340 KHz (in April 2007) and its DME beacon has the frequency 110.35 MHz (in April 2007). These Hawarden beacons are identified by the letters HAW in Morse Code. (Morse Code is no longer tested in pilot examinations, but a Morse Code tutor is included on **OAAmedia's CD-ROM, 'The IMC Rating and Instrument Flying'**). The Morse Code is printed at the lower left corner of the 'half-mil' chart. It is a good idea to put the morse code for any beacons on the VFR Flight Log, although our example log doesn't.

You will learn about the principles of operation and use of ADF in Chapter 16.

Option 2.

By tuning his VOR/DME equipment to the Shawbury VOR beacon and its co-located DME beacon, the pilot could determine his bearing and range from Shawbury Aerodrome and, thereby, obtain an immediate position fix. If the pilot wished, he could use his VOR equipment to track to Shawbury and land there, after obtaining a clearance from the RAF controller of the Shawbury/Ternhill Combined Military Aerodrome Traffic Zone (CMATZ). VOR is covered in Chapter 17.

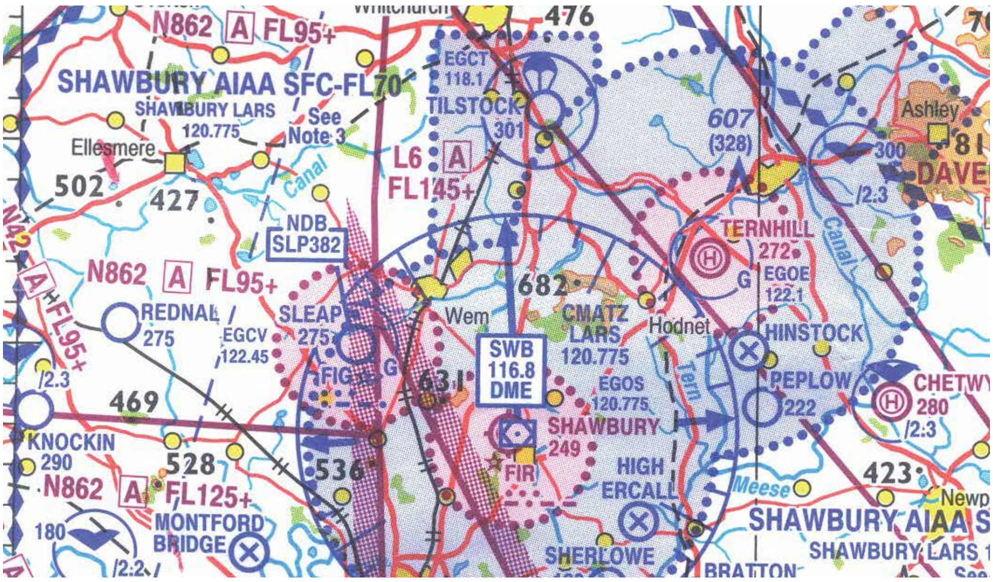

Figure 14.6 Shawbury is equipped with VOR/DME on 116.8 MHz (2010).

Again, the pilot must confirm that he is tuned to the Shawbury VOR and DME beacons by listening to the Morse Identification Code. The Shawbury VOR and DME beacons, both accessed through the same frequency of 116.8 MHz (in 2010), are identified by the letters SWB in Morse Code.

A visual confirmation of position must be made as soon as possible.

Option 3.

Though it would be a more cumbersome operation for a pilot-navigator operating alone, the pilot could obtain a DME range from Shawbury and a further DME range from his destination, Hawarden; drawing the two range arcs on his chart would give him a position fix. Beware the possibility of ambiguity, as two arcs can intersect twice, particularly if the aircraft is approximately between the beacons.

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As the pilot is almost certainly no more than 20 nautical miles from the aerodrome at Welshpool, he could, if he wished further confirmation of his “DME-arc” position, obtain a third DME range-arc from the DME beacon at Welshpool. The third arc would eliminate any ambiguity, but the whole plotting process is long and complex, and should be a last resort.

DME is dealt with in Chapter 18.

Option 4.

Welshpool also has an NDB, so, if the aircraft were equipped with ADF, the pilot could determine both his bearing and his range from Welshpool.

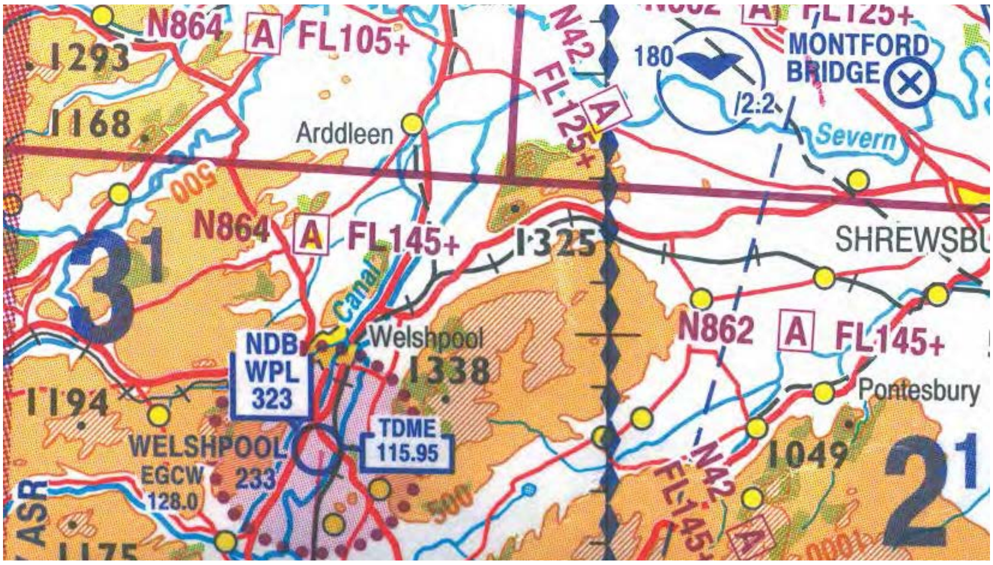

Figure 14.7 Welshpool has an NDB on 323 KHz, and DME on 115.95 MHz (2007).

Option 5.

As both Welshpool and Hawarden have NDBs, the pilot could use his ADF equipment to take bearings from both ground stations, enabling him to fix his position. Such an operation would, however, not be easy to carry out by a single pilot-navigator with one ADF set on board his aircraft.

Considerations for Using Pilot-Interpreted Radio Navigation Equipment.

Do not make being lost or unsure of your position any more difficult than it need be. Use the most logical navigation aid at your disposal and consider which is the easiest to interpret in re-establishing your position. Being already under some pressure to find out where you are, it may not be a good idea to have to think of drawing DME arcs or ADF bearing lines on your chart, in a cramped cockpit. Of course, you can, especially with practice, make good estimates of bearing and distance, by eye alone, but it is far easier to do this when you have only one direction and one distance to deal with.

When lost, you will probably not find it practicable to have to draw position lines on your chart. Estimate bearing and distance.

Consequently, in the imaginary situation that we have been considering above, the most straightforward radio-navigation solution to adopt would be to follow an ADF heading to Hawarden, while reading off the range from your DME equipment. This solution to your predicament requires no drawing of lines on the chart, and should leave you with adequate spare mental capacity to fix your position visually, as soon as possible.

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If you are not able to tune in to the Hawarden NDB, a VOR/DME position fix with respect to Shawbury would probably be the next best option.

Discuss the options we have considered with your flying instructor.

You should also re-read this chapter, after having worked through the chapters in the next section of this book which cover ADF, VOR and DME, in more detail.

Do not neglect your obligation to make an early visual fix of your position relative to the ground. Here, we are considering the use of pilot-interpreted radio-navigation aids as a means of helping you re-establish your position after getting lost on a visual navigation flight. Our considerations assume that you are flying VFR and that you hold neither an IMC Rating nor an Instrument Rating. You must, therefore, remain in Visual Meteorological Conditions (VMC) at all times, and, as soon as you are able, re-identify visually your track over the ground. Otherwise you may enter regulated airspace, unauthorised.

THE USE OF THE RADIO TO OBTAIN A POSITION FIX AND HEADING TO STEER.

A pilot who is lost may also obtain direct assistance from an appropriately equipped ATSU, even if his only radio aid is a normal VHF communications set.

Radar Assistance.

If you are receiving a Basic Service from a surveillance radar-equipped ATSU, you may be able to obtain an immediate radar fix and a steer to your destination or to a nearby aerodrome.

On the route from Ludlow to Hawarden, it would be reasonable for a pilot to request a Traffic Service or Deconfliction Service from RAF Shawbury. RAF Shawbury offers a Lower Airspace Radar Service (LARS), so the request could be met. (*Figure 14.6* indicates that the CMATZ of Shawbury and Ternhill offers a LARS.)

Consequently, if a pilot receiving a service from Shawbury were to become lost, the Shawbury CMATZ controller could identify the aircraft on his radar screen and give the pilot a bearing and range from Shawbury, as well as a heading to steer for Hawarden. The pilot would himself be responsible for remaining clear of terrain and applying the appropriate wind correction angle to the heading.

You will learn about LARS in Chapter 19.

VHF Direction Finding (VDF).

An ATSU which offers a VDF service can give you magnetic headings to steer, to fly directly to the aerodrome at which the ATSU is located. If there are two VDF-equipped ATSUs within radio range, each ATSU will be able to pass you the true bearing of your aircraft relative to the ATSU, which will enable you to plot your position. Bear in mind, though, the caveats we raised above about drawing lines on a chart in a cramped cockpit.

In our scenario of a pilot becoming lost approximately half-way between Ludlow and Hawarden, a reasonable action by a pilot whose aircraft was equipped with a

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radio only, would be to seek VDF assistance from Hawarden. Hawarden provides a VDF service, so, using his radio alone, the pilot could request a magnetic heading to steer directly to his destination. As you will learn in the chapters which follow, a magnetic heading to steer to a ground station is known as a QDM. The pilot could, therefore, request from Hawarden a series of QDMs as he flew towards his destination aerodrome.

As there is also a DME beacon at Hawarden, if the aircraft were fitted with DME, the pilot would also have range information to give him a constant read out of his distance to run to the aerodrome.

The Hawarden controller could also, using his VDF apparatus, give the pilot the true bearing of his aircraft with respect to Hawarden. A pilot whose aircraft had DME could, therefore, obtain both a true bearing and a range read-out from Hawarden, thus enabling him to fix his position.

The most straightforward and least cumbersome action to take, however, bearing in mind the need to keep the cockpit tasks as uncomplicated as possible, would be to request magnetic headings (QDMs) to steer to Hawarden.

The principles of operation and use of VDF are covered in Chapter 15.

The Distress and Diversion Cells on 121.5 MHz.

In the United Kingdom, a pilot who is lost can obtain a position fix and a heading to steer directly from one of the country's two Distress and Diversion (D&D) Cells which provide an emergency VDF positioning service on the international emergency frequency of 121.5 MHz. The D&D Cells are situated at Prestwick, in Scotland, and West Drayton, near London Heathrow. The D&D Cells are run by Royal Air Force personnel, but the service is also available to civilian pilots.

Should you become lost, if you are receiving a Basic Service from an ATSU, report your situation to that ATSU, in the first instance; if the ATSU cannot help you, it will give you the frequency of an ATSU which can, or it will advise you to contact the D&D service on 121.5 MHz. You may, of course, decide for yourself to contact 121.5 MHz directly; but do inform any ATSU from which you are receiving a service of your intentions. It would be wise to ask for a "Training Fix" on 121.5 MHz before you declare a "PAN PAN PAN" or "MAYDAY MAYDAY MAYDAY". A training fix can be obtained by transmitting "Training Fix, Training Fix, Training Fix," followed by the aircraft callsign, on 121.5 MHz.

When flying over that part of England roughly South and East of Manchester, the D&D controller at West Drayton will give a pilot an almost immediate position fix, using a process known as auto-triangulation. Elsewhere, an aircraft's position will need to be established by the D&D controller through manual plotting, following telephone calls to other VDF-capable units who will have picked up the urgency call on 121.5 MHz. This latter process may take a few minutes.

In order to be sure of obtaining a position fix and steer from a D&D Cell, a pilot needs to fly at an altitude of 3 000 feet, or above, in most parts of the United Kingdom. In mountainous or hilly terrain, an aircraft may need to be higher. Within about 40 nautical miles of West Drayton, an aircraft may be able to obtain a position fix above an altitude of 2 000 feet.

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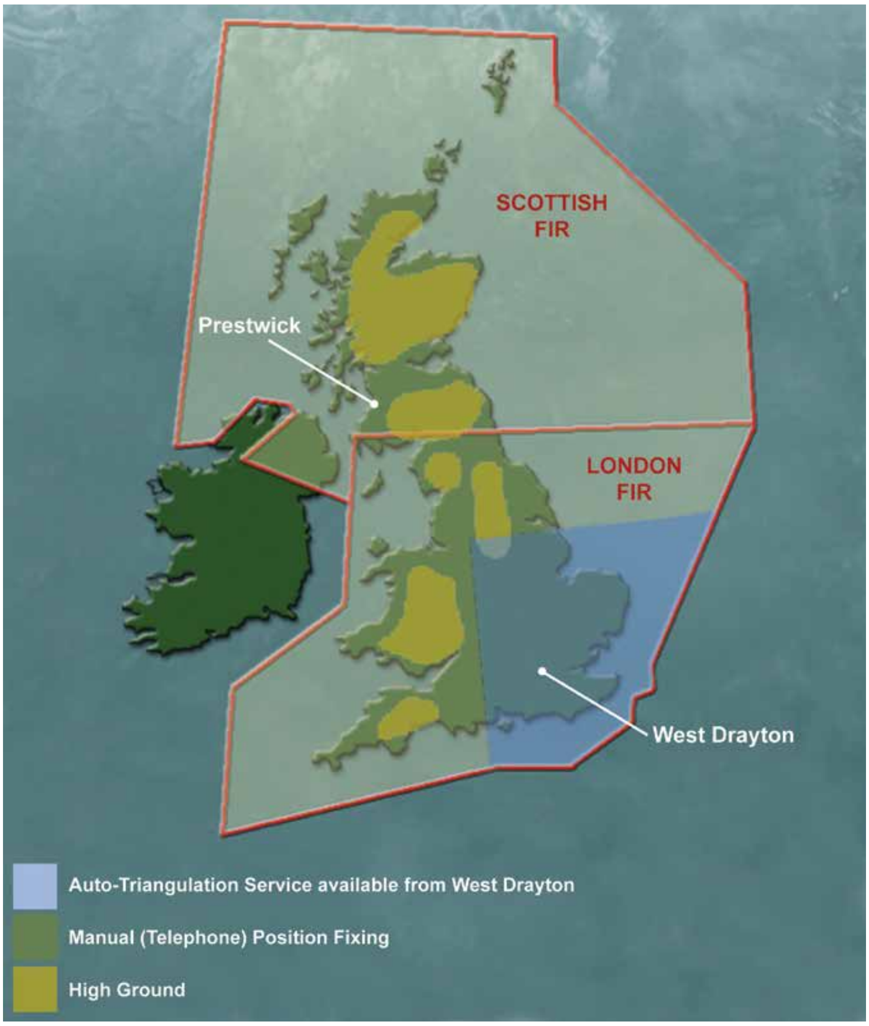


Figure 14.8 An emergency VDF service is provided in the United Kingdom by two Distress & Diversion Cells.

The emergency VDF service on 121.5 MHz is described in detail in Chapter 15.

AVIATE, NAVIGATE, COMMUNICATE.

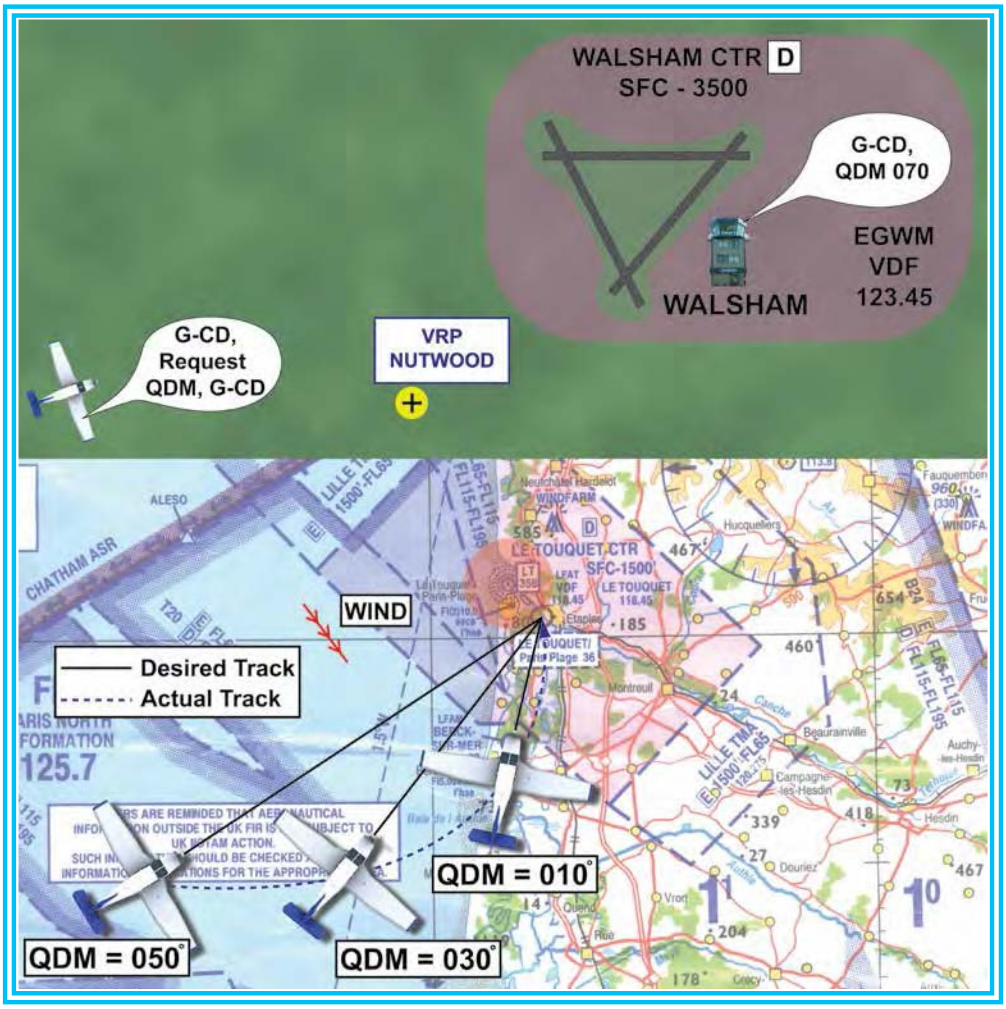
If you cannot re-establish your position in a reasonable time, seek help from an ATSU or D&D Cell. Do not allow the situation to deteriorate into an emergency.

Realising that one is lost is an unpleasant feeling, and may be a frightening one. Above all, remain calm and bear in mind, at all times, the pilot's order of flying priority: aviate, navigate, communicate. So, as top priority, fly the aircraft, then concentrate systematically on finding out where you are, and the direction in which you need to head.

If you have to report a deteriorating situation to an ATSU, make the decision to do so in good time; but under no circumstance must you relegate the need to fly the aircraft from its place at the top of your priorities.

If the situation dictates, do not delay contacting a D&D Cell on 121.5 MHz to obtain an emergency VDF service.

CHAPTER 15
VHF DIRECTION FINDING



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INTRODUCTION.

The simplest radio aid to navigation is provided by the aircraft's radio itself.

Even if an aircraft is fitted only with a standard VHF voice communications radio (a VHF comms set), the pilot may obtain a heading to, or a bearing from, ground stations which have VHF direction finding equipment. These ground stations are equipped with special types of radio aerial, receiver and processors which make up a system able to sense the direction of VHF voice communications signals, received from an aeroplane, and are able to provide the pilot with a heading to or bearing from the ground station. *(See Figure 15.1.)*

Figure 15.1 VHF Direction Finding Ground Equipment.

Details of which aerodromes provide a VHF direction finding service (VDF) are to be found in the Communications Section of the Aeronautical Information Publication (AIP), as well as under the names of individual aerodromes in the Aerodrome (AD) Section of the AIP. Aeronautical charts will also indicate whether an aerodrome provides a VDF service. *Figure 15.2* depicts Le Touquet aerodrome on the 1:500 000 aeronautical chart of Southern England and Wales; the letters VDF beneath the four-letter ICAO aerodrome designator, LFAT, indicate that Le Touquet provides a VDF service on its main aerodrome frequency of 118.45. There is also a Non Directional Beacon for automatic direction finding, (LT 358).

Figure 15.2 The letters VDF on the aerodrome symbol indicate that a VDF Service is provided by that aerodrome.

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VDF SERVICES.

The bearing information given by **VDF** equipment at a ground station can be provided to pilots in three ways: magnetic heading to steer to the station, true bearing from the station and magnetic bearing from the station.

QDM is the Q-code designation of the magnetic heading to steer to reach the ground station, assuming no wind.

The Magnetic Track to Steer to the Station (QDM).

An air traffic controller can pass to a pilot the magnetic track that he must steer to arrive overhead the ground station (assuming no wind). In the Q code, which was developed almost 100 years ago to facilitate communication between morse-code operators, the magnetic bearing required to reach a station is known as the **QDM**. A few of these Q codes are still used today.

A request from a pilot to a controller for a QDM, or 'steer', is probably the most common use of VDF. By steering the QDM, a pilot is said to "home" to the ground station, i.e. to head towards it. Formerly, VDF-equipped ground stations were identified by the term "Homer". Today, the expression "homing" usually refers to the phenomenon of an aircraft being given repeated QDMs by a controller which enable the pilot to arrive at the ground station, in a prevailing cross wind, by continually changing heading to match successive QDMs, all of which are different because the aircraft drifts with the wind. Homing is regarded as an inefficient way to fly to the ground station. *(See Figure 15.3.)*

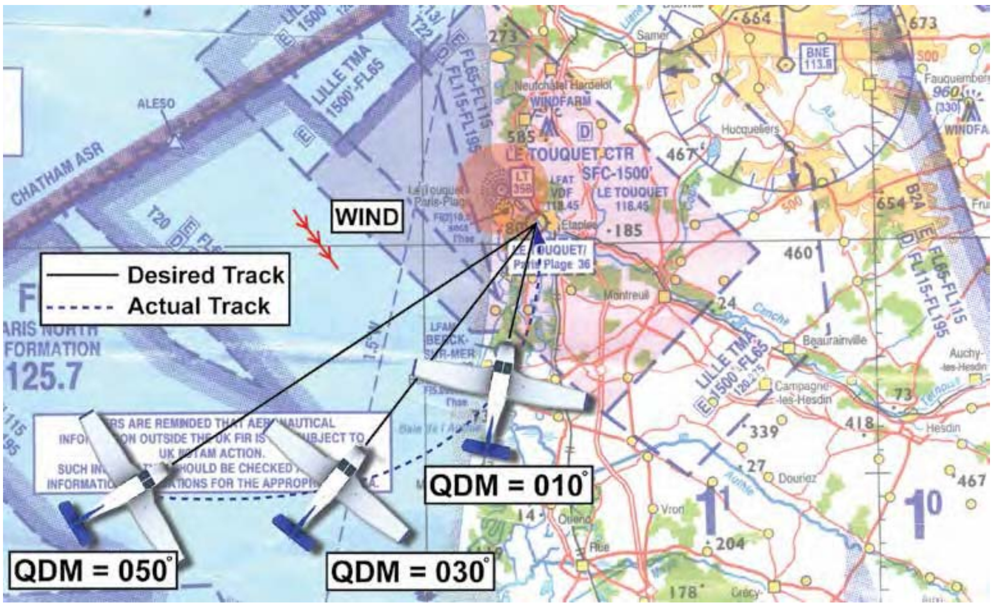

Figure 15.3 Homing to a VDF-equipped aerodrome.

The correct way to fly to a ground station on a QDM is to track to the station, compensating for any drift by adopting a suitable wind correction angle, just as you would do to maintain a desired ground track in a cross wind, when navigating visually.

When tracking correctly to a VDF station, the pilot would continue to request a QDM, regularly, in order to check that the QDM was remaining constant. Of course, when tracking in this way, the aircraft's heading would be different from the QDM read out from the ground station by an amount equal to the wind correction angle. *(See Figure 15.4.)* Requests for a QDM are normally made by the pilot every few minutes,

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during the initial stages of tracking towards a VDF station. The requests increase in frequency as the station is approached.

Figure 15.4 Tracking to a VDF-equipped aerodrome, compensating correctly for drift.

The piloting techniques of tracking to a VDF station in a crosswind are similar to those described in Chapter 16 on Automatic Direction Finding.

Requesting QDMs.

Figure 15.5, overleaf, depicts an aircraft requesting a QDM to fly to Walsham aerodrome.

The initial RT exchange between the pilot and, Walsham Approach would be along the following lines:

Pilot: *"Walsham Approach, G-ABCD, Information Delta, Request Homing."*

Controller: *"G-ABCD, Walsham Approach, Pass your message."* *

Pilot: *"G-ABCD, PA-28, 15 miles South West of Walsham, Flight Level 45, VFR, Inbound to Walsham, Request Homing."*

Controller: *"G-CD, Roger, QDM 065, Class Bravo, Report Nutwood and aerodrome in sight."*

Pilot: *"QDM 065, Wilco, G-CD."*

** Note: In the United Kingdom, an ATC Unit (ATCU) will instruct a pilot to "Pass your Message" on initial contact with the ATCU, to indicate to the pilot that he is to transmit his details. The standard ICAO equivalent of "Pass your Message" is "Go Ahead".*

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Following this initial exchange, the pilot requests a series of QDMs until he makes visual contact with the Visual Reference Point (VRP) of Nutwood and with the aerodrome itself. *Figure 15.5* depicts an exchange between pilot and VDF station, during a VDF tracking procedure, after initial contact has been established.

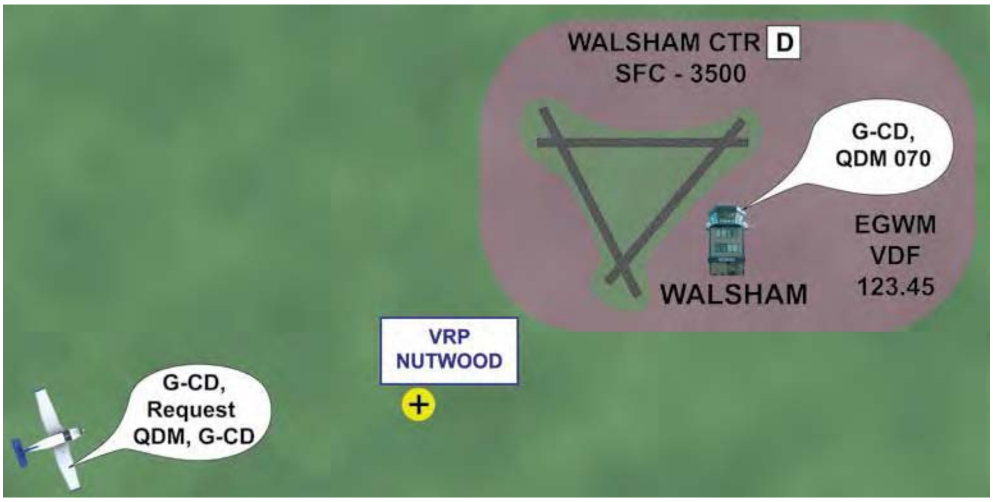

Figure 15.5 A VDF radiotelephony exchange between pilot and VDF station.

During the pilot's series of requests for QDMs, he places his call sign at the beginning and end of his transmission.

When an aircraft arrives overhead the VDF station, the controller's VDF equipment will be unable to determine the direction from which the pilot's transmissions are coming and will reply, "No Bearing". Of course, when VDF is being used to back up a visual navigation flight, the pilot will have made visual contact with the aerodrome before arriving overhead and will be able to join the aerodrome circuit in an approved manner.

If, however, a pilot were tracking to the aerodrome on VDF QDMs in Instrument Meteorological Conditions (IMC), and flying in accordance with the Instrument Flight Rules (IFR), the receipt of the "No Bearing" message would be the indication that he was, in fact, overhead the aerodrome, and that he must now begin to fly the VDF approach procedure. You will learn about instrument approach procedures if you go on to train for an Instrument Rating or, perhaps, in the United Kingdom, an IMC Rating.

QDR is the Q-code designation of the magnetic bearing of the aircraft from the ground station.

Magnetic Bearing from the Station (QDR).

An air traffic controller can pass to a pilot the magnetic bearing of his aircraft from the ground station. In Q code, this is known as the **QDR**. The QDR gives the pilot similar information to that which he would read from the tail of the needle on a cockpit ADF display, (see Chapter 16). The QDR is, therefore, useful to the pilot in determining a position line along which his aircraft must be located.

QTE is the Q-code designation of the true bearing of the aircraft from the ground station.

True Bearing from the Station (QTE).

A controller can also pass to a pilot the true bearing of his aircraft from the ground station. In Q code, this is known as the **QTE**. As aerodromes providing a VDF service have no Magnetic North reference, the QTE is more accurate than the QDR in enabling a pilot to plot his position on his chart, as the line may be drawn on the

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chart, using a navigational protractor, referenced to the True North indication of a meridian of longitude, in a similar manner to the way in which a pilot measures a track-line during flight planning.

By obtaining a QTE from two VDF stations, and plotting them on a chart, a pilot may obtain an accurate position fix.

A request from a pilot for a QTE is made in the following manner:

Pilot: *"True Bearing, True Bearing, Walsham Approach, G-ABCD, Request True Bearing, G-ABCD."*

Controller: "*G-ABCD, Walsham Approach, True Bearing 246 degrees True, I say again, 246 degrees True, Class Bravo."*

The pilot pronounces the words "*True Bearing, True Bearing*" at the beginning of his transmission in order to give the controller time to select QTE on his VDF equipment before the transmission comes to an end. (*See Figure 15.1.*)

Limitations to the Provision of a VDF Service.

You will read in the UK AIP that some aerodromes which indicate that they provide a VDF service also stipulate that the service is not available for the purposes of en-route navigation, unless the pilot is in difficulty. This stipulation is probably made because, invariably, the VDF service is provided on the same frequency as the aerodrome's main approach or tower frequency, so providing en-route VDF information would overcrowd an already busy radio frequency. During the flight planning stage, therefore, you should check in the AIP (AD Section) whether an aerodrome from which you plan to request an en-route VDF service applies the aforementioned restriction.

Aerodromes which do apply the restriction may wish to limit the VDF service to an instrument approach service.

THE ACCURACY OF VDF BEARINGS.

VDF bearing information will be given to a pilot only when the bearings that a VDF station is able to give fall within prescribed limits of accuracy. Normally, if the provision of a VDF service is not possible, the pilot will be told the reason.

The accuracy of a Class Bravo bearing is +/- 5°.

The accuracy of VDF bearing information is classified as follows. The class of any bearing passed to a pilot will normally be included in the initial transmission of the bearing from the VDF station.

CLASS OF BEARING	ACCURACY OF BEARING
Alpha	+/- 2°
Bravo	+/- 5°
Charlie	+/- 10°
Delta	Less accurate than Class Charlie

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FACTORS AFFECTING ACCURACY.

The accuracy of VDF equipment may be affected by the following phenomena.

Site Error.

Site error may be caused by transmissions being reflected from nearby high ground, or from buildings or vehicles at the site.

Propagation Error.

Propagation error is error in the diffusion of radio waves over different types of terrain, especially when the distance between the aircraft and the VDF station is great.

Aircraft Attitude.

As the VDF system and VHF communications are vertically polarised, the attitude of the aircraft can affect accuracy. The best reception and results will be obtained if the aircraft is flying straight and level.

Direct and Ground Reflected Waves.

The reception of both direct waves and ground reflected waves can cause signal fading although this phenomenon is usually short lived. Multi-path signals can also give rise to bearing errors.

Range.

VDF operates in the VHF radio wave band, and so its range is limited by the line-of-sight principle.

Intervening high ground, between an aircraft and the VDF transmitter, will limit range, especially for low flying aircraft in hilly terrain. The power of the airborne and ground transmitters also limits VDF range.

VHF DIRECTION FINDING IN AN EMERGENCY.

In the United Kingdom, a pilot who is lost or uncertain of his position may be able to obtain direct help from the ground station with which he is in contact, or he may seek assistance, or be advised to seek assistance, from a Distress and Diversion (D&D) Cell on the international aeronautical VHF distress frequency of 121.5 MHz.

An emergency VDF service is provided in the United Kingdom on the international urgency frequency of 121.5 MHz.

There are two D&D Cells; one at Prestwick to serve the region North of Latitude 55° N, and one at West Drayton to serve the area South of 55° N. Although both D&D Cells are manned by Royal Air Force personnel, they provide a service to civil aircraft in an emergency, in addition to the service they provide to military aircraft. This includes the provision of a position fixing service.

The D&D Cells obtain information on the position of an aircraft in distress from VDF equipment, and are able to fix with good accuracy the position of aircraft transmitting on 121.5 MHz at altitudes of 3 000 feet, and above, over the United Kingdom land area and coastal waters. However, the ability to locate aircraft below 3 000 feet is poor and will probably be severely inhibited over the mountainous areas of Scotland, Wales and North-West England.

The D&D service is available around the clock to pilots flying within United Kingdom airspace.

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For aircraft flying in the London FIR, overland, South of the River Humber and East of Manchester, auto-triangulation position fixing is possible which can give the West Drayton D&D Cell an almost immediate fix on the position of an aircraft in distress. Within a radius of about 40 nautical miles of West Drayton, auto-triangulation position fixing is possible in respect of aircraft flying at 2 000 feet or above.

In other areas, bearing information has to be obtained by the D&D controller through telephone contact with other VDF-equipped aerodromes, and then plotted manually. In this second type of procedure, fixing the position of an aircraft in distress may take several minutes, as opposed to seconds with auto-triangulation.

Figure 15.6 depicts the approximate boundary of the area of the United Kingdom in which the West Drayton D&D Cell can carry out auto-triangulation position fixing. In the remaining area of the United Kingdom, manual plotting is required.

With both types of position-fixing procedures, the accuracy of the fix depends very much on the quality of the bearings, which in turn depends upon the height of the aircraft and its distance from the ground station.

Practice Pan and Training Fix Calls.

Pilots may simulate emergency incidents, **but not the state of distress**, on 121.5 MHz, in order to enable them to gain experience of the service provided.

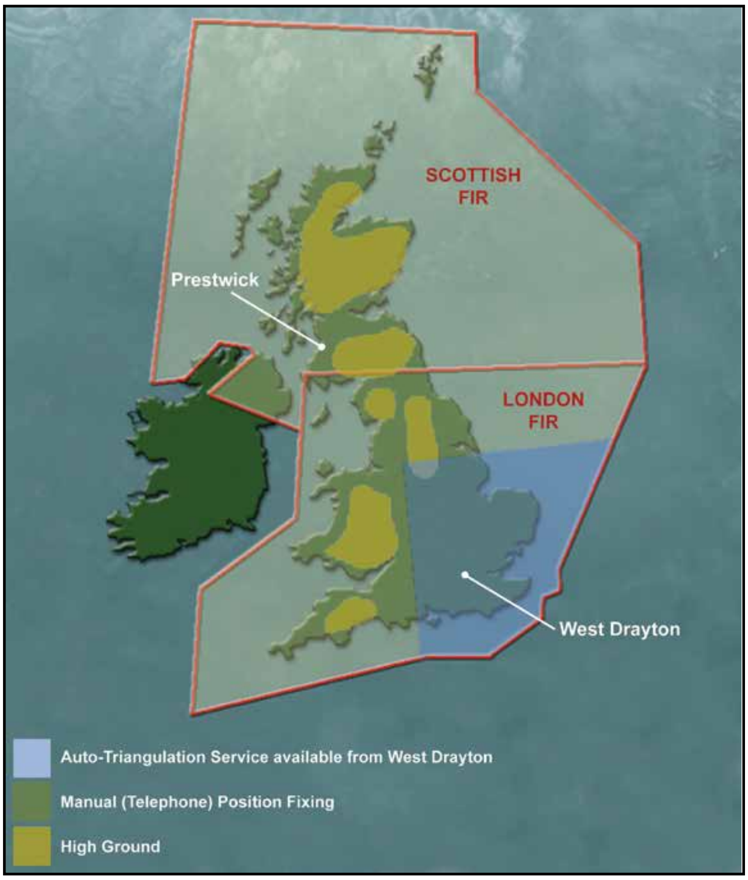

Figure 15.6 An emergency VDF service is provided in the United Kingdom by two Distress & Diversion Cells.

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Before calling a D&D Cell, pilots should listen out on the emergency frequency, in order to ensure that no actual or practice incident is already in progress. Practice calls need not disrupt a planned flight or involve additional expense in fuel or time, since the pilot can request a 'diversion' to his intended destination or cancel the exercise when necessary.

Simulated emergency calls must be prefixed 'PRACTICE' and should be brief.

Pilot: *"Practice Pan, Practice Pan, Practice Pan, London Centre, G-ABCD."*

The Emergency Controller will then indicate whether or not he is prepared to accept the **Practice Pan** call. If he did accept, he would reply along the following lines:

Controller: *"G-CD, London Centre, Practice Pan acknowledged, continue when ready."*

The pilot would then pass details of the emergency he wished to simulate. The simulated message should contain relevant information that might help the D&D Cell, but should be as brief as possible.

Pilot: *"Practice Pan, Practice Pan, Practice Pan, London Centre, G-CD, PA-28, Simulated shortage of fuel, Position Uncertain, Last known position Northampton, Time 25, Request Diversion to nearest airfield, 2000 feet, QNH 998, Heading 090, Student Pilot, 1 POB."*

Controller: *"G-CD, Roger, Trace indicating your position just West of Poddington, 8 nautical miles North of Cranfield, Nearest aerodrome is Cranfield, Steer 185."*

Pilots who do not wish to carry out a practice emergency, but require only to confirm their position, may request a 'Training Fix' on 121.5 MHz. The Training Fix is secondary in importance to actual emergency calls but takes precedence over practice emergency calls, in the event of simultaneous incidents. This type of call is initiated by words along the lines of:

Pilot: *"Training Fix Training Fix Training Fix, G-ABCD."*

Controller: "*G-ABCD, Scottish Centre your position is 7 miles South of Pitlochry"*

Seek the advice of your instructor, and consult CAP 413 for the latest information on RT phraseology to be used in a real or simulated emergency.

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Representative PPL - type questions to test your theoretical knowledge of VHF Direction Finding.

1. The accuracy of VHF Direction Finding (VDF) could be affected by:

   a. Propagation and site errors
   b. Night effect
   c. Airframe quadrantal errors
   d. Coastal refraction

2. Having received a request for a QDM, the controller responds 'QDM 080 Class Bravo'. This means the controller has passed:

   a. The magnetic bearing of the aircraft from the VDF station, accurate to within +/- 10º
   b. The true bearing of the aircraft from the VDF station, accurate to within +/- 10º
   c. The magnetic bearing of the VDF station from the aircraft, accurate to within +/- 5º
   d. The true bearing of the VDF station from the aircraft, accurate to within +/- 5º

3. On which frequency would you request an emergency VDF positioning service from a D&D Cell?

   a. 112.5 MHz
   b. 112.5 KHz
   c. 121.5 KHz
   d. 121.5 MHz

4. Which of the following statements is wrong?

   a. QDM - magnetic heading TO the station
   b. QDR - magnetic bearing FROM the station
   c. QTE - true bearing FROM the station
   d. QDR - true bearing TO the station

5. Requesting a training fix takes priority over:

   a. A Mayday call
   b. A pan pan call
   c. a practice pan call
   d. a distress call

Question	1	2	3	4	5
Answer					

The answers to these questions can be found at the end of this book.

CHAPTER 16 AUTOMATIC DIRECTION FINDING (ADF)

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INTRODUCTION.

The simplest type of **pilot-interpreted radio-navigation instrument**, and one that has been in use since World War 2, is the **Automatic Direction Finder (ADF)** which is fitted to almost all aircraft. At first glance, the ADF looks like a compass. In fact, the instrument was formerly known as the radio compass. The ADF needle, however, does not indicate Magnetic North, but always points to the beacon to which it is tuned. The beacon in an ADF system is called a **Non-Directional Beacon (NDB)**.

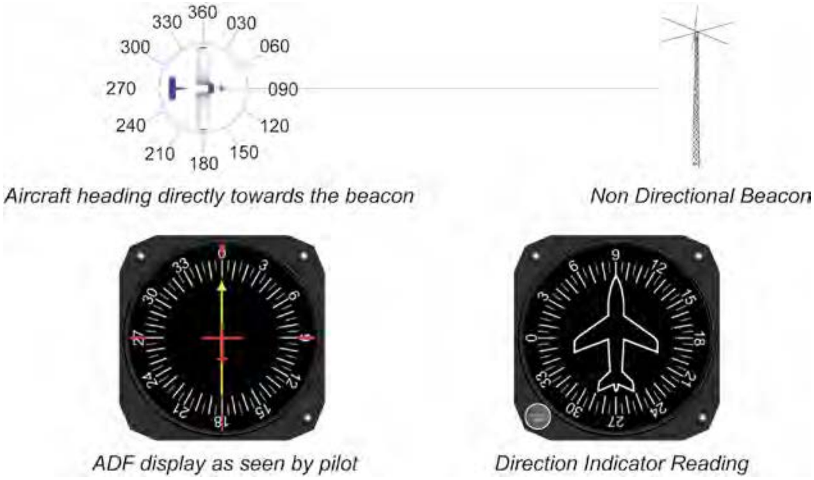

Figure 16.1.

The needle in an ADF instrument display always points in the direction of the NDB to which the ADF equipment is tuned.

In *Figure 16.1*, we depict an aircraft flying directly towards the NDB on heading 090°. The pilot, therefore, sees that his Direction Indicator is reading 090° and his ADF needle is in the 12 o'clock position, indicating straight ahead.

The ADF instrument may be thought of, in simple terms, as comprising a needle which points towards the NDB. A pilot, then, whose aircraft is fitted with ADF equipment can tune to and track towards an NDB. If the NDB is located at an airfield, this basic ability of the ADF can be of enormous help to a pilot who is having difficulty in visually locating the airfield.

A Non Directional Beacon (NDB) is a radio transmitter which sends out a radio signal in all directions (Hence, the term "non directional"). The radio signals from NDBs also

Figure 16.2a ADF Receiver and instrument display.

Figure 16.2b A Non - Directional Beacon (Photo courtesy of Trevor Diamond www.trevord.com).

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carry a Morse Code signal so that a pilot may identify an individual NDB. *Figure 16.2* depicts an ADF instrument display and an NDB.

When a pilot has tuned his ADF equipment to a particular NDB, the pilot may track towards the NDB very much in the same way that an earthbound hiker might follow a compass needle pointing towards Magnetic North. When tracking towards an NDB, the relationship between the NDB and the ADF instrument may be likened to the relationship between Magnetic North and a magnetic compass. Of course, just like using a compass, a pilot may use his ADF to track away from an NDB. However, a hiker trekking away from Magnetic North with the compass needle pointing directly behind him will always be heading 180° (M), whereas a pilot tracking away from an NDB may do so in any specified or non-specified heading, depending on his intentions and instrument fit.

An NDB, then, can "lead" an aircraft tracking towards it, to a position overhead the NDB, from which point the aircraft may either track to another NDB or leave the NDB on any heading selected by the pilot. The pilot may also elect to perform an instrument approach procedure using the NDB for guidance in azimuth, (i.e. in the horizontal plane).

As an alternative to tracking towards or away from an NDB, a pilot may use his ADF equipment to take a bearing from an NDB which provides a position line from the NDB along which the aircraft is situated. A positive position fix can be taken from two NDBs. If the pilot chooses the NDBs judiciously (say, with one of the NDBs being in front of the aircraft, on the nose, and another NDB abeam, port or starboard), a position fix can be taken using one ADF instrument only.

Generally speaking, NDBs in the United Kingdom are either short-range homing devices, or locators for Instrument Landing Systems or for non-precision approaches. The expression "homing" basically means following the indications of the ADF needle until arrival overhead the NDB. As you will discover, homing (without applying drift) can be useful to a pilot but is poor radio-navigation technique, if the aircraft is under the influence of a cross-wind.

The principle of operation of the ADF - NDB system is similar to that of the aerial of a portable radio. If you can recall the phenomenon of the reception of a portable radio varying as you turn the radio set to attempt to increase the strength of the signal, then you have experienced the principle of operation of an ADF - NDB system. With the radio, signal reception is maximised when its aerial is in line with the transmitting station. The ADF works in the same way, but the direction of the NDB can be read off in degrees on the face of the ADF instrument in the cockpit.

THE NON DIRECTIONAL BEACON.

The **Automatic Direction Finding** system is the oldest of the pilot-interpreted navigation aids currently in use, and its demise has been foretold for decades. Nevertheless, it does have one advantage over the system which followed it, the **VOR (Very High Frequency Omni-Directional Ranging).** NDB signals do not operate on the VHF line-of-sight principle but are able to follow the curvature of the Earth, and, thus, can be received at much greater distances and at lower altitudes than are VOR transmitters. (VOR is dealt with in the next chapter.)

However, NDB signals are more affected by atmospheric conditions, mountainous terrain, coastal refraction and electrical storms than are VOR signals, particularly at long range.

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An NDB (Non Directional Beacon) is a ground beacon which emits radio waves in the low and medium frequency range, from 190 kHz to 1750 kHz. The frequencies of most NDBs lie between 250 and 450 kHz.

NDBs emit radio waves in all directions, within the frequency range 190 kHz to 1750 kHz. These are low and medium frequency bands.

NDBs used for long range navigation may have useable ranges from 50 nautical miles (nm) to several hundred nautical miles over the oceans. In the United Kingdom, NDBs usually have a range of between 10 and 80 nm. Range depends on the operating power of the NDB transmitter. Low power NDBs are often found on airfields as the locator element in conjunction with an Instrument Landing System. Locators usually have a range of between 10 - 25 nm. The Designated Operational Coverage (DOC) of each NDB in the United Kingdom is published by the United Kingdom Civil Aviation Authority in the UK Aeronautical Information Publication (AIP), En-route (ENR) Section.

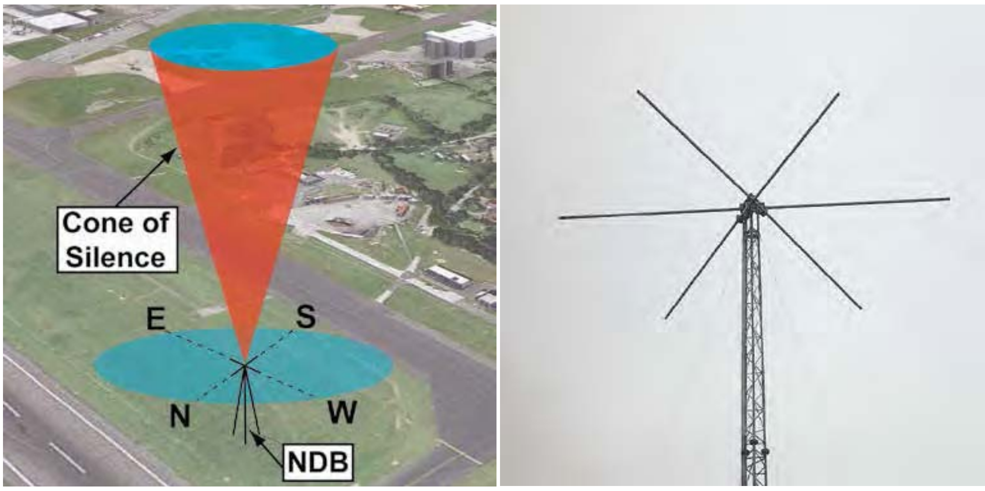

Figure 16.3 The Cone of Silence above a Non - Directional Beacon (Photo by courtesy of Trevor Diamond www.trevord.com).

Directly overhead an NDB transmitter, a "cone of silence" exists in which no signal will be received by the aircraft. The diameter of the cone of silence will increase with height above the beacon.

The required NDB is identified by the pilot from a morse identification code broadcast by the NDB.

On the 1:500 000 chart, NDB facilities are identified in the manner shown in *Figure 16.4, below.*

Figure 16.4 The NDB located near Le Havre, in France. Its Morse identification is LHO, and its frequency is 346 KHz.

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The NDB depicted is the one near the airport of **Le Havre**, in France. The **NDB** is identified on the chart as **LHO 346**. **LHO** is the morse identification code of the **NDB**, and **346 kHz** is its frequency.

AIRCRAFT EQUIPMENT - THE AUTOMATIC DIRECTION FINDER.

Aircraft Automatic Direction Finding (ADF) equipment fitted to the aircraft comprises the following elements:

- A loop and sense aerial.

Figure 16.5 An ADF Loop and Sense Aerial.

- A control unit.

Figure 16.6 A Control Unit and Receiver.

- ADF receiver and instrument display.

When an ADF display incorporates a Relative Bearing Indicator (RBI), with a fixed compass card, 000° on the RBI is always aligned with the nose of the aircraft, being in the 12 o'clock position on the face of the instrument. The compass rose of the RBI does not move automatically.

The pilot-interpreted instrument in the cockpit is likely to be of the type shown in *Figure 16.7*. This type of **ADF** display is called a **Relative Bearing Indicator (RBI)**. The compass card on the face of the instrument can be either fixed, with 000° in the 12 o'clock position, aligned with the nose of the aircraft, as shown in *Figure 16.7*, or the compass card can be manually rotated by turning a knob on the instrument, in which case the instrument is known as a Relative Bearing Selector (RBS). With an **RBI** such as that depicted by *Figure 16.7*, the head of the needle always indicates the relative bearing of the NDB with respect to the aircraft's heading.

Figure 16.7 An ADF Display, incorporating a Relative Bearing Indicator (RBI).

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The Receiver

Using the ADF receiver, (see *Figure 16.6*), the pilot selects the frequency of the NDB which he wishes to use. The pilot confirms, from the Morse signal, that he is tuned to the desired NDB and then checks that the ADF needle is responding to the NDB signals as expected.

THE ADF INSTRUMENT DISPLAY.

The Relative Bearing Indicator.

The Relative Bearing Indicator (RBI) *(See Figure 16.7)* is the name given to an ADF instrument display which comprises an ADF needle and a fixed compass-card with 000° at the top of the top of the instrument, usually aligned with a small aircraft symbol printed on the instrument glass, and with 180° at the bottom. For the compass card of the RBI, then, the nose of the aircraft is always 000°.

The ADF needle, as you have learnt, will always point towards the NDB to which your ADF receiver is tuned. Consequently, with an RBI, as its name suggests, the ADF needle will indicate the relative bearing of the NDB; that is, its bearing in degrees relative to the nose of the aircraft, which is taken as being 000°. The RBI readings, then, have nothing to do with compass readings. For the pilot, the cardinal RBI readings signify the following directions relative to the aircraft's nose.

An RBI needle always indicates the relative bearing of the NDB to which the ADF receiver is tuned.

RBI Reading	Direction with respect to the aircraft's nose
000°	Directly Ahead
090°	Directly Right (Starboard)
180°	Directly Behind
270°	Directly Left (Port)

If your ADF has an RBI, therefore, in order to determine the magnetic bearing to the NDB (known as the QDM), you will need to read the RBI indications along with the indications of the aircraft's compass or Direction Indicator (DI). Obviously, the DI is the easier of the two to interpret.

In *Figure 16.8*, overleaf, the DI shows that an aircraft is heading 150° (M) while the RBI indicates that the NDB to which the aircraft's ADF equipment is tuned has a relative bearing of 330°, (that is, relative to the aircraft's nose). A relative bearing of 330° tells the pilot that the NDB is 30° to the left of the aircraft's nose. Consequently, the magnetic bearing to the NDB (the QDM) is 120°(M), that is (150° - 30°), and, if there were no wind, 120°(M) that would be the heading that the pilot would steer to fly towards the NDB. Of course, there is almost always wind to reckon with, and that has to be taken into account when determining the heading to steer.

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Figure 16.8 A DI used in conjunction with an RBI to determine the QDM to the NDB.

Another way of calculating the QDM to the NDB, from the RBI indication, is to add the relative bearing to the magnetic heading. Thus, in *Figure 16.8*, we get 150° + 330° giving us 480°. This is obviously not a useful figure, so we subtract 360° from 480° to give us 120°(M), the QDM.

The Relative Bearing Selector (RBS).

On the RBS, the compass card can be manually set by rotating it to place the aircraft's heading (read from the DI or compass) at the top of the ADF instrument display, in the 12 o'clock position. This would be under the red Index Marker in our diagram. (*See Figure 16.9.*) As long as the aircraft is holding a steady heading, this type of display is a great help to the pilot in determining the QDM.

With an RBS fitted to the ADF display, the bearing display can be manually set by the pilot to indicate the aircraft's heading, thus enabling the pilot to read the QDM to the NDB directly from the ADF display.

Figure 16.9 With an RBS, the QDM can be read directly from the ADF display.

Figure 16.9 depicts the same situation as *Figure 16.8* but with the RBS rotated so that the compass card indicates the aircraft's heading as shown on the DI. Note that the RBS now indicates the QDM of the NDB, directly: 120° (M).

Obviously, an RBS compass card needs to be readjusted every time the aircraft settles down on a new heading.

Figure 16.10 depicts a further example of the use of an RBS. In *Figure 16.10*, an aircraft on a heading of 325° (M) has its RBS rotated to indicate that heading, and, thus, the ADF needle indicates directly the QDM to the Haverford West NDB. The QDM is 008° (M). The bearing from the beacon, the radial or QDR, is 188º (M).

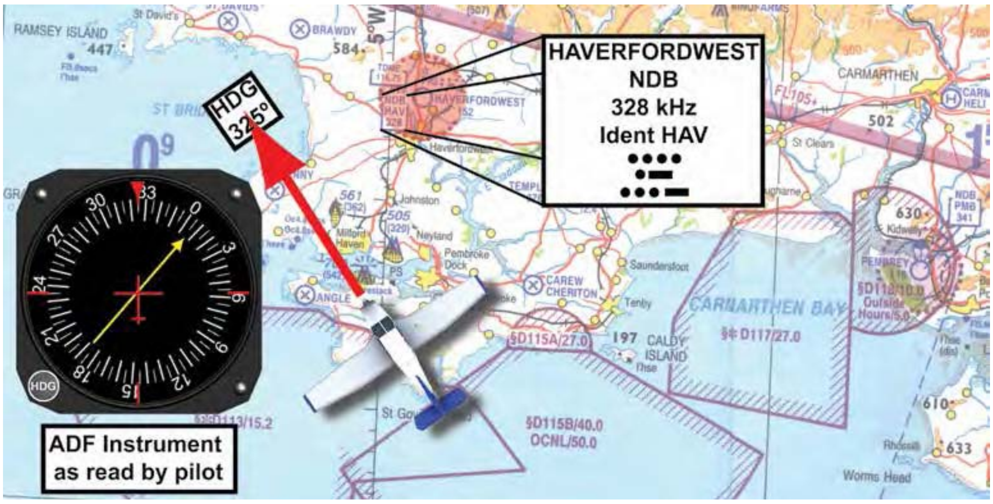

Figure 16.10 An aircraft on heading 325º, with the ADF display showing a TO bearing of 008º, and a FROM bearing (radial) of 188º. The RBS of the ADF display is aligned with the DI and therefore reads the QDM directly.

The Radio Magnetic Indicator.

An ADF display which incorporates a Radio Magnetic Indicator is the easiest of ADF displays for the pilot to interpret. The Radio Magnetic Indicator (RMI) consists of a standard ADF receiver but with the ADF needle combined with a DI compass card which always shows the aircraft's heading with respect to Magnetic North. The RMI, then, interprets both radio and magnetic inputs to provide continuous heading, and bearing information.

The north-indicating compass card behind the ADF needle is similar to a Direction Indicator, in that it is a gyroscopic device which indicates North by virtue of the spatial rigidity of its gyroscope. However, unlike the DI, the RMI does not need to be periodically aligned with the magnetic compass. The RMI's gyro is connected to a remotely located magnetic compass and is automatically fed directional signals which keep the RMI aligned with Magnetic North, as the aircraft changes direction.

The magnetic bearing from the aircraft to the beacon is known as the QDM. The magnetic bearing from the beacon to the aircraft is known as the radial or QDR.

A single-needle RMI looks exactly like the instrument at *Figure 16.10*, except that it will not have a heading knob. The compass card of the RMI does not need to be re-set; the RMI will, at all times, indicate the present magnetic heading of the aircraft as well as the magnetic bearing to reach the NDB, the QDM. (*See Figure 16.11.*)

Of course, it is the head of the RMI needle which indicates the QDM; the tail of the needle will indicated the magnetic bearing from the NDB, the radial or QDR. The QDR information from an RMI, then, gives the pilot an immediate indication of the position line (or radial) from the NDB along which his aircraft is situated.

The head of the RMI needle always gives a direct reading of the QDM, while the tail indicates the radial or QDR.

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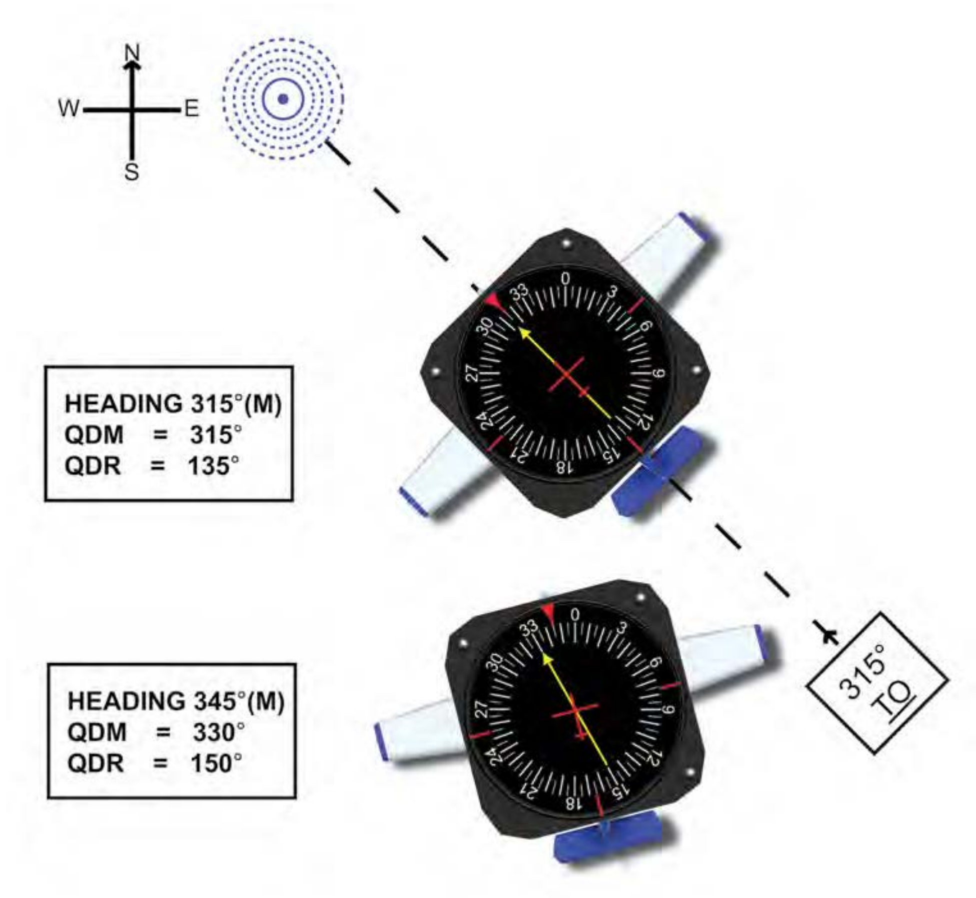

Figure 16.11 Intercepting an NDB radial to track to the NDB on a heading of 315°(M), using an ADF fitted with an RMI.

Twin-needle Radio Magnetic Indicator.

You may fly in aircraft which are fitted with a twin-needle RMI as depicted in *Figure 16.12*.

In *Figure 16.12*, the broad green needle is an ADF indicator, indicating a QDM to an NDB of 290° (M) while the narrow yellow needle is a VOR indicator (see Chapter 17), pointing towards a VOR beacon, for which the QDM is 010°(M). This twin-needle indication permits bearings FROM two different beacons to be taken, and is, therefore, particularly useful in fixing the location of an aircraft.

Figure 16.12 A twin - needle RMI with ADF and VOR indicators.

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Interpreting ADF Indications.

The interpretation of ADF indications is direct and straightforward when the instrument is equipped with an RMI. However, RMIs are expensive to acquire, and many club aircraft will be fitted with ADFs which incorporate only an RBI, or, at best, an RBS. Interpreting the RBI requires some mental arithmetic agility from the pilot; but if you learn to track NDBs successfully and effectively using an RBI, flying with an RMI should present you with no difficulty at all.

An ADF needle always points to the NDB to which the ADF receiver is tuned.

The CD-ROM from **OAAmedia** devoted to the **IMC Rating ('The IMC Rating and Instrument Flying')** will teach you all you need to know about intercepting NDB radials and tracking to and from NDBs, using an RBI.

The most fundamental concept to bear in mind when considering how ADF can be used to assist you in navigating is that the ADF needle always points to the NDB to which the ADF receiver is tuned.

NAVIGATING USING THE ADF.

By implication, then, one of the most basic and useful ADF applications, in navigation, is to be able to fly directly towards an NDB which is located at a pilot's airfield of destination. However, in order to ensure that his ADF equipment will enable him to carry out this most basic of radio - navigation operations, the pilot must:

After tuning your ADF to the desired NDB, always confirm that it is the NDB you require by checking its morse identification code.

- Switch on the ADF receiver and select the correct frequency for the NDB beacon he wishes to fly towards.

- Confirm that the NDB is indeed the beacon he requires by checking, with the receiver set to 'ANT' (antenna), that the NDB's identifying morse code signal is the one he expects.

- Reselect ADF and check that the ADF needle is responding sensibly.

Having carried out these basic actions, the pilot can be confident that the ADF needle is pointing to the correct NDB at the destination airfield.

Homing

Homing towards an NDB refers to a procedure whereby the pilot flies towards the NDB by maintaining the head of the ADF needle at the top of the ADF display, in the 12 o' clock position. If there is no wind, the pilot will fly directly to the NDB in a straight line. However, if there is a crosswind component, the wind will cause the aircraft to drift, and the pilot will constantly need to change his heading in order to keep the needle in the 12 o' clock position. In this situation, the aircraft will follow a curved path to the NDB, as depicted in *Figure 16.13.* This is called homing.

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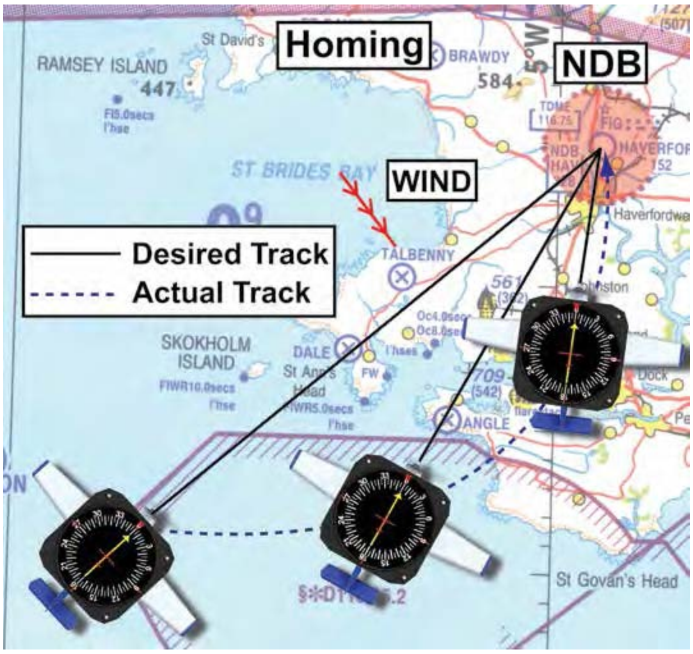

Figure 16.13 Homing towards a beacon.

Although homing eventually brings the aircraft to its destination, it constitutes poor piloting and poor airmanship. Homing would be unacceptable for IFR navigation, for instance, because the aircraft would stray from its assigned track.

Tracking.

The correct way to fly towards an NDB is to track towards it in the same way that you would maintain a desired track using visual navigation techniques. Consequently, again as in visual navigation, you must assess the drift and compensate for it by applying the appropriate wind correction angle. (*See Figure 16.14.*)

In order to track correctly to an NDB, a pilot needs to apply the appropriate wind correction angle.

Figure 16.14 Tracking directly towards an NDB, compensating correctly for drift, and maintaining a constant QDM, with a relative bearing of 030° on the RBI.

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Do not attempt to follow a moving ADF needle; hold your heading and correct for drift systematically. (See also the OAAmedia CD-ROM: 'The IMC Rating and Instrument Flying'.)

Maintaining a Desired Track to an NDB in a Crosswind.

Let us assume that you wish to fly directly towards an NDB at your destination airfield, on a QDM of 060°(M). Your ADF display is an RBI so the ADF compass card does not rotate but indicates only the relative bearing of the NDB with respect to your aircraft's nose. You do, however, have a serviceable Direction Indicator (DI), and so you must use the RBI and the DI together to maintain your desired track.

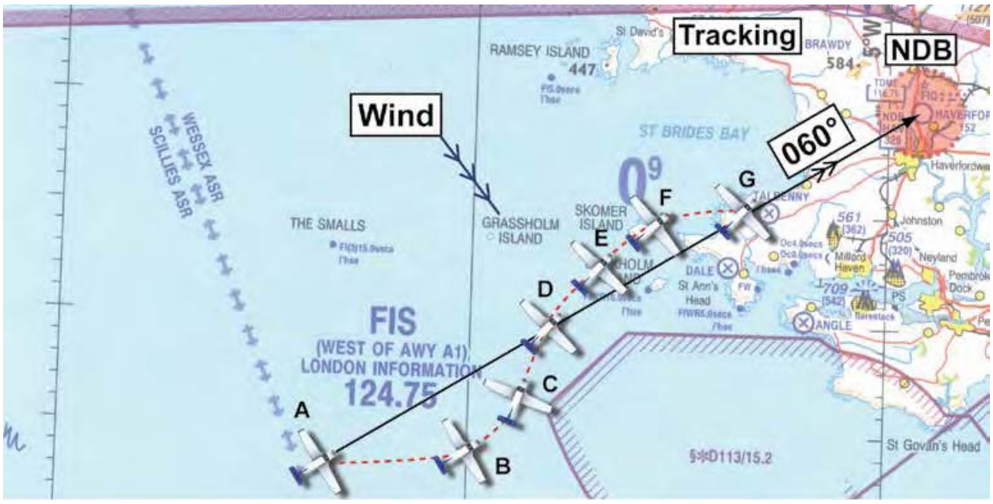

Figure 16.15 Bracketing a track of 060° to an NDB.

Figure 16.15 depicts your aircraft being blown off track by a cross wind, then regaining it and, finally, tracking 060° to the NDB with the correct wind correction angle applied. This action is called bracketing.

The following table depicts your RBI and DI displays for the situation in *Figure 16.15* and describes your actions at the various **positions** (**A, B, C** etc,) of your aircraft as you regain track. Remember, the main principle of ADF tracking: the ADF needle always points at the NDB. Note, too, that to regain track, you always turn the aircraft towards the head of the ADF needle.

A		**Position A**. The aircraft is pointing directly at the NDB along the desired track of 060°(M) to the NDB. The DI reads 060°(M) and the ADF needle is in the 12 o'clock position.
B		**Position B**. By holding your heading of 060°(M), the crosswind has caused you to drift to the right of track. The RBI needle is pointing 15° to the left showing a relative bearing of 345°, so the QDM is no longer 060° but 045°(M) (060° + 345° = 405° - 360° = 045°). You decide to double the drift of 15° and turn to the left, towards the needle, by 30°.

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C		**Position C**. Now, heading 030°(M), you close again with the desired track to the NDB of 060°(M). With your RBI indicating 020°, you see that you are momentarily on the 050° radial to the NDB (030° + 020° = 050° QDM) still to the left, so you hold your heading of 030°(M).
D		**Position D**. As the RBI needle falls towards 030° you know that you are once again about to intercept the 060° radial to the NDB. So, aware that the wind is from the left, you gently turn right onto a heading of 045°(M), hoping that this heading will keep you on track. The RBI needle rises to indicate a relative bearing of 015° so confirming that you are again on the 060° radial to the NDB; so you are hopeful that you have got it right.
E		**Position E**. If the 15º Wind Correction Angle (WCA) had been correct, then the ADF needle would have continued to indicate a relative bearing of 015º while you maintained a heading of 045º(M) and the aircraft would have remained on the 060° radial to the NDB. However, the WCA is too great, so the aircraft has moved to the left of the QDM radial by 5° onto a QDM of 065°, with the RBI indicating a relative bearing of 020°.
F		**Position F**. Assessing that you have overestimated the WCA, you turn right 10º onto a heading of 055º magnetic, judging that, on this heading, the wind will cause you to drift back onto the 060° radial to the NDB. The RBI needle will still initially indicate something greater than 005º, say 008º, but will move towards 005º as you close with the required radial track. (055° + 05° = 060°, the desired QDM.)
G		**Position G**. With a heading of 055°(M), and the RBI needle indicating a relative bearing of 005°, you know that you are back on the 060° radial to the NDB. At this point, you turn left 5° onto a heading of 050°(M). Seeing that the RBI needle is now indicating 010° and remains there, you know that you are tracking to the NDB on a QDM of 060°(M) and have correctly applied an accurate wind correction angle of 10°

Note: A useful trick is to imagine the ADF needle superimposed on the DI to give the QDM - this is explained in the following pages.

ADF and Radio-Navigation.

The primary aim of this book is to prepare you for the PPL theoretical knowledge examinations; it is not a flying instructional manual, and does not aim to teach airborne radio-navigation techniques. However, the above account of the basic considerations of tracking towards an NDB includes the fundamental principles of ADF navigation. Always remember that:

- The ADF needle always points at the NDB.

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- The pilot must always turn towards the head of the ADF needle in order to intercept, or regain, any desired QDM. This rule applies whether flying inbound to, or outbound from, an NDB.

An aircraft must always be turned towards the head of the ADF needle in order to intercept or regain any desired QDM.

If your ADF display is an RBI, you will need to use the RBI in conjunction with the DI and use basic mental arithmetic in order to work out the magnetic bearing to the NDB (the QDM), or the magnetic bearing from the NDB (the QDR). For instance, as you have just seen in the example on how to regain a desired QDM, the QDM at any point is given by the aircraft's magnetic heading, read from the DI, plus the relative bearing to the NDB indicated by the RBI needle, in terms of degrees right or left of the aircraft's nose. If this calculation gives a figure of greater than 360°, subtract 360° from the figure to get the QDM.

With an RBI, the QDM is given by the aircraft's magnetic heading plus the relative bearing.

If your aircraft has an RMI, the QDM to any NDB you are tuned to, and its reciprocal the QDR, are indicated constantly by the head and tail respectively of the RBI needle.

In the navigational element of the airborne skills test for the JAR-FCL PPL, the candidate is required, amongst other things, to determine his position, and to intercept and maintain given tracks or radials using nominated radio navigation aids. Your flying instructor will teach you these skills; but, if you are using ADF, the theory that you have learned in this chapter should help you acquire the corresponding flying skills.

You have learned the fundamental considerations of maintaining a selected track <u>to</u> an NDB. As your flying instructor will teach you, the same fundamental principles are involved in tracking <u>away from</u> an NDB. Furthermore, the principles involved in regaining a desired NDB radial from which your aircraft has drifted away, are the same as the principles employed in intercepting a desired NDB radial. Let us take a brief look at this latter situation.

Intercepting a Desired NDB Radial.

At some point during your PPL navigational skills test, usually after the first leg, you will probably be asked to track towards an NDB or VOR beacon on a nominated QDM, rather than just fly directly towards the beacon as we have described above. In other words, you will know where you want to go but you will have to work out how to get there using a specific route; therefore you have to intercept a nominated beacon radial, and track towards it on the correct QDM.

Let us look at an example of how to intercept a desired NDB radial and track towards it, using an RBI. The example is illustrated in *Figure 16.16*.

In *Figure 16.16*, at Position A, the aircraft is heading 015°(M), with an RBI indicating a relative bearing of 340°, which gives a bearing 355°(M) with respect to the NDB.

However, let us assume that you wish to track to the NDB on a QDM of 330°(M).

You must try to visualise where the track of the desired QDM lies in relation to your present heading, and to work out an intercept course. It is easy from *Figure 16.16* to see exactly which way you need to turn and the approximate track which will intercept the desired QDM, but you will not be able to draw diagrams in the cockpit, so you need a method of visualising the air situation, using what means you have at your disposal, namely the RBI and the DI.

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You should, therefore, mentally transfer the RBI needle to the face of the DI; the head of the imagined needle points towards the NDB, and your aircraft sits on the needle's tail, aligned just as the small aircraft in the centre of the ADF instrument is aligned. *Figure 16.16* indicates this situation, for the aircraft at Position A, by the yellow dotted line on the DI.

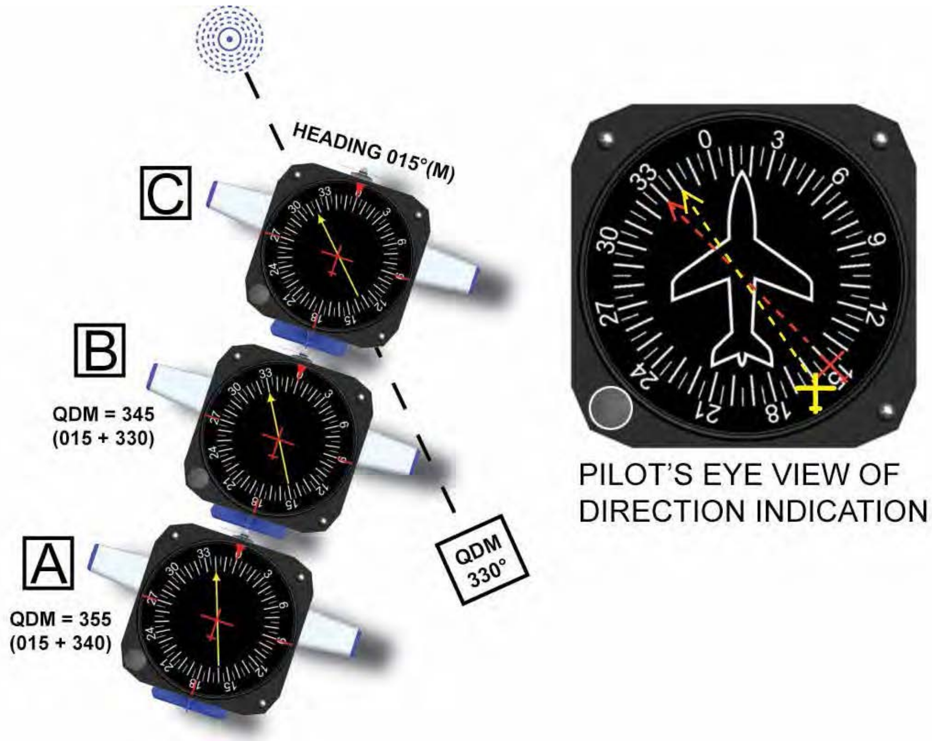

Figure 16.16 Intercepting a desired NDB radial using an RBI.

When intercepting an NDB radial, the head of the ADF needle will always fall.

Now, you must visualise another imaginary RBI needle (shown as red in Figure 16.16) sitting on the DI face with a small aircraft on its tail pointing inbound to the NDB on the desired QDM of 330° (M). Comparing the relative positions of the imaginary needles and aircraft, it is relatively easy to see that a left turn will be required to maintain the QDM once it is reached. The situation, for the aircraft in **Position A**, is shown on the DI in *Figure 16.16*.

The next principle to grasp when intercepting an NDB radial is that the head of the needle will always fall; that is, it will move further towards the 6 o'clock position on the RBI (180° Relative Bearing). But you now need to determine what the RBI will indicate when you arrive at the interception point with the 330° QDM.

If your ADF display is an RBI, the QDM to any NDB is given by the sum of aircraft's Magnetic Heading and the Relative Bearing. If this sum gives an answer greater than 360°, subtract 360° to obtain the QDM.

When working with an RBI, the QDM, for any aircraft position, with respect to any NDB to which you are tuned, is given by the DI heading plus the relative bearing indicated by the RBI.

QDM = (Magnetic Heading + Relative Bearing)

Therefore, in Position A, the QDM is (015° + 340°) = 355° (M).

(You could of course reason that 340° indicated on the RBI is 20° left of your magnetic heading of 015°(M), which also gives 355°(M).)

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In Position B, the QDM is (015° + 330°) = 345° (M). Consequently, if you hold your heading of 015°(M), which will give you a reasonable interception angle of 45°, the desired QDM of 330°(M) is given by the expression:

330°(M) = 015° + Relative Bearing.

It is fairly easy to work out, then, that you will arrive at the desired QDM of 330°(M) when the RBI indicates 315°. This is the position indicated by Position C, in *Figure 16.16*.

As we have mentioned, the ADF needle will continue to fall (to the left) as the required QDM of 330°(M) is approached. It is appropriate to begin turning onto the QDM when you are 5° short of it, so, when the relative bearing is 320°, initiate a medium turn to the left (about 20° angle of bank should be appropriate at light aircraft speeds), to head 330°(M). As you apply bank, you will probably find that the ADF needle will fall a little further because of the phenomenon of "dip" but ignore this and roll out on the heading required. When the aircraft is steady, wings level, on 330° (M), as indicated by the DI, check the RBI. If the RBI needle is indicating 000°, (*See Figure 16.17*), you will have judged your turn perfectly; if it is not, then you will have to make an adjustment.

Figure 16.17 Established on a QDM of 330°(M).

It is, of course, very difficult to achieve perfection with an RBI, and so when the wings are level you will usually find that the relative bearing is not 000° but three or four degrees left or right. There will also be the wind to contend with. You will, therefore, almost certainly have to make adjustments to your heading similar to those described previously.

Your flying instructor will teach you the ADF tracking procedures required for the PPL navigation skills test. If, after gaining your PPL, you wish to gain an IMC Rating, OAAmedia produce an interactive multimedia CD-ROM covering the whole of the IMC theoretical knowledge and practical flying course, entitled 'IMC Rating & Instrument Flying'.

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USES OF AUTOMATIC DIRECTION FINDING.

Although Automatic Direction Finding (ADF) is the oldest extant pilot-interpreted radio-navigation system, it still has numerous uses in aviation. We have covered NDB tracking in some detail in this chapter, other uses are:

Position Fixing.

Taking bearings from two NDBs enables a pilot to fix his position en route. NDBs on aeronautical charts do not have compass roses around them; neither is there any indication of Magnetic North. So, when taking a bearing from an NDB, based on determining what NDB radial the aircraft is positioned on, the pilot must establish the true bearing of the radial from the NDB, using the lines of longitude and a navigational protractor. Therefore, if a bearing indication shows that your aircraft is on, say, the 150° radial from an NDB, this radial, having been established from instruments which indicate magnetic bearings, must be converted into a radial expressed in degrees true. 150° (Magnetic) would be 146° (True) if the local magnetic variation at the aircraft were 4° West. (Variation West, Magnetic Best.) The pilot, then, would draw a line from the NDB of 146° (True) in order to represent the 150° (M) radial. The true bearing from a beacon or aerodrome is known as the QTE.

The True Bearing from the beacon to the aircraft is known as the QTE.

Airways NDBs.

A very small number of NDBs are still used as waypoints on airways, but have mostly been replaced by the more accurate and longer-range VOR/DME. Area navigation systems (INAS and GPS) have also made them largely redundant for IFR navigation.

Holding.

NDBs are still used for aircraft to hold awaiting clearance to commence an instrument approach procedure; the race-track holding pattern is flown at a FL or altitude assigned by Air Traffic Control.

Instrument Approaches.

NDBs are used in NDB approach procedures. The NDB approach is a non-precision approach, that is, it gives no electronic glidepath information. Because of this, and the lower accuracy tolerances of the NDB, the weather minima (cloudbase and visibility) are higher than those of other instrument approach aids.

NDBs are also used as locators in conjunction with Instrument Landing System (ILS) approaches, both as the holding fix and the Initial Approach Fix for the start of the procedure.

FACTORS AFFECTING ACCURACY.

Accuracy.

The best guaranteed accuracy of NDBs is **±5°**.

Designated Operational Coverage.

The designated operational coverage **(DOC)** of an NDB defines the maximum range from an NDB at which a pilot will receive the required level of bearing accuracy of **±5°**, by day only. DOCs are typically between 15 and 50 nms. Information on the DOC of NDBs is contained in the United Kingdom, Aeronautical Information Publication (AIP) in the GEN and ENR sections.

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Precipitation Static.

Precipitation static is generated by the collision of water droplets and ice crystals with the aircraft. This phenomenon causes a wandering needle and a background hiss in the audio, and effectively reduces the reception range.

Thunderstorms.

The powerful discharges of static electricity in thunderstorms will cause significant bearing errors in the ADF. For this reason, caution must be exercised when using the ADF in the vicinity of thunderstorms, as the needle can actually point at the thunderstorm.

Night Effect.

At night, the characteristics of the atmosphere change with respect to the transmission of radio waves. **Night Effect** is most marked around dawn and dusk, and is characterised by needle hunting and audio fade.

Station Interference.

Due to the number of stations in the MF and LF bands, there is the possibility of interference between NDBs which are on or near the same frequency. By day, the DOC will afford protection from interference. By night, interference can be experienced even within the DOC. Identification of an NDB should, therefore, be carried out with particular care at night.

Mountain Effect.

Mountainous areas can cause reflections and diffraction of the transmitted radio waves, leading to errors in ADF systems. These errors will increase at low altitude, so they can be minimised by flying higher.

Coastal Refraction.

Radio waves speed up over water compared to over land. This phenomenon leads to a bending of the waves as they cross the coast, and is the cause of errors in indicated bearings.

Quadrantal Error.

The theoretical polar diagram of the loop aerial is distorted by the airframe which produces a strong electrical field along the fore and aft axis of the aircraft. Incoming NDB signals are, thus, refracted towards the fore and aft airframe axis. This is known as **quadrantal error**.

Dip Error.

The angle of bank during a turn causes a current to be induced in the horizontal elements of the loop, thereby leading to a bearing error which is referred to as “dip” error. This error is present only when the aircraft is banked, with the ADF needle falling towards the low wing of the aircraft. This error is maximum when the beacon is on the nose/tail axis (typically up to 10º), and at a minimum when the beacon is on the wing axis.

The Absence of Failure Indications in the ADF Display.

Finally, it is important to realise that false indications due to a failure in the ADF system are not readily detectable because of the absence of failure warning within most ADF instruments. Particular care should therefore be exercised in identifying and monitoring the NDB, and independent crosschecks made with other navigational aids where possible.

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FACTORS AFFECTING ADF RANGE.

The following are the major factors which effect the range of NDB/ADF equipment:

NDB Transmission Power.

Range is proportional to the square of the power output of an NDB. In order to double the range of an NDB, its power output must be increased by a factor of 4.

Precipitation.

All precipitation reduces the effective range and accuracy of ADF bearings.

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Representative PPL - type questions to test your theoretical knowledge of Automatic Direction Finding (ADF).

1. Which of the following statements concerning an ADF display fitted with an RBI is true?

   a. The display comprises a course deviation indicator and receiver
   b. The RBI needle indicates the selected NDB radial
   c. The head of the RBI needle indicates the bearing of an NDB relative to the nose of the aircraft
   d. The tail of the RBI needle measures the bearing of an NDB relative to the lateral axis of the aircraft

2. Which of the following statements best describes a Non-Directional Beacon (NDB)?

   a. A combination of aerials which provides a VOR display with information concerning NDB signals
   b. A relative bearing indicator and ADF needle
   c. A surface based transmitter which transmits radio signals in all directions
   d. A special aerial providing a controller with VDF information

3. Which of the following are items of airborne ADF equipment?

   1. Cockpit display
   2. Receiver
   3. NDB
   4. Sense aerial
   5. Loop aerial

   The correct combination of statements is:

   a. 1,2,4,5
   b. All of the above
   c. 1,2,3,4
   d. 1,2,3,5

4. Which of the following phenomena does not affect the accuracy of the ADF?

   a. Thunderstorms
   b. Precipitation
   c. High ground
   d. Extensive cloud cover

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5. How would a pilot positively identify an NDB to which his ADF equipment is tuned?

   a. By the NDB's morse code indication
   b. By the direction in which the ADF needle swings
   c. By the movement of the Radio Magnetic Indicator
   d. By the accuracy of the QDM

6. An ADF display equipped with a Relative Bearing Indicator indicates 120° when tuned to an NDB located at the pilot's destination aerodrome. If the aircraft's Direction Indicator gives the aircraft's magnetic heading as 090°, what is the QDM to the destination aerodrome?

   a. 030° (M)
   b. 120° (M)
   c. 210° (M)
   d. 090° (M)

7. An aircraft is heading 150° (M) and wishes to approach its destination aerodrome by flying a QDM of 100° (M) towards an NDB situated on the aerodrome. The aerodrome lies ahead of aircraft and to port, so the pilot is on a reasonably satisfactory heading to intercept the required NDB radial. The pilot, therefore, elects to hold his heading. What will be the indication on his RBI when he intercepts 100° (M) QDM radial?

   a. 310° (R)
   b. 050° (R)
   c. 250° (R)
   d. 100° (R)

8. If a pilot's magnetic heading is 170° and his RBI indicates 330° as the relative bearing of an NDB to which his ADF equipment is tuned, what is the QDM to the NDB, and which way must the pilot turn to fly towards the NDB?

   a. 160° (M)/port
   b. 140° (M)/port
   c. 330° (M)/starboard
   d. 140° (M)/starboard

9. If an ADF display consists of a basic (non-rotatable) RBI, how is the QDM (magnetic bearing) to an NDB determined?

   a. Magnetic Heading + QDR
   b. Magnetic Heading + Relative Bearing
   c. Relative Bearing + True Heading
   d. QDM + QDR

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10. What is the difference between a basic (non-rotatable) Relative Bearing Indicator (RBI) and a Radio Magnetic Indicator (RMI) in an ADF display?

    a. The basic RBI indicates a relative bearing to the NDB, whereas the RMI allows a desired NDB radial to be set with its Omni Bearing Selector
    b. The needle of a basic RBI always indicates the QDM to an NDB directly, whereas an RMI requires the indications of the needle to be added to the Magnetic Heading to obtain the QDM
    c. The basic RBI indicates a relative bearing which shows the magnetic heading to steer to an NDB, whereas an RMI only indicates the QDR
    d. A basic RBI has a compass rose which is fixed in the ADF instrument, with 000° at the 12 o'clock position, while the RMI always indicates the aircraft's magnetic heading. In both RBI and RMI, the ADF needle always points towards the NDB.

11. What is the difference in the needle indications of an ADF incorporating a basic (non-rotatable) Relative Bearing Indicator (RBI) and an ADF which incorporates a Radio Magnetic Indicator (RMI)?

    a. The RBI needle indicates only the relative bearing of the NDB with respect to the nose of the aircraft, whereas the RMI needle gives the QDM directly
    b. The RBI needle gives the QDM directly, whereas the RMI indicates the relative bearing of the NDB with respect to the nose of the aircraft
    c. The RBI needle gives the magnetic bearing to the NDB directly, whereas the RMI needle indicates the relative bearing of the NDB with respect to the nose of the aircraft
    d. The RBI needle always indicates the magnetic heading, whereas the RMI needle is fixed

12. An aircraft is heading 005°(M), as indicated on its DI. The ADF's RBI indicates a relative bearing of 030° to an NDB to which the pilot has tuned his ADF receiver. What are the QDM and QDR, respectively?

a.	030° (M)	210° (M)
b.	025° (M)	205° (M)
c.	205° (M)	025° (M)
d.	035° (M)	215° (M)

13. An aircraft is heading 200°(M), as indicated on its DI. The ADF's RBI indicates a relative bearing of 275° to an NDB to which the pilot has tuned his ADF receiver. What are the QDM and QDR, respectively?

a.	075° (M)	255° (M)
b.	285° (M)	105° (M)
c.	255° (M)	075° (M)
d.	115° (M)	295° (M)

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14. An aircraft is heading 085°(M), as indicated on its DI. The ADF's RBI indicates a relative bearing of 040° to an NDB to which the pilot has tuned his ADF receiver. If the local magnetic variation is 3° West, what are the QDM and QTE, respectively?

    a. 125° (M) 302° (T)
    b. 045° (M) 228° (T)
    c. 040° (M) 217° (T)
    d. 125° (M) 308° (T)

15. An aircraft is heading 085°(M), as indicated on its DI. The ADF's RBI indicates a relative bearing of 350° to an NDB to which the pilot has tuned his ADF receiver. If the local magnetic variation is 4° West, what are the QDM and QTE, respectively?

    a. 075° (M) 258° (T)
    b. 265° (M) 081° (T)
    c. 075° (M) 251° (T)
    d. 350° (M) 166° (T)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Answer											

Question	**12**	**13**	**14**	**15**
Answer				

The answers to these questions can be found at the end of this book.

CHAPTER 17
VHF OMNI-DIRECTIONAL RANGE (VOR)

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INTRODUCTION.

The **Very High Frequency Omni-directional Range** navigation system, known everywhere as **VOR**, was developed in the United States of America in the 1940s and, in 1960, was adopted by ICAO member states as the standard short range navigation system for aircraft. The VOR is one of the most significant radio-navigation inventions, permitting pilots of all types of aircraft, to navigate easily and accurately from one VOR beacon to another. As far as light aircraft are concerned, and despite the rapidly increasing use of **Global Positioning Navigation Systems (GPNS)**, the VOR remains the primary navigation system.

Figure 17.1 VOR Receiver and Display.

Figure 17.2 A VOR Beacon.

Figure 17.1 depicts a typical VOR display and receiver as might be fitted in a light aircraft instrument panel. VOR beacons generally look like the one illustrated in *Figure 17.2*.

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Principle of Operation of the VOR.

The principle of operation of the VOR, illustrated in *Figure 17.3*, is simple. The VOR beacon transmits two signals at the same time. One signal is a stationary pattern of signals, broadcast in all directions (i.e. omni-directionally), while the other is a rotating pattern of signals. The two signals are in phase on Magnetic North from the VOR beacon; in all other directions there is a phase difference between the two sets of signals which identify the magnetic bearing of the aircraft from the transmitter.

The VOR receiver measures the phase difference between the two signals, and displays it as a bearing on the VOR display. The bearing of the aircraft from the beacon is known as a radial.

VOR beacons transmit in the frequency range 108 Megahertz (MHz) to 117.95 MHz.

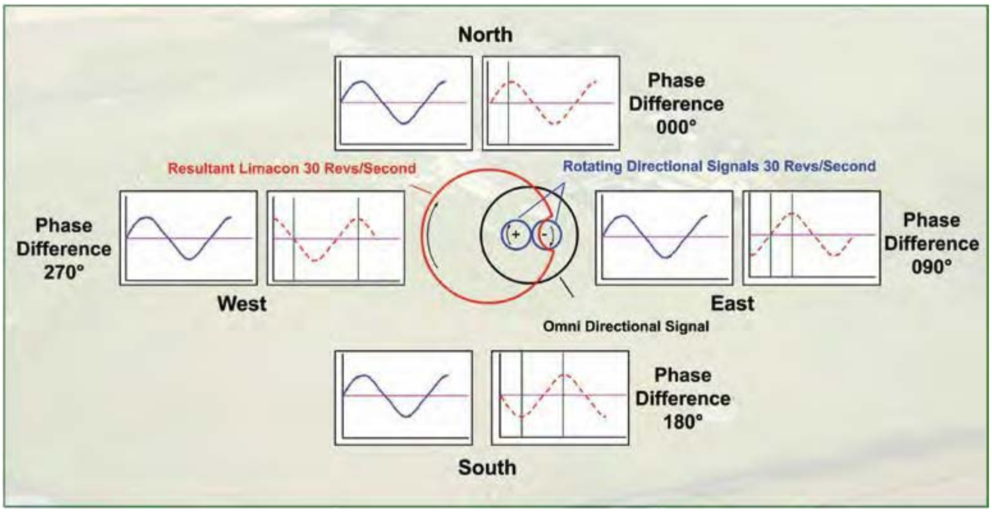

Figure 17.3 The two signals from the VOR beacon are in phase on Magnetic North. In all other directions, there is a phase difference between the two sets of signals which identifies the appropriate bearings.

Morse identification codes are also broadcast by VOR transmitters so that pilots can confirm that they are tuned to the desired beacon. Some VORs broadcast voice transmissions containing an Automatic Terminal Information Service (ATIS), giving weather and operational information for a particular airfield; for example, Bovingdon and Biggin VORs both transmit the Heathrow ATIS.

Chart Indication of VOR Stations.

On the ICAO 1:500 000 Chart, locations of VOR beacons are indicated as shown in *Figure 17.4*.

Figure 17.4 The Strumble VOR/DME, near Fishguard (Photo by courtesy of Mr Trevor Diamond.)

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Figure 17.4 shows the VOR beacon (co-located with a Distance Measuring Equipment (DME) Facility) located at Strumble near Fishguard, indicated by a compass rose aligned with respect to Magnetic North. A photograph of the actual beacon is also shown.

Notice how the four arrows of the VOR compass rose point away from the beacon symbol. This fact should help you remember that VOR radials are always identified by their bearing away (radiating) from the VOR beacon.

VOR radials are always identified by their bearing away from the VOR beacon

Range and Accuracy.

The range of a VOR transmission depends on the power of the beacon and on the VHF line-of sight limitation. For a transmitter of a given power rating, the higher an aircraft's altitude, the greater will be the range at which it can receive and use VOR transmissions. When aircraft, such as airliners, operate at very high altitude they are liable to suffer interference from VORs which, though widely separated from one another, are transmitting on the same frequency.

Information on the lateral and vertical range (Designated Operational Coverage (DOC)) of VORs is contained in the En-Route (ENR) section of the United Kingdom Aeronautical Information publication (UK AIP) (ENR 4-1-1). For instance, the AIP tells us that the Strumble VOR/DME has a DOC which varies from 85 nautical miles (nm) to 300 nm, depending on the bearing sector of the transmission, and that it can be used up to an altitude varying from 50 000 feet to 70 000 feet (again depending on the bearing sector), without the likelihood of interference from other VOR beacons. Coastal VOR beacons tend to be more powerful and have a longer range than inland VOR beacons. Cranfield VOR, an inland beacon, has a published DOC of 50 nm/25 000 feet.

VOR systems are very accurate, capable of achieving an accuracy of under **2°** of error. However, airborne equipment error can be up to about **+/- 3°**. The aggregate of all errors to which the VOR is susceptible is around **+/- 5°.**

Uses of VOR.

The VOR has become one of the world's primary short range radio-navigational aids because of its accuracy, reliability and ease of pilot-interpretation. Though the range of VOR is restricted by the VHF line-of-sight limitation, the system suffers from few of the disadvantages to which the NDB/ADF system is prone. VOR is not so liable to be affected by the proximity of electrical storms, and, because its signals are line-of-sight, the VOR does not suffer from night effect caused by the reflection of lower frequency signals from the ionosphere. Neither are VOR signals susceptible to bending around terrain features or when crossing coastlines.

Using the VOR system, a pilot may navigate from one VOR beacon to another, or, if he has two VOR receivers and displays in his aircraft, track towards or away from one VOR beacon, along any chosen radial, and then intercept a designated radial from a second VOR beacon, and turn to track towards that beacon.
A pilot may determine his position by selecting two different VOR beacons, noting his magnetic bearing from each beacon, and drawing the lines on his chart. The compass rose, aligned on Magnetic North, which surrounds the VOR beacon locations on the 1:500 000 Chart, helps the pilot to fix his position in the air.

Ground fixes may also be determined approximately by drawing a VOR radial which cuts a large angle across a significant and unique line feature on the ground, such as a particular stretch of coastline. And, as you will learn in a later chapter, position may be determined by reading off a DME range along a selected VOR radial.

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Most airways systems were developed with VORs determining the routes, giving aircrew much better instrument presentation than the older NDBs and Marker beacons. Navigational reference points, or waypoints, can also be defined by the point at which two radials from different VOR beacons intersect each other, or by a VOR radial and a DME distance intersection.

Other uses of VOR are:

- As a let-down and approach aid at aerodromes, using published procedures.
- As a holding beacon.

VOR AIRBORNE EQUIPMENT.

Aerials.

On low-speed, light aircraft, the VOR aerial is normally a whip-type aerial fitted on the fin or beneath the forward part of the fuselage. (*See Figure 17.5.*)

Figure 17.5 A whip-type VOR aerial.

On high-speed aircraft, VOR antennae are usually blade-type aerials, or else are mounted flush with the airframe; again, often on the fin.

The VOR Receiver.

The frequency operating range of the VOR beacon is from 108.00 MHz to 117.95 MHz, a range which is just below the VHF voice communication range of 118 MHz to just under 137 MHz.

The airborne element of VOR requires a dedicated receiver, often labelled NAV, and which in many aircraft is located alongside the COMM receiver. (*See Figure 17.6.*)

Figure 17.6 The VOR receiver (NAV) alongside the VHF voice communication receiver (COMM).

VOR Instrument Displays.

Omni Bearing Indicators.

You may see several types of VOR instrument display, but the most widely used in light aircraft are the types illustrated at *Figures 17.7* which are sometimes called Omni Bearing Indicators (OBI) for reasons which should become clear as you work your way through this chapter.

Figure 17.7 Two types of Omni Bearing Indicator.

Radio Magnetic Indicators.

A VOR indicator may also be incorporated in a Radio Magnetic Indicator (RMI) (*see Chapter 16*), as depicted in *Figure 17.8*. RMIs of this type usually have two pointers often of a different colour, one which receives inputs from an ADF receiver, normally the broader of the two needles, and one, the narrower of the two, which receives inputs from the VOR receiver. The head of each needle indicates the QDM to the respective beacon. When an aircraft has two VOR receivers with one RMI, the needle will be switchable between the VORs.

Figure 17.8 An RMI with VOR and NDB indiacations.

Horizontal Situation Indicators.

The **Horizontal Situation Indicator (HSI)** (*see Figure 17.9*) combines a direction indicator, slaved to a master magnetic compass, with a VOR indicator. The HSI shows the aircraft's magnetic heading and its orientation with respect to a selected

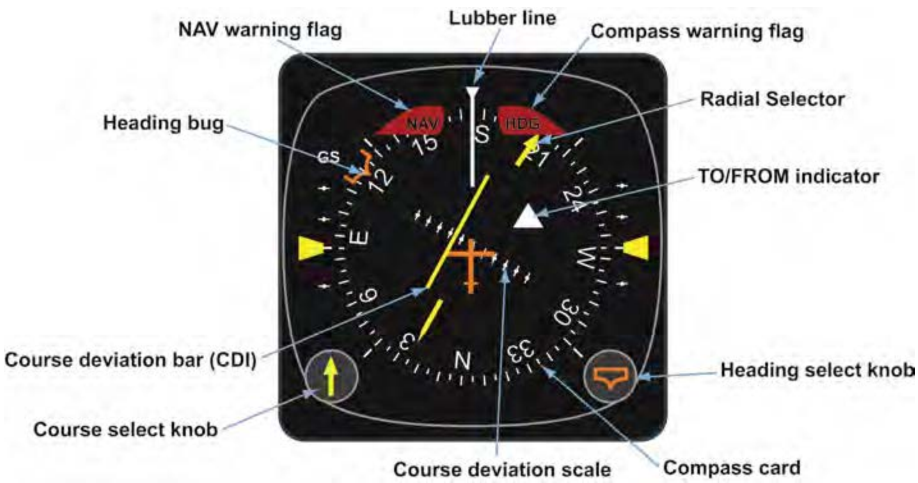

Figure 17.9 A Horizontal Situation Indicator.

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VOR radial, whether the aircraft is on the radial, paralleling the selected radial, on an interception heading to the radial, or diverging from it. HSIs are very easy to interpret and are fitted to almost all commercial aircraft. But, being expensive to acquire, they are not often found in light aircraft operated by flying clubs. For this reason, we will use the Omni Bearing Indicator (OBI) to illustrate the teaching points made in this chapter.

For the purposes of this chapter, we will use the OBI type of VOR indicator, as it is the most common VOR instrument display in basic single engine general aviation aircraft.

OBI Indications.

As you have already learnt, a VOR beacon transmits radials relative to Magnetic North at the VOR beacon's location. (*See Figure 17.10.*)

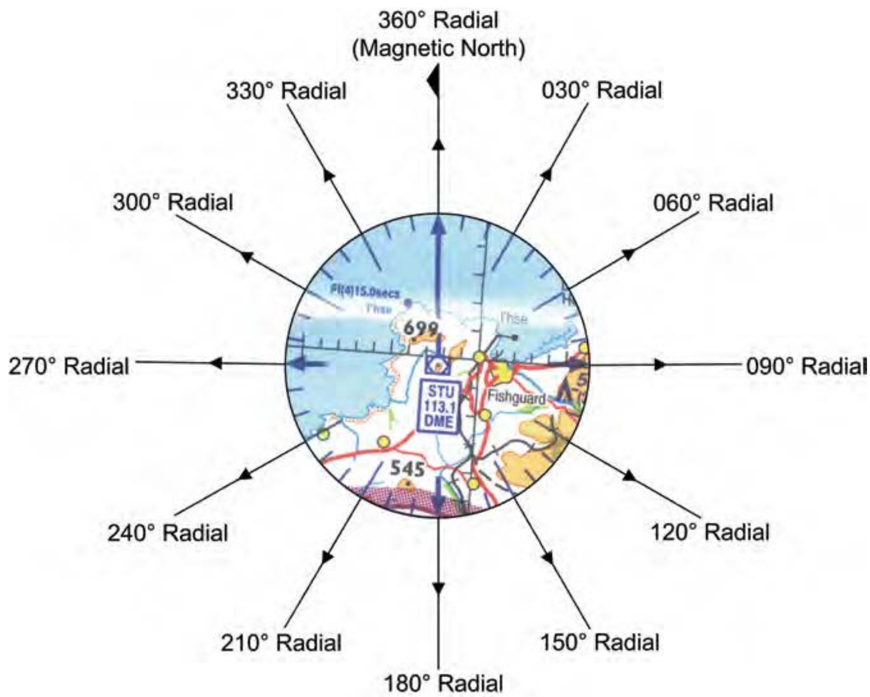

Figure 17.10 A VOR beacon transmits continuous radials through 360º.

A VOR display of the OBI type is able to indicate any radial selected by the pilot, using the Omni Bearing Selector (OBS) knob on the front of the instrument. Consequently, any radial emanating from the VOR beacon can be used by the pilot as position lines to help him fix the position of his aircraft, or as tracks that he can follow, either to or from the VOR beacon.

Let us examine, first of all, the component parts of the OBI VOR display, how the instrument functions, and the nature of its indications. The different elements of the OBI instrument and its display are illustrated at *Figure 17.11, opposite*.

The radial ring, calibrated from 0° to 360° at 5° intervals, is rotated by the pilot to select any VOR radial, either in order to obtain a position line or to select a track along which he wishes to fly TO or FROM the VOR beacon. In *Figure 17.11, opposite*, the

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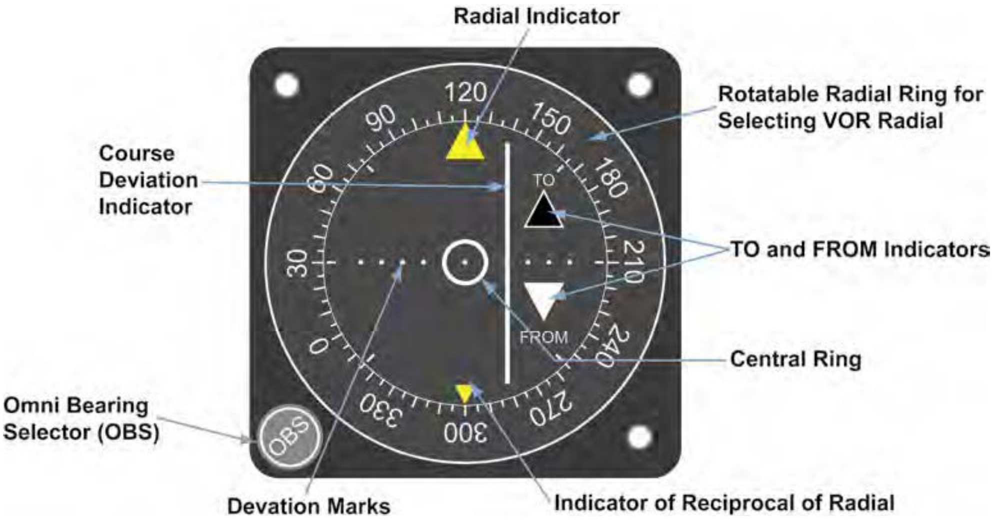

Figure 17.11 The Omni Bearing Indicator.

120° radial has been selected against the radial indicator, in the 12 o'clock position. The pilot uses the Omni Bearing Selector, or OBS knob, to rotate the radial-ring and select a radial which he wishes to intercept and along which he wishes to fly to or from the VOR beacon, or to display a radial to be used for fixing.

When the **Course Deviation Indicator (CDI)** (the word "Course" here is synonymous with "track") is on the middle dot within the white ring at the centre of the instrument, the aircraft is on the radial which has been selected in the 12 o'clock position by the OBS knob. Because the CDI can be placed in the centre position by turning the OBS knob, the pilot can determine, any time he wishes, what radial he is on, relative to the VOR beacon to which the VOR receiver is tuned.

Once a radial is selected under the radial indicator, the CDI, as its name implies, will indicate any deviation from the selected radial. The CDI will move left or right of the centre marker to indicate by how many degrees the aircraft is off the selected radial. Each marker, which has the form of a dot, represents a 2° deviation from the selected radial. The maximum deviation indicated is 10°. When showing a deviation from a desired radial, the CDI also acts as an indicator of which way the pilot must turn to regain the radial. (You will learn more about this function, below.) In *Figure 17.11*, the aircraft is 4° off the selected radial of 120°. (Note that the circumference of the white central ring represents the first 2° deviation from the selected radial.)

When a radial has been selected under the radial indicator, the TO-FROM indicator (in the form of a white arrowhead visible through one of the two triangular apertures) tells the pilot whether, by heading in the direction of the selected radial, he would be flying to or from the VOR beacon.

Flying TO or FROM the VOR Beacon.

Figure 17.12,overleaf, represents three radials emanating from a VOR beacon. You will see that for each of the three aircraft situated at a position on the three radials, the CDI of the OBI is in the middle. We will assume that the pilot of each aircraft, wishing to locate the position of his aircraft with respect to the VOR beacon, has tuned his VOR receiver to the VOR beacon's frequency and rotated the OBS on the OBI until the CDI is positioned in the middle of the central ring, with the FROM indicator showing.

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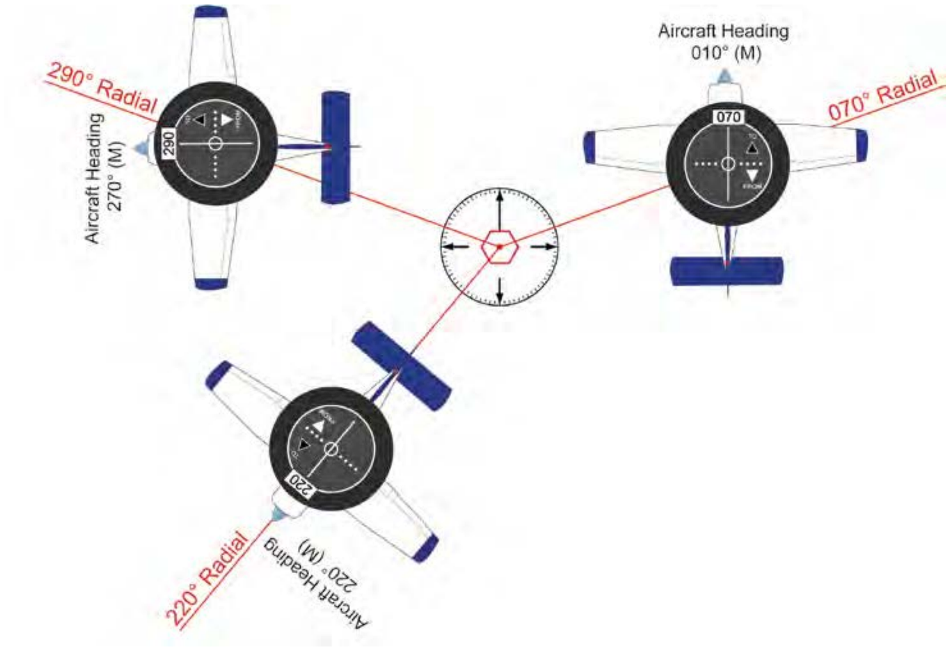

Figure 17.12 With the aircraft in the positions shown relative to the VOR beacon, and the respective radials selected on the OBI, the CDI will be in the middle, and the OBI will indicate FROM, whatever the aircrafts' heading.

This action on the part of the pilot has identified the radial by indicating its bearing from the VOR beacon against the radial indicator on the OBI. The three radials selected are 070°, 220° and 290°.

Note that the OBI does not register or display heading information. When the aircraft is situated on the radial selected against the radial indicator, the CDI will be in the middle of the OBI regardless of heading.

Of course, if the pilot wished his aircraft to remain on the selected radial, he would have to track along that radial. If there were no wind, that would mean that, in order to track away from the VOR beacon on the selected radial, he would have to fly the same heading as the bearing which appears against the radial indicator. If he wished to track to the VOR beacon along the selected radial, still assuming no wind, he would have to fly on the reciprocal heading.

The TO and FROM arrowheads make it easy for the pilot to orientate himself with respect to the VOR beacon.

Radials, as you have learnt, are, by convention, identified by their bearing in degrees magnetic from the VOR beacon. Consequently, in *Figure 17.12,* with the 070°, 220° and 290° radials selected on the OBI against the radial indicator, the FROM arrowhead indication is displayed.

It is important to note, however, that, for any given radial, the CDI can be centralised by selecting either of two numbers against the radial indicator: the number of degrees identifying the radial itself; that is, its bearing from the VOR station, and the number of degrees which identifies the reciprocal of the radial and, thus, indicates the bearing to the VOR station.

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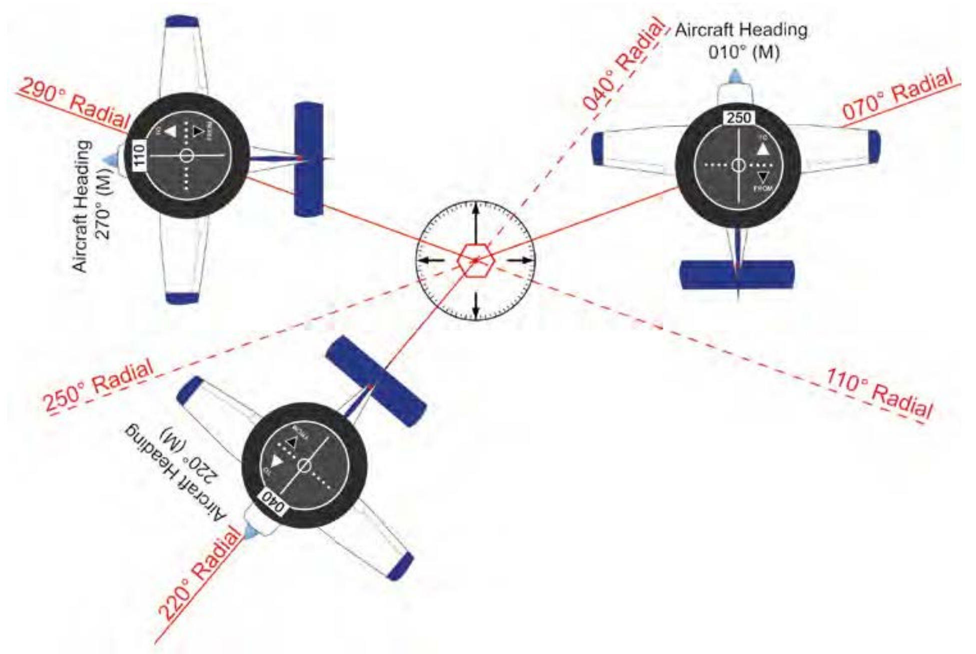

Figure 17.13 With the aircraft in the positions shown relative to the VOR beacon, and the reciprocal of the respective radials selected on the OBI, the CDI will be in the middle, and the OBI will indicate TO, whatever the aircrafts' heading.

The OBI does not give any indication of an aircraft's heading. It only indicates the position of the aircraft with respect to the selected radial.

Consequently, with the reciprocal of the radial selected, the CDI is again centred, indicating to the pilot that if he flies in that direction he will be flying to the VOR station. As you see in *Figure 17.13*, with the reciprocals 250°, 040° and 110° selected, the TO arrowhead appears on the OBI, irrespective of the heading of each aircraft.

The TO flag, then, is telling the pilot that, from his present position on the 220° radial, if he tracks in the direction of the reciprocal radial, which he has selected on the OBI, he will be flying to the VOR beacon. But the OBI takes no account at all of the present heading of the aircraft. The OBI simply tells the pilot where his aircraft is positioned, with respect to the selected radial, or its reciprocal (*Figure 17.13* shows that he is on the reciprocal), and the TO or FROM indication tells the pilot whether he will fly to or from the beacon by steering the heading indicated by the selected radial.

Figure 17.14, overleaf, depicts an aircraft in two positions relative to a VOR beacon. In Position A, the aircraft is on the 220° radial with 040° selected on the OBI against the radial indicator. Whatever the aircraft's heading (*See Figure 17.14*), the OBI would indicate TO, because, from its present position, a heading of 040° on the 220° radial will take the aircraft to the VOR beacon. The pilot also knows, from the central position of the CDI, that he is on the required radial and, that, with no wind blowing, by heading in the direction selected on the OBI, he is flying directly to the VOR beacon. In Position B, the pilot has overflown the VOR beacon, and is holding the heading 040°; the OBI now indicates FROM, telling the pilot that he is flying away from the VOR beacon. The OBI would have changed its indication from TO to FROM as the pilot flew over the VOR beacon. The CDI remains in the central position, so the pilot knows that he is tracking away from the VOR beacon on the 040° radial.

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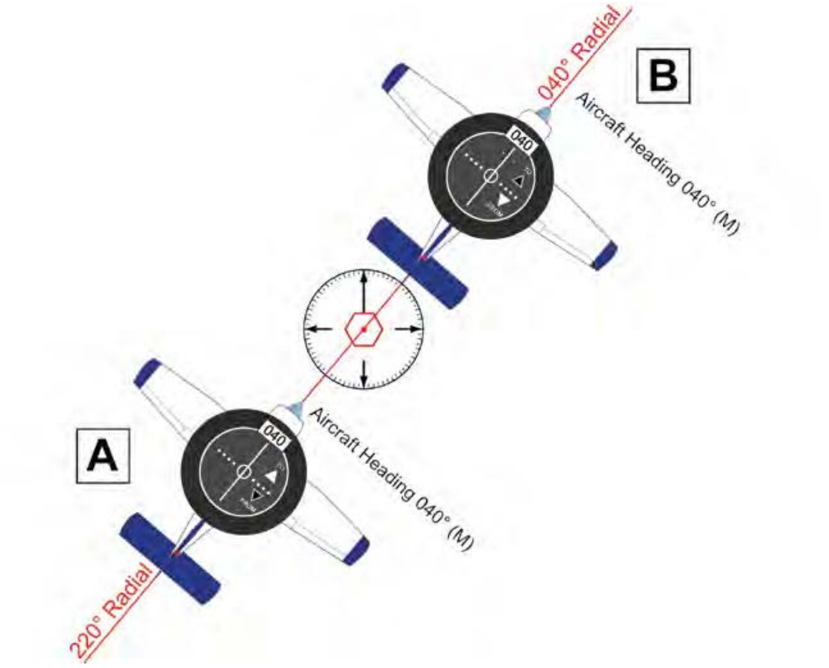

Figure 17.14 In Position A, the aircraft is on the 220° radial with 040° set on the OBI. The CDI is in the middle and the OBI indicates TO because a heading of 040°(M) will take the aircraft to the VOR beacon. In Position B, the aircraft is now tracking away from the beacon along the 040° radial and the OBI indication has changed to FROM.

A Wind Correction Angle Must be Applied to Maintain Track Along a Selected Radial.

If there were a wind blowing (as there almost invariably will be), and if there were a crosswind component relative to a selected radial along which a pilot wished to track, the pilot would have to apply a wind correction angle in order to make good the track, in exactly the same manner as making good a track using visual navigation techniques.

TRACKING TO OR FROM A VOR BEACON.

Let us summarise briefly the main points that we have learned so far about using the OBI type of VOR indicator. First of all, in order to use the information available from the VOR system, you must carry out the following initial actions.

- Tune the VOR receiver to the desired VOR beacon by selecting the VOR beacon's frequency on the receiver.

- Check that your VOR equipment is functioning by checking that no Off-flag is displayed on the OBI, if so equipped.

- Confirm that the VOR beacon is the one you wish to use by listening to its morse identification.

Once you are happy that you are tuned to a desired VOR beacon, by rotating the Omni Bearing Selector (OBS) knob and positioning the Course Deviation Indicator (CDI) in the centre of the instrument, and ensuring that the FROM flag is displayed,

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you can determine on which radial your aircraft is situated relative to the beacon. (*See Figure 17.12.*) A handy mnemonic is **TIDY** - **T**une and **I**dent the beacon, set or check the **D**isplay is as required or expected, and then you can **Y**use it (!).

Regaining Track.

If you centralise the CDI so that the TO flag is displayed, the OBI would display the reciprocal of the radial against the radial indicator, and you could, if you wished, turn onto the heading indicated against the radial indicator and fly directly to the VOR beacon. (*See Figure 17.13 and Figure 17.14.*)

If there were no wind, you would probably have no difficulty flying directly to the beacon. However, if there were a crosswind, or if you did not fly the heading accurately enough, you would doubtless find that you would stray from your **desired** track along the selected radial. If this were the case, the CDI would give you your angular deviation from the desired track (i.e. the selected radial).

Each dot on the horizontal scale which passes through the middle of the CDI, represents a 2° deviation from the selected radial. The circumference of the ring in the centre of the OBI (*see Figure 17.11*) passes through the first dots either side of the central dot, so if the CDI is touching the circumference of the ring, you will be 2° to the left or right of the selected radial. The maximum deviation indicated is 10°; above 10º, the CDI will stay at full scale deflection..

In *Figure 17.15*, the aircraft in Position A is shown by the CDI to be 5° to the right of the desired track of 040° (M). The CDI is positioned between the second and third dots to the left of the centre dot, each dot indicating 2° deviation from the selected radial. (Remember, the first dot is coincident with the circumference of the central ring.) The aircraft, then, is actually now on the 215° radial.

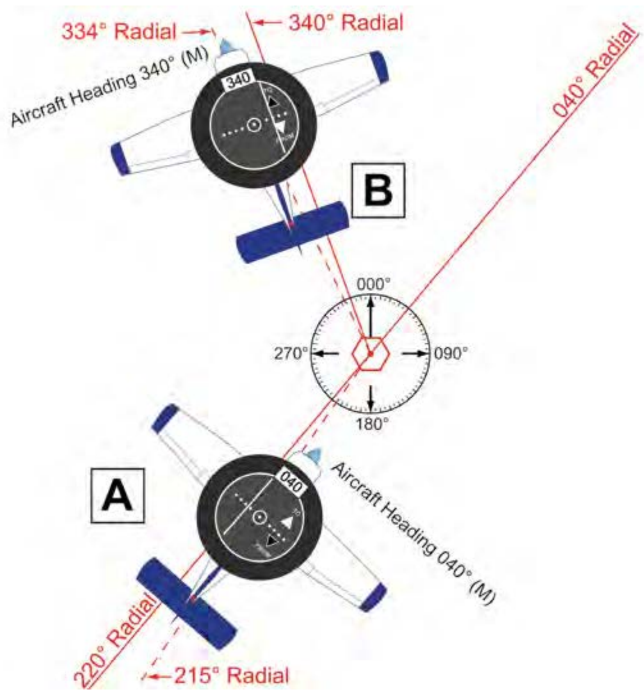

Figure 17.15 The CDI indicates angular deviation from the desired track (i.e. the selected radial). Whenever the aircraft is flying on a heading the same as or similar to the selected radial, the CDI acts as a demand indicator.

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You should note that when showing a deviation from a desired radial, the CDI also acts as an indicator of which way the pilot must alter heading to regain the selected radial.

Whenever the aircraft is flying on the same heading, or on approximately the same heading, as that selected on the OBI against the radial indicator, the CDI acts as a demand indicator.

This means that with the aircraft heading in, or approximately in, the direction selected on the OBI, if the CDI is out to the left, the pilot must alter heading left to regain the desired track, and with the CDI out to the right, the pilot must turn right to regain track.

In *Figure 17.15*, the aircraft in Position A is flying a heading identical to the track selected on the OBI, and so must turn left to regain the selected track.

The aircraft in Position B is 6° to the left of its selected track of 340° (M), and because it is also heading 340° (M), and the CDI is over to the right, the pilot must turn to the right to regain his desired track.

If you are not on the VOR radial you have selected, it is a good rule of thumb to alter heading towards the desired radial by twice the track error, so if you were **5°** to the right of track, as depicted by Position A in *Figure 17.15*, you might elect to alter heading by 10° to the left and steer 030° (M), and, then, just before the CDI reaches its central position again, turn back onto 040° (M). If there were a crosswind, you would obviously need to lay off an appropriate wind correction angle, in order to maintain the selected radial. Your flying instructor will teach you the flying techniques involved in tracking to or from a VOR beacon.

Bear in mind that, when going towards a beacon, you must have **TO** displayed, and when going away, **FROM**; otherwise the CDI operates in the reverse sense. A useful rule to remember is to set '**T**rack at the **T**op' of the OBI.

Intercepting a Desired Radial.

Having looked at how a pilot may determine what radial he is on, relative to a selected VOR beacon, and how he might then track directly to the VOR beacon, let us take a brief look at how VOR tracking may be used to assist a pilot with his visual navigation.

Let us assume that you are planning a visual navigation flight from Swansea to Welshpool. Flying the direct route will take you over mountainous terrain, with few good ground features to serve you as visual fixes, en-route. You, therefore, elect to fly a dog leg and to track approximately 050° (M) from Swansea, intercept a suitable radial from the Brecon VOR/DME just north of the gliding site of Talgarth, and then track outbound from the VOR towards Welshpool. (*See Figure 17.17, p318*).

Consult your own copy of the 1:500 000 chart of Southern England and Wales, (with the route Swansea - Welshpool - via Brecon/Talgarth drawn on the chart), as you read through the following paragraphs.

Brecon has a Distance Measuring Equipment (DME) facility co-located with the VOR beacon, so you will be able to pinpoint your position on the VOR radial at any time. The DME instrument and receiver in your aircraft may also give you a groundspeed

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Figure 17.16 The Brecon VOR/DME and its location on the 'half-mil' chart.
(Photo by kind permission of Trevor Diamond –www.trevord.com).

readout while you are tracking along the radial that leads to Welshpool, so that will be another vital piece of information to help you with your visual navigation and ETAs. Welshpool is about 55 nautical miles (nm) from the Brecon VOR/DME, but you have read from the En-Route (ENR) Section of the UK AIP that the Brecon VOR has a range of 65 nm, so that should be OK. In any case, at about 10 nm from Welshpool, you should be able to get a reliable signal from the Welshpool NDB to help you locate the airfield. You have checked the range of the Welshpool NDB in the Aerodrome (AD) Section of the AIP, and seen that it is 10 nm. You note, too, that Welshpool has a DME with a range of about 15 nm.

Because you will be flying over mountainous terrain you elect to fly at Flight Level 50. At that level, you should not suffer from terrain errors with either radio-navigation aid, although you have noted the warnings in the AIP concerning range and reception at Welshpool being affected by the surrounding high terrain. If the ambient pressure is within the normal range, Flight Level 50 will also put you well over 1 000 feet above the highest obstacle known to be en-route.

We will assume that the wind at Flight Level 50 is 230º/20 knots.

During your flight planning, you measure from the 1:500 000 Chart that the radial you require to intercept from Brecon VOR/DME, and along which you may track directly to Welshpool, is the 007° (M) radial. You note that as you will be tracking 007°(M), your chosen Flight Level of 050 is also in accordance with the Quadrantal Rule. Although your flight is a VFR navigation flight, and you are not legally required to fly the Quadrantal Rule, doing so is recommended by the UK CAA and is good airmanship.

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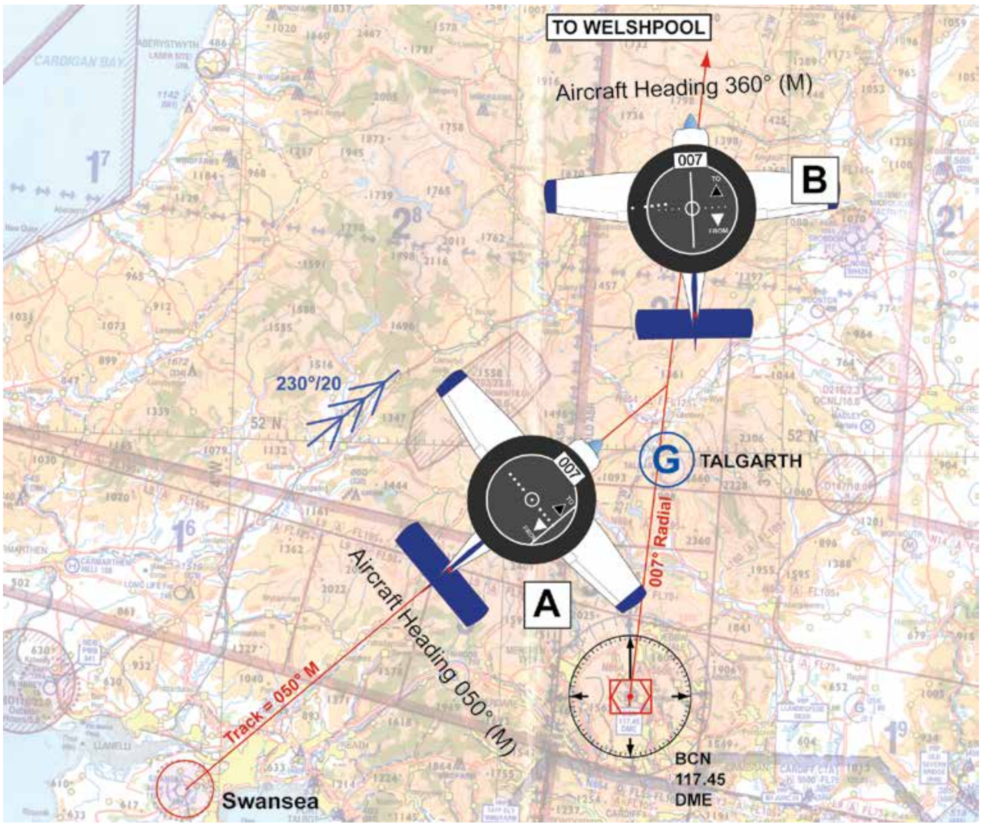

Figure 17.17 Intercepting and maintaining a track of 007°(M) from the Brecon VOR/DME with a wind of 230°/20 knots.

Check for yourself all the basic flight planning considerations mentioned above by referring to your own copy of the 1:500 000 Chart of Southern England and Wales.

During the flight itself, provided everything works out as planned and provided you have set up your OBI correctly, you should expect the OBI to begin to respond about 4 or 5 nm beyond the town of Brecon as you track 050° (M) from Swansea. You wish to track along the 007° radial from the Brecon VOR, so, after having tuned your VOR receiver to Brecon (currently on 117.45MHz), and confirmed the expected morse identification code (BCN), you will have selected 007° against the radial indicator of the OBI. Because, when you are overhead the town of Brecon on a track of 050°(M), intercepting a 007°(M) track relative to the VOR beacon would lead you away from the beacon, the FROM flag will be showing, and the OBI is correctly set up for what you are planning to do, with the CDI acting as a demand indicator. As you close on the 007° radial from the Brecon VOR, you will be within 10° of that radial (i.e. 10° to the left of the radial) as you pass the 1093 feet spot height on your starboard side. The CDI will show, therefore, that you need to continue converging with the 007° radial from left to right. The CDI, being a demand indicator, in this OBI configuration, will, thus, be over to the right of the horizontal deviation scale “demanding” that you fly right. (*See Figure 17.17* Position A.)

As you are on a track of 050°(M), you are already converging with the 007° radial from left to right, so you continue on track. From **Position A** in *Figure 17.17* you will quickly close with the radial, especially given that you have a tail wind of 20 knots. The CDI will, therefore, quickly move towards the central position on the OBI. As the CDI reaches the right hand side of the inner circle showing that you are 2° to the left

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of the 007° radial, you begin a gentle turn to the left onto a suitable heading which will enable you to track 007° (M) away from the VOR beacon towards Welshpool. As the wind is from 230° (T) at 20 knots, you know that you will need to adopt an appropriate wind correction angle to maintain the track of 007°(M) once you are established on it. With no wind, you could simply head 007°(M), but life is rarely that simple. Therefore, you make any fine adjustments required to establish yourself on the 007° radial and then lay off the drift by a suitable amount.

You learned earlier in this chapter how to establish yourself on a VOR radial, and in Chapter 9 you learned how to correct for drift. So, if your true airspeed were to be 120 knots, you would have already calculated that the maximum drift you would experience in a 20 knot wind would be 10°. With a wind from 230° (T) (say, 233°(M)), then, your track of 007° (M) will mean that the wind is meeting your track at about 45° from behind. This means that you will be experiencing ¾ of the maximum drift; that is, a drift angle of about 7° or 8°. The drift will be to starboard, so you quickly work out that turning left by, say, 7° onto a heading of 360° (M), or, otherwise expressed, 000°(M), should enable you to stay on the 007° radial from Brecon VOR. You also work out, using the mental dead reckoning (MDR) techniques that you have mastered, that, with the wind from behind you at 45°, you will have a tailwind component of 15 knots (¾ x 20 knots), giving you a groundspeed of 135 knots. You will be able to check your MDR calculations from the read-out of groundspeed on your DME display.

Your flying instructor will teach you the airborne techniques of intercepting and maintaining a track along a selected VOR radial.

Fixing Position using Radio-Navigation Aids.

Using the knowledge you have learnt in this and preceding chapters, you should readily appreciate that you may fix your position over the ground, by using two selected radio-navigation aids and an aeronautical chart.

Provided you have the necessary airborne equipment, you may fix your position using a VOR/DME, two VORs, a VOR and an NDB, or two NDBs, in order of preference,, as depicted in *Figure 17.18.* Note that the ideal cross-cut between position lines is a right angle, which a VOR/DME fix will automatically provide. For a two-beacon fix, if tracking along a radial, choose a second beacon as nearly as possible abeam the aircraft.

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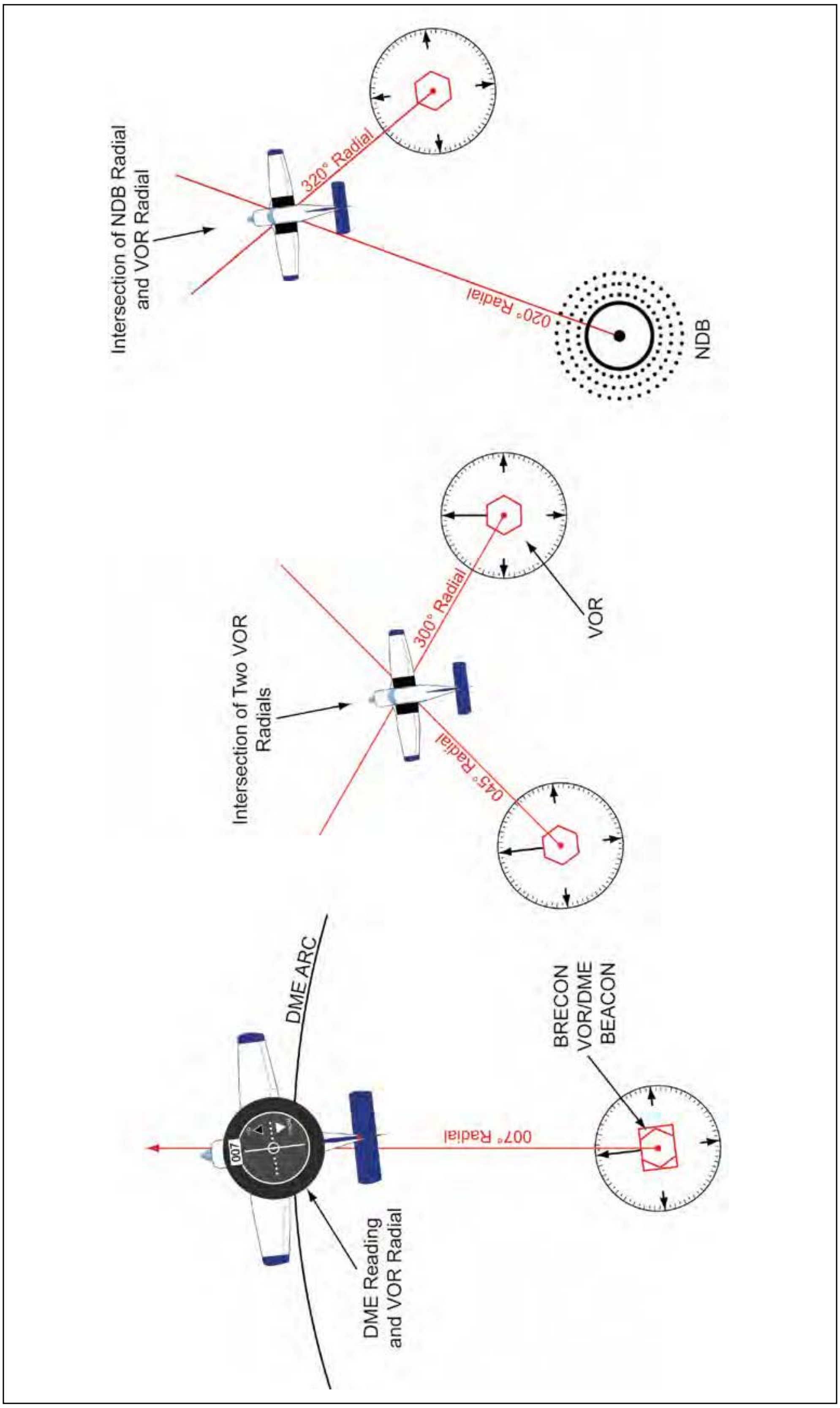

Figure 17.18 Fixing position using different combinations of radio-navigation aids.

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Establishing a Position Line When Passing Abeam a VOR Beacon.

During a visual navigation flight, noting the time at which you pass at 90° abeam a VOR beacon, or any radial required for a specific fix, is a useful procedure for monitoring the progress of the flight. (*See Figure 17.19*)

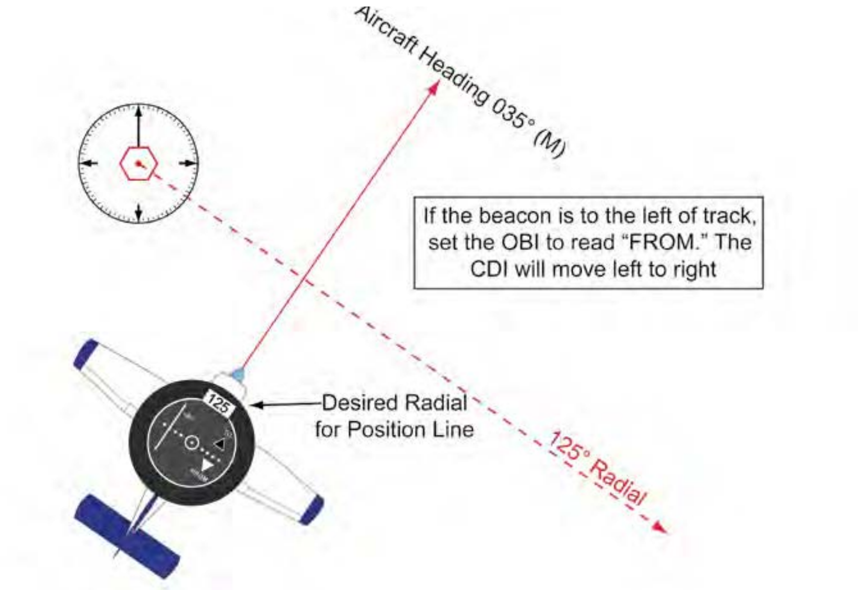

Figure 17.19 Setting up an OBI so that the pilot knows when he is passing 90° abeam a VOR beacon. If the beacon is to the left of track, select the radial FROM the beacon. The CDI will then move from left to right as you pass abeam the beacon.

When using a VOR in this way, it is convenient to set up the OBI so that the CDI always moves in the same direction, say from left to right, as the aircraft passes abeam the VOR beacon, so that you are always aware when the aircraft has passed abeam and not left wondering whether the CDI has yet moved or not, because you cannot remember which side of the OBI it was on to start with. This simple procedure - of the CDI always moving from left to right - is easy to set up.

If the VOR beacon is to the left on your track, select on the OBI, using the OBS, the radial from the VOR beacon at which you wish to take your fix (usually the radial running at 90° to your track). The FROM flag will then be displayed and the CDI will be over to the extreme left of the OBI until you arrive within 10° of the selected radial. This situation is depicted in *Figure 17.19.* The CDI will, then, begin to move from left to right. As it passes through the centre of the OBI you are exactly abeam the VOR beacon or crossing your chosen radial, and the time at which you reach that position line is a good check on the progress of your flight.

If the VOR beacon is to the right on your track, using the OBS, you select on your OBI the reciprocal of the radial at which you wish to take your fix (and, again, this will probably be the radial running at 90° to your track). Confirm that the TO flag is displayed. By doing this, the CDI will again be over to the extreme left of the OBI until you arrive within 10° of the selected radial. This situation is depicted in *Figure 17.20, overleaf*. The CDI will then begin to move from left to right. As before, when the CDI passes through the centre of the OBI you are crossing the radial.

This technique is known as the' Port Published Rule' - if the beacon is to **P**ort, use the **P**ublished radial, if it is to the **R**ight, use the **R**eciprocal.

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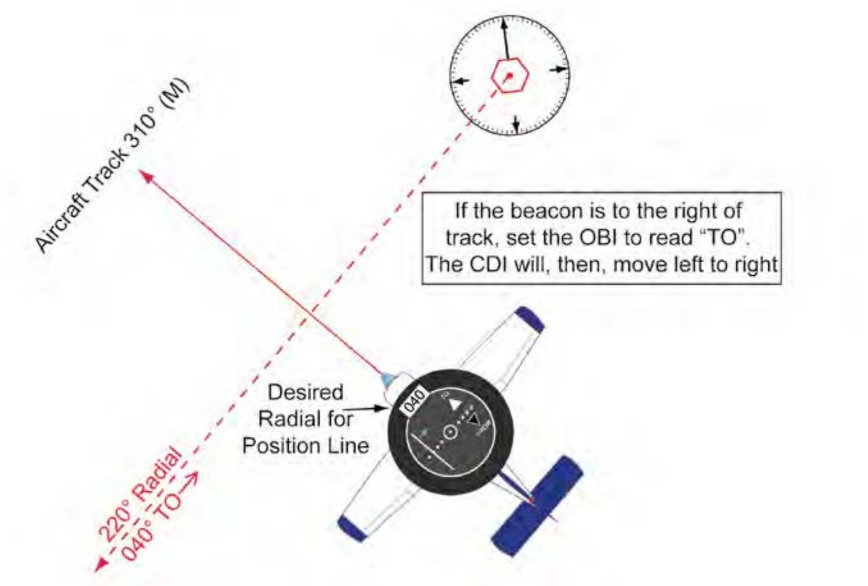

Figure 17.20 Setting up an OBI so that the pilot knows when he is passing 90° abeam, a VOR beacon. If the beacon is to the right of track select the radial TO the beacon. The CDI will then move from left to right as you pass abeam the beacon.

TYPES OF VOR.

There are various types of VOR. A brief description of each type is given below.

Broadcast VOR (BVOR).

A **Broadcast VOR** gives weather and airfield information **(ATIS)**.

Doppler VOR.

A **Doppler VOR** has improved bearing accuracy.

Terminal VOR.

A **Terminal VOR** has low power and is used at major airfields, usually as a **locator** in conjunction with an **Instrument Landing System (ILS)** or for a VOR approach procedure.

VORTAC.

Co-located **VOR** and **TACAN** beacons. **TACAN** stands for **Tactical Air Navigation** and is military equipment fulfilling, in the civil and general aviation world, a similar function to **VOR/DME**.

FACTORS AFFECTING THE OPERATIONAL RANGE OF VOR BEACONS.

Transmitter Power.

The higher the transmitter power of the VOR beacon, the greater the range of the VOR signals. Thus, en-route VORs with a 200 Watt transmitter will have a maximum range of about 200 nm, while a terminal VOR will normally transmit at 50 Watts to give a maximum range of about 100 nms.

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Transmitter Elevation and Receiver Height.

The transmitter elevation and receiver altitude will also have an effect on the operational range of VOR beacon. The transmissions, being VHF transmissions are line of sight. The range of VHF signals can be assessed by using the following formula:

Signal Range = 1.25 $(\sqrt{h_1} + \sqrt{h_2})$ nautical miles.

where h_1 is receiver altitude in feet
and h_2 = transmitter elevation in feet

Uneven terrain, intervening high ground, mountains, man-made structures, and so on, cause VOR bearings to be stopped (screening), reflected, or bent (scalloping), all of which give rise to bearing errors. Where such bearing errors are known to exist, Air Information Publications will publish details.

APPROACHING AND FLYING OVERHEAD A VOR BEACON.

In the proximity of the VOR beacon, the radials are very close together, so as an aircraft approaches the beacon, a CDI, which is indicating that the aircraft is on a selected radial, becomes very sensitive, and will indicate large angular deviations from the selected radial, whenever an aircraft strays from track. Near the beacon, then, it is very important for a pilot to hold a steady heading. As the VOR-overhead is approached, the CDI may oscillate rapidly, and the 'OFF' flag may appear momentarily.

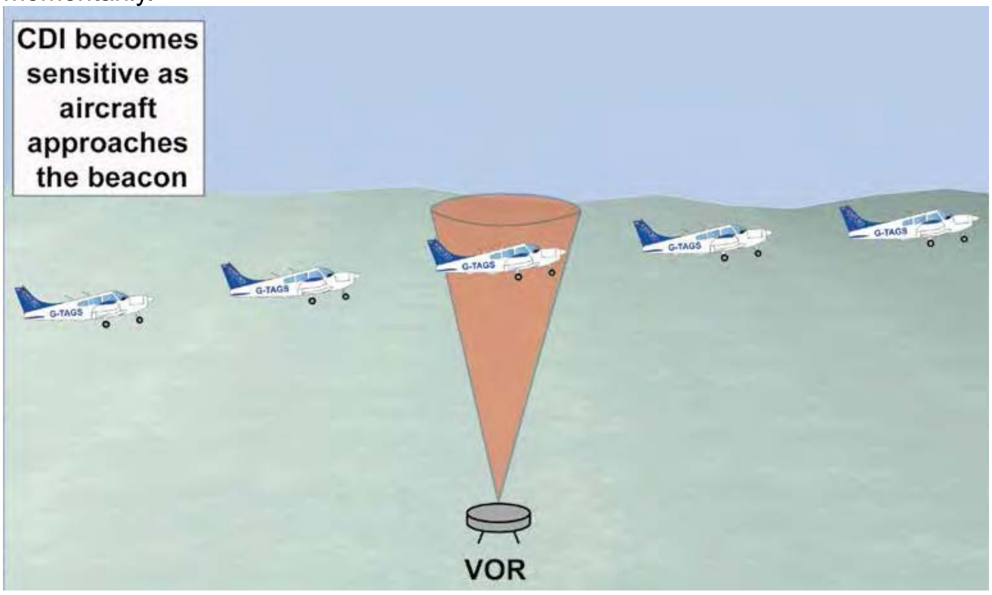

Figure 17.21 The Cone of Silence or Cone of Ambiguity.

The CDI will behave in this manner in the VOR overhead, because no signals are being sensed by the aircraft's VOR receiver directly overhead the beacon. For this reason, the cone overhead the beacon is known as the cone of silence, or cone of ambiguity.

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DESIGNATED OPERATIONAL COVERAGE.

In order to guarantee that there is no interference between VOR beacons operating on the same frequency, known as co-frequencies, among the 160 frequencies available worldwide, it would be necessary to separate co-frequency beacons by at least twice their anticipated line-of-sight range. Transmitter power, propagation paths and the degree of co-frequency interference protection required necessitate that co-frequency beacons be separated for planning purposes by a greater distance.

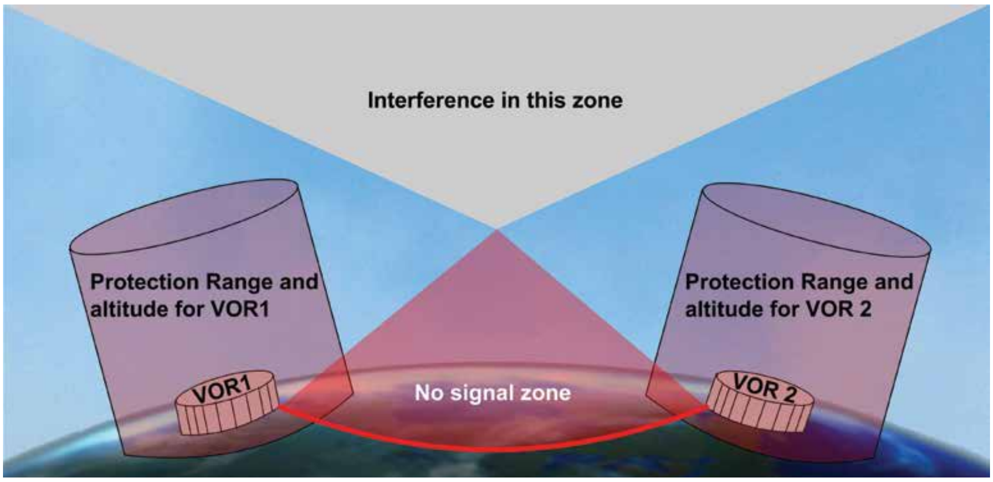

Figure 17.22 Designated Operational Coverage of two VOR beacons.

In the United Kingdom, this protection is denoted by **Designated Operational Coverage (DOC)** figures, specified as a range and altitude. For example, a **DOC** of **50/25000** published in the UK AIP means that an aircraft should not experience co-frequency interference within 50 nms of a VOR beacon, up to a height of 25 000 feet. The DOC may also vary by sectors, (e.g. in the sector 315° to 345° from the beacon.).

Use of VOR beacon beyond its DOC can lead to navigation errors.

FACTORS AFFECTING VOR ACCURACY.

Site Error.

Site error is caused by uneven terrain such as hills and man-made structures, trees and even long grass, in the vicinity of the VOR transmitter. The error to radiated bearings is termed VOR course-displacement error. Ground VOR beacon site error is monitored to **± 1°** accuracy.

Propagation Error.

Propagation error is caused by the fact that, having been broadcast with **±1°** accuracy, the transmissions are further affected by terrain and distance. At considerable range from the VOR, bending or scalloping can occur.

Scalloping.

VOR scalloping is defined as an imperfection or deviation in the received VOR signal. Scalloping causes radials to deviate from their standard track and is the result of reflections from buildings or terrain. Scalloping can also cause the Course Deviation Indicator to flick from side to side.

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Airborne Equipment Errors.

Airborne equipment errors should be within a maximum of **+/- 3°**.

Aggregate Errors.

The above errors combine (or **aggregate**), to give a total error of **+/- 5°**. This will give a 5 nm across-track error at a range of 60 nm. (1 in 60 Rule)

Variation.

Variation is set at the ground station by the technicians, but if not updated frequently,as in the UK, can give rise to bearing errors. The rate of change of variation in the UK at present is -7'/year, but in some parts of the world is significantly higher.

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Representative PPL - type questions to test your theoretical knowledge of VHF Omni-Directional Range (VOR).

1. A VOR radial is most accurately defined as:

    a. A magnetic bearing from the VOR station
    b. A true bearing from the VOR station
    c. A magnetic bearing to the VOR station
    d. A true bearing to the VOR station

2. What is the approximate theoretical maximum range that a pilot would obtain from a VOR situated at 400 feet above mean sea level, in an aircraft flying at 2 500 feet?

    a. 3750 feet
    b. 100 nm
    c. 88 nm
    d. 70 nm

3. In which of the radio frequency bands does VOR operate?

    a. Ultra High Frequency
    b. Very High Frequency
    c. Low Frequency
    d. Micro Frequency

4. In what frequency range does VOR operate?

    a. 118 MHz to137 MHz
    b. 190 to 1750 kHz
    c. 1000 to 2000 MHz
    d. 108 MHz to 117.95 MHz

5. Which of the following phenomena does not affect VOR reception?

    a. The terrain surrounding the VOR beacon
    b. Transmitter elevation and receiver altitude
    c. The cone of ambiguity overhead a VOR beacon
    d. Coastal Refraction

6. For which of the following purposes may VOR be used?

    a. To fly certain approach procedures
    b. Identification of aircraft track by ATC controllers
    c. Identification of individual aircraft by ATC controllers
    d. The interpretation of heading guidance from radar controllers

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7. What is the normal maximum aggregate error of a VOR system ignoring pilot error?

   a. +/- 2°
   b. +/- 5°
   c. +/- 1°
   d. +/- 3°

8. Which of the following instruments cannot incorporate VOR indications?

   a. Horizontal Situation Indicator
   b. Radio Magnetic Indicator
   c. Direction Indicator
   d. Omni Bearing Indicator

9. What is the function of the Course Deviation Indicator in a VOR OBI?

   a. To point in the direction of the VOR beacon
   b. To select the desired VOR radial on the OBI
   c. To indicate an aircraft's angular deviation from a selected VOR radial
   d. To align itself with Magnetic North when synchronized with the compass

10. When the OBI is correctly set up under certain circumstances, the CDI acts as a 'demand indicator.' What does this mean, and what are the circumstances?

   a. When the aircraft is heading in approximately the direction of the track selected on the OBI, if the CDI is to the left of centre it is indicating to the pilot to turn right to intercept the selected track, and if it is to the right of centre it indicates to the pilot that he should turn left to regain the selected track

   b. When the aircraft is heading in approximately the reciprocal direction of the track selected on the OBI, if the CDI is to the left of centre it is indicating to the pilot to turn left to intercept the selected track, and if it is to the right of centre it indicates to the pilot that he should turn right to regain the selected track

   c. When the aircraft is heading at approximately 90° to the direction of the track selected on the OBI, if the CDI is to the left of centre it is indicating to the pilot to turn right to intercept the selected track, and if it is to the right of centre it indicates to the pilot that he should turn left to regain the selected track

   d. When the aircraft is heading in approximately the direction of the track selected on the OBI, if the CDI is to the left of centre it is indicating to the pilot to turn left to intercept the selected track, and if it is to the right of centre it indicates to the pilot that he should turn right to regain the selected track

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11. When will an OBI indicate FROM?

    a. When the radial selected on the OBI is equal to, or approximately equal to, the aircraft's heading, and that heading will take the aircraft away from the VOR beacon

    b. When the radial selected on the OBI is equal to, or approximately equal to, the reciprocal of the aircraft's heading, and that heading will take the aircraft away from the VOR beacon

    c. When the radial selected on the OBI is equal to, or approximately equal to, the aircraft's heading, and that heading will take the aircraft towards the VOR beacon

    d. When the radial selected on the OBI is equal to, or approximately equal to, the reciprocal of the aircraft's heading, and that heading will take the aircraft towards the VOR beacon

12. When will an OBI indicate TO?

    a. When the radial selected on the OBI is equal to, or approximately equal to, the aircraft's heading, and that heading will take the aircraft away from the VOR beacon

    b. When the radial selected on the OBI is equal to, or approximately equal to, the reciprocal of the aircraft's heading, and that heading will take the aircraft away from the VOR beacon

    c. When the radial selected on the OBI is equal to, or approximately equal to, the aircraft's heading, and that heading will take the aircraft towards the VOR beacon

    d. When the radial selected on the OBI is equal to, or approximately equal to, the reciprocal of the aircraft's heading, and that heading will take the aircraft towards the VOR beacon

13. A pilot is instructed to track inbound to a VOR beacon on the 120° Radial. What track will he select on the OBI in order that he can use the OBI to intercept that radial, with the TO flag showing, and what heading will he fly along the radial, assuming no wind?

    a. 120° and 120° Magnetic
    b. 120° and 300° Magnetic
    c. 300° and 300° Magnetic
    d. 300° and 120° Magnetic

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14. A pilot is instructed to track outbound from a VOR beacon on the 270° Radial. What track will he select on the OBI in order that he can use the OBI to intercept that radial, with the FROM flag showing, and what heading will he fly along the radial, assuming no wind?

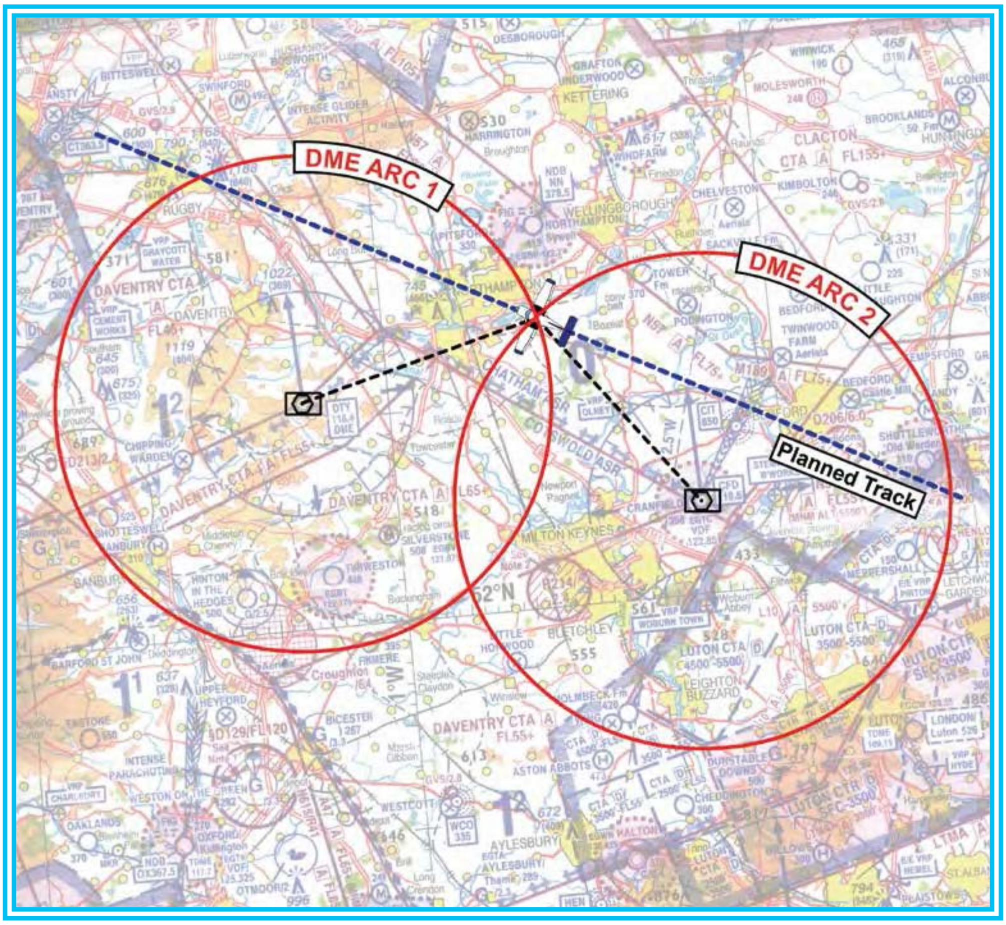
a. 270° and 270° Magnetic
b. 090° and 270° Magnetic
c. 270° and 090° Magnetic
d. 090° and 090° Magnetic

Question	1	2	3	4	5	6	7	8	9	10	11
Answer											

Question	12	13	14
Answer			

The answers to these questions can be found at the end of this book.

CHAPTER 18
DISTANCE MEASURING EQUIPMENT (DME)



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INTRODUCTION.

You have learned that a pilot may fix his position by taking bearings from two NDBs, two VOR beacons, or from an NDB and a VOR beacon. However, for the pilot-navigator, operating alone, such a procedure is inconvenient. Nowadays, though, most VOR beacons are co-located with a second radio-navigation device called **Distance Measuring Equipment (DME)**. DME also operates through 360° and enables the pilot to establish the distance of his aircraft from the VOR/DME beacon along any selected radial, so that he can fix his position precisely. The DME itself works on the secondary radar principle, and the equipment fitted to the aircraft is an interrogator which measures the time taken by signals to travel from the aircraft to the beacon and back again, in order to measure range.

Figure 18.1 Aircraft DME Display and Controls.

As well as giving the distance from the beacon, the DME display in the aircraft may also show an aircraft's groundspeed and the time required to arrive overhead the beacon. The groundspeed shown is meaningful only when the aircraft is tracking directly to or from the station, and the time required readout is only meaningful when the aircraft is tracking directly to the station, since the equipment calculates groundspeed and time from the rate of change of distance..

The groundspeed shown is only meaningful when the aircraft is tracking directly to or from the station, and the time required readout is only meaningful when the aircraft is tracking directly to the station.

OBTAINING AN ACCURATE POSITION FIX.

By selecting a desired radial from a VOR beacon and reading distance from a co-located DME, the pilot obtains an accurate fix, giving him his exact position.

Figure 18.2, overleaf, shows an aircraft approaching a VOR/DME beacon on the 180° radial. As the pilot is tracking to the beacon, he has selected the reciprocal radial, 000°, on his OBI, and so the TO flag is showing.

The pilot can read from his DME display that the distance of his aircraft from the VOR/DME beacon is 15 nautical miles (nm), that his groundspeed is 120 kts and that the time required to reach the station is 7.5 minutes.

The radial on which an aircraft is positioned relative to the VOR/DME beacon is in degrees magnetic, so as the compass rose around the beacon is aligned on Magnetic North, the radial can easily be drawn or estimated by eye. On the

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1:500 000 aeronautical chart, one inch is about 7 nautical miles and the average distance between the knuckle of the thumb and the tip of the thumb is about 10 nm, while a hand span is about 55 nm. So, with or without a rule, distance along a radial can be estimated on the chart to confirm a ground position.

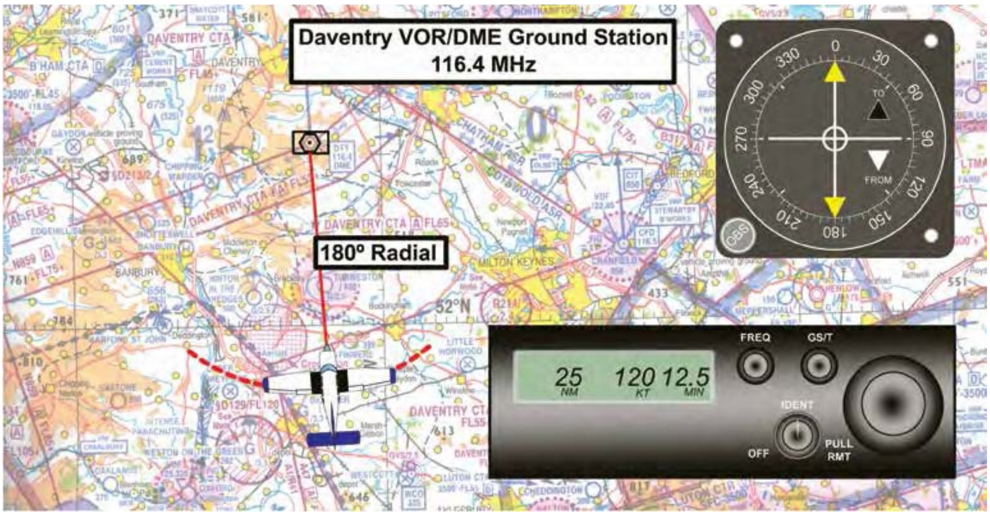

Figure 18.2 DME Position Fix.

An aircraft's position can be established by identifying the intersection of two DME circular position lines, provided ambiguity is resolved.

If the on-board DME display has no groundspeed readout, an aircraft's groundspeed can, nevertheless, be easily calculated when flying directly to or from a VOR/DME beacon. The pilot simply times the interval between two DME range readings and carries out a mental calculation.

For example if, in the time of **1 min**, the aircraft has travelled **1.5 nm** directly towards the beacon the groundspeed of the aircraft will be **60 x 1.5 = 90 knots**.

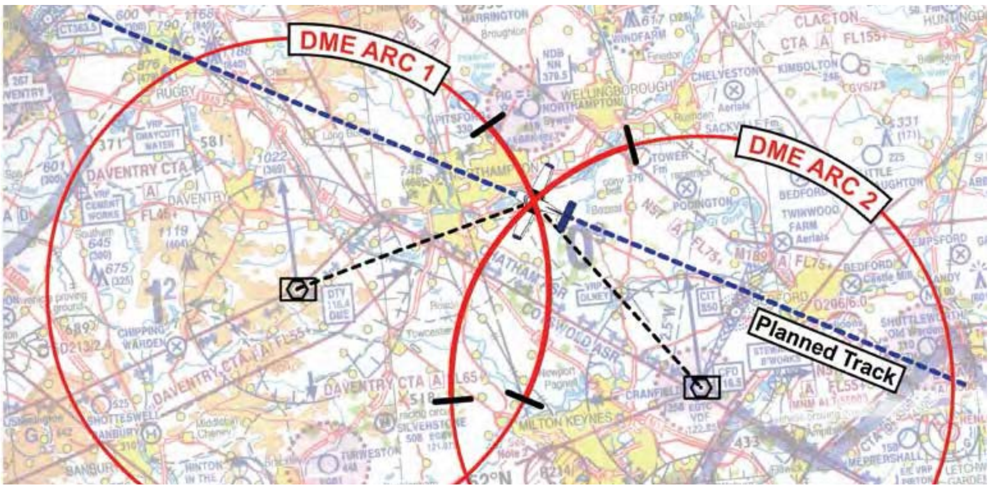

Figure 18.3 Determining position by taking two DME range readings.

A DME "position line" is the circumference of a circle, the centre of which is the DME beacon.

Because the DME read-out in the cockpit indicates distance from the ground station, but not direction, a DME position line is the circumference of a circle, the centre of which is the DME beacon. (*See Figure 18.3.*) When en-route, therefore, a pilot can obtain a reasonably accurate position fix by ascertaining the range of his aircraft from 2 separate DME stations. The aircraft's position is at the intersection of the two circles. Note, however, that the circles will usually intersect at two points, giving rise to an ambiguity which must be resolved by a third position line, particularly if both DMEs are on or near the aircraft's fore and aft axis.

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DME ARCS LEADING TO AN INSTRUMENT APPROACH.

The curved path of a DME arc is often used as a transitional path from the en-route phase of a flight to an instrument approach procedure.

DME can also be paired with centreline localisers in instrument landing systems (ILS), so that a pilot knows his distance from touch down.

DME OPERATING FREQUENCIES.

DME operating frequencies fall within the UHF range of **962 - 1213 MHz**. However, these frequencies are not directly selectable. The DME control unit in the DME receiver has an associated VHF frequency selector and the DME frequency is paired with the co-located VOR beacon's VHF frequency.

SLANT RANGE CONSIDERATIONS.

DME measures the slant distance of an aircraft from the ground station. Though the slant distance from a beacon is slightly greater than the horizontal distance, in practice the distances are close enough for the purpose of navigation. For instance, an aircraft at 3000 feet and a horizontal distance of 15 nm from a DME beacon would subtend an angle of only 2º at the DME station. At this angle, the slant distance between the aircraft and the beacon would be 15.01 nm. The difference between the horizontal and slant distances would, therefore, be only 0.01 nm.

DME measures the slant distance of an aircraft from the ground station. For practical navigation purposes, the difference between slant range and horizontal range is negligible.

When the aircraft in *Figure 18.4* is overhead the ground station, the horizontal distance will, of course, be zero, although the DME display will indicate about 0.5 nm. While the position overhead the beacon is the position of greatest error, 0.5 nm is a negligible value and can be ignored. The groundspeed indication, however, will reduce to a very low figure in the overhead, so is unreliable within a couple of miles of the overhead.

Figure 18.4 For practical, navigation purposes, the difference between slant range and horizontal range is negligible.

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PRINCIPLE OF OPERATION.

Secondary Radar.

DME works on the secondary radar principle which is covered in Chapter 20. For the purpose of this chapter, it is sufficient for you to note that the DME ground station is equipped with a type of transponder which responds to interrogation signals from aircraft tuned to the DME beacon's frequency.

An aircraft sends out an interrogating pulse, and the ground station responds by re-transmitting a strong answering signal which is received in the aircraft. The DME receiver on board the aircraft converts this signal, using simple speed and time formulae, into a digital readout of distance in nautical miles.

Range and Coverage.

DME transmissions are subject to the line-of-sight rule.

DME transmissions are subject to the line-of-sight rule. Thus, the higher the aircraft and the ground station, the greater the theoretical reception range. The formula for calculating the maximum line-of-sight range is the same as that given for VHF signals from a VOR beacon, in Chapter 17.

Of course, if there is intervening high ground, in order to receive DME readings an aircraft will have to be at higher altitude than that suggested by the maximum range formula.

If we assume that the elevation of the DME beacon is negligible (i.e. near sea level) the range formula simplifies to:

DME range = 1.25 x $\sqrt{\text{aircraft altitude}}$.

Range errors may also be caused by co-channel interference from 2 or more ground beacons having the same frequency. A designated operating area is published in the ENR section of the UK AIP for all DME stations within which co-channel interference is unlikely to be experienced.

Accuracy.

DME is very accurate. The total system error should be no more than +/- 0.2 nm for recently manufactured aircraft.

DME is very accurate. The total system error should be no more than +/- 0.2 nm for recently manufactured aircraft. For older aircraft, registered before 1 Jan 1989, the error is 0.25 nm + 1.25% of the range. Slant error is significant only when the aircraft's range is less than 3 times its height above the beacon.

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Representative PPL - type questions to test your theoretical knowledge of Distance Measuring Equipment (DME).

1. The accuracy of DME equipment fitted to a modern aircraft is:

   a. ± 3% of range or 0.5 nm whichever is the greater
   b. ± 1.25% of range
   c. ± 3% of range
   d. ± 0.2 nm

2. What condition must prevail for DME equipment on an aircraft's instrument panel to give a usable groundspeed reading?

   a. The aircraft must have the DME ground station on its port beam
   b. The aircraft must have the DME ground station on its starboard beam
   c. The aircraft must be heading directly towards the ground station
   d. The aircraft must be heading directly towards or away from the ground station

3. In a time interval of one minute, your DME instrument shows that your aircraft has travelled 1.7 nautical miles directly towards a VOR/DME beacon, what is the groundspeed of the aircraft?

   a. 102 knots
   b. 110 knots
   c. 96 knots
   d. 100 knots

4. On which of the following principles does Distance Measuring Equipment function?

   a. The principle of VHF direction finding
   b. The principle of primary radar
   c. The principle of secondary radar
   d. The principle of VHF omni-directional ranging

5. The DME instrument in the aircraft gives the ……………. distance read out from the beacon.

   a. Horizontal
   b. Slant
   c. Oblique
   d. Return

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6. What is the nature of a DME "position line"?

   a. It is the circumference of a circle, centred on the ground beacon whose radius is the distance of the aircraft from the beacon
   b. It is a radial emanating from the ground beacon whose length is the distance of the aircraft from the beacon
   c. It is a straight position line measured in degrees magnetic
   d. It is a straight line from the ground beacon, which is identified by a Course Deviation Indicator and whose length is the distance of the aircraft from the beacon

7. Give an approximate value for the theoretical maximum range of a DME beacon in respect of an aircraft flying at 3000 feet?

   a. 55 nautical miles
   b. 60 nautical miles
   c. 70 nautical miles
   d. 3000 nautical miles

Question	1	2	3	4	5	6	7
Answer							

The answers to these questions can be found at the end of this book.

CHAPTER 19
RADAR

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INTRODUCTION.

When radar was first developed in Britain, and used to great effect in the defence of the country in World War 2, it was called Radio Direction Finding (RDF). The word "radar" is an American acronym, coined in 1941, which stands for Radio Detection and Ranging. It is the American word which survived - better describing the capability of the system - and became current worldwide.

Radar is based on the principle of transmitting radio waves from a special type of rotating antenna, or radar head *(see Figure 19.1)*, and then detecting the return-signals after they have been reflected from a remote object, as depicted in *Figure 19.2*.

Radar is based on the principle of transmitting radio waves from a ground station and then detecting the return-signals which have been reflected from a "target" aircraft.

Figure 19.1 A terminal area surveillance radar at an airport. The radar head makes approximately 10 rotations per minute.

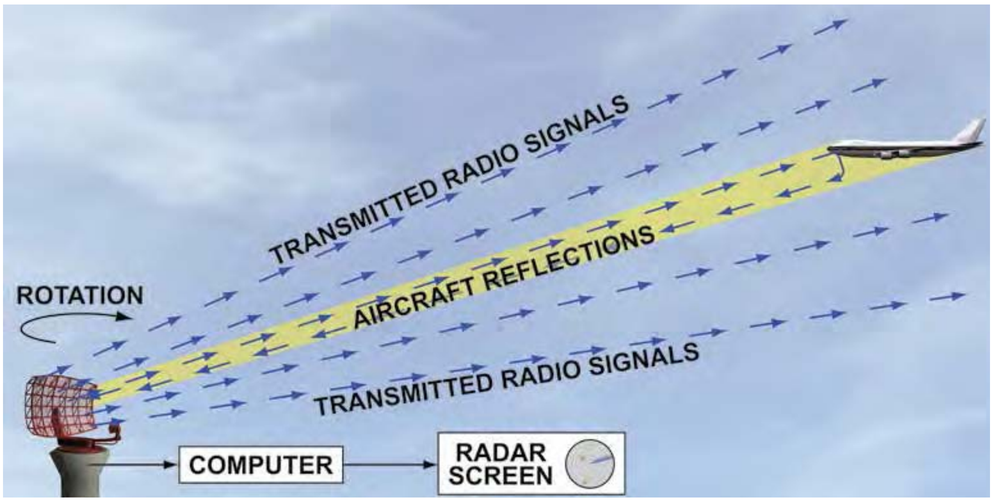

Figure 19.2 Radar is based on the principle of transmitting radio waves, and then detecting the direction and range of the target-object from the reflected signals.

THE PRINCIPLE OF OPERATION OF RADAR.

Radar is able to detect the direction and range of objects at distances from the ground station over which the object is invisible to the human eye, even when aided by powerful telescopes. As the reflected radar signals are received at the ground station, the precise direction of the target object is detected, while the time lapse, from transmit to receive, of the radio signals is also measured to give the range of the target. You have learned about the relationship between speed, distance and time in Chapter 4, and may remember the formula:

distance = speed × time

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Radio waves are electromagnetic waves which travel at the speed of light, so given that light travels at 299 792 458 metres per second, or 161 888 nautical miles (nm) per second, you can see that a computer can instantly calculate the range of an aircraft from the simple expression:

$$\textbf{range in nm} = \textbf{161 888 nm/sec} \times \frac{\textbf{signal out and return time}}{\textbf{2}} \textbf{ secs}$$

PRESENTATION OF RADAR INFORMATION.

One of the primary aims of a radar controller is to keep aircraft safely separated from one another.

The reflected signal from a "target" aircraft appears as a "trace" on the radar screen, enabling an air traffic controller to "see" the aircraft. *(See Figure 19.3.)*

When radar is not available, separation is achieved procedurally, based on position and altitude reports from pilots.

Maps and coastlines within a particular airspace can also be represented on the radar screen so that an air traffic controller can relate the blips on his screen to an aircraft's position over land or sea. The controller can also see the position of aircraft in relation to one another and the direction in which they are flying; this information is used to ensure that the aircraft under his control are kept safely separated from one another.

In the days before radar (or where radar is not available) separation was achieved procedurally, based on position and altitude reports from pilots. This type of separation is called procedural separation.

THE RADAR SCREEN.

The rotating radar head transmits a radio beam which will detect a "target" aircraft when the beam is directed at it. The return from the aircraft is "painted" on the air traffic controller's radar screen as a trace. As the aircraft advances in its flight, the trace also moves across the radar screen, leaving a tail of light behind it, as depicted in *Figure 19.3*. On computer processed radar screens, the **trace** is shown with a trail of dots.

The reflected signals from a "target" aircraft appear as a trace on the controller's radar screen.

From the direction of movement and the trail of the trace, the air traffic controller can see the direction and speed of flight of the target aircraft.

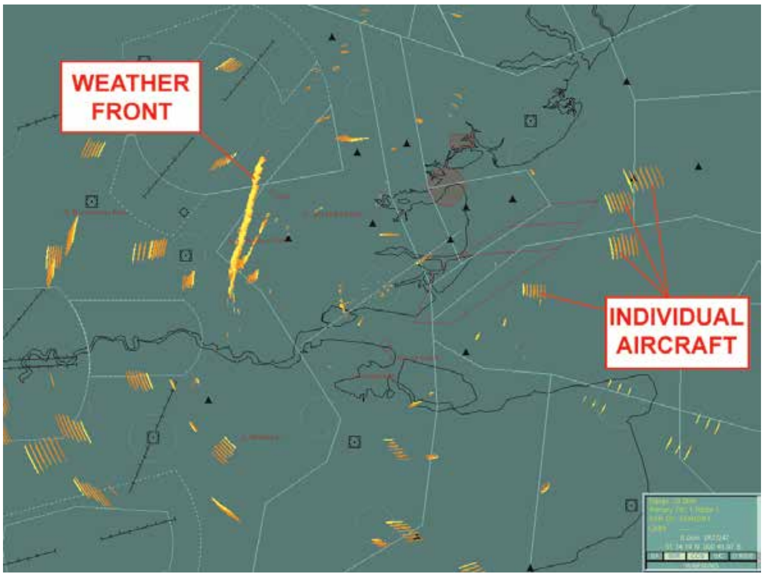

Figure 19.3 Primary Radar returns in the East London area, shown on a radar display of London Southend Airport.
(Photo by kind permission of London Southend Airport Co Ltd.)

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APPLICATIONS OF GROUND-BASED RADAR SYSTEMS.

Ensuring separation between aircraft is a prime responsibility of radar controllers. Other applications of ground-based radar systems are listed below.

- Aircraft under radar control can be instructed to steer given headings, climb, descend, and maintain altitude.

- Aircraft may be “slotted” into to a landing sequence, with adequate spacing, in order to ensure the safety of all on board. In this way, radar systems enable aircraft movements to take place at the speeds required by today’s high-volume air traffic environment without any detriment to safety.

The issuing of instructions to pilots by radar controllers in order that aircraft may avoid conflicting with other traffic, or be led into an instrument or procedural landing system, is known as “radar vectoring”.

- Radar enables a controller to provide pilots of aircraft who may, or may not, be under his direct control with headings to steer (known as radar vectoring) in order to avoid conflict with other aircraft. In the United Kingdom, general aviation pilots may request this type of radar advisory service using the Lower Airspace Radar Service (LARS) provided by certain aerodromes.

- Radar vectors are also given by controllers to pilots in order to lead aircraft into an Instrument Landing System approach.

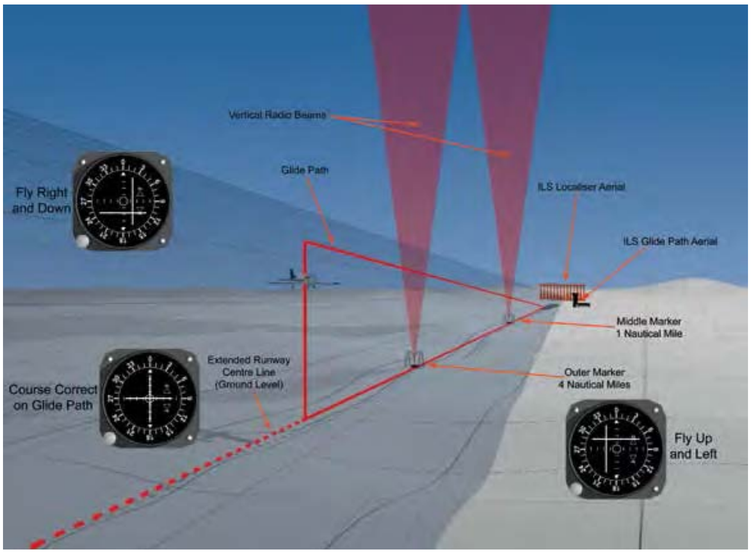

Figure 19.4 Controllers can pass radar vectors to pilots to lead them into an Instrument Landing System procedure.

- The radar controller can provide basic information to pilots about the position and heading of other potentially conflicting traffic. This type of radar information service is a further service provided in the United Kingdom by LARS.

General aviation pilots flying in uncontrolled airspace may benefit from a radar service by requesting a Lower Airspace Radar Service from participating ATCUs.

- Ground radar, or Airfield Surface Movement Radar is used to assure the safety of aircraft and vehicles on runways, taxiways and aprons, particularly in poor visibility.

The previous examples of radar applications fall under the heading of surveillance or primary radar. Primary surveillance radar requires no particular equipment to be carried aboard the aircraft for a pilot to be able to benefit from the radar service.

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The term secondary surveillance radar is used to describe the use of ground radar systems which operate in conjunction with aircraft fitted with specialised equipment known as “transponders”. Secondary surveillance radar is covered in Chapter 20.

USE OF RADAR.

Air Traffic Control Services use radar extensively to serve a large number of requirements and users. The most common radar systems used by ATC are described briefly below.

En-Route Surveillance Radar (RSR).

En-route surveillance radars are long-range radars, typically of 200 to 300 nm range, which are used for airways surveillance to provide air traffic control with the range and bearing of all aircraft flying in airways, within their area of responsibility.

Figure 19.5 **shows the locations and coverage of the London Area Control Centre and the Scottish Area Control Centre radars.**

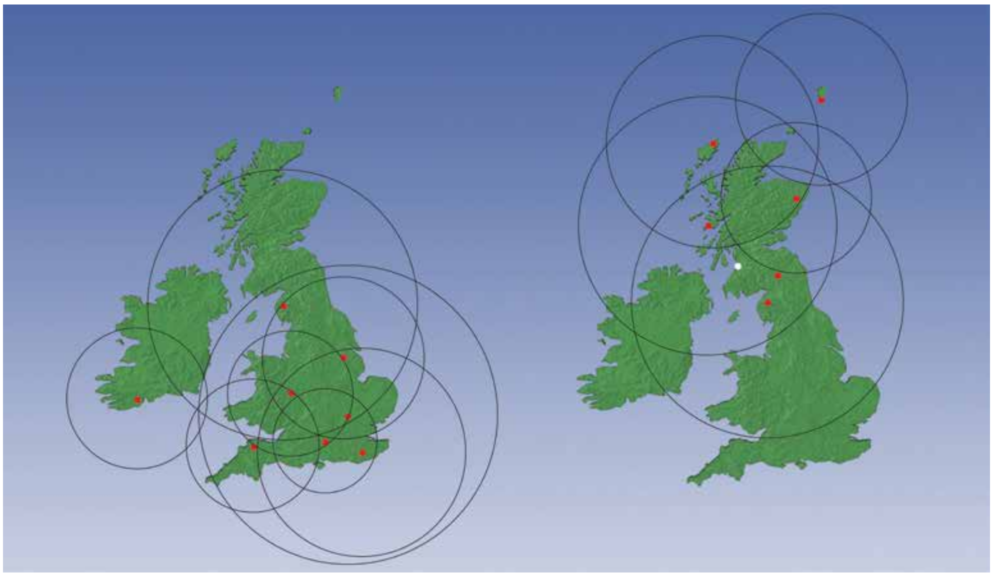

Figure 19.5 En-route surveillance radar.

Terminal Area Surveillance Radar.

Terminal area surveillance radars have a range of up to 75 nm, and are used for controlling traffic in Terminal Areas.

Aerodrome Surveillance Approach Radars.

Aerodrome surveillance approach radars are short-range radars, providing positional information up to 25 nm range. They provide:

- Positional information and control of aircraft approaching an aerodrome.
- Radar vectoring to the final approach of an Instrument Landing System (ILS).
- Surveillance radar approaches.

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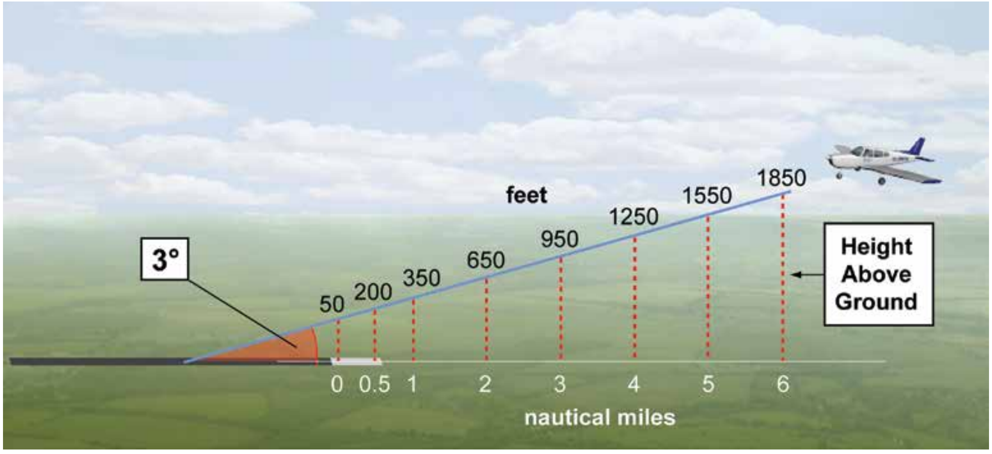

Figure 19.6 A Surveillance Radar Approach.

A surveillance radar approach is a non-precision airfield approach aid. Surveillance radar approaches usually require the aircraft to approach on a 3° glideslope. To maintain a 3° glideslope, the aircraft must lose approximately 300 feet of height for every one nautical mile travelled horizontally. Therefore, if the aircraft's groundspeed is 120 knots (2 nm per minute), it must descend at 600 feet per minute, and, at a groundspeed of 90 knots (1½ nautical miles per minute), an aircraft must descend at 450 feet per minute. Therefore, if carrying out a surveillance radar approach, in order to remain on the glideslope of 3°, the pilot may calculate rate of descent using the following approximate rule:

To descend at an angle of approximately 3°, take your groundspeed in knots (e.g. 90 knots), halve it (45 knots) and add 0 to obtain the required rate of descent of 450 feet per minute.

Halve groundspeed in knots and add "0" to the result to obtain the rate of descent, in feet per minute, which will result in a glideslope of 3°.

Precision Approach Radar (PAR).

Precision Approach Radar is a runway approach aid. precision approach aid which can be aligned with any runway at its base airfield. PAR is only available at certain military airfields.

Airport Surveillance Detection Equipment.

Airport Surveillance Detection Equipment, also known as Airfield Surface Movement Radar, is installed at major airfields. It provides a very accurate radar display, in all weathers and visibilities, of the aerodrome infrastructure: taxiways, runways, aprons etc. *(See Figure 19.7.)* In particular, it shows vehicular traffic and aircraft that are stationary, taxiing, landing or taking off.

Figure 19.7 Airfield Surface Movement Radar.

This type of radar is designed to provide a detailed, bright and flicker-free display of all aircraft and vehicles on runways and taxiways so that Air Traffic Control Officers can be certain that runways

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are clear of traffic before landings or take-offs. Using this surface movement radar, controllers can also ensure the safe and orderly movement of traffic on taxiways; it is especially valuable in very poor visibility.

RADAR FREQUENCIES.

Radar frequencies are VHF and higher, the frequency band for air traffic control radars being in the 1-4 Gigahertz (GHz) range. The short wavelengths at these frequencies mean that signals are transmitted in narrow beams which are required for effective target discrimination and bearing measurement. Furthermore, the reflection of radar transmissions from aircraft is more effective, in terms of clear target discrimination, the greater the difference between the wavelength of the signal and the size of the object being targeted.

In general, the higher the frequency of the radar transmissions, the smaller the object that can be detected by the radar beam.

RANGE.

The range of primary surveillance radar is affected by the following factors.

- Transmitter power. A radar signal attenuates with increasing distance from the transmitter, and, of course, a radar signal has to travel from the transmitter to the target aircraft <u>and back again</u> to the transmitter. The theoretical range of a radar transmitter is proportional to the fourth root of the transmitter power. The higher the transmitter power, the greater the range.

- The properties of the target object. Metal is more effective than wood at reflecting radar signals. The size and shape of the target also affect the effective range of radar. The design of military stealth aircraft exploits all of these parameters.

- Elevation of the radar head and altitude of the aircraft. Radar transmissions, because of their frequency band, travel in straight lines, and, thus, their range is subject to the line-of-sight limitation. Aircraft may be undetectable by radar because of the curvature of the Earth and because they are flying low, and are screened by intervening high ground. The theoretical maximum range of a radar transmitter is, thus, arrived at by using the same formula as that which gives the range of a VOR beacon:

Maximum range in nautical miles = $1.25 \times (\sqrt{h_1} + \sqrt{h_2})$

where h_1 = elevation of radar head in feet
h_2 = altitude of aircraft in feet

- Atmospheric conditions. Certain atmospheric conditions, such as temperature inversions and increasing humidity with altitude, can <u>increase</u> the range of radar by causing beam refraction. Other atmospheric conditions, for instance, very heavy rain, can <u>reduce</u> the range of radars.

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DISADVANTAGES OF PRIMARY SURVEILLANCE RADAR SYSTEMS.

The main advantage of primary surveillance radar is its ability to give air traffic controllers information about aircraft in their area of watch, without any participation required from an aircraft's equipment in order for it to be detected by the radar head. However, primary radar does have the following disadvantages.

- Primary radar transmitters need to operate at very high power in order that an effective return signal is obtained from the target aircraft, especially if the radar transmitter is part of a long-range, en-route surveillance radar system.

- With long-range radars, return signals may be weakened by changes in target aircraft attitude, or attenuated by heavy precipitation. Both of these phenomena may cause traces on the radar screen to fade.

- A primary radar which is powerful enough to detect returns from distant target aircraft may also detect and display returns from high ground and precipitation. These types of return produce "clutter" on the radar screen.

- With primary radar, matching a given radar trace to an individual aircraft requires the aircraft to participate in an identification manoeuvre.

The only way that Primary Surveillance Radar can positively identify a specific aircraft is for the controller to instruct the aircraft to perform an identifying manoeuvre.

This latter disadvantage of primary radar systems can be overcome by the use of secondary surveillance radar. Secondary surveillance radar is covered in the next chapter.

LOWER AIRSPACE RADAR SERVICE (LARS).

The Lower Airspace Radar Service (LARS) was introduced in 1979 as a funding scheme to reimburse Air Navigation Service Providers for the provision of the radar service element of the Air Traffic Services Outside Controlled Airspace (ATSOCAS).

All traffic flying IFR in controlled airspace will generally be in receipt of a radar service. In the United Kingdom, aircraft flying VFR in uncontrolled airspace may also be able to receive a surveillance radar service when in receipt of a Traffic or Deconfliction Service as part of the UK FIS , although provision of a service is at the controller's discretion, depending on primary workload. LARS forms an integral part of ATSOCAS.

A LARS is available from 29 participating Air Traffic Control Units, 15 of which are military and 14 of which are civil.

Participating aerodromes are depicted in Figure 19.8. Aerodromes offering a LARS are listed in the En-Route Section of the United Kingdom Aeronautical Information Publication (UK AIP).

Significant Features of LARS.

- **LARS** is available **outside controlled airspace** up to and including **FL 95,** within the limits of radar/radio cover.

- **LARS** is provided within approximately **30 nms** of each participating aerodrome.

- **LARS** is normally available Mondays to Fridays between 0800 & 1700 hrs, in summer, and 0700 & 1600 hrs, in winter, although sometimes the service will be available outside these hours.

- While receiving a **LARS**, the pilot-in-command remains responsible for maintaining terrain clearance.

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- The controller providing a **LARS** will not be aware of all aircraft which are operating in the airspace in which the aircraft <u>receiving</u> the **LARS** is flying. Therefore, a sharp lookout should be maintained at all times by pilots receiving a **LARS**.

When the LARS controller and the pilot requesting a LARS have established contact, and the LARS has been confirmed, the pilot should:

- Maintain a listening watch on the allocated frequency.

- Follow advice issued by the controller or, if unable to do so, inform the controller.

- Advise the controller when the service is no longer required.

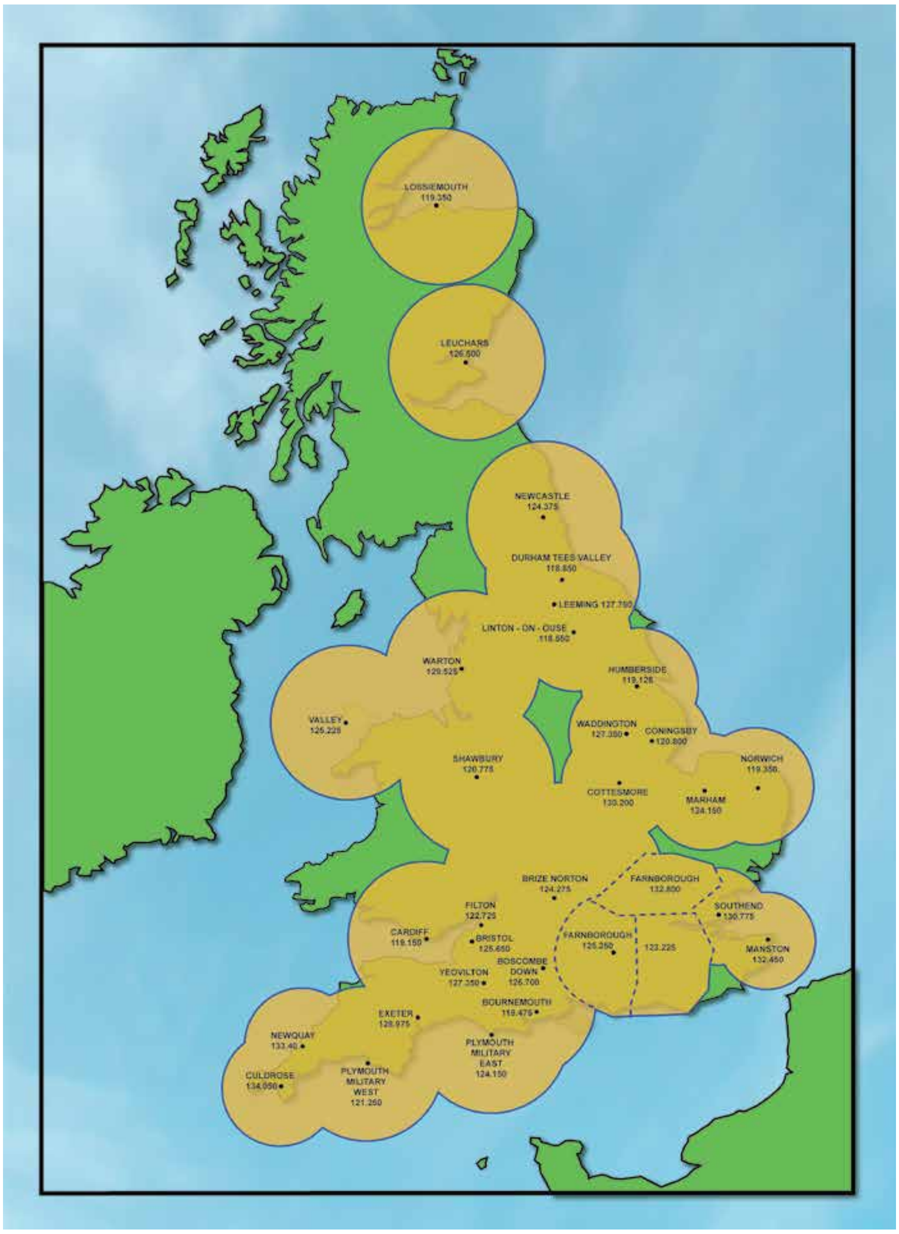

Fig 19.8 Air Traffic Control Units participating in LARS.

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RADAR SERVICES.

General.

As part of the UK Flight Information Service (FIS) a radar surveillance service may be provided in the form of a Traffic Service or Deconfliction Service. These services may be provided by Air Traffic Service Units (ATSUs) to aircraft outside controlled airspace (in classes F and G). The Lower Airspace Radar Service (LARS) forms an integral part of these services.

A pilot may ask for either a Deconfliction Service or a Traffic Service. If, however, the Radar Controller is busy, only Traffic Service may be offered. The pilot remains responsible for terrain clearance at all times whether receiving a Deconfliction Service or Traffic Service.

Difference between Deconfliction Service and Traffic Service.

Deconfliction Service.

In a Deconfliction Service, information about other traffic is passed to aircraft receiving the Deconfliction Service. Additionally, the controller passes advice on avoiding action to be taken by the pilot in the form of headings to be steered (radar vectors), and, if necessary, height changes. A Deconfliction Service is available to IFR flights whether in IMC or VMC, but should be accepted by a VFR pilot only if VMC can be maintained at all times in the event of any suggested heading or level changes.

Traffic Service.

In a Traffic Service, information about other traffic is passed to aircraft in receipt of the Traffic Service, but no advice is given on avoiding action to be taken. The pilot of the aircraft receiving the Traffic Service is responsible for his own separation. A Traffic Service is available to all aircraft whether IFR or VFR, and in any meteorological conditions.

Should a VFR Pilot Request a Deconfliction Service or a Traffic Service?

Unless a pilot is qualified to fly in IMC and is flying IFR, he should accept a Deconfliction Service only in conditions where compliance with ATC advice permits the flight to be continued in VMC. Bear in mind that you cannot fly VFR in any conditions other than VMC.

A pilot requesting a Deconfliction Service or Traffic Service should adopt the following procedure, having first established contact with the radar controller:

- State whether he is flying IFR or VFR.
- Request either Deconfliction Service or Traffic Service. The radar controller will attempt to identify the aircraft and then confirm the type of service about to be provided.
- The pilot reads back the service offered.

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Representative PPL - type questions to test your theoretical knowledge of Ground Radar.

1. En Route Surveillance Radars are:

   a. Long range radars with typical ranges of 200 - 300 nms.
   b. Radars providing positional information above 25 nms.
   c. Radars with a range of 75 nms used for controlling traffic in a Terminal Area.
   d. Radars providing surveillance below FL 245.

2. Consider the following statements concerning air traffic control primary surveillance radar, and then choose the combination of correct statements from the options given.

   1. ATC primary surveillance radar (PSR) can provide radar vectoring to pilots to fit aircraft into a safe and effective landing sequence.
   2. ATC PSR provides information to pilots about significant weather.
   3. ATC PSR range depends on the elevation of the radar head and the altitude of the aircraft.
   4. ATC PSR enables controllers to ensure safe separation between aircraft under their control.
   5. ATC PSR enables radar controllers to provide basic information to pilots about the position and heading of other potentially conflicting traffic.
   6. ATC PSR is a pilot-interpreted aid which enables aircraft to determine their position and heading with respect to radar beacons.

   a. 1, 3, 5 & 6
   b. 1, 3, 4 & 5
   c. 1, 2, 4 & 5
   d. 2, 3, 4 & 6

3. The issuing of instructions to pilots by radar controllers in order that aircraft may avoid conflicting traffic or be led into an instrument landing system is known as:

   a. Primary Radar Surveillance
   b. Secondary Radar Surveillance
   c. Radar Vectoring
   d. Radar Information Service

4. In the absence of a radar service, the process used by air traffic control units to maintain separation between aircraft, based on the reported position and altitude of participating aircraft, is known as:

   a. radio separation
   b. procedural separation
   c. altitude separation
   d. position separation

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5. A radar approach service whereby the radar controller passes advice to the pilot on his position relative to centreline and glideslope is called:

   a. Surveillance Radar Approach
   b. Instrument Landing System
   c. Procedural Approach
   d. VOR approach

6. If an aircraft's groundspeed is 100 knots, what rate of descent must a pilot fly in order to obtain a glideslope approach of approximately 3 degrees?

   a. 500 feet per minute
   b. 100 feet per minute
   c. 450 feet per minute
   d. 600 feet per minute

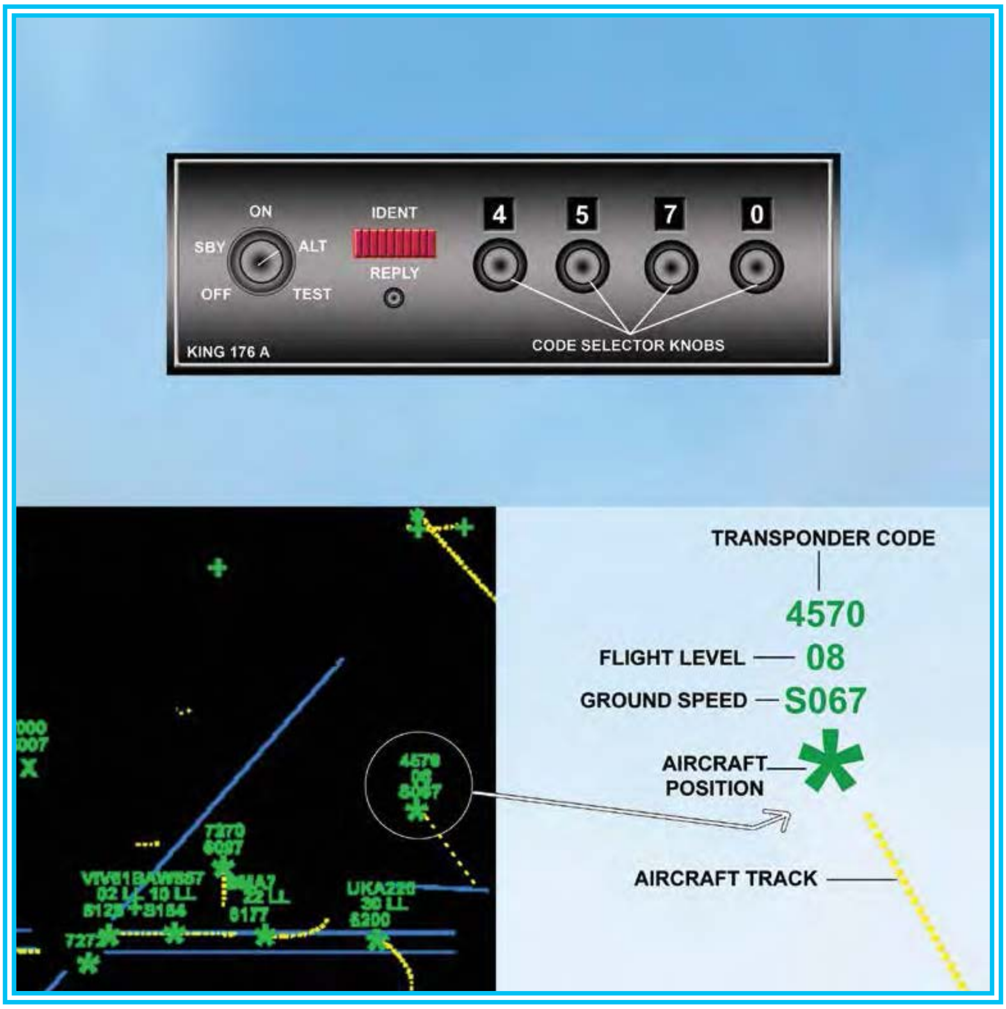
7. The approximate maximum range of a primary radar transmitter situated at mean sea level to detect aircraft flying at an altitude of 5000 feet is:

   a. 105 nautical miles
   b. 70 nautical miles
   c. 5000 nautical miles
   d. 90 nautical miles

Question	1	2	3	4	5	6	7
Answer							

The answers to these questions can be found at the end of this book.

CHAPTER 20
SECONDARY SURVEILLANCE RADAR (SSR)



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PRINCIPLES OF OPERATION OF SECONDARY SURVEILLANCE RADAR.

You have learnt that one of the main advantages of Air Traffic Control Primary Surveillance Radar (PSR) is that it does not rely on the target aircraft carrying any specialist equipment for effective radar surveillance to be carried out. Only a radio is needed for the pilot of an aircraft to be able to participate in a PSR radar control service.

PSR has one major disadvantage, however, which is closely related to its independence of operation, namely that, in order to identify a particular aircraft so that specific assistance or instructions may be given to that aircraft, a PSR controller is obliged to request or instruct that aircraft to carry out a manoeuvre, usually a change in heading, which can be seen and recognised from the aircraft's trace on the radar screen.

This disadvantage is overcome by Secondary Surveillance Radar systems. Secondary Surveillance Radar grew out of the World War 2 Identification Friend or Foe (IFF) system. IFF depended on dedicated receiver/transmitter units located in aircraft which responded to coded radar interrogations signals, retransmitting coded replies to indicate that the aircraft was not an enemy machine.

Nowadays, Secondary Surveillance Radar (SSR) functions alongside Primary Surveillance radar (PSR) and enhances the performance of PSR. With SSR, on every sweep of the radar head, a second, high-frequency interrogation signal is emitted along with the primary radar signal. An aircraft fitted with airborne SSR equipment, known as a transponder (a contraction of 'transmitter-responder'), receives the signal and in response to the interrogation emits in return, its own coded signal, which not only enhances the clarity of the radar trace but also carries within the coded signal additional information such as an identification code, or altitude and speed read-out, which is received at the ground station and displayed on the radar screen.

SSR, then, enables the air traffic controller to identify an individual aircraft without any identifying manoeuvre having to be performed by the target aircraft, though the pilot does have to select a code on his transponder, assigned by the controller.

The enhanced intensity of the SSR radar trace can also eliminate radar returns from unwanted sources, such as terrain, and, thus, reduce clutter on the radar screen.

SSR transmissions, being one-way only, in order to key a response from the aircraft's transponder, require much less power than PSR signals. SSR radar transmitters and antenna are, thus, smaller than their PSR equivalents, being, in general, narrower. *(See Figure 20.1.)*

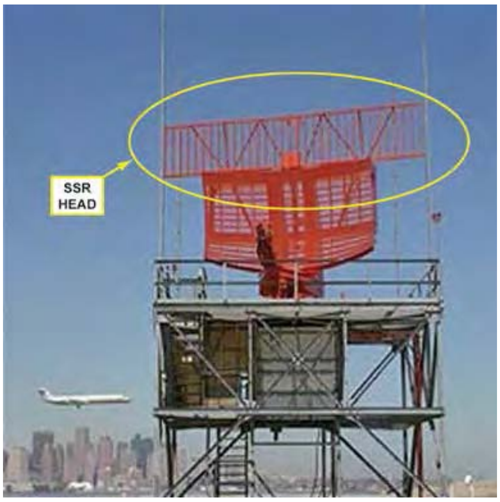

Figure 20.1 A secondary surveillance radar head, on top of a PSR head.

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SSR FREQUENCIES.

The ground station transmits and interrogates on 1030 MHz, and receives on 1090 MHz. The aircraft receives on 1030 MHz and transmits and transponds on 1090 MHz. The SSR ground antenna transmits in a narrow beam, while the aircraft transmits omni-directionally, in a circular pattern, around the aircraft.

THE BASIC LIGHT AIRCRAFT TRANSPONDER

The current types of basic transponder carried by general aviation aircraft mostly operate in two modes:

- **Mode A**. The basic transponder function which puts an identification code against the trace of an aircraft on the radar screen. The air traffic controller assigns the four-digit identification code (called a "squawk") - a remnant of WW2 terminology when the IFF was codenamed 'Parrot'), to a pilot, over the radio, and the pilot selects the code on his transponder.

- **Mode C**. Transponders with a Mode C function also transmit altitude information, based on the standard pressure setting of 1013.2 millibars (hectopascals), from an encoding altimeter which must also be fitted to the aircraft.

  (A requirement for aircraft to carry transponders with a **Mode S** capability is being introduced in Europe. Mode S transponders will emit a signal which is unique to a particular aircraft and which stays with that aircraft throughout its operational life. Mode S is covered in more detail later in this chapter.)

On the typical light-aircraft transponder of the type depicted in *Figure 20.2*, selecting ON activates Mode A. Selecting ALT activates Mode C alongside Mode A. If the aircraft is not fitted with an encoding altimeter, the transponder will function in Mode A only. *Figure 20.2* depicts the transponder selected to ALT; with the selector in this position, the transponder is operating in both Mode C and Mode A.

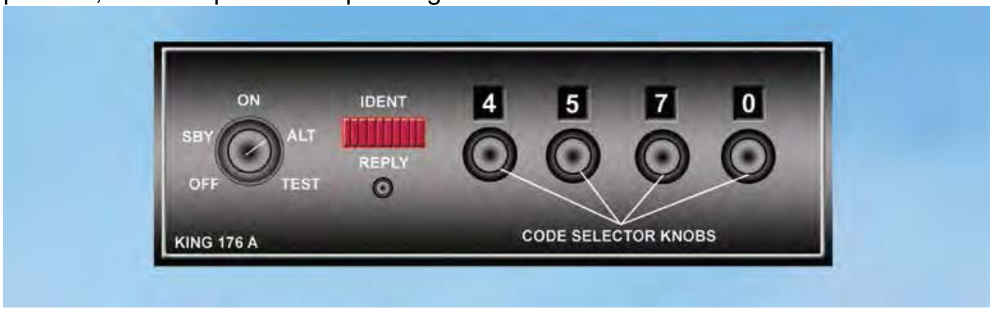

Figure 20.2 A transponder with ALT selected.

If SBY, signifying STANDBY, is selected on the transponder, the instrument is switched on but the transponder function itself is not activated. In the SBY mode, the transponder function will, however, be instantly available as soon as the pilot moves the selector to the ON or ALT positions.

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With the selector moved to the TEST position, the pilot can check whether the transponder is operating correctly. If the transponder is serviceable and functioning as it should, the transponder generates a self-interrogating signal and the REPLY-IDENT light illuminates.

The IDENT button is activated by the pilot only on the request of air traffic control. When the pilot presses the IDENT button, a pulse is generated by the transponder which causes a particular display to appear, for several seconds, next to the aircraft's trace on the controller's radar screen, so that the controller can easily pick out the trace from other traces on his screen. When a controller wishes a pilot to activate the IDENT function, he will instruct the pilot to "Squawk Ident". The pilot acknowledges, and complies by pressing briefly on the IDENT button, once only.

The transponder code or SQUAWK that a controller wishes a pilot to select on his transponder is a four-digit code passed to the pilot using words along the lines of "Squawk 4570". The pilot then uses each of the four code-selector knobs on the transponder set to select the required code. The code selectors are numbered 0-7, giving a total of 4096 possible codes. Because there are several special codes which signify emergency or equipment failure, when selecting a code, the pilot must first switch the transponder to SBY, make his code selection, and then reselect ON or ALT, as appropriate, to avoid inadvertent selections.

The controller will ask an aircraft to set a transponder code by using the RT phrase 'SQUAWK', followed by the required code, e.g. G-ABCD, Squawk 4570.

SPECIAL TRANSPONDER CODES.

By international agreement some transponder codes are reserved for special purposes.

- **7700** indicates an **emergency condition**. This code should be selected by the pilot as soon as is practicable after declaring an **emergency**. However, if the aircraft is already transmitting an **assigned code**, and also receiving an air traffic service, the original code may be retained at the discretion of either the pilot or controller.

- **7600** indicates **radio failure**.

- **7500** indicates that **unlawful interference** has occurred with the planned operation of the flight.

- In the United Kingdom, **7000** is known as the **conspicuity code**. This code is squawked by an aircraft whose pilot has received no instructions from an ATC Unit to squawk an assigned code. In the United Kingdom, the code 2000 is squawked by an aircraft re-entering a United Kingdom Flight Information Region (FIR) from an FIR where no transponder code has been assigned.

- Since 2007, in the United Kingdom, at aerodromes with a high concentration of visual circuit traffic, a specific **VFR Aerodrome Traffic Pattern Conspicuity Code of 7010** has been used. This is to facilitate greater exploitation of the collision avoidance 'safety net' provided by Airborne Collision Avoidance Systems (ACAS), which are increasingly available to light aircraft. ACAS systems respond to SSR transmissions.

MODE C should be operated with all of the above codes.

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RADAR DISPLAYS OF TRANSPONDER RETURNS.

Figure 20.3 shows a radar display of aircraft movements in the London Terminal Control Area where most of the traces are enhanced by SSR radar returns. The enlarged return shows a transponder - enhanced trace with the SSR information alongside it.

Secondary surveillance radar returns are displayed on the same screen as primary radar information.

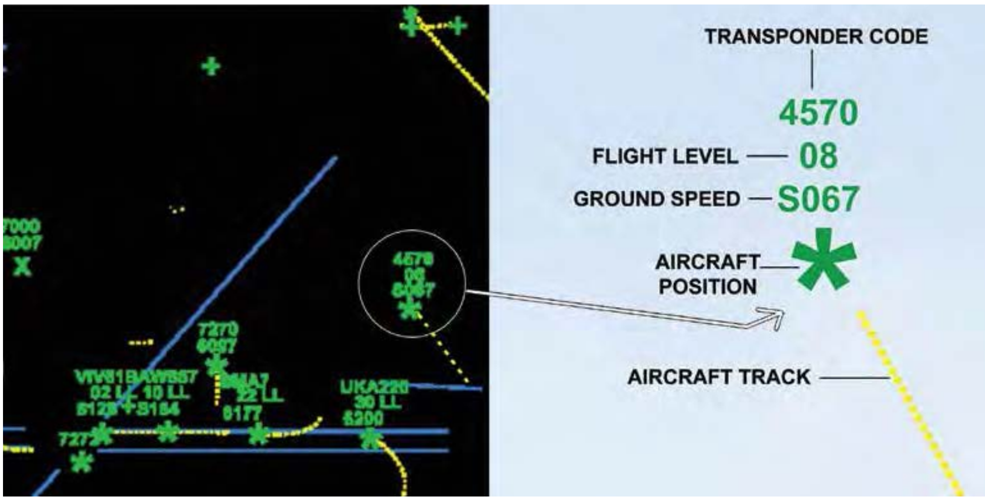

Figure 20.3 A typical ATC Radar display, with SSR enhanced traces.

The aircraft's pilot-selected transponder code of 4570 is shown at the top. The radar controller will have instructed the pilot to select this four-digit code on the transponder. The digits 08 indicate that the aircraft is at Flight Level 80 (8000 feet above the pressure datum of 1013.2 millibars), and the digits S067 show that the aircraft has a groundspeed of 67 knots.

MODE S.

Although Secondary Surveillance Radar (SSR) gives air traffic controllers greater capability to ensure safe and effective surveillance of air traffic than Primary Surveillance Radar (PSR) alone, existing Mode A and Mode C SSRs do have some deficiencies. Current SSR suffers from interference in the returns from aircraft which are on, or almost on, the same bearing from the ground station, and other types of interference, too. But, more importantly, when operating in Modes A or C, whether a transponder is selected to an assigned code or merely transmitting on the UK conspicuity code of 7000, all transponders in all aircraft within the coverage area of an SSR ground station are interrogated on every sweep of the SSR radar head.

A Mode S transponder will transmit a unique identification code which remains with the aircraft throughout its life.

In order to overcome these and other deficiencies, Secondary Surveillance Radar Mode S, a development and enhancement of classic SSR, is currently being introduced. Mode S radar surveillance will enable improved position determination of SSR targets while reducing the number of required replies by transponders, as well as improving other aspects of SSR operation. A Mode S-equipped aircraft will have a unique identification code which will remain with the aircraft throughout its life. The selective nature of Mode S SSR means that air traffic control will be able to restrict interrogations to specified targets. Following initial acquisition and identification by a Mode S ground station, an aircraft will be subsequently interrogated in accordance with a specific "schedule" and not on every sweep of the SSR radar head. Furthermore,

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only the individually interrogated aircraft will respond.

Mode S, therefore, requires far fewer interrogations of aircraft than at present, in order to track an aircraft. This fact means that position reporting will be more accurate.

Additionally, Airborne Collision and Avoidance Systems (ACAS) work more efficiently in a wholly Mode S environment.

Figure 20.4 Mode S Transponder.

With Mode S, aircraft can be interrogated individually.
Mode S interrogation is selective interrogation.

As mentioned above, the selective character of Mode S operations will also reduce problems associated with interference between transponder returns from aircraft on a similar bearing from the ground station, as well as interference caused by replies from one transponder responding to interrogations from another. This latter phenomenon is sometimes known as "Fruiting" **(FRUIT = False Replies Unsynchronised In Time).**

The United Kingdom Civil Aviation Authority is proposing that light aircraft operating in accordance with the Visual Flight Rules should be fitted with the elementary level of Mode S transponder when flying in uncontrolled airspace, and some classes of controlled airspace, by March 2012. This is also a requirement within Europe.

ADVANTAGES OF SECONDARY SURVEILLANCE RADAR.

Secondary Surveillance Radar (SSR) has the following advantages over primary radar:

- SSR requires much less transmitting power to provide coverage up to 200 to 250 nm.
- SSR gives clutter-free responses as it is does not rely on low-energy reflected signals.
- SSR positively identifies an aircraft by displaying its code and call sign alongside the radar trace on the controller's screen.
- SSR returns can indicate an aircraft's track history, speed, altitude and destination.
- SSR can indicate on a controller's screen that an emergency situation exists on board an aircraft, that an aircraft has lost radio communications, or is being hi-jacked.

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DISADVANTAGES OF SSR.

SSR has the following deficiencies:

Garbling.

Garbling is caused by overlapping replies from two or more transponders having nearly the same bearing from the ground station and within a distance of **1.7 nm** from each other, measured on a line from the antenna.

Fruiting.

Fruiting is interference at one interrogator caused by replies from one transponder which is responding to interrogations from another transponder.

Ghosting.

Ghost targets which are due to reflections from obstacles or high terrain.

Shielding.

Shielding occurs when the aircraft attitude shields the antenna, resulting in loss of signals.

SSR PHRASEOLOGY.

The following are examples of ATC phraseology used when instructing pilots to operate the transponder.

- ***Squawk (Code)*** Select the code, as instructed.
- ***Confirm Squawk*** Confirm mode and code set on the transponder.
- ***Recycle*** Reselect assigned mode and code.
- ***Squawk Ident*** Operate the IDENT function.
- ***Squawk Standby*** Select SBY.
- ***Squawk Charlie*** Select Mode C by turning selector switch to ALT.
- ***Verify Your Level*** Check and Confirm your Level.

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Representative PPL - type questions to test your theoretical knowledge of Ground Radar.

1. A transponder fitted to an aircraft is essential equipment to provide a controller with what type of information?

   a. Primary radar returns
   b. Secondary Surveillance Radar returns
   c. Precision Approach Radar returns
   d. Area Radar returns

2. The special code to set on a transponder to indicate an emergency condition is:

   a. 7600
   b. 7500
   c. 7700
   d. 2000

3. What is the significance of the expression of 'Mode Charlie' when applied to the capability of an aircraft-mounted transponder?

   a. The transponder provides positional information only
   b. The transponder provides information on both position and altitude
   c. The transponder provides QDM information only
   d. The transponder provides QDM and QDR information only

4. What is the result of a pilot pressing a transponder's IDENT button?

   a. It causes a special symbol to appear briefly on the controller's radar screen, around the aircraft's transponder return, allowing positive identification of the aircraft.
   b. It confirms to the controller that the pilot has the correct transponder code selected
   c. It selects the transponder's Mode Alpha capability
   d. It selects the transponder's Mode Charlie capability

5. SSR information is:

   a. presented in analogue form on the controller's strip
   b. displayed digitally on the secondary radar screen via a computer
   c. displayed by a system of lights on the controller's console
   d. displayed on the same screen as primary radar information

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6. What is the significance of the Mode S transponder?

   a. It will transmit aircraft position, as in Mode A
   b. It does not have a standby mode
   c. It will transmit a signal always unique to the aircraft in which the transponder is fitted
   d. It will transmit details of the aircraft's position, height and separation from other aircraft

7. How is a transponder's Mode Charlie position selected?

   a. The pilot moves the transponder selector knob to the SBY position
   b. The pilot moves the transponder selector knob to the TST position
   c. The pilot presses the IDENT button
   d. The pilot moves the transponder selector knob to the ALT position

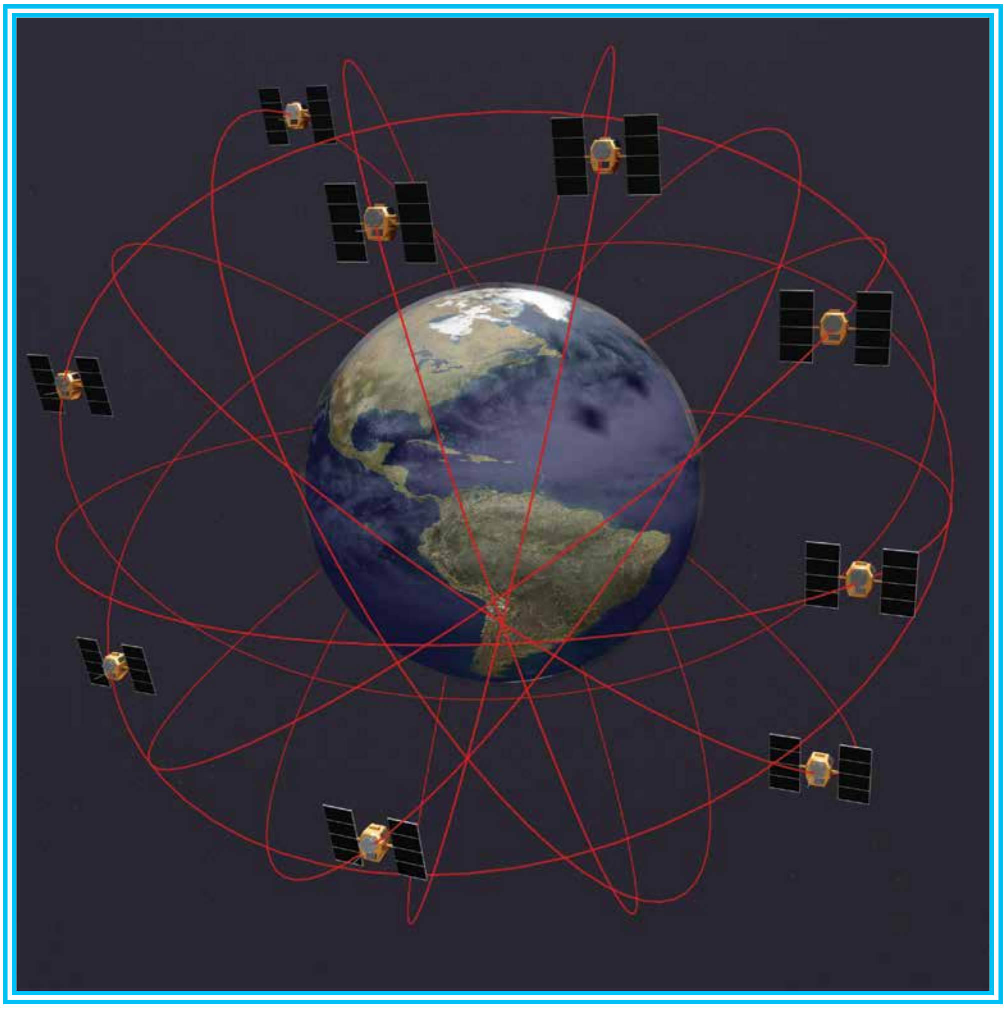
8. If a controller asks you to "SQUAWK IDENT", you should:

   a. Confirm to him what code you have set on your transponder
   b. Enter onto the transponder the code he has given to you
   c. Press the IDENT button once, briefly
   d. Enter 7600 on your transponder and press the IDENT button

Question	1	2	3	4	5	6	7	8
Answer								

The answers to these questions can be found at the end of this book.

CHAPTER 21
GLOBAL POSITIONING SYSTEMS (GPS)



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INTRODUCTION.

The generic term used by the International Civil Aviation Organisation (ICAO) to refer to satellite navigation systems is Global Navigation Satellite System (GNSS). However, at present (2010), there is only one fully functioning system: the Global Positioning System, usually called GPS, operated by the United States Department of Defence (DOD) and which is available to civilian users worldwide.

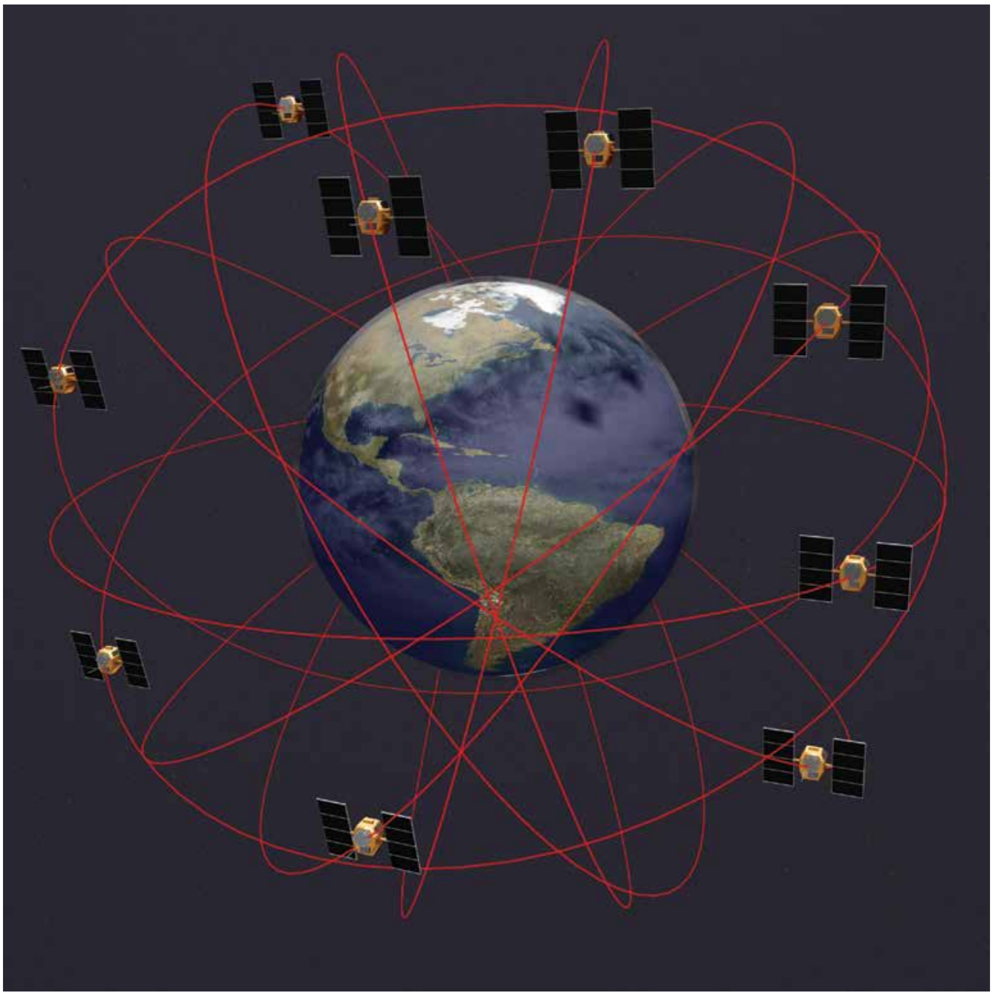

Figure 21.1 The GPS Space Segment.

Russia operates a GNSS called Global Orbiting Navigation Satellite System (GLONASS) which is also available for civilian use but is currently not widely exploited commercially.

Europe plans to establish a GNSS under the name of Galileo. Currently, however, Galileo remains in the development stage. It is expected to be available for aviation use within the next decade.

As the US-operated and controlled GPS is the only fully operational GNSS at the present time, this is the system we shall refer to in this chapter.

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GPS is a very accurate navigational aid, and is very widely used by pilots of all categories of aircraft for area navigation, and is now also approved in the UK, USA and Europe as a sole aid for specified non-precision approaches.

The GPS satellite constellation, known as NAVSTAR (Navigation Signal Timing and Ranging) contains between 24 and 32 GPS satellites, orbiting the earth twice a day at an altitude of 10 900 nautical miles (20 200 km).

The satellites are arranged in six separate orbital planes of four satellites, each giving global coverage.

The complete GPS system consists of three segments:

- **The Space Segment.** The space segment *(see Figure 21.1)* is the constellation of of a minimum of 24 satellites plus a number of back-ups. Each satellite has a very accurate atomic clock and, at precise intervals, transmits a unique code with navigation information. The receiver (or "user segment") is thereby able to identify signals from individual satellites.

- **The Control Segment.** The control segment is located on the surface of the Earth, and comprises a master control station and a number of monitoring stations and ground antennae. The control segment monitors the orbital accuracy and serviceability of the satellites.

- **The User Segment.** The user segment comprises all individual GPS receivers. Each GPS receiver relies on maintaining line of sight between itself and the satellite, and interprets the data from the individual satellites that it can "see". Because the exact time of each signal transmission and the exact position of the satellite at the time of transmission are known, the position of the receiver can be accurately measured, too. An accurate two-dimensional fix can be made if the receiver can lock on to three satellites, and a three-dimensional fix (including altitude) can be obtained if the receiver is capturing signals from 4 satellites. Most aviation GPS receivers incorporate an aeronautical database that pilots can use to programme their desired route, which will be shown on a map display with various options of detail and scale; most sets can also show track, heading, timings, groundspeed, etc. In conjunction with an air data computer, the unit can also calculate wind vectors. However, the database does need to be updated regularly. GPS is a very good system, but is not infallible; therein lies the danger that pilots can become reliant on GPS, and get caught out by a malfunction if basic navigation planning has not been done.

Accuracy of GPS.

GPS has brought a new dimension of accuracy to navigation systems, with the fixing of position measured in metres; one manufacturer quotes an average accuracy of 15m, but in reality, accuracy of less than one metre is possible.

GPS ERRORS.

The GPS system has proved to be very reliable and accurate. However, the system is susceptible to a variety of errors.

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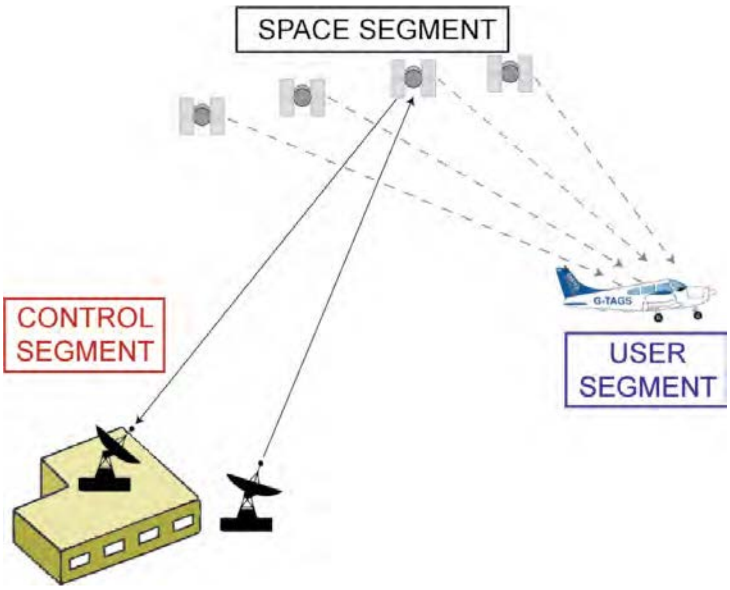

Figure 21.2 The GPS Space, Control and user Segments.

Ephemeris Error.

Ephemeris errors are errors in the satellite's calculation of position, caused by the gravitational effects of the sun, moon and planets and solar radiation.

Satellite Clock Error.

As with ephemeris, the **satellite clock** is checked at least every 12 hours by the control segment, and any error corrected. The satellite clock may malfunction, the satellite may stray from its path, or its transmitter may fail.

Receiver Noise Error.

All radio receivers generate internal noise which can cause errors in the measurement of the time difference.

Multi-path Reception Error.

Reflections from the ground and parts of the aircraft result in **multi-path reception**. These errors affect the accuracy of range measurements, and may affect position, drift and groundspeed information.

Geometric Dilution of Precision.

Geometric Dilution of Precision (GDOP) is the term for a poor cut between position lines. GDOP occurs when the satellites are relatively close to one another. Errors caused by GDOP are minimised by the geometry of the positioning of the satellites in their orbits and by the receivers selecting the four "best" satellites to determine position.

The satellite geometry which provides the most accurate position-fixing information is with one satellite directly overhead the receiver, and a further three satellites close to the horizon, spaced 120° apart.

Effect of Aircraft Manoeuvres.

Aircraft manoeuvres may result in part of the aircraft shadowing one or more of the in-use satellites.

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While the satellite is shadowed, the signal may be lost, resulting in degradation of accuracy. The effect of manoeuvres can be minimised by careful positioning of the aerial on the aircraft.

Terrain Shielding.
When an aircraft is at low level in a mountainous region, satellites may became masked with respect to the GPS receiver in the aircraft. This situation may cause sudden loss of GPS position fixing capability.

Interference and Jamming.
The GPS signal which arrives at the receiver is a low power signal and is susceptible to interference, either intentional or unintentional. UHF, microwave signals, and VHF RT transmissions may be sources of unintentional interference.

Intentional jamming is also a danger, though military excercises which include deliberate GPS jamming are notified through NOTAMs.

Sunspots and Solar Flares.
Solar radiation can affect GPS satellite transmissions. Sunspots and solar flares, which influence solar radiation, cannot be forecast.

Availability of GPS Service.
The **NAVSTAR** satellite system is the property of the United States government which may choose to adjust the availability of satellites as it wishes. The US government has undertaken to make GPS signals available for civilian use, but has the capability to reduce the accuracy of the system for military or other reasons, or to switch the system off completely.

GPS USE BY THE GENERAL AVIATION PILOT.

GPS is used by many pilots as a back-up system to more traditional navigation methods. GPS equipment will provide information that relates to aircraft:

- **Speed** and **track over the ground.**
- **Wind velocity (in conjunction with an air data computer)**.
- **Time and distance**.
- **Waypoint, alternate aerodrome, and destination information. However, this is only if the aeronautical database is updated regularly.**

GPS equipment is very accurate and can be a valuable navigational aid, but it is important to remember that GPS systems should not be relied upon as primary navigation aid, for the reasons given earlier in this chapter. GPS should be used only as a back-up aid, supporting other means of navigation. Notice Advisories to Navstar Users (NANUs) are the means of informing GPS users of a planned degradation of the system. NANUs are available in the UK through the NOTAM system.

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GPS-System Familiarisation.

Before attempting to use GPS equipment in the air, pilots should learn as much as they can about the system they intend to use. In particular, pilots should ensure that they understand the following:

- Principles of GPS.
- System installation and limitations.
- Pre-flight preparation and planning.
- Cross-checking data entry.
- Use of the system in flight.
- Confirmation of accuracy.
- Database integrity.
- Possible sources of human error.
- System error and malfunctions.

Flight Planning.

The attention that a pilot needs to give to his GPS equipment, in flight, may be minimized by careful flight planning. Always plan your flight using the standard methods taught in Section One of this book. Then, having completed your flight log, you may enter the route information into your GPS receiver. Using this method you will be able to navigate visually in the approved manner, while using your GPS to confirm the accuracy of your navigation. If the GPS should fail, you will not be taken by surprise and will be able to continue the flight in the traditional way.

In-Flight Use of GPS.

You should continually bear in mind that GPS signals may become subject to degradation or complete loss, with the attendant possibility of position error. Furthermore, the risk of human error in data input and display reading is high, so great diligence must be exercised when using GPS equipment. If in IMC, or above cloud, use GPS only in combination with other radio aids with which the GPS data may be compared. If your GPS display confirms the information given by other radio aids, and by your dead reckoning calculations, you will know that the GPS is likely to be providing accurate data.

Be aware that hand held GPS equipment, running on batteries, can become discharged quickly.

Above all, you should never become totally dependent upon a GPS. Always question your GPS data and ask yourself:

- Does the information I am receiving from my GPS agree with at least one other independent and confirmed source of navigational data?
- Could I safely continue with my flight without my GPS if it were to fail completely, at this very moment?

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Other Potential Hazards Arising From the Use of GPS.

General Aviation reports have indicated that, with increasing use of GPS, pilots are often tracking exactly overhead features which they nominate as turning points, or other points of reference. This practice increases the risk of collision with other aircraft whose pilots are doing the same thing.

When flying towards Visual Reference Points (VRP), for instance, pilots are reminded they should not overfly the VRP, but report their position with reference to the VRP.

ANNEX A THE FLIGHT INFORMATION SERVICE

ANNEX A: THE FLIGHT INFORMATION SERVICE

WHAT IS A FLIGHT INFORMATION SERVICE?

A Flight Information Service (FIS) is an Air Traffic Service provided by Air Traffic Service Units (ATSU) and Flight Information Region (FIR) Centres to aircraft flying outside controlled airspce for the purpose of supplying information to pilots which is useful for the safe, orderly and efficient conduct of flights.

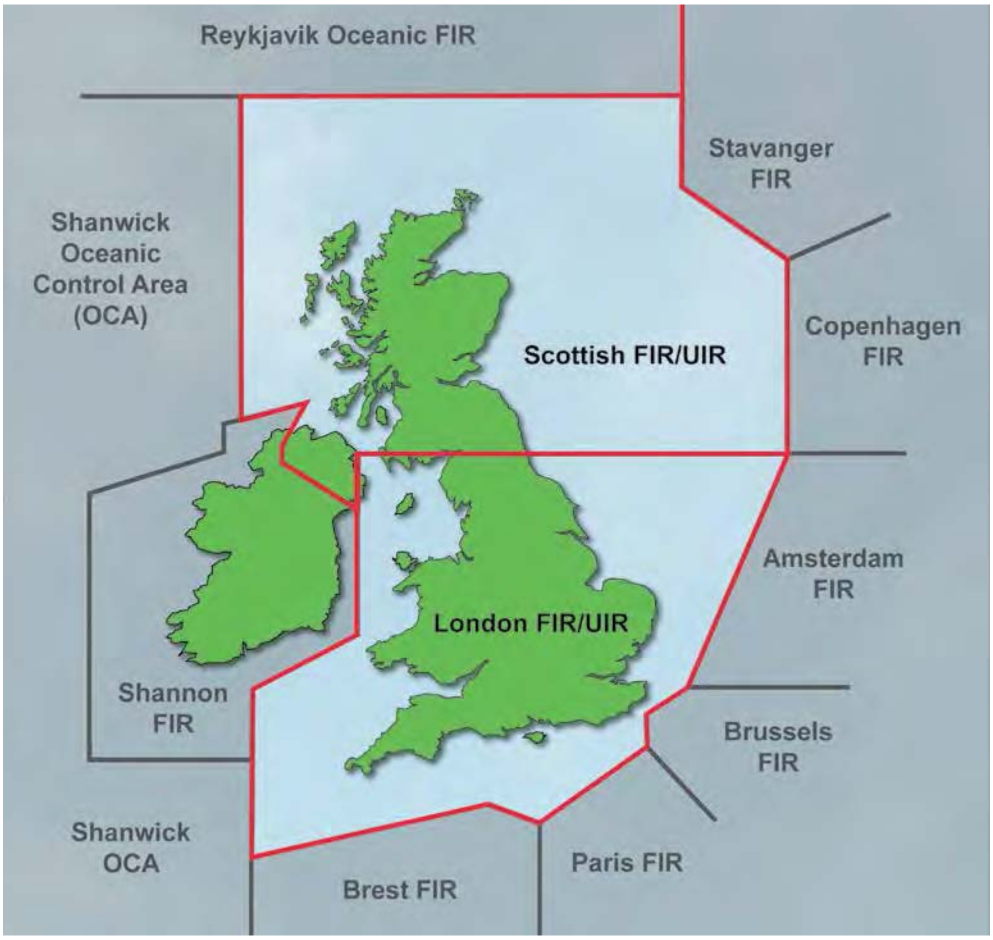


Figure Annex A.1 The lateral limits of the London and Scottish Flight Information Regions.

The FIS is probably the service most frequently used by VFR pilots who are on cross country flights in uncontrolled (Class G) airspace, sometimes known as the Open FIR. Of course, there is no reason why a pilot should not ask for an FIS from a convenient ATSU while on a local flight.

UK FLIGHT INFORMATION SERVICE

In the UK, Air Traffic Services Outside Controlled Airspace (ATSOCAS) are provided by a variety of air traffic units and used by a wide variety of users from General Aviation to commercial flights and military aircraft.

The suite of services is collectively known as the “UK Flight Information Service”. They are detailed in CAP 774 and summarised here.

Outside controlled airspace, it is not mandatory for a pilot to be in receipt of an air traffic service. This principle generates a traffic environment over which air traffic controllers have no oversight. Consequently, outside controlled airspace, it is the pilot who bears responsibility for collision avoidance and terrain/obstacle clearance.

There are 4 distinct services to the new "UK Flight Information Service":

1. Basic Service; 2. Traffic Service; 3. Deconfliction Service;
4. Procedural Service

The various services are designed to cater for a wide variety of airspace users and tasks. It is essential that controllers and pilots all have a detailed knowledge of the services. Within an FIR, the only service that is required to be offered, as mandated by ICAO, is the Basic Service. The other three services may be provided by ATSUs if they are suitably equipped and have the capacity to do so. However, the UK Lower Airspace Radar Service (LARS) will, within their operating hours, offer the more comprehensive Traffic and Deconfliction Service which require radar surveillance equipment.

Pilot compliance is relied upon in order to promote a safer operating environment, but it is not mandatory.

Pilots should determine the most appropriate service for the phase and conditions of the flight and request that service from the controller.

You should note that a FISO will provide a Basic Service only.

Basic Service.

A Basic Service is intended to offer the pilot maximum autonomy. Avoidance of other traffic and terrain is solely the pilot's responsibility.

The controller/FISO will pass information pertinent to the safe and efficient conduct of flight. This can include weather, changes of serviceability of facilities, conditions at aerodromes and general activity information within an air traffic service unit's (ATSU) area of responsibility. Pilots should not expect traffic information when outside an ATZ.

It is not necessary to have an ATS surveillance system to offer a Basic Service. It is important that pilots should know this fact. The Basic Service is, therefore, not an appropriate service for flight in IMC.

It is of supreme importance that pilots understand that, while receiving an FIS, they are not under air traffic control and are responsible for their own collision and terrain avoidance.

Within a Basic Service, "Agreements" between pilots and controllers (and FISOs) can be established to restrict an aircraft to a specific flight level or altitude, level band, heading, route, or operating area.

Please note that the Flight Information Service referred to by ICAO is the same as the Basic Service as provided in the UK.

Traffic Service.

A Traffic Service provides the pilot with surveillance-derived traffic information on conflicting aircraft. No deconfliction advice is passed and the pilot is responsible for collision avoidance.

A Traffic Service contains the information available in a Basic Service, and additionally, controllers will endeavour to provide surveillance-derived traffic information on relevant traffic which is anticipated to pass within 3 nm and 3000 ft.

Deconfliction advice is not offered.

A Traffic Service is available under any flight rules or meteorological conditions. However, it is not an appropriate service for flight in IMC if another more suitable service can be offered.

Agreements can be established to restrict an aircraft to a specific level, level band, heading, route, or operating area.

A pilot may operate under his own navigation or a controller may provide headings or levels for positioning, sequencing or navigational assistance.

A pilot must not change general route, manoeuvring area, heading or levels or a controller-allocated heading without first advising and obtaining a response from the controller.

Allocated levels will be terrain safe.

Deconfliction Service.

A Deconfliction Service provides the pilot with traffic information and deconfliction advice on conflicting aircraft.

However, the avoidance of other aircraft is ultimately the pilot's responsibility.

A Deconfliction Service contains the information available in a Basic Service, and, additionally, controllers will aim to assist the pilot with his responsibility for the safety of the aircraft by passing traffic information and deconfliction advice.

Headings and/or levels will also be issued for positioning, sequencing and/or deconfliction advice.

The pilot may decide not to act on the advice, in which case he must inform the controller and then accept responsibility for deconfliction.

A Deconfliction Service is available under any flight rules or meteorological conditions.

Controllers will expect the pilot to accept headings and/or levels that may require flight in IMC.

A Deconfliction Service is to be provided only to aircraft operating at or above the ATC unit's terrain safe level unless the aircraft is on departure from an aerodrome or on an instrument approach.

A pilot must not change heading or level without first advising and obtaining a response from the controller. If a heading or level allocation is unacceptable, the controller must be immediately informed.

Procedural Service.

A Procedural Service is a non surveillance service during which instructions are provided which, if complied with, will achieve deconfliction minima with respect to other aircraft in receipt of a Procedural Service from the same controller.

The avoidance of other aircraft is the pilot's responsibility.

A Procedural Service contains the information available in a Basic Service, and, additionally, controllers will aim to assist the pilot with his responsibility for the safety of the aircraft by providing vertical, lateral, longitudinal, and time instruction, aimed at achieving deconfliction from other aircraft to which the controller is also providing a Procedural Service.

A Procedural Service is available under any flight rules or meteorological conditions.

Controllers will expect the pilot to accept radial, track, level and time allocations that may require flight in IMC.

Pilots who do not require deconfliction advice should not request a Procedural Service.

Under a Procedural Service, high reliance is placed on the pilot's ability to follow radial, track and time allocations; therefore in high controller workload and/or where airspace availability is limited, controllers may not be able to provide a Procedural Service to a pilot who is flying purely by visual references.

Controllers will provide deconfliction instructions by allocating levels, radials, tracks and time restrictions, or use pilot position reports, aimed at achieving planned deconfliction minima with respect to other aircraft receiving a Procedural Service.

If a radial, track, time or level allocation is unacceptable to the pilot, the controller must immediately be informed, and pilots must not change radial, track or time allocation without first advising and obtaining a response from the controller.

In a Procedural Service, controllers may specify required altitudes or flight levels.

A VFR PILOT'S RESPONSIBILITIES WHEN RECEIVING A FLIGHT INFORMATION SERVICE?

In any exchange of radio transmissions between a pilot and an ATSU, the pilot bears the general responsibility for transmitting his intentions, requests and responses succinctly, clearly and effectively to the ground operator. Professional pilots are specifically trained in radio communication techniques, but the typical private pilot, flying VFR, will not have received such training. It is, therefore, incumbent on the VFR pilot wishing to become an effective user of airspace and of air traffic control services to take responsibility for his own training and skill-development in this field.

Of one thing you may be certain: if you are to gain maximum benefit from the services that ATSUs can provide you, as a VFR pilot, the manner in which you use your radio must make it clear to the ATSU operator that you are a competent and proficient pilot, navigator and radio operator.

Being aware of your responsibilities in this field will help you attain that level of proficiency. Here is a list of some of the responsibilities of a **VFR** pilot when receiving a Flight Information Service.

- Prepare each flight thoroughly.
- Keep an attentive listening watch on the FIS frequency you are working.
- Maintain good radio discipline.
- Learn how to pass your position messages in a professional manner.
- When transmitting, use standard operating procedures and RT speech groups.
- Make your radio transmissions as succinct as possible to avoid congesting the frequency.
- Always report leaving an FIS frequency to avoid any uncertainty arising in the mind of the FIS provider about your whereabouts and/or safety.
- Remember that receiving an FIS does not free you from your obligation to plan your flight thoroughly.
- Always be aware of your present location and be prepared to report your position whenever you are asked to do so by the FIS provider.
- Finally always remember that you are not under air traffic control and that you remain responsible at all times for avoiding collision.

INITIAL CALL - VFR.

Normally, the initial call to an ATSU should only include the minimum information needed to establish:

a) the service that an en-route flight requires.

b) the clearance/information that a joining or departing flight requires.

When you contact an **ATSU** to request one of the four services of the UK Flight Information Service, (we will use the Basic Service in our example), your transmission will take the form:

"Stephenville Approach, G-ABCD, Request Basic Service"

The Controller will reply:

"G-ABCD, Stephenville Approach, Go Ahead"
(In the United Kingdom: "G-ABCD, Stephenville Approach, Pass your message.")

Your response, as a pilot, to the instruction "Go Ahead" ("Pass Your Message") will be to pass a standard report combining details of your **aircraft type**, **position**, **altitude**, **route** and **intentions**. A typical pilot response to the "Go Ahead" ("Pass Your Message") instruction would be:

"G-ABCD, PA-28, From Rissington Parva to Georgetown, 15 miles East of Stephenville, altitude 2500 feet, QNH 987 millibars, VFR, Estimate Wicken, 46."

You will notice that the pilot has passed his details in the order:

- Aircraft call-sign. **G-ABCD.**
- Aircraft type. **PA-28.**
- Route or operation information. **From Rissington Parva to Georgetown.**
- Position. **15 miles East of Stephenville.**
- Altitude. **2 500 feet.**
- Altimeter setting. **QNH 987.**
- Flight rules (VFR or IFR). **VFR**
- Estimate of time at next waypoint. **Estimate Wicken, 46.**

A reply composed in this way will help the ATC controller to visualise your details, and, thus, to give you a better service. By passing your details in this way, i.e. clearly and crisply, you will also do a lot to convince the controller that he is dealing with a competent pilot/radio operator.

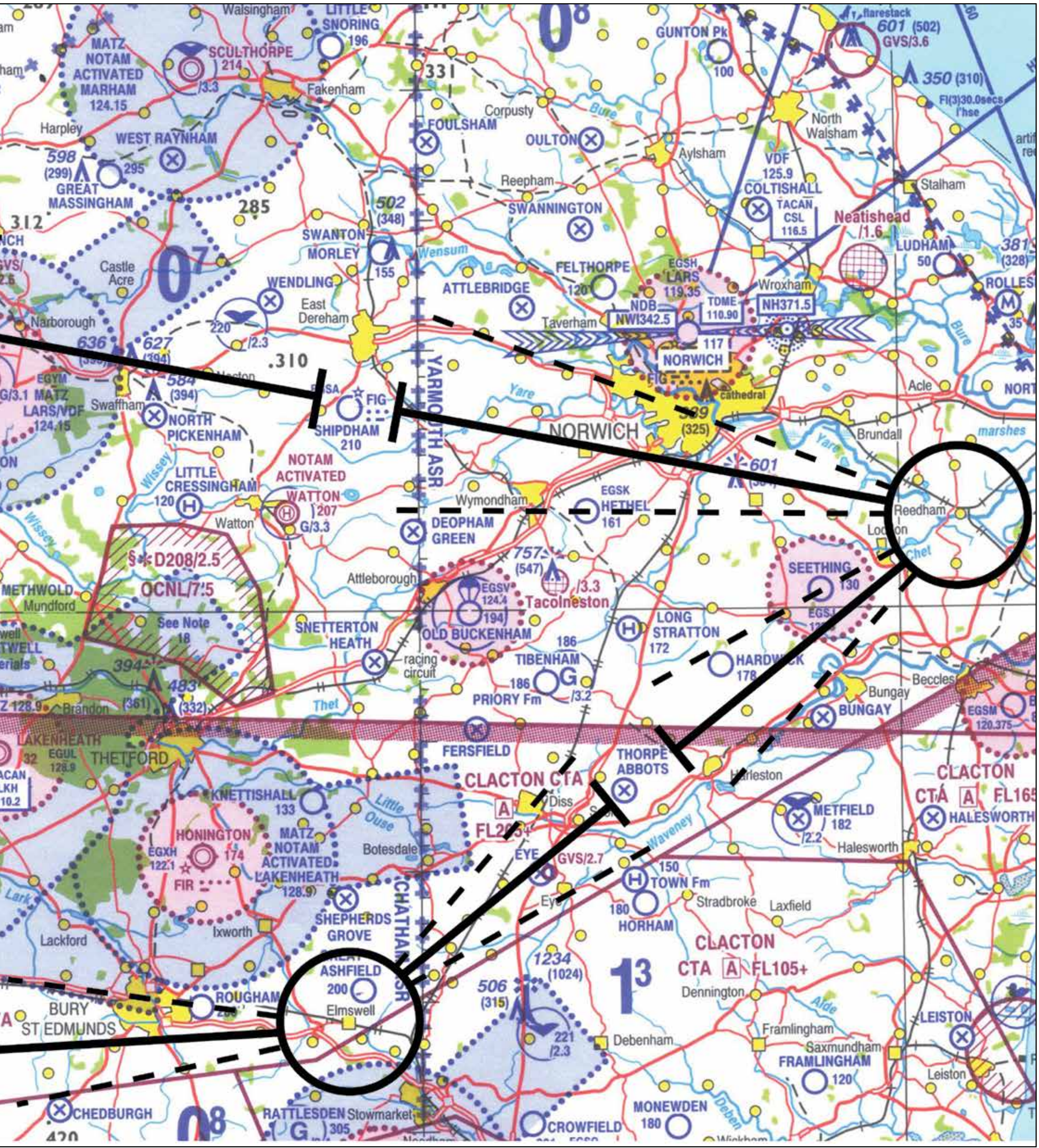
LONDON FLIGHT INFORMATION SERVICE - INTRODUCTION OF SSR CODE 7401.

The volume of air traffic around the world's major cities has increased tremendously in recent years, particularly in the United Kingdom, in the London area. From 23 November 2006, in order to prevent and mitigate the consequences of controlled airspace incursions inside the London FIR, all pilots requesting an FIS from London FIS will be requested to "squawk" SSR Code 7401. This will enable radar equipped ATSUs in the London FIR, which observe aircraft displaying this code, following tracks which could infringe their airspace, to contact London FIS and ask for the flight details of the aircraft concerned. ATSUs will also request that the aircraft be advised to contact them so that they may resolve the situation as expeditiously as possible.

This procedure in no way implies that London FIS is providing a radar service. The London FIS will continue to provide a Flight Information Service only. Pilots who contact London FIS making short-duration calls, e.g. for weather reports, and are in contact with London FIS for only short periods of time, will not be required to squawk 7401.

APPENDIX I
PRACTICAL NAVIGATION TEST ROUTE

APPENDIX 1: PRACTICAL NAVIGATION TEST ROUTE


Walsingham
LITTLE SNORING
196
SCULTHORPE
214
MATZ
NOTAM
ACTIVATED
MARHAM
124.15
Fakenham
Harpley
WEST RAYNHAM
598
(299)
GREAT MASSINGHAM
295
285
331
FOULSHAM
Corpusty
OULTON
Reepham
SWANNINGTON
GUNTON Pk
100
North Walsham
Aylsham
VDF
125.9
COLTISHALL
TACAN
CSL
116.5
Stalham
Neatishead
/1.6
LUDHAM
50
601 (502)
GVS/3.6
350 (310)
312
Castle Acre
Narborough
SWANTON MORLEY
155
502
(348)
Wensum
WENDLING
East Dereham
ATTLEBRIDGE
FELTHORPE
120
EGSH
LARS
119.35
NDB
NW1342.5
TDME
110.90
NH371.5
Wroxham
Taverham
117
NORWICH
636
627
(394)
.310
584
(394)
Swaffham
NORTH PICKENHAM
SHIPDHAM
210
FIG
YARMOUTH ASR
Yare
NORWICH
cathedral
589
(325)
Acle
Brundall
marshes
601
Reedham
Loddon
Chet
LITTLE CRESSINGHAM
120
NOTAM
ACTIVATED
WATTON
207
G/3.3
Watton
Wymondham
DEOPHAM GREEN
EGSK
HETHEL
161
D208/2.5
OCNL/7.5
METHWOLD
Mundford
757
(547)
/3.3
Tacolneston
Attleborough
EGSV
124.4
194
OLD BUCKENHAM
SEETHING
130
See Note 18
SNETTERTON HEATH
racing circuit
LONG STRATTON
172
TIBENHAM
186
HARDWICK
178
394
483
(332)
(361)
Brandon
Thet
PRIORY Fm
/3.2
Bungay
BUNGAY
Beccles
EGSM
120.375
LAKENHEATH
EGUL
128.9
THETFORD
FERSFIELD
THORPE ABBOTS
Harleston
CLACTON
CTA
FL165
CLACTON CTA
FL265+
Diss
KNETTISHALL
133
Little Ouse
METFIELD
182
/2.2
HALESWORTH
Halesworth
HONINGTON
EGXH
122.1
174
FIR
MATZ
NOTAM
ACTIVATED
LAKENHEATH
128.9
Botesdale
EYE
GVS/2.7
Waveney
150
TOWN Fm
Eye
180
HORHAM
Stradbroke
Laxfield
SHEPHERDS GROVE
Ixworth
Lackford
Lark
WATTISHAM ASR
CLACTON
CTA
FL105+
1234
(1024)
Dennington
ASHFIELD
200
Elmswell
506
(315)
221
/2.3
Debenham
Framlingham
Saxmundham
FRAMLINGHAM
120
LEISTON
Leiston
Alde
BURY ST EDMUNDS
ROUGHAM
CHEDBURGH
420
RATTLESDEN
305
Stowmarket
CROWFIELD
MONEWDEN
180
Deben

APPENDIX 2
SOLUTIONS FOR QUESTIONS ON PRACTICAL NAVIGATION

APPENDIX 2: SOLUTIONS FOR QUESTIONS ON PRACTICAL NAVIGATION

FLIGHT LOG AND SOLUTIONS FOR QUESTIONS ON CHAPTER 13: PRACTICAL NAVIGATION

DATE:	T/O:			LDG:			FLT TIME:						
FROM	TO	ALT/FL	SAFETY ALT	W/V	TAS	TK(T)	HDG(T)	VAR	HDG(M)	G/S	DIST	TIME	ETA
CAMBRIDGE	ELMSWELL	FL35	2300	230/15	100	085	090	2ºW	092	111	27	14.5	
ELMSWELL	REEDHAM	FL35	2300	230/15	100	051	052	2ºW	054	115	30	15.5	
REEDHAM	FENLAND	FL35	2300	230/15	100	282	276	2ºW	278	92	59	38.5	
ALTERNATE													
FENLAND	SIBSON	FL35	2300	230/15	100	230	230	2ºW	232	85	17	12	

FUEL	
TO DESTINATION	12
TO ALTERNATE	2
10% CONTINGENCY	2
45 MIN HOLDING	8
MINIMUM RESERVE	5
TOTAL REQUIRED	29
TOTAL ON BOARD	40
ENDURANCE	4HRS

COMMUNICATIONS					
STATION	FREQ	STATION	FREQ	STATION	FREQ
CAM	123.6	FENL	122.925		
WATT	125.8				
LAKEN	128.9	FNL NDB	401		
SEETH	122.6				
NORW	119.35	NWI NDB	342.5		
MARHAM	124.15				

Answers to Questions not given in Flight Log

8. 7.5 minutes
9. 28 minutes
12. 8º port
13. 4 minutes
14. Your altimeter would indicate a lower reading
15. HDG(M) 254º, G/S 88 knots, 20 minutes
16. 7 knots
17. 13º port
18. ADF
19. 26 LH, 18RH
20. FL 45
21. At weekends and on public holidays
22. Runway 24, 1 000 feet on the airfield QFE, Left hand, Power lines on the approach.

APPENDIX 2: SOLUTIONS FOR QUESTIONS ON PRACTICAL NAVIGATION

APPENDIX 3
AERODROME PLANS

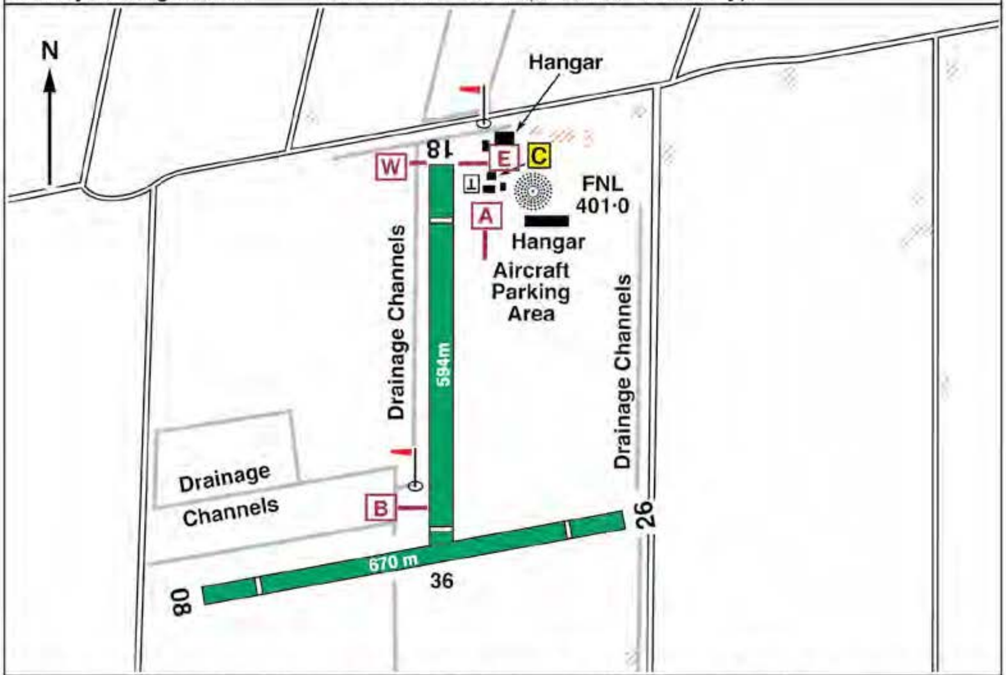
APPENDIX 3: AERODROME PLANS

EGCL **2007**

N52 44·37 W000 01·80 — **FENLAND** — 6 ft AMSL

6 nm SE of Spalding. **BKY 116·25 358 45·1**
GAM 112·80 137 46·4

c/s Fenland Radio 122·925 A/G. c/s Information 122·925 AFIS - Sat, Sun & PHs and by arrangement. **NDB 'FNL' 401·0** (On A/D. Nav. only).



Rwy	Dim(m)	Surface	TORA(m)	LDA(m)	Lighting
18/36	594x30	Grass	18-594 36-594	18-512 36-591	† Thr Rwy LITAS 4·5° † Thr Rwy
08/26	670x18	Grass	Unlicensed		Nil.

† Lighting by prior notice. Rwy 36 unlicensed for night flying. IBn 'FE' Gn.

Op hrs: 0900–Dusk Tue-Sun, closed Mon. O/T by arrangement.

Landing Fee: Microlights £5; Fixed wing and Helicopters £6; Twins £12.50.

Hangarage: Ltd. **Maintenance:** Available **Customs:** 24 hrs PNR.

Remarks: Operated by Fenland Aero Club (Licensing) Ltd, Fenland Airfield, Holbeach St. Johns, Spalding Lincs PE12 8RQ.

Flying Instruction by Fenland Flying School..

PPR at night and to non radio aircraft. Visitors welcome.

See Noise Abatement Chart on the opposite page.

Departing helicopters should air taxi to Hold A before departing via runway-in-use.

Warnings: Inset lighting on Rwy 18/36. Aircraft movements confined to marked grass runways & taxiways. Displaced thresholds on Rwys 18 and 26 due to public roads.

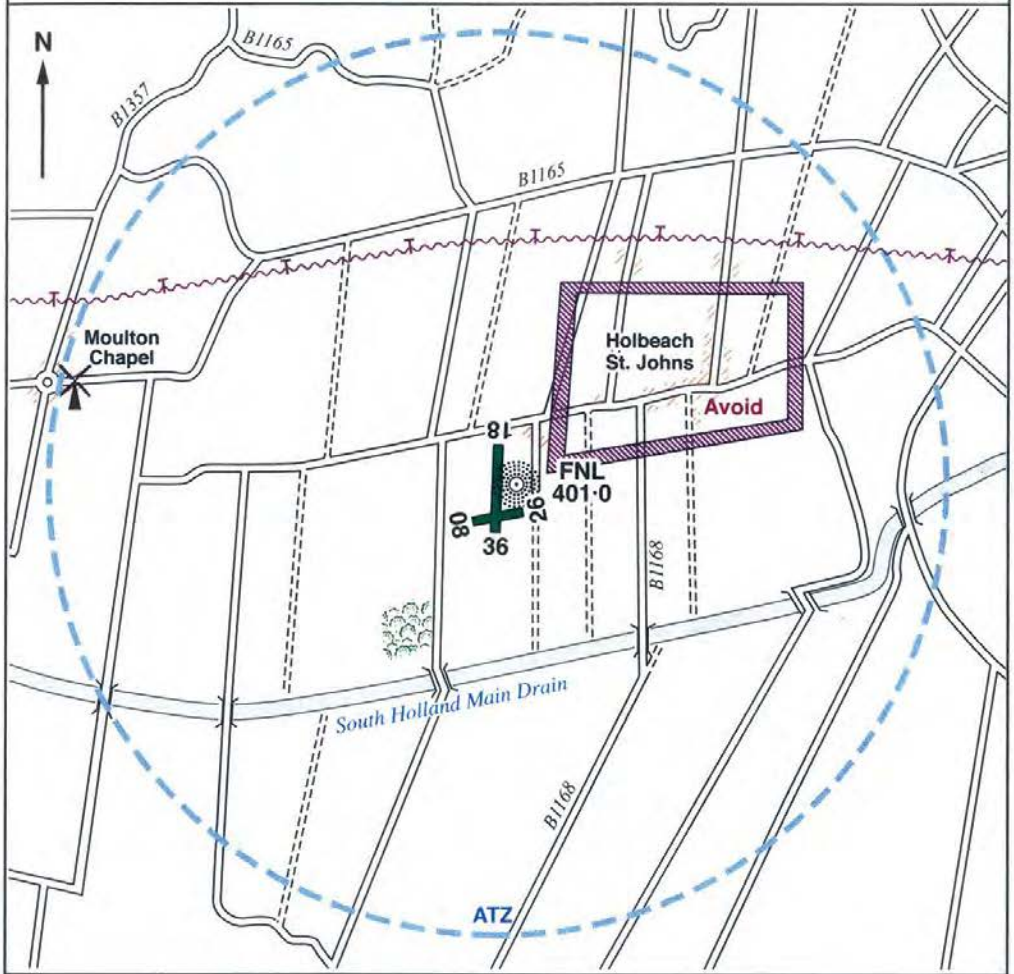
Restaurant: Licensed Restaurant Fri-Sun only, Tel: 01406-540330.

Fuel: 100LL, Jet A1.

Tel: 01406-540330 Clubhouse/ATC.
Tel/Fax: 01406-540461 Flying School.
Web: www.fenlandairfield.co.uk

EGCL **2006**

FENLAND
Noise Abatement



Noise Abatement:

Do not overfly the shaded area indicated above.

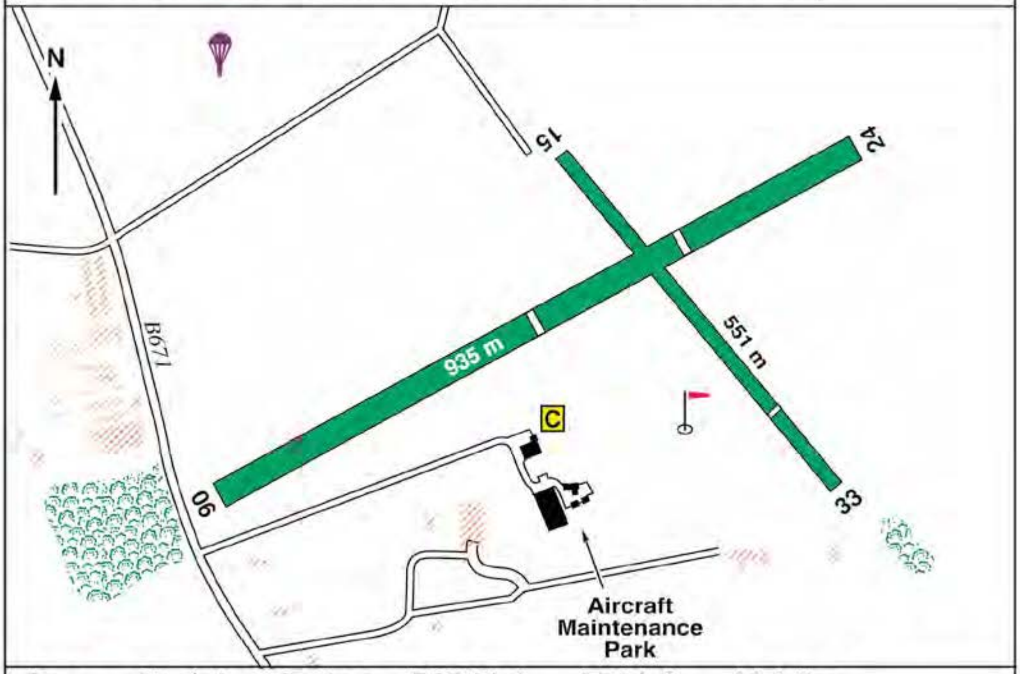
Circuits at 1000 ft aal, LH on Rwy 26 and 36, RH on Rwy 08 and 18.

EGSP 2007

N52 33·35 W000 23·18 **PETERBOROUGH (Sibson)** 130 ft AMSL

6 nm W of Peterborough. **DTY 116·40 052 34·9.**
WIT 117·60 130 **5·2**

c/s Sibson Radio 122·30 Cottesmore Zone 130·20 (MATZ & LARS)



Rwy	Dim(m)	Surface	TORA(m)	LDA(m)	Lighting
06/24	935x30	Grass	06-676	06-468	Nil.
			24-468	24-676	Nil.
15/33	551x18	Grass	15-551	15-551	Thr Rwy APAPI 4°
			33-551	33-424	Thr Rwy APAPI 4°
					ABn Wh

Op hrs: 0800-2000 (and by arrangement). PPR by phone.

Landing Fee: Microlights £5; Singles £10; Twins £20. Half price with fuel uplift.

Hangarage: Phone. **Maintenance:** Available, CAA approved **Customs:** Phone.

Remarks: Operated by NSF Sibson. Non-radio aircraft not accepted.
Caution as power lines on Rwy 24 approach. Trees on Rwy 06 approach.
Inbound aircraft to call Cottesmore Zone 130·20 when15 nm from Wittering.
No deadside and no overhead joining due to free-fall parachuting up to FL135.
Circuit height 1000 ft QFE, LH on Rwy 15 and 24, RH on Rwy 06 and 33.
Avoid overflying Elton SW of the airfield, and Stibbington to the N.

Whilst parachuting in progress:

- Transitting aircraft (fixed & rotary) may not penetrate the ATZ;
- Rotary wing aircraft may not operate in the ATZ.

Mast 586' aal 686' amsl 145°/2·1 nm.
Restaurant: Available Tue-Sun, Tel: 01832-280404.
Car Hire: Avis - 01733-349489. Hertz - 01733- 893083. **Taxi:** Tel: 01733-310777.

Fuel: 100LL

Tel: 01832-280289. **Fax:** 01832-280675
Web: www.nsof.co.uk

Customer: Oleg Ostapenko E-mail: ostapenko2002@yahoo.com

JAR-FCL PPL THEORETICAL KNOWLEDGE SYLLABUS

NAVIGATION & RADIO AIDS

The table below contains the principal topics and subtopics from the current outline syllabus for the theoretical knowledge examination in **Navigation & Radio Aids** for the **Private Pilot's Licence**, as published in **JAR-FCL 1**. Syllabuses may be modified, so always check the latest examination documentation from your national civil aviation authority, or from JAR-FCL/EASA.

NAVIGATION	
Form of the Earth:	axis; poles; meridians of longitude; parallels of latitude; great circles; small circles; rhumb lines; hemispheres; north/south, east/west.
Mapping:	aeronautical maps and charts (topographical); projections and their properties;conformality; equivalence; scale; great circles and rhumb lines.
Conformal Orthomorphic Projection (ICAO 1: 500 000 chart):	main properties; construction; convergence of meridians; presentation of meridians, parallels, great circles and rhumb lines; scale, standard parallels; depiction of height.
Direction:	true north; Earth's magnetic field, variation; annual change; magnetic north; vertical and horizontal components; isogonals, agonic lines.
Aeroplane Magnetism:	magnetic influences within the aeroplane; compass deviation; turning, acceleration errors; avoiding magnetic interference with the compass.
Distances:	units; measurement of distance in relation to map projection.
Charts in Practical Navigation:	plotting positions; latitude and longitude; bearing and distance; use of navigation protractor; measurement of tracks and distances.
Chart reference material/map reading:	map analysis; topography; relief; cultural features; permanent features (e.g. line features, spot features, unique or special features); features subject to change (e.g. water); preparation; folding the map for use; methods of map reading; map orientation; checkpoint features; anticipation of checkpoints; with continuous visual contact; without continuous visual contact; when uncertain of position; aeronautical symbols; aeronautical information; conversion of units.

Principles of Navigation:	IAS, CAS and TAS; track, true and magnetic; wind velocity, heading and groundspeed; triangle of velocities; calculation of heading and groundspeed; drift, wind correction angle; ETA; dead reckoning, position, fix.
The Navigation Computer:	Use of the circular slide rule to determine: TAS, time and distance, conversion of units, fuel required, pressure, density and true altitude, time en-route and ETA. Use of the computer to solve triangle of velocities, application of TAS and wind velocity to track, determination of heading and ground speed, drift and wind correction angle.
Time:	relationship between universal co-ordinated (standard) (UTC) time and local mean time (LMT); definition of sunrise and sunset times.
Flight Planning:	selection of charts; route and aerodrome weather forecasts and reports; assessing the weather situation; plotting the route;considerations of controlled/regulated airspace, airspace restrictions, danger areas, etc. use of AIP and NOTAMS; ATC liaison procedures in controlled/regulated airspace; fuel considerations; en-route safety altitude(s); alternate aerodromes; communications and radio/navaid frequencies; compilation of flight log; compilation of ATC flight plan; selection of check points, time and distance marks; mass and balance calculations; mass and performance calculations.
Practical Navigation:	compass headings, use of deviation card; organisation of in-flight workload; departure procedure, log entries, altimeter setting and establishing IAS; maintenance of heading and altitude; use of visual observations; establishing position, checkpoints; revisions to heading and ETA; arrival procedures, ATC liaison; completion of flight log and aeroplane log entries.

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RADIO AIDS	
Ground D/F (VHF Direction Finding):	application; principles; presentation and interpretation; coverage; errors and accuracy; factors affecting range and accuracy.
ADF, including associated beacons (NDBs) and use of the RMI:	application; principles; presentation and interpretation; coverage; errors and accuracy; factors affecting range and accuracy.
VOR/DME:	application; principles; presentation and interpretation; coverage; errors and accuracy; factors affecting range and accuracy.
GPS:	application; principles; presentation and interpretation; coverage; errors and accuracy; factors affecting reliability and accuracy.
Ground Radar:	application; principles; presentation and interpretation; coverage; errors and accuracy; factors affecting reliability and accuracy.
Secondary Surveillance Radar:	principles (transponders); application; presentation and interpretation; modes and codes.
THE NAVIGATION SKILLS TEST	
Orientation, Timing and Revision of ETAs, Log Keeping:	navigate by means of calculated headings, ground speed and time; achieve destinations or turning points within 3 minutes of estimated time of arrival (ETA); maintain a navigation log and radio log by recording all pertinent information such that the whole route may be reconstructed if necessary after the flight.
Diversion to alternate aerodrome, Planning & Implementation:	calculate heading, ground speed, ETA and fuel required during any unscheduled diversion; calculate Safety Altitude for track to new destination; navigate by means of calculated headings, ground speed and time; maintain the heading height and speed as computed in navigation log or advised to the Examiner within the prescribed limits.

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The United Kingdom CAA adds the following details (accurate, April 2007) concerning the PPL Navigation skills test, in the CAA Personnel Licensing document, entitled: 'Notes for the Guidance of Applicants taking the PPL Skill Test (Aeroplanes)'.	
Flight plan, dead reckoning and map reading:	complete all elements of VFR planning for the route prescribed with particular reference to planned altitudes and safe levels of operation; identify position visually by reference to ground features and map.
Maintenance of altitude, heading and speed:	control aeroplane using visual attitude flying techniques; maintain the heading height and speed as computed in navigation log or advised to the Examiner within the prescribed limits.
Orientation, timing and revision of ETAs, log keeping:	navigate by means of calculated headings, ground speed and time; achieve destinations or turning points within 3 minutes of estimated time of arrival (ETA); maintain a navigation log and radio log by recording all pertinent information such that the whole route may be reconstructed if necessary after flight
Diversion to alternate aerodrome, planning & implementation:	calculate heading, ground speed, ETA and fuel required during any unscheduled diversion; calculate Safety Altitude for track to new destination; navigate by means of calculated headings, ground speed and time; maintain the heading.
Use of radio navigation aids, position fix and tracking:	select and identify appropriate radio and navigation aids as required or nominated by Examiner; locate and record the aeroplane position by using radio navigation equipment when required by the Examiner; intercept and maintain given tracks or radials using the navigation aids nominated.

ANSWERS TO NAVIGATION AND RADIO AIDS QUESTIONS

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Chapter 1 Form of the Earth

Question	1	2	3	4	5
Answer	b	c	d	b	d

Chapter 2 Time

Question	1	2	3	4	5	6
Answer	b	a	a	d	c	a

Chapter 3 Direction

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	c	b	b	c	d	b	a	d	a	c	d	b

Question	13
Answer	c

Chapter 4 Speed, Distance and Time

Question	1	2	3	4	5	6	7	8
Answer	c	b	c	b	d	b	a	c

Chapter 5 Aeronautical Charts and Map Making

Question	1	2	3	4
Answer	d	b	d	b

Chapter 6 Features on Aeronautical Charts

Question	1	2	3	4
Answer	d	c	a	b

Chapter 7 Measuring Track Angle and Track Distance

Question	1	2	3	4	5	6
Answer	b	b	d	b	c	d

Chapter 8 Map Reading

Question	1	2	3	4	5	6	7
Answer	a	c	d	b	d	b	d

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Chapter 9 — Principles of Dead Reckoning Air Navigation

Question	1	2	3	4	5
Answer	b	a	b	a	d

Chapter 10 — Altimeter Settings

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	c	c	d	d	b	a	b	a	b	c	c	b

Question	13	14	15	16	17	18	19	20	21	22
Answer	c	b	b	d	a	c	a	d	b	b

Chapter 11 — The Navigation Computer

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	c	b	b	d	d	a	d	c	d	d	a	a

Question	13	14	15	16	17	18
Answer	b	c	a	d	d	c

Chapter 12 — Flight Planning

The answers to the questions in Chapter 12 are given on Page 230.

Chapter 13 — Practical Navigation

The answers to the questions in Chapter 13 are given at Appendix 2, Page 383.

Chapter 15 — VHF Direction Finding

Question	1	2	3	4	5
Answer	a	c	d	d	c

Chapter 16 — Automatic Direction Finding (ADF)

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	c	c	a	d	a	c	a	b	b	d	a	d

Question	13	14	15
Answer	d	a	c

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Chapter 17 VHF Omni-Directional Range (VOR)

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	a	c	b	d	d	a	b	c	c	d	a	c

Question	13	14
Answer	c	a

Chapter 18 Distance Measuring Equipment (DME)

Question	1	2	3	4	5	6	7
Answer	d	d	a	c	b	a	c

Chapter 19 Ground Radar

Question	1	2	3	4	5	6	7
Answer	a	b	c	b	a	a	d

Chapter 20 Secondary Surveillance Radar

Question	1	2	3	4	5	6	7	8
Answer	b	c	b	a	d	c	d	c

Index