1 INTRODUCTION

This tutorial is specifically designed for Microsoft Flight Simulator pilots flying VFR flight in the UK. It is part of a series of tutorials being produced by the Cix VFR Club.

Navigation theory can be complex, and needs to be thoroughly understood by real world pilots, but is less important for Flight Simulator pilots. There is probably more basic theory than is necessary in this Exercise, to help the Flight Simulator pilot understand practical navigation in flight, but it is difficult to draw a line between what is necessary and what is useful in this regard.

If you are confused by any issue, Cix VFR Club members may post a message in the Cix conference, email the Club CFI (see web site) and we will try to clarify any points you are having difficulty with. Because you don't have the benefit of an instructor to bounce questions off, you are actively encouraged to discuss the material in this way.

Practical navigation for Flight Simulator pilots is covered in Exercise 18D.

2 DEFINITIONS

Some less commonly used definitions are not shown in this section, but are identified in bold face type in the text.

Navigation Navigation is the art of knowing where you are, so that you are able to move in the right direction towards an intended destination. Navigation tasks are additional to and secondary to flying the aircraft. One of the definitive mantras of flying is

Aviate, navigate, communicate.

VFR Visual Flight Rules

IFR Instrument Flight Rules

Position The definition of an object's position from a known fixed point in two dimensions is expressed in distance and direction. In flight the third dimension, height or altitude, must be added.

Distance Distance is defined as the length of the shortest line between two points. On a flat surface this is a straight line, on a sphere, such as the earth, this is a line which follows the sphere's circumference.

Direction The angle of a line between two points on the earths surface, usually expressed in terms of points of the compass – e.g. Northeast, Southwest. Only used generally in aviation, most commonly for approximate position reporting to Air Traffic

Control when flying VFR.

Speed
: Speed is defined as the distance travelled in a specified unit of time. Speed may be expressed in many different units – miles per hour, kilometres per hour, feet per second, knots. In the UK the knot is the most widely used unit of speed in aviation. One knot is one nautical mile per hour (we flyers never get away from our seafaring past!).

Nautical Mile
: The nautical mile is defined as one minute (1/60th of a degree) of longitude at the equator, and the earth's circumference is of course 360 degrees. One minute is therefore

$$\frac{1}{60 \times 360}$$

or 0.0000463 of the earths circumference at the equator, which is 24901.55 statute miles. This calculates as 6087 feet, or 1.1528 statute miles. However, when the nautical mile was defined, the circumference of the earth had a slightly different value (how did they know in 1690 or whenever it was?), so today the nautical mile is officially 6080 feet.

Bearing
: The angle of a line between two points on the earth's surface, relative to north, is called the **bearing**.

Heading
: The angle which an aircraft flies on its direction indicating instruments in order to reach a destination is called the **heading,** and is expressed in degrees clockwise from North.

Track
: The angle relative to North which an aircraft achieves in order to reach a destination is called the **track made good,** or just **'track'**.

Course
: This is numerically the same as **bearing.** In VFR navigation, it is used imprecisely and generally, as in "set course for the coast". It is used precisely in connection with aircraft fitted with an autopilot. If the autopilot is set to follow a **course**, it uses the VOR instrument to calculate the **drift angle** due to the wind and makes the aircraft fly a heading which will achieve the required course. It is not used in this tutorial, and we don't need to concern ourselves any further about it.

Note: 1
: Because **bearing** is the angle on the ground between two points, whereas **track** is the path which the aircraft achieves through the air, if the pilot flies accurately, the bearing and the track will be the same.

Note 2:
: Any difference between **heading** and **track** is created by the

wind velocity. For example, if an aircraft intends to fly on a bearing of due north in a westerly wind, then the pilot will have to fly a heading which is into wind – say 345º.

Height	The vertical distance above the ground at any point
Altitude	The vertical distance above sea level at any point
Safety Altitude	Safety Altitude is 1000 feet above the highest known object within 5 nautical miles of the aircraft's track.
Controlled Airspace	Controlled Airspace is airspace in which a pilot may not fly in any circumstances without permission from Air Traffic Control.

3   MAPS AND CHARTS

First we need a map – or "chart" in aeronautical circles – those old sea salts again (they had charts and not maps). The word chart comes from the Latin *Carta* meaning a sheet of papyrus or paper, and is also the root of the word Charter which has a somewhat different meaning.

The UK is covered by a series of aeronautical charts at 1:500,000 scale, commonly known as "half million" or "half mill" charts.   Three such charts cover the whole of the UK, including Northern Ireland and part of Eire.

The Cix VFR Club members are encouraged to obtain these real aeronautical charts, either new at around £15.00 each or last years edition, scrounged from real world pilots who have to get a new one every year to keep up with changes. So this tutorial will assume that you have real aeronautical "half mill" charts.

3.1   Scale

Maps and charts may be drawn to any scale. The larger the scale used, the smaller the area which can be depicted, but the greater the amount of detail which can be shown.

In the UK, the normal aeronautical chart used for VFR navigation is at 1:500,000 **scale**, so 1 inch on the map is equivalent to 500,000 inches on the ground, or 6.85307 nautical miles to be precise. To work with aeronautical charts, you really need a scale rule graduated to 1:500,000, so that you can read off distances in nautical miles directly. These are obtainable from Pilots Supplies shops.

For general flight planning, charts at 1:1,000,000 or 1:2,000,000 are used, and for slow speed flight such as Microlight aircraft, gliders and hot air balloons, aeronautical charts at 1:250,000 scale are available.

One of the failings of Flight Simulator is that the map view gives no idea of scale, so it's value in knowing where you are is limited and its value in telling you how far you have to go is precisely nil!

3.2   Latitude and Longitude

Because the earth is round and a map is flat, the relationship between the two is complex, and the representation of the earth accurately on maps is an exercise which has taxed cartographers for almost two thousand years since the Greek astronomer and philosopher Ptolemy (A.D.85 to 165) drew the first map of the known world. The method used to represent the spherical earth on paper is known as a **projection**. A point on the earth's surface is defined in terms of two axes, nominally at right angles to each other, called latitude and longitude.

There is an excellent treatise on the Internet on the art of navigation at sea, definitions of latitude and longitude, and the inventions that were necessary to achieve accurate position fixing.

http://rubens.anu.edu.au/student.projects97/naval/defin.htm

Aeronautical charts are drawn using the **Lambert Conformal Conic Projection**, in which the lines of longitude converge towards the pole (the north pole in the Northern Hemisphere, naturally). Lines of latitude are oriented east west, do not pass through the poles and can be thought of as slices of the earth. Lines of longitude, also called meridians, are oriented north-south, pass through the poles and are therefore segments of the earth. If you open your chart right out and you will see that the lines of latitude are parallel to each other, whereas the lines of longitude converge slightly to the north. At the equator, and only at the equator, lines of longitude are parallel.

On the half million chart, lines of latitude are shown horizontally on the half mill chart at intervals of 30 minutes (30') and are oriented east west. Each line includes graduations at 1-minute (1') intervals.

Lines of longitude are shown also at intervals of 30', and oriented north south. Each line of longitude is also marked with graduations at 1' intervals.

Because lines of latitude do not converge, they are always equidistant on the chart. This means that the 1' graduations *drawn on the lines of longitude* are always the same distance apart and because 1 nautical mile is (as near as makes no matter) 1 minute of arc when drawn on a meridian, these graduations represent 1 nautical mile. This can be useful if an aeronautical scale rule is not available.

Note: The graduations drawn on the lines of latitude do not represent 1 nm and cannot be used for distance measurement.

3.3   Distance

Distances between two points on the earth are measured along its circumference, and are known as "Great Circle Distances". For example, the Great Circle from London to New York is almost across the North Pole, whereas if one looks at any normal atlas, it would appear to be "straight across the Atlantic".

A Great Circle line may, depending on its bearing, intersect lines of longitude at different angles. On the half million chart, a straight line intersects lines of longitude at different angles, though the differences will be very small. Therefore, a straight line drawn on the half million chart is a Great Circle distance.

Lines which join two points on the earths surface such that the angle of intersection with lines of longitude is always the same, are necessarily curved. In the northern hemisphere, such a line drawn approximately east west will be concave towards the north. These lines are called **Rhumb lines**.

A pilot flying a constant magnetic heading will cross each line of longitude at the same angle. In other words, he will be flying along a Rhumb Line, which will result in him/her flying a slightly longer distance than if he/she flew the Great Circle track. Over distances of 200nm or less, the Great Circle and the Rhumb Line are almost identical, and even up to 1000 miles or so, the difference can be ignored in terms of significant track errors or extended flight distances. This is a tutorial on navigation within the UK which is only 1000 miles long from Lands End to John O'Groats, so there is no need to worry about such things any further here.

4 THE MAGNETIC COMPASS

Ancient Chinese sailors navigated by reference to North. They did this by dangling a special type of stone from a string, because the same point on the stone always pointed in the same direction. This stone was called a lodestone and was a type of iron ore now known as "Magnetite" for obvious reasons. The magnetic compass is a refinement of the lodestone, and comprises a needle on a fine balance bearing, which always points north south – well almost.

The compass needle points to **_Magnetic_** North which may, but rarely does, coincide with true north. The angular difference between true north and magnetic north is called "Magnetic Variation". The last determination of magnetic north - the North Magnetic Pole - was made in 1994. At that time it was located on the Noice Peninsula, southwest Ellef Ringnes Island, (Canada) at 78.3° N, 104.0° W. The North Magnetic Pole moves about 9.3 miles per year, and also wanders daily in an elliptical path around the average pole's position. When the magnetic field of the earth is disturbed, it may move as much as 50 miles from the average position.

In the UK in 2005, magnetic north is between 2º west of true north in Norwich, and 5.5º west of true north in Belfast. Lines of equal magnetic variation are called isogonals and are shown on the half mill chart. Variation may be east as well as west and in some places as much as 40º, which takes some getting used to by unfamiliar pilots I shouldn't wonder.

The magnetic compass in an aircraft is a primary direction indicating instrument and points to magnetic north, and to reduce any confusion in flight, all flight bearings and headings are referenced to magnetic north. So a bearing of 192° is measured on the chart in degrees **_true_** and written 192° T, but is converted to degrees magnetic (ºM) for flight. Because magnetic variation is west in the UK, we add the variation to the true bearing. As in

many areas of aviation, there is a "saying" to help pilots remember whether to add or subtract magnetic variation.

Variation west; magnetic best

Variation east; magnetic least

A further adjustment may be necessary in flight, because the compass fitted in the aircraft does not always point to magnetic north when the aircraft itself is oriented to magnetic north. This is due to electrical and magnetic fields generated within the aircraft itself which cannot be corrected by the adjusting magnets within the compass. The aircraft compass will typically carry a "deviation card" which tabulates the values for different bearings. Deviation is typically 1° or 2° only, but as Flight Simulator does not simulate this behaviour of the magnetic compass, it can be ignored.

5   SPEED

Because you are not travelling across the ground, the conventional method of measuring speed, measuring the distance travelled in a given time is a problem, because how do you measure the distance? There are also several different kinds of speed.

5.1   Measuring Speed in the Air

In an aircraft, the normal method of determining speed is to measure the speed of the air passing the aircraft, on the assumption that the speed of the air going backwards past the aircraft is equal to the speed of the aircraft going forwards through the air. In the old slow aircraft, this speed was measured either by a mini-propeller whose revolutions were counted – a bit like the car's wheel in a way, or by means of a venturi, or, at its simplest, a swinging vane hinged at the top. With the angle of inclination being directly proportional to the speed of the air passing it, a simple pointer and scale was added above the hinge to give a direct read out.

The venturi type of speed indicator funnelled the air past two small orifices at right angles to the air flow, and with a little bit of physics and some calculation, the differential pressure between the two orifices was found to be directly related to the speed of the air past them. Then it was found that a similar relationship was true if the air was not funnelled into the venturi tube, but allowed to flow across a hollow probe pointing into the airflow, with a separate orifice at right angles to the airflow placed nearby. This device is the pitometer, and is universally used on modern aircraft.

5.2   The Wind

So the speed of the air passing the aircraft is measured – say one hundred miles per hour. The aircraft is therefore travelling at 100 mph then? Yes, but only relative to the air. What we have measured is "Airspeed". If we

want to know "Groundspeed", then we have to know the speed of the air across the earth's surface – the wind.

If the wind is blowing at 15 miles per hour, and the wind is blowing in the same direction as the aircraft is travelling, the groundspeed is 115 mph (100+15). If the wind is blowing in the opposite direction, then the ground speed is only 85mph (100-15). However, if the wind is blowing at an angle to the aircraft's direction of travel, the groundspeed is not so easily calculated. We need to know about **velocity**.

5.3   Velocity – a Vector

A vector is a scientific definition of motion, and has both **magnitude** (speed) and **direction**. We talk generally of the speed of an aircraft, but what we really mean is its velocity, which has both speed and direction. Air traffic control will often provide "vectors" to an approach, and they are using the correct term, because they will pass both headings and required speeds to the pilot. In flying we also soon become familiar with wind speed being published as " 210 degrees at 10 knots". The direction is 210º, and the magnitude is 10 knots. The aircraft too has velocity – e.g. heading 260º at 100 knots.

To calculate the groundspeed in terms of velocity (both speed and direction), requires a little fairly simple trigonometry called the triangle of velocities.
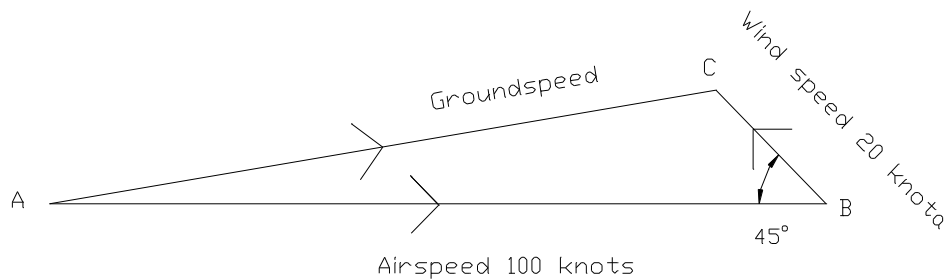
The triangle of velocities

Let us assume the aircraft is flying at 100 knots in an easterly direction (90º) and the wind is blowing at 20 knots towards the aircraft but at 135 °, (which is 45 ° from the right and front relative to the aircraft), we can draw the triangle of velocities to find the groundspeed.

In the diagram above, we first draw a line A – B at 90º relative to North (i.e. horizontal) to represent the aircraft's *direction*, and make it 10 inches long to

represent the aircraft's *speed*. We then draw another line at 135° to represent the wind *direction* and make it intersect the right hand end of the airspeed line. Then to make it represent wind *speed* measure 2 inches along it from the intersection and make a mark – position C. Now draw a line A – C to complete the triangle.

Measure the length of this line. It is 8.6 inches long (8.58557 to be precise). We represented 100 knots by 10 inches, and 20 knots by 2 inches, so 8.6 inches represents 86 knots - the groundspeed is 86 knots. In possibly one tenth of the time it took to explain this, you can draw the triangle. In about the same time, if you can remember your trigonometry from school, and have a calculator, you can calculate that the groundspeed is

Groundspeed = airspeed ± windspeed x cosine (relative wind direction)

In the real world there are specially designed circular slide rules for aviation with a graphical tablet on one side on which the triangle of velocities can be very quickly drawn, or nowadays, calculators are available with the correct aviation functions built in. In the Cix VFR Club, since we are sitting at a computer, we have a handy and sophisticated spreadsheet programme which we can use to do these calculations painlessly.

5.4 Airspeed

Airspeed is measured relative to the air, and the air is not a solid object you can mark off with your rule – "primary measurement". Our airspeed indicators rely on "secondary measurement" *measuring* differential air pressure to *calculate* speed. However, air pressure changes – with weather, with temperature, and with altitude. Fortunately for pilots, the only one of these three which affects the measurement of airspeed is altitude, for reasons which we don't need to know here. Our instrument always measures "Indicated Airspeed" and will do so at all altitudes, but an aircraft travelling at an indicated airspeed of 100 knots at 2000 feet will not be going as fast as an aircraft flying with an indicated airspeed of 100 knots at 30,000 feet. In fact, at 30,000 feet, the **true airspeed** is over 200 knots**.**

The effect of altitude on airspeed is modelled in Flight Simulator, so has to be taken into account, except that, for the purposes of 90% of our VFR flights, you can ignore the difference between indicated and true airspeed. Pilots always use indicated airspeed for setting climb, cruise and descent speeds etc., but if flying at high altitude, will use true airspeed for planning. If you really want to see your true airspeed, you can select within Flight Simulator whether you want the aircraft to use true airspeed or indicated airspeed. Within the Club, this should always be set to Indicated Airspeed.

6 VERTICAL NAVIGATION AND ALTIMETRY

Knowledge of vertical navigation is vital for pilots for three reasons

1) Terrain clearance – ensuring the aircraft doesn't collide with high ground.
2) Traffic separation – ensuring aircraft in the same vicinity are kept a safe distance from each other vertically as well as horizontally.
3) To be able to work within the performance limits of the aircraft and its engine.

6.1 Atmospheric Pressure

We mentioned in the definitions section that in the three-dimensional world of flight, the third dimension, height or altitude has to be taken into consideration. Measuring heights of many thousands of feet would be problematical if it wasn't for the fact that atmospheric pressure falls at a uniform rate with increasing height, so it can be used to measure height. Atmospheric pressure is *relatively* constant – varying between about 14.0 and 14.75 pounds per square inch or 985 – 1036 millibars at sea level, changes being caused by weather changes.

The international unit for measuring atmospheric pressure has been changed in recent years to "Hectopascals" (hPa), which happens to be numerically equal to the former unit of measurement – millibars (mb). In the UK, we have elected to continue using millibars. An instrument which measures atmospheric pressure – the aneroid barometer – can be used to measure height by simply marking the dial in feet instead of millibars. It is then known as an "Altimeter" and is a primary navigation instrument in all aircraft.

The altimeter is calibrated against an internationally defined "International Standard Atmosphere" (ISA). The ISA is defined as a pressure of 1013.25 hectopascals (or millibars) measured at mean sea level at a temperature of 15° Celsius. The ISA also defines the **pressure lapse rate**, the rate at which pressure decreases with height, which is approximately 30 feet per millibar, and the **temperature lapse rate**, which is theoretically 2° Celsius per thousand feet.

A hill top 600 feet above sea level will have an atmospheric pressure 20 (600/30) millibars less than the atmospheric pressure at sea level. Let us assume that we are standing at sea level, when the atmospheric pressure is 1013 millibars and the temperature is 15°C – ISA conditions. Our altimeter will read zero because it is calibrated to read zero at sea level in ISA conditions. We now climb to the top of the 600-foot hill, and as we do so the atmospheric pressure at sea level changes to 1033 millibars. On reaching the top of the hill, we discover that the altimeter still reads zero. How can that be?

Had the atmospheric pressure not changed, then the altimeter would have read 600 feet, because the pressure on its aneroid cell would have fallen by 20 mb (1 mb per 30 feet lapse rate, remember) to 993mb. But by the end of

the climb, the atmospheric pressure at sea level had risen by 20 mb from 1013 to 1033 and so on our hill it had also risen by 20 mb from 993mb to 1013 mb making the altimeter again read zero.

To overcome this problem, the altimeter is fitted with an adjusting knob and sub-scale, called a Kollsman scale, calibrated in millibars. This makes it possible to set the actual sea level atmospheric pressure at any time, ensuring that the altimeter always accurately displays its height above sea level. In our example above, if the atmospheric pressure at sea level changed from 1013 to 1033, and the Kollsman scale was adjusted to 1033, then because the atmospheric pressure there is still 20mb less than at sea level, the altimeter will detect that the pressure is 20mb (1033-1013) less than it would at sea level, and will display 600 feet.

Note: If you increase the Kollsman scale millibars setting, the indicated altitude increases, and vice versa.

It can take a while to get to grips with this idea, but it is vital that the pilot understands the importance of setting the right pressure value on the Kollsman scale for the following reasons.

At various times throughout a flight, the pilot may be given a new value for atmospheric pressure at sea level by Air Traffic` Control. If all pilots in the region set this pressure on their altimeter sub-scales, then all aircraft flying with an indicated altitude of 2000 feet will be flying at the same height, and more importantly, aircraft told to fly at 1000 feet vertical separation intervals will be 1000 feet apart vertically.

In the UK, and in some other parts of the world, the aviation term for the atmospheric pressure at sea level is called "QNH" pronounced kew-en-aitch. The term is one of the few "Q codes" still in use which originated in the days of Morse code only radio transmissions. It is simpler and quicker than trying to say "atmospheric pressure at sea level" over the radio. Similarly, another important value is atmospheric pressure at aerodrome level. This is called "QFE" pronounced "kew-eff-ee".

To try and clarify this a little more, if an aircraft is sitting on a runway with QNH set on the altimeter Kollsman scale, the altimeter will display the runway's height above sea level. If the aircraft has QFE set on the altimeter Kollsman scale, the altimeter will indicate zero. We will use this information when we cover in-flight altimeter setting procedures.

6.2 Height, Altitude and Flight Level

If an aircraft is flying with QFE set on the altimeter Kollsman scale, then its position above the ground is defined as "height" and the pilot will report his height to ATC if asked.

If an aircraft is flying with QNH set on the altimeter Kollsman scale, then its position above the ground is defined as "altitude" and the pilot will report his altitude to ATC if asked.

If the aircraft is flying above the "Transition Altitude" (normally 3,000 feet in the UK, except over part of Scotland) then the pilot must set his altimeter Kollsman scale to 1013 and report his "Flight Level" to ATC if asked. Flight levels are expressed without the last two zeros, so 4500 feet is "Flight Level 45", and 45000 feet is "Flight Level 450".

One important proviso of the Flight Level system is that on days of low pressure, setting 1013 on the altimeter and flying at 3000 feet (flight level 30) could result in the aircraft *actually* flying as low as 2, 200 feet. For this reason, Flight levels 30 and 35 are not generally used. Also, in general, flight levels are not used on VFR flights, although there is no regulatory reason why they shouldn't be.

6.3 Pressure Altitude

This is a term which you may come across occasionally. It has a complicated definition, but this can be simplified to "Pressure altitude is the altitude displayed on the Altimeter when 1013 is set on the Kollsman sub-scale." In other words, it is the altitude relative to the ISA pressure datum. For VFR pilots, it is important mainly for helping to determine an aircraft's performance at high altitude, particularly take off from high altitude airfields.

6.4 Density Altitude

The temperature of air affects its density – cold air is denser than warm air – and density affects pressure. The Altimeter will over read on a cold day and under read on a warm day. When flying from warmer air to colder air at a constant indicated altitude, therefore, the aircraft will actually descend. If terrain clearance is an issue, this could be important.

On a day when the temperature at sea level is 15ºC, (ISA temperature) the temperature at a pressure altitude of 3000 feet will be 6 ºC less; 9 ºC, because the temperature decreases by 2 ºC per thousand feet as explained above. So at 3000 feet, 9 ºC may be called the "ISA temperature" for that altitude. Similarly, on a day when the temperature at 3000 feet is 18 ºC, because the ISA temperature is 9 ºC, the temperature can be described as "ISA+9". The temperature at sea level will be 24 ºC, and you should be able to calculate why.

The density altitude can be determined in three ways:

1) By calculation from Pressure Altitude and temperature
2) Graphically (there are usually graphs in aircraft Manuals)
3) By using an aeronautical slide rule or calculator.

Method 1) uses the pressure altitude correction factor of 1 °C per 120 feet, and is the method used in the calculation below.

Let us take an airfield at 825 feet above sea level on a blistering hot July day - 28 °C at the airfield, and the QNH is 999 mb. First calculate the pressure altitude

If the altimeter Kollsman scale is advanced from 999 to 1013 to display pressure altitude, 14mb will be added, equivalent to 14 x 30 feet = 420 ft.

So the pressure altitude will be 825+420 = 1245 feet on that day.

The ISA temperature at that pressure altitude will be

15 °C – (2 x 1245/1000) = 12.5 °C, but the actual temperature is 28 °C

The density altitude correction to the pressure altitude value is therefore

(28-12.5) x 120 feet = 1860 feet

The density altitude on that very hot day is therefore 3,105 feet, a significant difference from the airfield elevation of 825 feet. What is important here is that the aircraft and its engine will perform as if the airfield were at 3,105 feet in ISA conditions.

One can immediately see that take off at an airfield 7,000 feet above sea level when the pressure is low and the ambient temperature is high, could result in a very long take off run being required to get airborne. In some conditions, the aircraft's performance capability could be exceeded.

7 ALTIMETRY PROCEDURES

7.1 The Transition Altitude

The rules for vertical navigation are somewhat simpler than the physics! Take off is normally conducted using the airfield QNH, unless remaining in the circuit, when QFE may be used. Below the **Transition Altitude**, en route flight is conducted using *Regional* QNH. The UK is divided into a number of Altimeter Setting Regions, so that all aircraft flying below the Transition Altitude across a large tract of country should all be using the same altimeter setting, which is essential for safe separation of traffic.

Above the Transition Altitude, flights are normally conducted using Flight Levels. The Kollsman sub-scale is set to 1013 by all aircraft, wherever they may be – again ensuring safe traffic separation. In the UK Transition Altitude is 3000 feet with the Regional QNH set, except in part of Scotland, where it is 6000 feet. In the USA, transition altitude is 18,000 feet.

For landing, pilots may choose to set the airfield QNH, or (more usually) airfield QFE. The advantage of using QFE is that if the circuit height is 1000 feet, then with QFE set, the pilot flies with 1000 feet displayed on the

altimeter to fly the circuit. With QNH set, he has to do the mental arithmetic of adding 1000 feet to the airfield elevation and fly the circuit with that value set. Many places in the world (e.g. USA) do this routinely and do not use QFE at all. (In fact in the USA the "Q code" abbreviations are not used).

To confuse a little further, two further definitions are necessary. The Transition *Level* is the flight level below which QNH is used for control of aircraft altitude. This is Flight level 35 normally, but can be higher if the atmospheric pressure is below 1013mb. Finally, the Transition *Layer* is the band of vertical airspace between the Transition Altitude and the Transition Level. The Transition Layer will vary in thickness depending on the regional QNH. Cruising flight within the Transition Layer is permitted, but is best avoided if possible.

7.2   Safety Altitude and Safety Height

We have already defined Safety Altitude as "1000 feet above the highest known object within 5 nautical miles of the aircraft's track." It really requires little further explanation. For IFR flight it is a legal requirement to fly above the safety altitude at all times, and instrument approach paths to landing always take this fact into consideration. For VFR flight, however, it is not a legal requirement to fly above the safety altitude, and it is sometimes not possible because of Controlled Airspace restrictions, but it should always be determined for any flight and should be a target minimum altitude. If a non-instrument rated pilot flying VFR inadvertently enters cloud, his first immediate action must be to turn 180º and try to exit cloud, and his second immediate action must be to climb to safety altitude if necessary.

How to determine safety altitude will be covered in exercise 17.

7.3   Selecting a Cruising Altitude

On a VFR flight the pilot must always fly in sight of the surface, clear of cloud and with an in-flight visibility of 5 kilometres or more. He/she must also remain clear of controlled airspace unless he/she has received specific permission to enter a particular zone. In the UK, with so much controlled airspace, and with much of it having a lower level of 2,500 feet above the surface (less in some areas), selecting a cruising altitude is often determined by this factor first.

The only other consideration to the pilot flying VFR is the recommendation to follow the "Quadrantral Rule" if flying above the transition altitude. The quadrantal rule is not mandatory because it is often simply not possible to obey it because of vertical constraints of twrrain, cloud and controlled airspace. A pilot flying in a northwesterly direction from Leicester EGBG to Sleap EGCV, for example should fly at either 2,500 feet, 4500 feet, or 6500feet etc. However, the route crosses the East Midlands Control Area, whose "floor" in that area is 4000ft, so the pilot is immediately constrained

to 2,500 feet only. On a typical English overcast day betwwen September and May, the cloud is very often lower than 2500 feet, so obeying the quadrantal rule on that flight would be impossible. Similarly, flight across Wales or Scotland where terrain may rise to 2,500 feet and cloud, even in summer, may well be lower than 4,500 feet cannot obey the quadrantal rule.

Magnetic Track (N.B. not heading)	Recommended Cruising Altitude
000°M to 089°M	Odd thousands of feet
090°M to 179°M	Odd thousands of feet + 500 feet
180°M to 269°M	Even thousands of feet
270°M to 359°M	Even thousands of feet + 500 feet

7.4 Controlled Airspace.

Controlled Airspace is airspace in which a pilot may not fly in any circumstances without permission from Air Traffic Control. This is true in both VFR and IFR flight. Some controlled airspace is out of bounds at all times to VFR pilots. This is designated "Class A" airspace and comprises mostly the commercial airways system. There are rules about when and how a pilot may fly in controlled airspace, but this is covered in the Aviation Law tutorial. The presence of controlled airspace is important to navigation, however, because it determines just as much as physical obstacles, where a pilot may fly.

8 DEFINING A ROUTE

Let us take our Southern England half-mill chart and make a mark at, say, Liverpool Airport, then make a mark at Welshpool Aerodrome and draw a line between the two – the track line.   I personally use green for track lines, as there is less green on the chart than other colours, so it stands out better.

Because the surface of the chart is laminated, you will need either a chinagraph pencil or a fine-point spirit-based pen (Staedler make a series in different colours, branded "Lumograph"). For FS purposes, the chinagraph pencil will probably sufficient, but in real world flight, the spirit pen lines do not rub off as easily, so survive better the rough handling a chart may get within the cockpit. In either case, you will need a small supply of methylated spirit to erase the lines when you no longer need them.

8.1 Distance

If we measure the length of the line between Liverpool and Welshpool on the chart with an ordinary rule, it is 6.4 inches or, if you prefer, 162.5 millimetres. This represents 6.4 x 500,000 inches on the ground. Thanks to Microsoft Excel, this calculates as 43.8596 nautical miles (nm) – 44nm as

near as we need it. Of course you don't have to do that calculation – you use your 1:500,000 scale aeronautical rule.

8.2 Direction

Because the lines of longitude are oriented north south, we can measure the direction of our line relative to north along a line of longitude, using a protractor. Do this where the line crosses the 3ºW(est) line just south of Wrexham. What do you get? 12º? That is correct. However, if we jump into our aircraft at Liverpool and fly a heading of 12 degrees, we will end up somewhere near Preston, not Welshpool. We need an Aeronautical protractor, which measures a full 360º, with zero always being set to north, east therefore being 90º, south 180º and so on. With the aeronautical protractor, the direction you get is 192º – a little west of south.

8.3 The Route Defined

So, having ploughed through a lot of theory to get to this point, we can say that from Liverpool to Welshpool the distance is 44 nautical miles on a **bearing** of 192 ºT. Finally we **add** magnetic variation (*variation west, magnetic best*). For Liverpool, magnetic variation is 4 º, so the magnetic bearing from Liverpool to Welshpool is 196 ºM.

That is all there is to defining a route between two points, and is as precise a definition as is necessary. From Liverpool, fly on a compass heading of 196º and if there is no wind, you will arrive at Welshpool.

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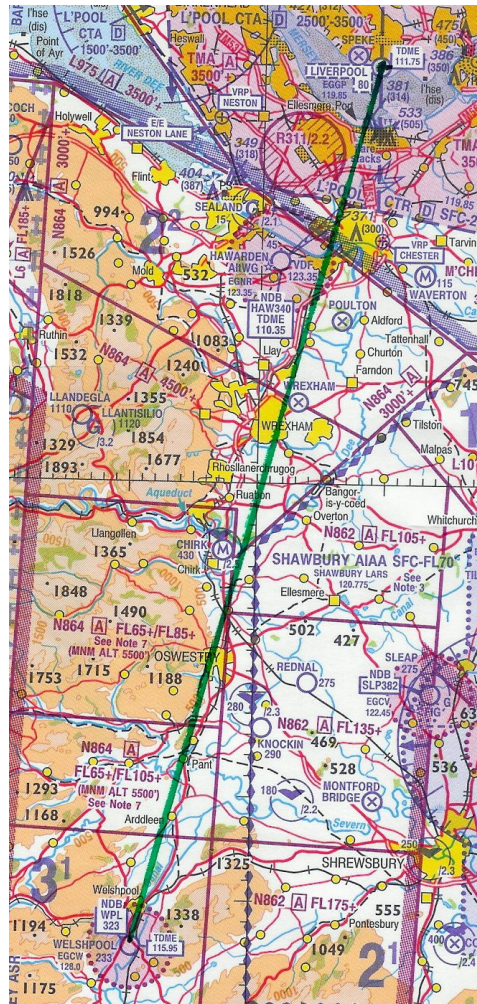
Track Line - Liverpool to Welshpool

(reduced from 1:500,000 scale)