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air cadet publication

ACP 32

navigation

volume 4 - pilot navigation

Amendment List		Amended by	Date Incorporated
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ACP 32

NAVIGATION

CONTENTS

Volume 4

Pilot Navigation

ISSUED 2000

CHAPTER 1

UNITS

Introduction

Metric Units

1. At school you will have been taught that in the modern world just about everything is measured in metric units. In real life, however, many people are still using non-metric quantities. One example is the continued use of miles and miles per hour on the roads in the British Isles. In addition, a wide variety of units are used in aviation, these units have been decided by the International Civil Aviation Organisation (ICAO); See the table at Fig 1-1. ICAO.

Fig 1-1 The ICAO system of Measurement

INDEX	MEASUREMENT	PRIMARY SI	NON-SI ALTERNATIVE	ICAO TABLE
A	Distances used in navigation, position reporting, etc, (generally in excess of 4km).	KILOMETRES	NAUTICAL MILES and TENTHS	NAUTICAL MILES and TENTHS
B	Relatively short distances such as those relating to aerodromes (eg rw lengths).	METRES	METRES	METRES
C	Altitudes, elevations, heights.	METRES	FEET	METRES
D	Horizontal speed including wind speed.	KILOMETRES PER HOUR	KNOTS	KNOTS
E	Vertical speed.	METRES PER SECOND	FEET PER MINUTE	METRES PER SECOND
F	Wind direction for landing and taking off.	DEGREES MAGNETIC	DEGREES MAGNETIC	DEGREES MAGNETIC
G	Wind direction, except for landing and taking off.	DEGREES TRUE	DEGREES TRUE	DEGREES TRUE
H	Visibility, including runway visual range.	KILOMETRES OR METRES	KILOMETRES OR METRES	KILOMETRES OR METRES
I	Altimeter setting.	HECTOPASCALS	HECTOPASCALS	MILLIBARS
J	Temperature	DEGREES CELSIUS	DEGREES CELSIUS	DEGREES CELSIUS
K	Weight (Mass) **Note** 1 Tonne = 1000KG).	TONNES OR KILOGRAMS	TONNES OR KILOGRAMS	TONNES OR KILOGRAMS
L	Time	HOURS & MINUTES	HOURS & MINUTES	HOURS & MINUTES
M	Cloud altitude and height.	METRES	FEET	METRES

Metres or feet

Units of measurement are based on the International System of Units (SI) and certain non-SI Alternative Units considered necessary to meet the specialised requirements of international civil aviation. It is of note that whilst only 5 countries use the SI units, 80 use the non-SI Alternative units and many others opt to use their own variants. For example in many countries feet are used to indicate vertical extent such as cloud base, whilst metres are used for horizontal visibility; this avoids confusion when meteorological information is being passed.

Vertical Distance and Speed

2. In ACP 32, Volume 3 we noted that in aviation, horizontal distances and speeds are mostly measured in nautical miles (nm) and knots (which are nm per hour) respectively. These units are logical because they are based on the length of part of a “great circle” on the surface of the Earth – one minute of arc measured at the centre of the Earth equals one nm on the Earth’s surface. As lines of longitude and the Equator are great circles, nm and knots are the logical units to use. Whilst you may use the Ordinance Survey grid for navigating on the ground, Latitude and Longitude is the standard method of navigating in the air. However, in the vertical axis the majority of countries use feet to measure aircraft height and altitude. Only the former communist bloc countries report vertical distance in metres. Aircrew need to be careful when using maps not designed for aviation (such as the Ordinance Survey) where the elevations are marked in metres, that they do not confuse metres with feet, as this could be very dangerous. The calculation of safety altitude, below which you must not fly unless you have clear sight of the ground or are under radar control, has to be done with great care and is the navigator’s number one priority.

3. For vertical speeds the units mirror those used for vertical distance (ie feet per minute or metres per minute). Vertical speed indicators, which show rates of climb or descent, are calibrated in thousands of feet per minute for most military aircraft.

Meteorological Units

4. Worldwide, the Met Office will use the ICAO units, with each country using the ICAO SI or non-SI units as declared by them when they signed the treaty. This subject is covered in much more detail later in this publication. One small detail of interest is that many countries now use the Hectopascal instead of the Millibar as the unit of atmospheric pressure (one Millibar equals one Hectopascal)!

Aircraft and Fuel

Pounds or Kilogrammes

5. Strictly speaking, aircraft and fuel should be measured by mass, but in practical terms it is weight (that is the effect of gravity on mass) that we use. For aircraft, the units used for weight will depend on the country of manufacture. Most American built aircraft (possibly 70% of the world’s output) measure weight in pounds or imperial tons, whereas most others now use kilogrammes (kg) or metric tonnes (1000 kg). The situation with fuel is rather more complicated. In theory, fuel should be measured by mass as the amount of thermal energy in

one unit of fuel relates directly to mass. Unfortunately, you cannot weigh fuel when an aircraft is airborne, so the alternative is to measure its volume – exactly as in cars. In a car we measure the fuel volume in litres (or gallons) and then calculate the fuel use in km per litre (or miles per gallon). In the air, the use of volume is not accurate enough, as the type of fuel used and its temperature both affect the mass per unit volume. In other words, the density of fuel varies from one type to another. Moreover, even if one particular type of fuel is always used, its density will change when its temperature changes – as it will when the aircraft climbs to a height where it is very cold, for example.

Fuel Conversion

Specific Gravity

6. Different types of fuel each have a Specific Gravity (SG). This is a measure of the ratio between the weight of fuel and the weight of the same volume of water. Water has an SG of 1.0; a typical jet engine fuel will have an SG of 0.80. This means that a litre of jet fuel weighs only 80% of the weight of a litre of water. Conversion can be done on a calculator, a DR computer or on the chart in the RAF Flight Information Handbook, part of which is shown in Fig 1-1. Incidentally, note that yet another conflicting unit is included on the chart – the US gallon, 12 ofwhich equal 10 imperial gallons.

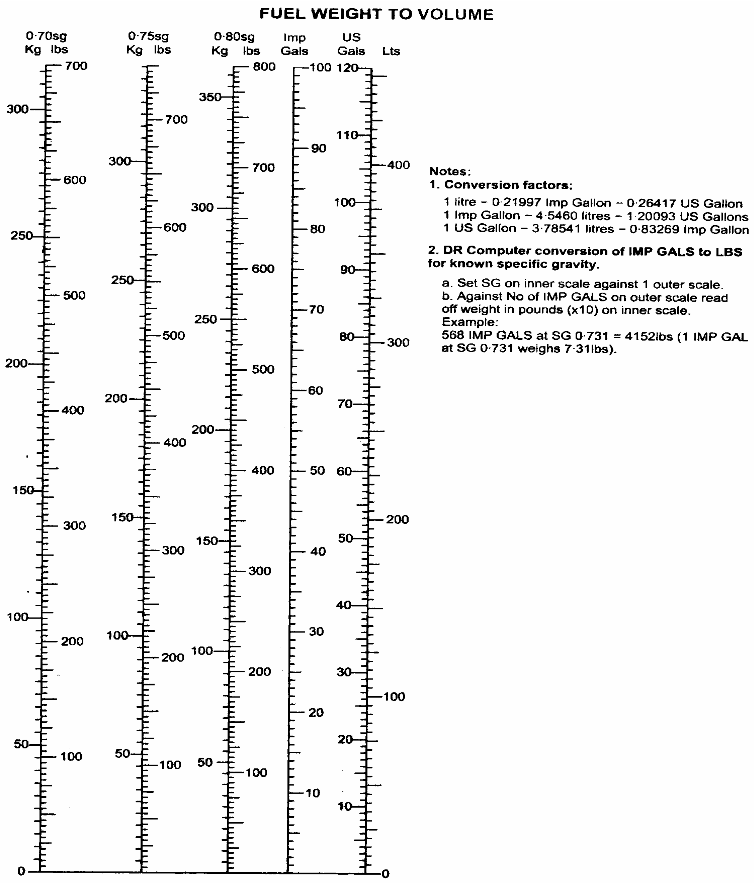


Fig 1-1 *Fuel Weight and Volume Conversion*

Pressure

7. Various gases and fluids in aircraft are pressurised, and several different units are used to express their pressures - again, mainly depending on the country of origin of the aircraft. Our main concern here, though, is pressure in the atmosphere, caused by the weight of the air above us. Clearly, the higher we go the less air there is above us, so the pressure is greatest at sea level and it gradually reduces as we climb through the atmosphere. Pressure can be measured in pounds per square inch, as inches of mercury (the method used in the USA), in mm of mercury or in millibars (mb). The latter is used everywhere outside the USA, and the average pressure at sea level is approximately 1013 millibars. The table at fig 1-2 shows how the atmosphere thins with altitude. Notice that for a commercial airliner's typical cruising height of 34,000 ft, the air outside has only one quarter of the pressure as the air at sea level. Consequently, the amount of oxygen available is only about one quarter of that at sea level, and those on board the aircraft would lose consciousness if it were not for the pressurisation system which maintains a higher air pressure inside the aircraft.

Fig 1-2 *Pressure Variation with Altitude*

ALTITUDE IN FEET	AIR PRESSURE IN MB
SEA LEVEL	1013
10,000	700
18,000	500
24,000	400
30,000	300
34,000	250
39,000	200

Standardisation

Conclusion

8. Aviation is the only major area of science still using such a wide variety of units. There is some slow movement towards metrication, but until countries agree to common units for the instruments used in the aircraft that each of them produces, and while latitude and longitude continue to be used for position, the confusion will remain.

Sample Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. In aviation how are horizontal distances and speeds measured?

2. How do the majority measure vertical distances?

3. How are Vertical Speed Indicators calibrated?

4. In practical terms, how are aircraft and fuel measured?

5. What is Specific Gravity?

CHAPTER 2

FLIGHT PLANNING

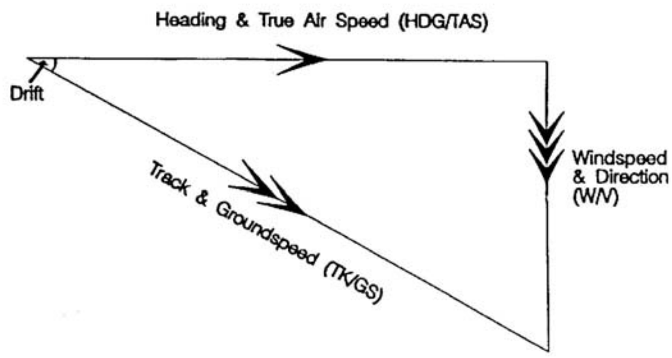
Introduction

1. In ACP 32, Vol 3 we discussed the triangle of velocities and looked briefly at how the triangle is solved (that is how we calculate some of the unknown components of the triangle from those that we know). In this chapter we shall revise the components of the triangle and learn how this helps us to plan a flight and then notify other people of our intentions.

2. The triangle of velocities comprises 3 vectors (a vector being a component of the triangle having both direction and speed) drawn to scale. One side represents the movement of the aircraft in still air, another defines the movement of that air (ie the wind), and the third side shows the actual movement of the aircraft over the Earth's surface as a result of the other 2 vectors. Thus the triangle has 6 components or elements: wind speed, wind direction and the aircraft's heading, true airspeed, track and groundspeed. These elements go together in pairs as shown in the diagram below. Note also that, by convention, each pair of elements (vector) is always represented by the number of arrows shown in Fig 2-1.

Triangle of Velocities

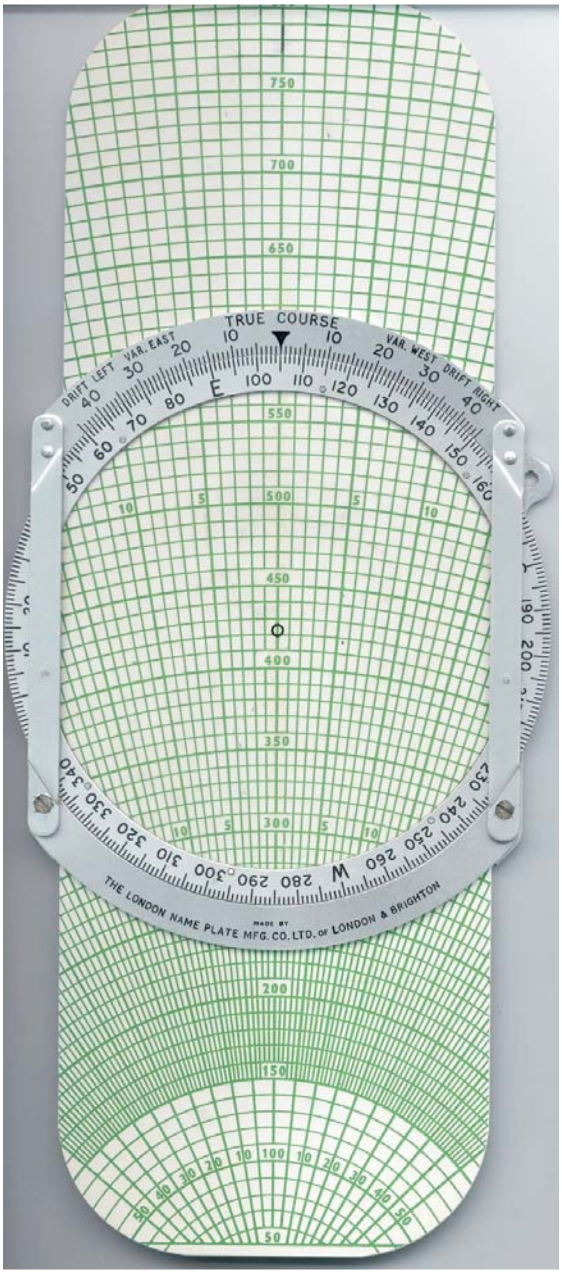
Fig 2-1 *The Triangle of Velocities*



The Vector Triangle

3. As long as we have 4 of the 6 elements of the triangle it can be solved by a variety of methods. The basic method involves a scale drawing of the triangle on graph paper, or very similarly (but much more quickly) on the rotatable

Dalton Dead Reckoning Computer



DR Computer, Mk 4A - Face

DR Computer, Mk 4A - Reverse

Fig 2-2 *The Dalton Dead Reckoning Computer* compass rose of the Dalton Dead Reckoning Computer (Fig 2-2). Alternatively, the problem can be solved mentally (though only approximately) by methods that are outside the scope of this publication. With the advent of modern systems, the micro-computer now uses trigonometry to solve the triangle continuously to a high degree of accuracy. This facility is not available to the beginner in aviation.

Flight Planning

4. Both in the world of the private pilot and in light military trainers, flight planning is carried out using a Pilot Nav Log Card as shown in Fig 2-3. On this card the flight is divided into a number of legs.

Pilot Nav Log Card

	LEG	1	2	3	4	5
	To					
	Heading					
4	Height / FL					
6	IAS / Mach					
	Time					
	ETA					
	FUEL Remaining					
	FUEL Required					
	Safety Alttitude					
7	TAS					
1	Track					
2	Distance					
3	W / V					
5	Temp					
	G / S					
8	Varn					

Fig 2-3 *Pilot Navigation Log Card*

Before the flight begins the triangle of velocities is solved for each of these legs, and the results are recorded on the log card. However, there is much to be done before the goal is reached. First, the pilot needs to know the tracks and distances of the various legs - so he draws them on a route chart. In the example at Fig 2-4 a Tutor is to fly from Leeming to Cottesmore and then to Marham, departing from Leeming at 1000 hrs. The wind is forecast to be Southerly for the first leg and

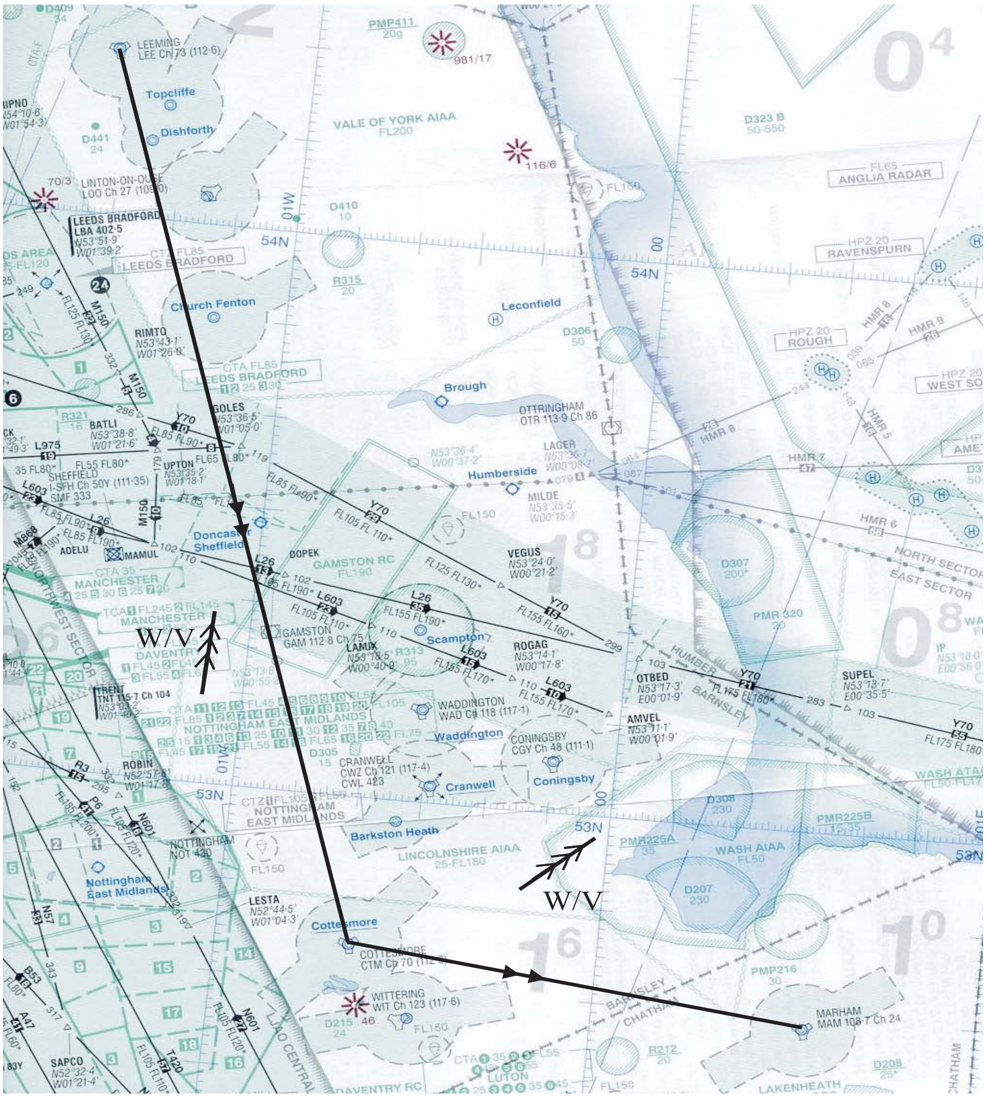


Fig 2-4 Tracks and Winds for the Leeming-Cottesmore-Marham Flight

South Westerley for the second leg. As a visual aid these winds have been drawn on the chart at Fig 2-4, near the leg to which they apply, so that you can visualize immediately that there should be a headwind on leg 1 (GS less then TAS) and a crosswind for leg 2 (Hdg and Track differ markedly, by drift). The pilot will make a mental note of the probable wind effect to use as a check that his subsequent calculations are along the right lines.

5. Before he can apply the triangle of velocities the pilot must enter various details on the log card. These are, for each leg:

a. Track, measured from the chart with a protractor (see entry marked (1) on Fig 2-5).

b. Distance, measured from the chart (entry (2)).

c. The forecast w/v (3).

d. The height at which the leg will be flown, as decided by operational, flight safety and or other needs (4).

e. The forecast air temperature for the chosen height (5).

f. The indicated air speed - normally the recommended cruising speed for the aircraft (6).

g. The true airspeed calculated from the IAS/CAS and air temperature (7).

h. Variation, found from the peripheral information on the chart (8).

6. Now the triangle of velocities can be used. We can calculate, for each leg:

a. What heading the aircraft must fly to counter the effect of wind and follow the desired track over the ground.

b. What the groundspeed will be.

7. In real life the pilot would use the rotatable compass rose on the Dalton Computer (Fig 2-2), and if you have access to one your instructor can show you how this is done. However, this is not practicable here, so we shall use graph paper. This, unfortunately, takes much longer than with the Dalton Computer, but the principle is the same. Dealing first with the leg from Leeming to Cottesmore, we already know 4 of the 6 elements of the triangle of velocities. They are:

a. Wind direction 180° (entry (3) on Fig 2-5)

b. Wind speed 30 kt (entry (3) on Fig 2-5)

c. Track 161° (entry (1))

d. TAS 125 kt (entry (7))

	LEG	1	2	3	4	5
	To	CTM	MRM			
	Heading					
4	Height / FL	3000'	3000'			
6	IAS / Mach	120	120			
	Time					
	ETA					
	FUEL Remaining					
	FUEL Required					
	Safety Alttitude					
7	TAS	125	125			
1	Track	161	096			
2	Distance	98	44			
3	W / V	180/30	220/25			
5	Temp	+5	+5			
	G / S					
8	Varn	4°W	4°W			

Fig 2-5 *Log Card entries made before Triangle of Velocities can be used*

---

8. Fig 2-6 shows the completed triangle, which was solved by constructing sides in the following order:

a. Draw the w/v line (3 arrows) from the direction 180°, and give it a length of 3 graph units (to represent 30 kt).

b. Starting at the downwind end of the w/v line draw the Tk/GS line (2 arrows) in the direction 161°, but with an unknown length (shown in Fig 2-6 by a broken line). The length of this line - the groundspeed - is one of the elements we intend to discover. Meanwhile all we know of it is from the chart at Fig 2-4, namely that the GS will be less than the TAS of 125 kt. That is, the line will be less than 12.5 graph units long - so at least we know the maximum limit of the broken line.

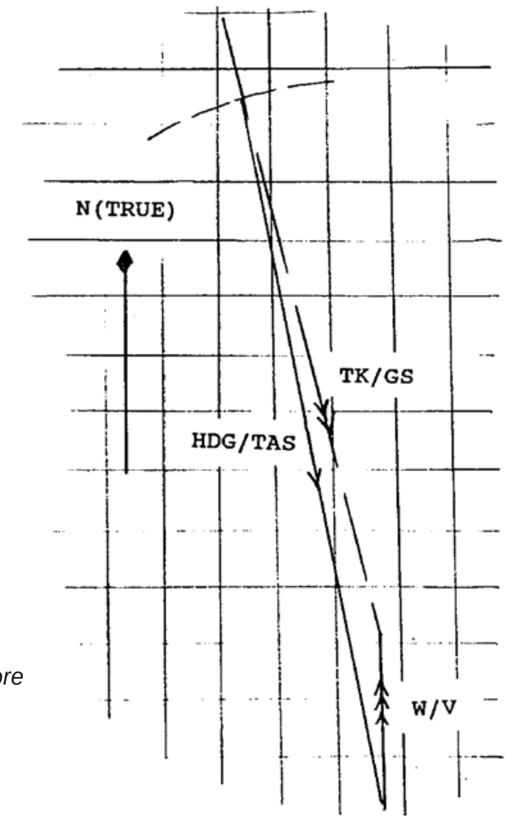


Fig 2-6 *Solving the Triangle - Leeming to Cottesmore*

c. From the other end of the w/v line, draw the HDG/TAS line (one arrow), to a length of 12.5 graph units (to represent the TAS of 125 kt), but with an unknown direction. The line's direction - the required heading - is the other element we intend to discover. All we now have to do is to find where this line (12.5 graph units long) intersects the dotted part of the Tk/GS line. Ideally, a pair of geometry compasses should be used, but it can be done with a ruler using a little trial and error. Having found the intersection we can now draw the HDG/TAS line - and we have completed the triangle.

9. From the completed triangle, we can measure that the length of the Tk/GS line is 9.6 units, hence the groundspeed will be 96 kt. Using a protractor we find

that the direction of the HDG/TAS line is 166°, hence the required heading will be 166° (T). Finally, to entry (8) on the card at Fig 2-5 we apply the magnetic variation of 7° W to 166° (T) to produce a magnetic heading for the leg of 173° (M) - and we are ready to complete the log card.

10. At Fig 2-6 we enter the heading of 173° (M) - entry (9) - and the GS of 96 kt - entry (10). From this GS and a leg distance of 98 nm we calculate and enter a leg time of 61$^{1}/_{4}$ minutes - entry (11) . Provided we set course at our planned time of 1000 hrs, we now have an ETA overhead Cottesmore of 1101 - entry (12). Obviously, if our actual departure time varies from the intended 1000 hrs, we shall have to amend the ETA. All of these distance/speed/time calculations can be done mentally, but in our example the Dalton Computer has been used to improve the accuracy.

11. For the remaining entries on the log card we need to know the heading and groundspeed for the Cottesmore to Marham leg. We shall not go through the graph paper exercise again - suffice it to say that using a Dalton Computer

	LEG	1	2	3	4	5
	To	CTM	MRM			
	Heading	173(M)	115(M)			
4	Height / FL	3000'	3000'			
6	IAS / Mach	120	120			
	Time	61½	22			
	ETA ETD 1000	1101	1123			
	FUEL Remaining	13.7	9.3			
	FUEL Required	12 3	4 4			
	Safety Altitude	3500'	2600'			
7	TAS	125	125			
1	Track	161	096			
2	Distance	98	44			
3	W / V	180/30	220/25			
5	Temp	+5	+5			
	G / S	96	120			
8	Varn	5°W	4°W			

Fig 2-7 *Log Card entries after the Groundspeed and required heading have been found*

the answers (108°T and 120 kt) can be found in about 30 sec. So, the next entries at Fig 2-6, for the second leg, are 115° (M) and 170 kt at entry lines (9) and (10) respectively. As before, we can calculate the leg time of 22 min (entry (11)) - that is, 44 nm at 120 kt and an ETA of 1123 hrs (entry (12)).

Fuel Planning

12. One of the main purposes of calculating flight times is to ensure that sufficient fuel is available. If a car runs out of fuel it can be inconvenient; in an aircraft it is very dangerous and over jungles, deserts, mountains or the sea it is often fatal. In our Bulldog examples we consume fuel at 12 gallons per hour, so 12.3 gallons are needed for the first leg (12÷60 x 61.25 = 12.25, but we round it up to 12.3), and 4.4 gallons for the second leg (12÷60 x 22) - see entry number (13) - thus, a total of 16.7 gallons will be consumed during the flight.

Other Information

Safety Altitude

13. There are other items on the card, the most important of which is Safety Altitude. This is the altitude that a pilot must climb to, or not descend below, in instrument meteorological conditions (IMC) to ensure that the aircraft will not hit the ground or any obstacle such as TV masts. It is calculated by adding 1000 ft to the highest obstacles on or near track and then rounding up to the nearest 100 ft (entry no (15)). A greater safety margin is added in mountainous regions. An aircraft may not descend below Safety Altitude unless its crew have good visual contact with the ground or are receiving a radar service from Air Traffic Control. In our Bulldog example, the planned transit height is less than the Safety Altitude for the first leg. This is perfectly acceptable for a flight that is flown visually or under radar control, but the pilot must always be prepared to climb above Safety Altitude if meteorological conditions deteriorate.

Air Traffic Control Flight Plan

14. It would be foolish for a pilot to set off in an aircraft without telling someone

where he was going, which route he intended to follow and his estimated time of arrival (ETA) at his destination. For the same reason that mountaineers leave their itinerary with someone else when they set off on a climb, so aircraft crews should always notify Air Traffic Control of their intentions so that overdue action can be initiated if the aircraft does not arrive on time. Additionally, aircraft entering busy airspace have to submit a Flight Plan so that their flight can be coordinated with other traffic. The Air Traffic Control Flight Plan uses a standard format world-wide and includes such details as callsign, type of aircraft, time and place of departure, speed and altitude, intended route, ETA at destination and a lot of safety information such as the number of people on board and the type and quantity of emergency equipment carried. Much of the information in the first part of the Flight Plan is extracted from the Pilot Navigation Log Card which was completed at the planning stage.

Conclusion

15. The principles of flight planning are the same whether we are planning a hop across the county in a light aircraft or an inter-continental flight in an Airbus. We measure the tracks and distances from the chart (or extract that information from a database), calculate the effect of the weather (the wind in particular), ensure that the aircraft carries sufficient fuel and then pass all of our details to the Air Traffic Control units along the route. These principles ensure that the flight is planned in the safest way possible and that, if something should go wrong, help is immediately available along the route should it be needed.

Sample Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What do you use to carry out flight planning?

2. What is one of the main purposes of calculating flight times?

3. What is Safety Altitude?

4. How is Safety Altitude calculated?

32.4.2-12

CHAPTER 3

POSITION FIXING

Introduction

Aircraft's Location

1. In the pioneering days of aviation aircraft could not fly unless the crew could see the ground, as map reading was the only means of navigating. Later aircraft were fitted with sextants and radio direction-finding equipment, but the big strides forward in navigation came during, and immediately after, the Second World War. However, it was not until the 1970s that world-wide coverage with a navigation aid was achieved with a fixing aid known as Omega and, more recently, with Satellite Navigation (SATNAV) or the Global Positioning System (GPS). Any process of finding out an aircraft's location is known as taking a fix, from "fixing the position".

Visual Fixing

Visual Fix

2. There are many factors which affect map reading, and these are discussed in the next chapter. For the moment all you need to know is that when you look out of an aircraft window and identify some unique feature below, that gives a visual fix known as a pinpoint. The accuracy of the pinpoint depends on many things, but the most important are the uniqueness of the feature, the accuracy of the map and the skill of the observer. Despite all of the high-technology equipments available, the pinpoint is still a very reliable and accurate method of fixing one's position which will continue to play a major part in aviation - especially in the early days of training.

Radio Aids

Radio Direction Finder

3. The next time you listen to a small portable radio try rotating the radio through 360° in the horizontal plane. You should find that for each radio station there are 2 points in the circle where reception is very poor and 2 points where it is at its best. The Radio Direction Finder (DF or radio compass) works on the same principle, showing on a dial in the aircraft the bearing from which a radio beacon is transmitting. If you know where the beacon is, a line can be drawn on the chart along this bearing, which is known as a "position line"; the aircraft is

on many things, but mainly on the range from the beacon. For the uncluttered skies of the 1920s and 1930s this procedure was sufficiently accurate. The majority of airfields had radio beacons, thus reaching the airfield in bad weather was simply a matter of “homing” to the beacon.

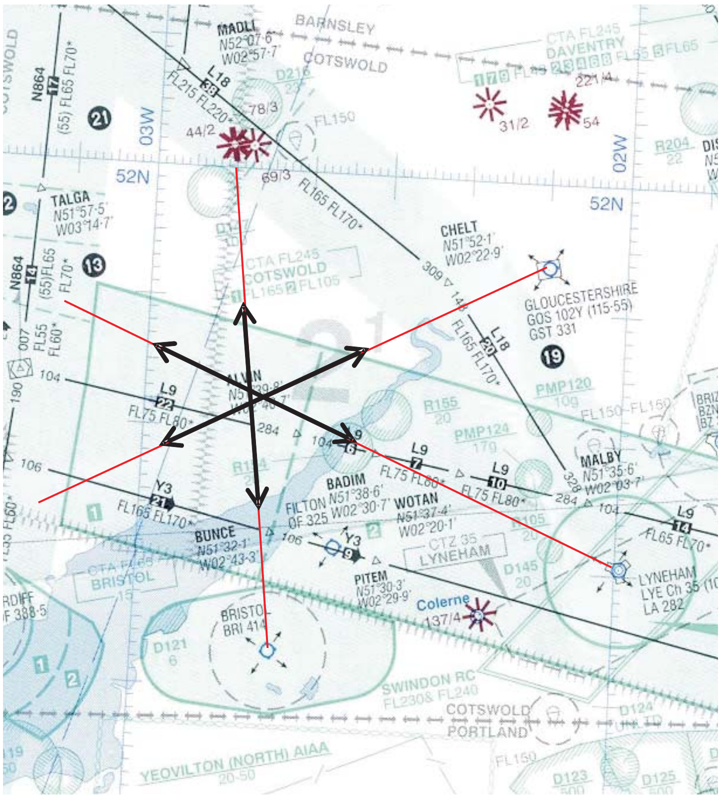


Fig 3-1 *The 3 Position Line Fix*

VOR/DME and TACAN

4. A rather more modern method of gathering position lines is from VOR/ DME or TACAN beacons. TACAN is the military system and gives the magnetic bearing, or radial, from the beacon to the aircraft, plus the slant range of the aircraft from the beacon. In Fig 3-1 you will see that Lyneham has a TACAN operating on channel 35 and its identification code, which is heard in Morse Code in the aircraft, is LYE (LIMA, YANKEE, ECHO). In the civilian system (VOR/ DME) the same information is available although the bearing is rather less accurate. Again, from Fig 3-1 you will see that at the intersection of airways G1 and A25 there is a VOR/DME beacon at Brecon (identification BCN - BRAVO, CHARLIE,

NOVEMBER). Its VOR element operates on a frequency of 117.45 MHz and its DME is on channel 121. Civilian aircraft fly along the centrelines of airways by homing from one beacon to the next. Navigation aids such as the GPS will gradually take over the functions of radio aids as we move into the 21st Century.

Astro Navigation

5. Although you might find it strange to find mention of Astro navigation in this publication it is worthy of mention if only to offer a comparison with the more modern systems.

Radio Beacons

6. Radio beacons are ideal for overland flights or those close to coastlines, but when the early pioneers of aviation started to navigate across the oceans they had to copy the mariners and use the sun, moon and stars to navigate. Astro navigation works on the simple principle that if you think you know your position (Deduced Reckoning or DR position) you can calculate the relative position of the heavenly body. By using a sextant to measure the angles accurately you can compare the actual position of the body with its calculated position. The difference between the 2 represents the error in the DR position. As with DF, each body gives a single position line, and 2 or 3 are needed to construct a fix. Astro navigation can be surprisingly accurate and reached its peak in the 1960s and 1970s when the RAF Vulcan aircraft won the United States Air Force (USAF) bombing competition using Astro to supplement their computers, and Transport Command aircraft such as the Britannia routinely circumnavigated the World using Astro as their prime navigation aid. The advent of GPS has lead to the demise of Astro navigation.

GPS - Navigation Aid

Radar Navigation

7. During the Second World War radar was invented, following which it developed very rapidly. Early airborne radar equipments were very crude and unreliable, but modern radar systems in aircraft such as the Tornado GRI and F3 are so effective that minute surface details can be displayed to the crews. Consequently, the navigation of the aircraft is a fairly simple process in which the radar picture is matched to a very accurate map (of the same scale) and can be fixed simply by the pressing of a button. This highly automated system leaves the navigator free to

Weapon Systems Operator

concentrate on the many other tasks in the aircraft and has led the RAF to abandon the title “Navigator” in fast-jet aircraft in favour of “Weapon Systems Officer” or “Wizzo”!

8. There are disadvantages of course; what happens when the radar fails? But the main problem with radar systems in the military context is that they transmit an electromagnetic signal which can be detected by the enemy. This detection has the potential to announce the arrival of an attack and enables the timely activation of enemy defensive forces.

Long Range Fixing

9. With the rapid development of electronics in the 1950s and the 1960s came what are known as area navigation systems such as Gee, Loran and Omega. In simple terms they all worked on a similar principle of measuring the time that it takes for 2 synchronized signals to arrive from 2 different transmitting stations. Each pair of stations gives a position line, and 2 or 3 of these make up a fix. Initially, a great deal of operator skill was required to operate these systems which were not very “user-friendly”. With the arrival of airborne micro computers such systems as GPS can provide an unskilled operator with a fix with an accuracy of a few metres.

Micro - Computers

Active/Passive Systems

10. We previously mentioned that a big disadvantage with radar navigation systems is their liability to disclose their presence and location to the enemy. This was realized almost as soon as radar was invented and has led to the development of radar-homing missiles, which home onto the source of a radar emission. Rather than abandon radar, scientists have developed electronic warfare (EW) systems which enable aircraft to continue to use radar systems by constantly changing frequencies and other parameters. Many of these procedures are at the forefront of technology and carry very high security classifications. You would probably think that EW has no place in the protection of navigation systems in civilian aircraft, but at various times they have carried EW systems when operating into or near to troubled areas. EW is a growth science and is the subject of a constant development race between nations.

Electronic Warfare Systems

11. EW measures are used to protect "active" navigation systems, but another approach is to use equipments which do not transmit, merely receiving signals such as those transmitted by GPS satellites and then combining that information with the output of Inertial Navigation (IN) systems. The absence of any transmission from the aircraft in these systems gives rise to their description as "passive".

<u>Conclusion</u>

The Future

12. Despite the availability of very accurate systems such as triple INs backed up by GPS, which can give accuracies of a few metres, a degree of aviation training time is devoted to "old fashioned" methods such as map reading and beacon homings. GPS/Inertial Navigation Computers now meet the demands of military and civilian flying. However, despite the different roles of aircraft, all novices in aviation will first have to master the fundamental principles of navigation and position fixing before graduating on to modern integrated navigation computers.

Sample Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What is any process of finding out an aircraft's location known as?

2. What is the military system TACAN used for?

3. What is GPS?

4. What is the big disadvantage with radar navigation systems?

CHAPTER 4

MAP READING

Introduction

1. We have seen that despite the development of very accurate navigation systems there is still no substitute for map reading. It is very accurate at low level, cannot be tampered with by the enemy, and is an essential basic skill for all aviators.

Limitations

2. All of the errors which can be made while map reading on the ground are just as likely to be made in the air. The extra mental pressures in the airborne environment demand that decisions usually have to be made very promptly - the opportunities to simply take one's time and confer over a map do not exist! With this in mind we rarely try to navigate by map-reading alone, but we use it in conjunction with a variety of equipments to ensure that we achieve the optimum results from the technique.

Weather

3. The weather will have a major influence on the accuracy of map reading and at times may prohibit its use. The lower the visibility, and the greater the cloud cover, the more difficult the map reading will be. At high altitude, even moderate cloud cover can make map reading virtually impossible.

Aircraft Altitude

Map Reading Problems

4. The altitude at which an aircraft flies has a major effect on map reading requirements and technique. Features which are ideal for high level map reading are virtually useless at low level, and vice versa. At low level it is important to choose features which have vertical extent (chimneys, windmills, small hills) so that they can be seen before the aircraft arrives overhead the feature. At high level, larger features are needed (lakes, woods, islands) and they must also have the necessary definition and contrast to stand out from their backgrounds. A further consideration at high level is the difficulty of obtaining an "on top" visual

fix - this is particularly difficult from an aircraft from which downward visibility is limited.

Unique Features

5. Very large errors can be introduced into map reading simply by confusing one feature on the map with another. A village comprising a few houses and a church will look very much like its neighbour, and so such features are not normally used - more unique features are needed. For example, on the map at Fig 4-1, there are several power stations South of York - all of them on rivers - but there is only one situated on a river and at a motorway crossroads (just North East of Pontefract - arrow A). Of course, if you need a totally unique feature in this area there is only one - the Humber Bridge (arrow B) - there is no other suspension bridge of that size within 200 miles!

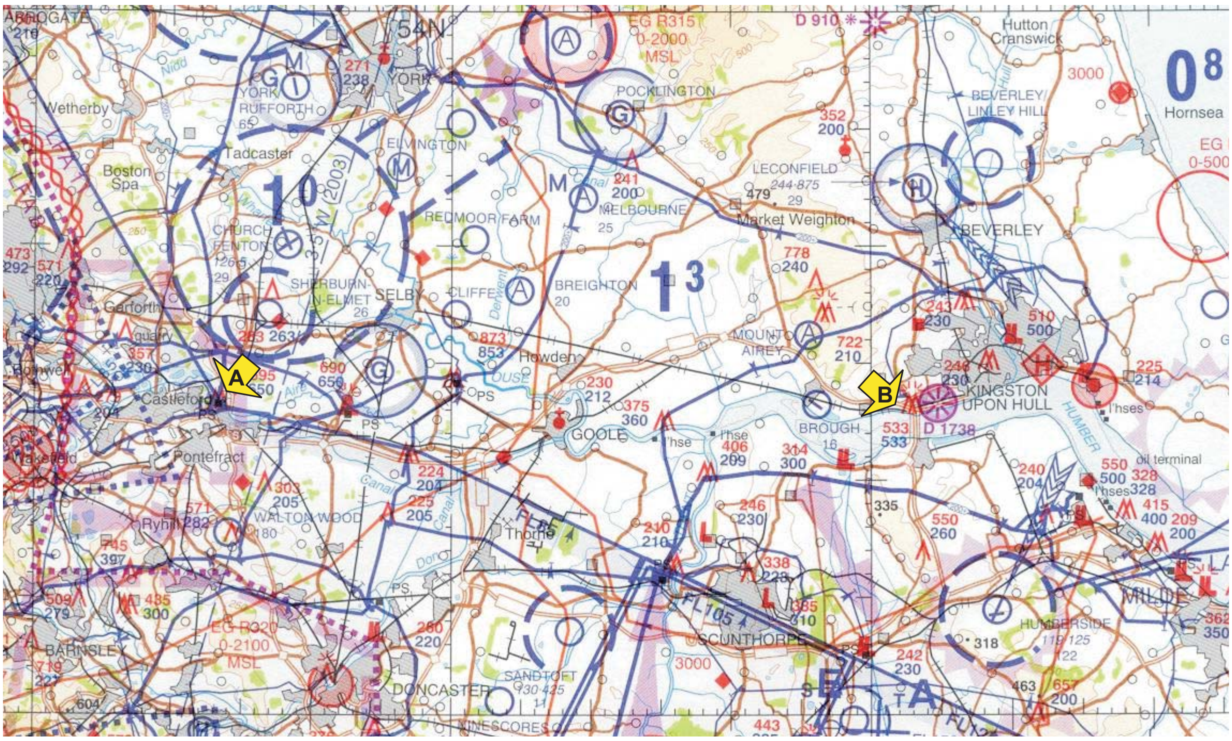


Fig 4-1 Unique Map Reading Features

Contrast, Colour and Season

6. Of the natural features used in map reading, rivers and coastlines are generally

the most useful, particularly in poor weather, because they show the greatest contrast and colour change between themselves and the land. Many land areas may seem ideal, but they change their appearance with the seasons. A wooded area which was used as a turning-point during Summer Camp would be much more difficult to identify in the winter when its leaves had fallen. Snow has a dramatic effect on the landscape, eliminating many features and rendering many of the man-made line-features, such as roads and railways, virtually invisible. Rivers in the UK are still visible as we do not have Winters sufficiently cold to freeze them over.

Map Scales

Which Map to use

7. In both military and civilian aviation, special maps are produced for map reading from the air. These differ from OS maps in that they place more emphasis on those features which are more easily identified from the air, such as airfields, towns, railway tracks and masts. Great care must be taken to ensure that the map you are using is up-to-date: finding a motorway to follow which does not appear on your out-of-date map can be very confusing, as can searching for a chimney which shows on your map but was demolished years ago! The choice of scale of your chosen map will depend on the speed of your aircraft, but most aircrew use the 1:500,000, widely known as the “half million”. In general, the slower you fly, and the more detail you require, the larger scale map you will use. For high-flying, long-range aircraft the opposite is true. Here, smaller-scale maps reduce the number of sheets required.

Timing Marks

8. In a modern sophisticated aircraft the navigation equipment will tell you where to look on your map if you become temporarily uncertain of your position while map reading. In a simple training aircraft this equipment is not available, and we have to rely on the most accurate instrument in the aircraft, which is your watch or stop-watch. When planning a map reading flight it is normal to put marks along each leg to show the distance covered by the aircraft in a set time - normally two minutes, based on the planned groundspeed for the leg. In the example at Fig 4-2, a Tutor is flying from the railway junction near Stowmarket

via the mast South West of East Dereham to the lighthouse at Cromer. If you lose your place along track while map reading, consult your watch, work out your time in minutes since the last point, and that will tell you where to look on the map.

Fig 4-2 *Timing Marks*

Conclusion

9. In common with so many aspects of aviation, successful map reading will benefit greatly from the amount of advance planning. Thorough study of the route, detailed preparation of your route and the careful selection of unique features on the ground will give you the best chance of recovery when you lose your way.

Sample Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What features are useful for map reading in an aircraft at low level?

2. What features are useful for map reading in an aircraft at high level?

3. If you lose you place along track in an aircraft while map reading, what would you do?

CHAPTER 5

WEATHER

Introduction

1. In previous publications you have learned how the weather affects the walker in the hills and the aviator in the airfield circuit. We are now going to look at certain aspects of the weather in greater detail to increase your understanding of how it affects aircraft en route between airfields.

The Air

What is air?

2. In order to understand the reactions involved when air is in motion we must first consider its constituents. Pure air consists of 79% nitrogen, 20% oxygen and 1% other gases. It also contains some pollution, both natural and man-made, such as sand, volcanic ash, smoke, vehicle exhaust gases etc. Additionally, human activity is also affecting the levels of some of the gases in the 1%, such as ozone and carbon dioxide, which in turn are affecting the weather. However, the major variable in the atmosphere is water, in all its forms, and we shall look at that in some detail a little later.

Temperature and Pressure

Boyle's Law

3. If you have studied physics at school you will probably remember Boyle's gas laws. Even if you have not you will know from watching television that high up in the atmosphere (for example on the top of a high mountain) it is very cold, and climbers there need to carry extra oxygen as the air pressure is very low. The air pressure at sea-level is caused by the weight of the air above us, and as an aircraft climbs to high altitude there is less air and the pressure of that air is reduced. Additionally, if a gas is compressed its temperature rises and conversely, if it expands it becomes cooler - hence the low temperatures and snow caps on mountain tops.

Water Vapour

4. A certain volume of air, under fixed conditions of pressure and temperature, can only hold a certain amount of water vapour, which is an invisible gas. If that same volume of air becomes cooler it will not be able to hold as much moisture,

and it will eventually become saturated with water vapour. The technical term is that the air will have cooled to its Dew Point. It is at this point that dew will form on the ground and on cold objects such as car roofs; alternatively, mist or fog will form. If the temperature drops to below freezing point that dew or fog will become frost or freezing fog. The best example of Dew Point occurs in the home: take a shower on a Summer’s day and the bathroom stays clear and dry; do the same thing in the Winter and the warm moist air will come into contact with the cold walls and windows, and the immediate result will be condensation.

Vertical Motion in the Air

How Clouds are formed

5. When unsaturated air is forced to rise by one of 4 trigger actions its temperature and pressure reduce as it climbs, the 4 actions are mechanical turbulence (wind blowing up over buildings/trees), convection (warm ground heating air above it), orographic uplift (mountain effect) and frontal uplift. As the temperature drops it reaches its Dew Point and at that altitude the base of cloud is formed. The height of the cloud will depend on the amount of moisture in the air and the strength of the uplift. In extreme cases cumulo nimbus thunder clouds form and these represent a severe hazard to aircraft. At high levels the clouds (cirrus) consist of ice crystals, but most other clouds are formed by visible droplets of water. Flying in a cloud is very similar to driving in thick fog.

Thunderstorms

6. A large thunderstorm presents a variety of hazards to an aircraft; they are best avoided by quite a wide margin as several of the hazards exist not only inside the cloud, but also within its general vicinity. The hazards, in no particular order, are:

a. Icing. Very severe icing is often present - this problem has been covered in a previous publication.

b. Precipitation. Many different forms of precipitation come from thunder clouds, but the most common is hail. Some hailstones can be large enough to damage airframes.

c. Turbulence. The air inside a thunder cloud can be in vertical motion (up or down) at speeds in excess of 50 knots, and the change from up, to down, and back again can be very sudden. This leads to very severe turbulence which, in the worst cases, has been known to destroy aircraft.

d. Lightning and Thunder. The most obvious effect of being hit by lightning is the surprise or fear which it creates. In fact, lightning does much less damage to an aircraft than you might expect because it tends to travel around the skin of an airframe and come out the other side. It can puncture the skin surface of the aircraft, but the most significant effect is normally on navigation systems, compasses and radios. Additionally, a lightning strike at night can temporarily blind the aircrew which can be quite upsetting in the landing stage!

e. Landing Hazards. All of the above hazards exist underneath the base of a thunderstorm - the most significant being the risk of a severe downdraught just as the aircraft is over the runway threshold and has little room, or ability, to manoeuvre. On the ground a flooded runway can cause problems on the landing or take-off run. It is also very dangerous to refuel an aircraft during a thunderstorm.

Most modern aircraft carry a radar which is specifically designed for detecting thunderstorms and very turbulent air within clouds. This detection gives aircrew the ability to avoid thunderstorms and all of the hazards which they present.

Isobars

Air Pressure and Wind

7. You will have noticed from watching the weather forecasts on television that the air pressure at sea level varies from place to place. The normal range of pressures is from approximately 930 to 1050 millibars in most conditions. The pressure is shown on weather charts as a series of lines known as isobars; these lines join points of equal pressure and can be likened to contour lines which join places of equal elevation on a topographical map. The lines on a weather chart can be seen surrounding areas of high or low pressure. Isobars also indicate how the air is moving - in other words they give us the wind velocity, which is always expressed as the direction from which the wind is blowing (in degrees) and its strength (in knots). Hence a wind velocity of 200/25 is a wind blowing from the direction of 200° with a strength of 25 knots. In the Northern Hemisphere the wind circulates clockwise around anti-cyclones (high pressure areas) and anti-clockwise around cyclones (low pressure areas). The easy way to remember this is that if you stand with your back to the wind the area of Low pressure is on your Left. These rules are reversed in the Southern Hemisphere. See Fig 4-4 (ACP32)

8. Isobar patterns represent the wind at about 2000 ft above the surface; the direction of the lines gives the direction of the wind, and the closer the lines are together the stronger the wind. At the surface the wind is approximately 25% less strong than at 2000 ft as a result of surface friction. It is also backed by about 25°. For example, if the wind at 2000 ft is 270/20, the surface wind will be approximately 245/15. On the weather chart at Fig 5-1 you can see that the 2000 ft wind over the UK is generally South Westerly, while in the Mediterranean the isobars are widely spaced and winds are very slack.

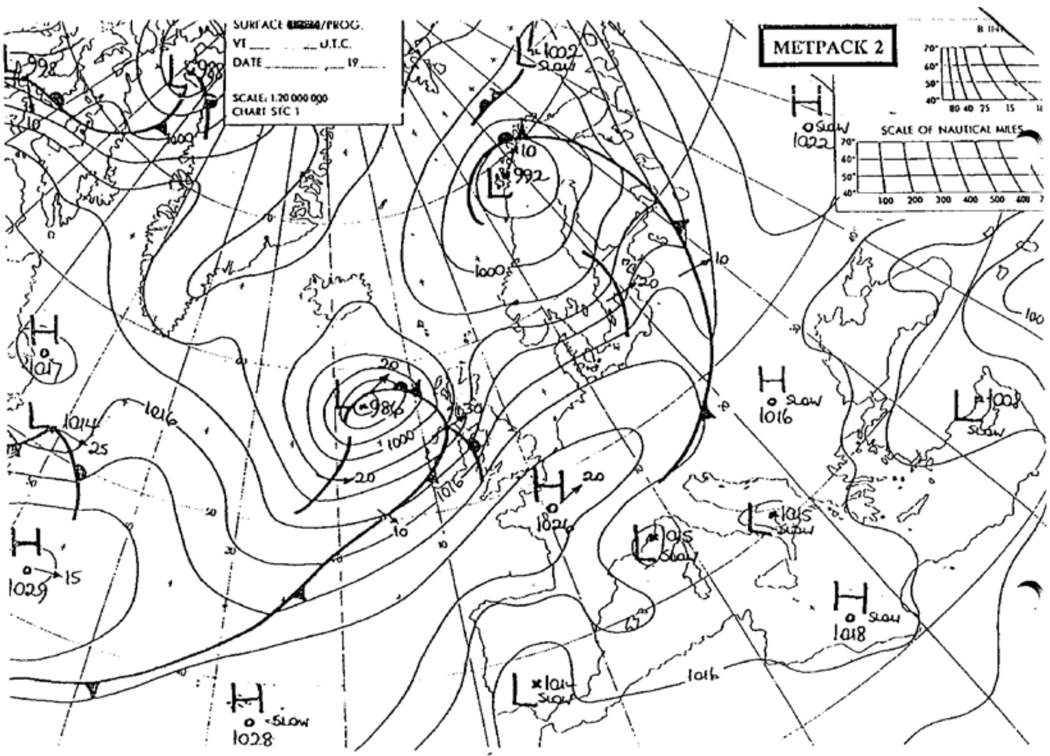


Fig 5-1 *Isobars on a Weather Chart*

TAFs and METARs

Weather Forecasts

9. The weather forecaster uses many charts and symbols to convey the details of the weather over the whole country. For an aviator, who has to receive the information by radio, the weather situation has to be coded as word pictures are too vague.

The code used is standardized to avoid language barriers, and apart from some variation in the units involved, is common to virtually every country except Canada. The code is used in 2 formats; one is the TAF (short for Terminal Aerodrome Forecast) and the other is the METAR (short for Meteorological Actual Report). In other words, one records a forecast and the other reports actual conditions. The full codes are complex, but the Annex to this chapter contains simplified versions, which are all that you need to know at this stage.

10. TAF. A TAF is usually published for a 9 hour period and starts with 4 figures which represent that period. Hence 0615 introduces a forecast which will be valid from 0600 hrs to 1500 hrs. TAFs do not include temperatures or pressures, but may include information on changes expected during the forecast period - whether permanent or temporary. These changes are prefixed by BECMG (becoming) or TEMPO (temporary). If the forecaster is unsure, then a probability is given - PROB 30TS means a 30% probability of a thunderstorm.

11. METAR. The actual report gives the conditions at an airfield and is normally recorded hourly. It is the report which is given to aircraft which are inbound to an airfield. The report is normally prefixed by a time, which is the time at which the conditions were observed. If the weather is changing rapidly a SPECI (special) report is issued in the same format. METARs and SPECIs do not forecast any conditions, but they do include temperatures and pressures.

The Code

12. Examples of a TAF and METAR are given below for the same day, and you will notice that some of the code is the same in each line - the decode then follows.

TAF CRANWELL 0615 260/05 4000 HZ SCT030 BECMG CAVOK=

Forecast for Cranwell for the period 0600 hrs to 1500 hrs/surface wind 260° (true) at 5 knots/visibility 4000 metres in haze/scattered cloud base at 3000 ft above the airfield/becoming “cloud and visibility OK”, which means that the visibility will be at least 10 km and there will be no cloud below 5000 ft

METAR CRANWELL 0900 250/07 8000 FEW 035 +17/+13 1028=

Actual weather at Cranwell at 0900 hrs zulu/surface wind 250° (true) at 7 knots/ visibility 8 km/lowest cloud - few (eighths) at 3500 ft/temperature +17°C, Dew Point +13°C/pressure 1028 mb.

Notes: 1. Temperatures in the USA are given in °F.

2. The end of the messages is indicated by an "equals" sign.

3. The pressure given is the QNH at the airfield.

The Decode

13. The symbols and figures used are given in the Annex. A full copy of the TAF/METAR decode is available in the RAF Flight Information Handbook (yellow).

Conclusion

14. The weather is a very complex subject, and this syllabus barely scratches the surface. To follow a career in civilian or military aviation will involve a detailed study of meteorology as the weather affects most aspects of aviation and is of great significance in the safe operation of all aircraft.

Annex:

A. TAF and METAR Decodes.

ANNEX A

TAF AND METAR DECODES

TIME	TAF:	Four figure group giving hours of start and finish of forecast period.
	METAR:	Four figure group giving time (in hours and minutes) of the observation.
WIND		Wind speed in knots and direction in degrees true. In gusty conditions a letter 'G' is added after the wind speed and then a higher number indicates the range of the gusts (eg 18G28 - 18 knots, gusting to 28 knots).
VISIBILITY		Four figures ranging from 0000 to 9999. 0000 means the visibility is less than 50 metres. 0400 means 400 metres. From 5000 upwards visibility is measured in kms. 9999 means a visibility of better than 10 kms.
WEATHER		Two-letter groups to indicate weather conditions which can affect aircraft adversely. Some codes are obvious; others originate from French words. (Note that there is not a code for sunny!)

BR	Mist	FZ	Freezing	SN	Snow
DZ	Drizzle	HZ	Haze	TS	Thunderstorm
FG	Fog	RA	Rain	-	Slight
FU	Smoke	SH	Shower	+	Heavy

These codes can be used in any combination; for example:

RASN	Rain and snow mixed (we call it sleet!)
+SHRA	Heavy rain shower
FZDZ	Light freezing drizzle

CLOUD

A 6-item code which indicates cloud amount and height of cloud base. The type of cloud is not given unless it is significant (for example, with TS expect to see CB for cumulo nimbus). More than one group can be given if there are several layers of cloud.

Cloud Amounts

FEW	One or 2 eighths coverage
SCT	Scattered - 3 or 4 eighths
BKN	Broken - 5 to 7 eighths
OVC	Overcast - 8 eighths

Cloud Base

Three numbers to indicate cloud base height above airfield in hundreds of feet - 018 = 1800 ft

ie 018 BKN means 5-7 eighths cover at 1800 ft.

Sample Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What is a TAF?

2. What is a METAR?

3. What is a SPECI?

Self Assessment Questions - Answer Sheet

Chapter 1 Page 32.4.1-5

1. Measured in nautical miles (NM) and knots (NM per hour).
2. In feet, very few use metric.
3. In thousands of feet per minute for most military aircraft.
4. By weight.
5. Measure of the ratio between the weight of the fuel and the weight of the same volume of water.

Chapter 2 Page 32.4.2-11

1. Pilot Nav Log Card.
2. To ensure sufficient fuel is available.
3. This is the altitude that a pilot must climb to, or not descend below, in instrument meteorological conditions (IMC) to ensure that the aircraft will not hit the ground or any obstacle such as TV masts.
4. By adding 1000 ft to the highest elevations on or near track and then rounding up to the nearest 100 ft.

Chapter 3 Page 32.4.3-6

1. Taking a fix, from ‘fixing the position’.
2. To provide a magnetic bearing, or radial, from the beacon.
3. Global Positioning System.
4. They disclose their presence and location to the enemy.

Self Assessment Questions - Answer Sheet cont...

Chapter 4 Page 32.4.4-5

1. Features that have vertical extent (chimneys, windmills, small hills), so that they can be seen before the aircraft arrives overhead the feature.
2. Large features such as lakes, woods, islands and they must have the necessary definition and contrast to stand out from their backgrounds.
3. Consult your watch, work out your time in minutes since the last point, and that will tell you where to look on the map.

Chapter 5 Page 32.4.5-9

1. Terminal Aerodrome Forecast, usually published for a 9 hour period
2. Meteorological Actual Report, gives the weather conditions at an airfield.
3. If the weather is changing rapidly a SPECI (special) report is issued.