1 INTRODUCTION

This tutorial is specifically designed for Microsoft Flight Simulator pilots flying VFR flight in the UK. It describes the effect of the wind on an aircraft and the calculations a pilot has to make to adjust his heading to allow for this effect, and thus fly an accurate track. Much of this information is also containing in Exercise 17 of the the Club's Training Manual.

2 DEFINITIONS

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

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, and is known as a "Great Circle Distance".
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.
Nautical Mile	The nautical mile is defined as one minute (1/60th of a degree) of longitude at the equator. For aeronautical purposes, it is defined as 6080 feet.
Bearing	The **bearing** between two points is the angle of a straight line between them, measured on the ground and is expressed in degrees clockwise from North. E.g. a bearing of 360^{o} is North; a bearing of 90^{o} is East, and a bearing of 225^{o} is South West, etc.
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'**.
Heading	An aircraft's **heading** is the angle, expressed in degrees clockwise from North, which it flies according to its direction indicating instruments.

3 TRUE NORTH AND MAGNETIC NORTH

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 towards **magnetic north**.

Magnetic North 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, the year at which FSX is “frozen” in time, magnetic north was between 2° west of true north in Norwich, and 5.5° west of true north in Belfast. Lines of equal magnetic variation are called isogonals and are shown on the half million aeronautical chart. Variation may be east as well as west and in some places as much as 40°.

The magnetic compass in an aircraft is the primary direction indicating instrument and points to magnetic north. In aviation all bearings and headings are referenced to magnetic north. So although a bearing of 192° will be measured on the chart in degrees ***true*** and written 192°T, it must be converted to degrees magnetic (°M) for flight. Because magnetic variation is currently 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.

4 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.

4.1 Airspeed

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, 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 passing 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. What the pitometer (and the other devices) measure is **airspeed**.

4.2 Groundspeed

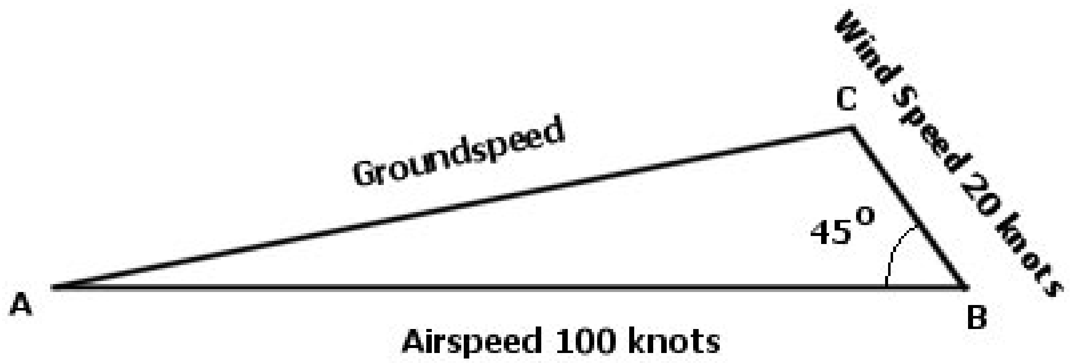
If an aircraft is travelling due north at 100 knots airspeed, how long will it take to travel 100 nautical miles? In still air (no wind) it will take one hour (100 knots is 100 nautical miles per hour). If the wind is blowing at 20 knots from the north, then although the airspeed is still 100 knots, the the aircraft's speed as observed by someone on the ground – the aircraft's **groundspeed** – will be 100-20=80 knots, and it will take 100 divided by 80 = 1.25 hours (1 hour and 15 minutes) to cover 100 nautical miles. Similarly, if the wind is 20 knots from the south, then the speed as observed by someone on the ground will be 100+20=120 knots, and it will take 100 divided by 120 = 0.8333 hours (50 minutes) to cover 100 nautical miles.

So in order to know how long it will take an aircraft to fly a given distance we need to know the wind, in order to calculate the groundspeed.

4.3 Velocity – a Vector

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**. 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 210°, and the magnitude is 10 knots. The aircraft too has velocity – e.g. heading 260° at 100 knots.

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



The triangle of velocities

Let us assume the aircraft is flying at 100 knots in an easterly direction (90°) 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 90° 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 from 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 spreadsheet program which we can use to do these calculations painlessly.

DRIFT CALCULATOR									
True	Wind		Mag Var	Track		Drift	Heading		Ground
Airspeed	Direction	Speed		True	Mag	Angle	True	Mag	Speed
100	240	08	4	121	125	-4	125	129	103

The 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. The Airspeed Indicator instrument measures Indicated Airspeed 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.

5 FLYING WITH WIND

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". Pointing the nose of the aircraft a calculated number of degrees towards the direction from which the wind is coming will result in the aircraft flying slightly crabwise relative to the ground. Indeed, if the pilot flies accurately, the intended bearing and the **track made good** will be the same.

From the illustration of the Drift Calculator above, the aircraft is flown at 100 knots with the intention of maintaining a track of 121° true between two points. The wind is 8 knots from a direction of 240°. The airspeed, the wind direction and speed, the magnetic variation and the required true track are all entered. The calculator immediately shows that if the aircraft is flown at 121° true (125° magnetic), it will slowly drift left following a track 4° more northerly than intended (the 4° drift angle is negative or anticlockwise). The heading required to maintain the intended track therefore, is equal to the drift angle, but in the opposite direction – 4 degrees to the ***right***, so the heading to fly is 121 PLUS 4 = 125° true or 129° magnetic. The calculator makes this left or right decision for you. As long as you fly the magnetic heading calculated, you will arrive at your planned waypoint or destination. ***When*** you arrive can be found by dividing the distance by the Drift Calculator calculated groundspeed.

6 AUTOPILOT

When you set a **course** on the autopilot, this is numerically the same as a bearing. In VFR navigation, it is used only generally, as in “set course for the coast”, but it is used precisely in connection with aircraft fitted with an autopilot. If the autopilot is set to follow a course, it uses data from 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.