AIR NAVIGATION

Introduction

In the earlier stages of Aviation a pilot's efforts were completely absorbed in the problem of taking off and keeping his plane in the air. Improvements in aircraft design and engines have done a great deal towards simplifying this problem. The aviator's attention is drawn more and more to the problem of finding his way in the air.

Without a sound knowledge of Navigation a pilot would be of no value on Active Service Once out of sight of his own aerodrome the safety of the aircraft, the crew, and the success of his mission depend largely upon accurate Navigation.

It is the general belief of those who have never studied Navigation, that it is a very difficult subject, mastered only by those who have had advanced training in science and mathematics. This conception is not true for it is possible, with a fair knowledge of mathematics, to master even the more difficult problems of Navigation. A sound knowledge of the fundamentals, and practice in working rapidly and accurately are the essentials to good Navigation.

THE EARTH

Before studying the theory of navigation, it is necessary to study the method used to designate position on the surface of the Earth. The Earth is usually considered to be a sphere rotating daily about an axis. The extremities of the axis are quite arbitrarily called the North and South Poles. (Fig. 1). The Earth rotates eastwards, that is, seen from above the North Pole the direction of rotation is anti-clockwise. Actually the Earth is not a perfect sphere, but is slightly flattened at the poles. However, it is so nearly a sphere that for purposes of navigation we will consider it as such. Although all places, i.e. cities, towns, villages, etc., have been given names, the name does not signify the location of the place or the relationship it bears to other points on the surface of the Earth. A system was therefore devised so that the position of any point on the Earth's surface and its relationship to any other point could be easily recorded.

Position on the Earth

In order to fully understand the system of denoting position on the surface of the earth it is necessary to define several terms which will be in constant use. If we consider a plane (flat surface) cutting through the Earth, or any sphere, the shape of the section so formed is a circle. If the plane passes through the centre of the Earth it bisects it in two halves and the section so formed is called a *Great Circle* (Fig. 2.). Only one Great Circle may be drawn through two places on the surface of the Earth that are not diametrically opposite each other. The smaller arc of the Great Circle joining two places is the shortest path between them. This is a very important definition in Air Navigation.

The *Equator* is the Great Circle whose plane is perpendicular to the Axis of the Earth.

Any number of Great Circles can be drawn around the

Earth passing through the poles. Each of these cuts the Equator at right angles.

Meridians of Longitude and Parallels of Latitude (Fig. 1)

Fixing position on the surface of the earth is facilitated by a network of lines called *Meridians* and *Parallels of Latitude*. This network is called a *Graticule*.

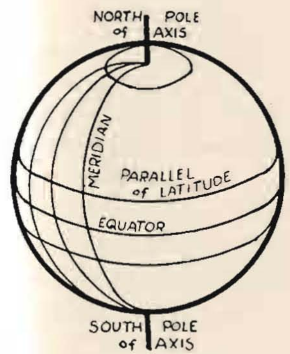


Fig. 1.

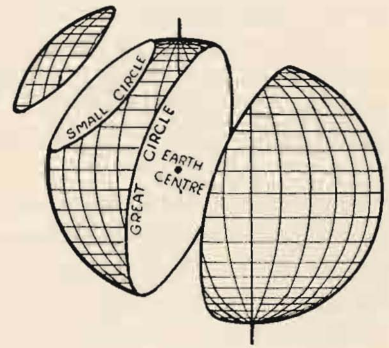


Fig. 2.

The *Meridians* are semi-great circles joining the poles. It follows that every place on the Earth's surface has its own meridian. It is necessary to select one meridian as a standard from which to number all the others. The meridian passing through Greenwich, England, is generally adopted as most convenient and is called the Prime Meridian. The other meridians are numbered from this meridian and are termed East or West according to the side on which they lie. The angular system of measurement is used to number the meridians. That is, if the plane of a meridian makes an angle of 60° with the plane of the Prime Meridian, the meridian is said to be the 60°

Meridian. Meridians may, therefore, have any value from 0 to 180° East or West, measured in degrees, minutes, and seconds.

When a plane cutting through the earth, or any sphere does not pass through the centre, the shape of the section so formed is a Small Circle. (Fig. 2). *Parallels of Latitude* are small circles on the earth whose planes are parallel with the plane of the Equator. They lie in an East to West direction and are parallel to the Equator. These small circles are largest at the Equator and decrease in size toward either pole. The angular system of units is also used to number the Parallels of Latitude. They are numbered from 0 to 90° North or South in degrees, minutes and seconds beginning at the Equator.

Latitude and Longitude (Figs. 3 and 4)

The position of a point on the Earths surface is given by the intersection of its Parallel of Latitude and its Meridian of Longitude i.e. its Latitude and Longitude.

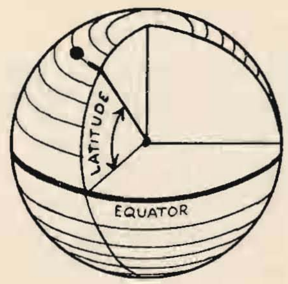


Fig. 3.

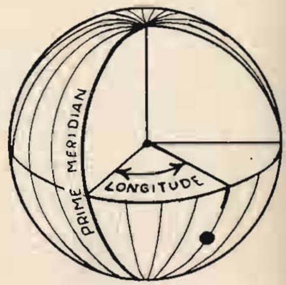


Fig. 4.

The *Longitude* of a place is given by the meridian on which it lies and so may have any value from 0° to 180° East or West. It may equally well be expressed as the

angle between the plane of the Prime Meridian and the meridian of the place, or, as the shorter arc of the Equator intercepted between the Prime Meridian and the meridian of the place, and is named East or West according to whether the place is East or West of the Prime Meridian.

The *Latitude* of a place is given by the parallel of latitude on which it lies, and so may have any value from 0° to 90° North or South. It may also be expressed as the arc of the meridian between the Equator and the place, and is named North or South according to whether the place is North or South of the Equator.

Recording the Position of a Place in Latitude and Longitude

The group of figures expressing Latitude are written first, followed by those expressing Longitude. It is not necessary to write the word "Latitude" or "Longitude" since they are understood. All figures below 10 are preceded by 0 i.e. 4 degrees West is written 04°W. For example, the position of a place situated at latitude 41 degrees, 23 minutes, 15 seconds North, and longitude 2 degrees, 7 minutes, 24 seconds West is written.

41° 23′ 15″N	02° 07′ 24″W.	or simply as
41 23 15 N	02 07 24 W.	

Calculating Change of Latitude and Longitude. (Ch. Lt. and Ch. Long.) (Fig. 5)

It is sometimes necessary to calculate change of Latitude and change of Longitude between two places. The change of Latitude (Ch. Lat.) between two places is the arc of a meridian contained between the parallels of Latitude of the two places. It is named North or South according to the direction of the change. It may also be expressed as the angle at the centre of the Earth subtended by the parallels of Latitude of each place.

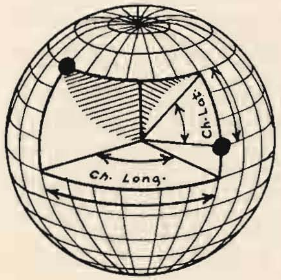


Fig. 5.

The change of Longitude (Ch. Long.) between two places is the smaller arc of the Equator contained between the meridians of the two places. It is named East or West according to the direction of the change. It may also be expressed as the smaller angle contained between the planes of the two meridians.

Example:

Calculate change in Latitude and Longitude between the following:

1st position	Lat. 27° 29′N		Long.	40° 19′W
2nd position	Lat. 39° 19′N		Long.	27° 25′W
Ch. Lat.	11° 50′N	Ch. Long.		12° 54′E

Problems:

1st position	Lat. 25′° 18′N		Long.	62° 25′W
2nd position	Lat. 21° 43′S		Long.	37° 13′E
Ch. Lat.		Ch. Long.		

Problems:

2nd position	Lat. 48° 25′N		Long.	125° 52′E
1st position	Lat. 26° 46′N		Long.	42° 36′W
Ch. Lat.		Ch. Long.		

Great Circle and Rhumb Line (Fig. 6)

As has been previously stated, the shorter arc of the Great Circle passing through two points on the earth's surface is the shortest distance between the points. However, as will be seen later, the Great Circle path is not the most convenient for a navigator to follow. A regular curve which cuts all the meridians at the same angle is easier to follow. This type of a curve is called a Rhumb Line. A Rhumb Line may be drawn through any two points on the earth's surface. The meridian and the Equator are the only examples of Rhumb Lines that are also Great Circles. The following Scale shows the difference between Rhumb Line and Great Circle distances.

From	*To*	*Rhumb Line dist. Nautical Miles*	*Great Circle dist. Nautical Miles*
New York	Boston	166.4	165.4
New York	Chicago	621.9	618.8
Calshot, Eng.	Tokyo, Japan	6182.0	5219.0

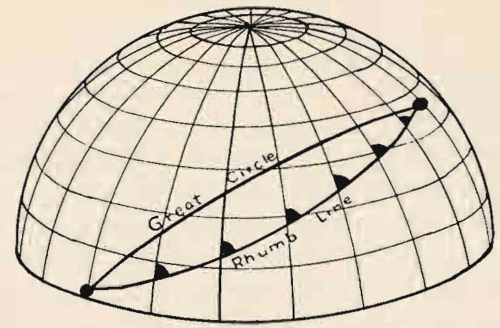


Fig. 6.

Measurement of Distance

There are several units used for the measurement of distance on the surface of the earth.

(1) A *statute mile* (m) is a length of 5,280 ft. This

unit is used on almost all maps and is usually used for short flights in Elementary Navigation.

(2) *Nautical Mile* (n.m. symbol) is the average length of a minute of latitude, taken to be 6,080 ft. Because the curvature of the earth is less pronounced at the poles than at the equator, the length of one minute of latitude increases from 6,046 ft. at the equator to 6,107.8 ft. at the poles. Some maps and all charts have a scale of nautical miles. In practical work a nautical mile is taken to be the length of a minute of arc along any great circle of the earth.

Conversion of Units

A distance of 66 Nautical miles is equal to 76 Statute miles. This is a convenient formula for converting nautical miles to statute miles.

Problems:

Convert the following to Statute miles.	Convert the following to Nautical miles.
27 Nautical miles	138 Statute miles
33 " "	107 " "
60 " "	122 " "
66 " "	154 " "
81 " "	182 " "
87 " "	200 " "
93 " "	210 " "
120 " "	226 " "

AIR NAVIGATION DIRECTIONS

As has been previously explained, the earth rotates about an axis the extremities of which are the North and South Poles, and therefore, the directions in which the

Poles lie are arbitrarily called North or South. The Earth rotates anti-clockwise when viewed from above the North Pole. This rotation causes the heavenly bodies, such as the sun, to rise and set. The general direction from which they rise is called East, and the opposite direction is called West.

The meridians join the two poles and so always run in a north-south direction. By convention we use the meridian as a datum line in measuring directions. Directions are measured to the nearest degree, clockwise from North i.e. from 000° to 360°. They are expressed in 3 figures i.e. East which is 90° from North is written 090°, and South 180°.

True and Magnetic Meridians

Since the meridians are purely imaginary lines, it is necessary to have some instrument to indicate their direction so that other directions may be measured from them. Unfortunately, there is no simple instrument which indicates their direction directly. However, it is a well-known fact that the earth behaves as a magnet and therefore has a magnetic North and a magnetic South pole. A piece of magnetized metal when freely suspended and influenced only by the earths magnetic field always comes to rest with its North-seeking pole pointing towards the North magnetic pole and its South-seeking pole towards the South magnetic pole. By convention we call the direction of a freely suspended magnetic needle the Magnetic Meridian. To distinguish between geographic and magnetic poles, we call the former the True poles and the meridians joining them True Meridians. Since the Earths magnetic field is not uniform, the magnetic meridians are not perfect semi-great circles as the diagrams would suggest.

Magnetic Variation

The magnetic poles do not coincide with the True poles. The magnetic North pole is situated in North Eastern Canada. Therefore, there will be an angle between the True Meridian and the Magnetic Meridian. This angular difference between the direction of True North and Magnetic North is called *Variation.* Variation is measured in degrees and is called East (+) or West (–) according to whether the North-seeking end of a freely suspended magnetic needle, influenced only by the Earth's magnetic field, lies to the East or West of the True Meridian at any given place. The angle of Variation differs in different parts of the world as can be seen in the diagram where all the magnetic needles are pointing to the Magnetic North Pole. (Fig. 7).

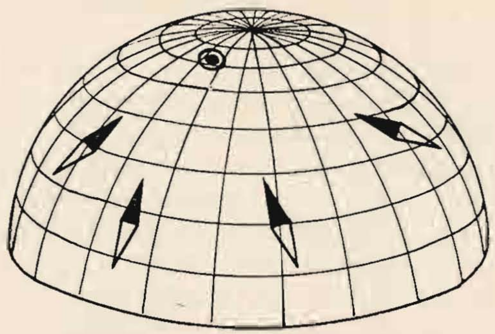


Fig. 7.

Lines drawn through places where the Variation is the same are called Isogonals. These are drawn on maps and charts so that True directions may be readily converted to Magnetic directions and vice versa. As the Earths magnetic field changes slightly from year to

year, the angle of Variation will also change. The amount by which the Variation changes every year is also marked on charts and maps.

The instrument which employs the magnetic needle to indicate the direction of Magnetic North is called the Magnetic compass. While there are a great many types of magnetic compasses, they all employ a similar freely pivoted magnetic needle. True directions may be obtained from maps, but if we want to travel in any true direction we employ a magnetic compass. The true directions must, therefore, be converted to magnetic directions by applying the angle of Variation. A simple rule is:—

Variation East Magnetic is least
Variation West Magnetic is best

Here "best" means "greater", "least" means "lesser".

Thus

Direction (*T*)	*Variation*	*Direction* (*M*)
090°	10° E (+)	080° (Fig. 8)
100°	10° W (–)	110° (Fig. 9)

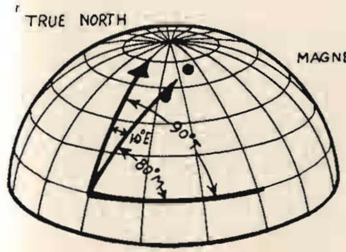


Fig. 8.

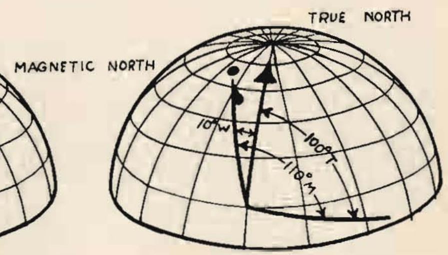


Fig. 9.

Problems: (Fill in the blanks).

Direction (T)	*Variation*	*Direction (M)*
030°	6° W	?
342°	11° E	?
195°	?	187°
358°	?	006°
?	11° W	008°
?	15° E	346°

Deviation

A compass is mounted in an aircraft for the purpose of indicating directions. There may be many metal and electrical parts of the aircraft that become magnetized either temporarily or permanently, and so these parts will disturb the compass needle causing its North-seeking end to deviate from the direction of Magnetic North. The direction of the North-seeking end of this particular compass needle is called Compass North. The angular difference between the direction of Magnetic North and the direction of Compass North is called *Deviation.* Deviation is measured in degrees and is called East (+) or West (–) according to whether the North-seeking end of a compass needle, under various disturbing influences, points to the East or West of Magnetic North. It should be noted that the magnetic field of the aircraft changes from time to time thus changing the Deviation. Also, since the magnetic field of the aircraft moves with the aircraft, the deviation varies for different directions in which the aircraft points. When using the compass in the aircraft it is necessary to convert magnetic directions to Compass directions. A useful rule is:

Deviation East Compass is Least
Deviation West Compass is Best

Thus

Direction (M)	*Deviation*	*Direction (C)*
080°	4°W (–)	084° (Fig. 10)
080°	4°E (+)	086° (Fig. 11)

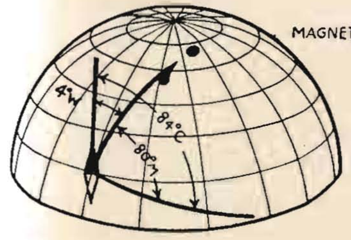


Fig. 10.

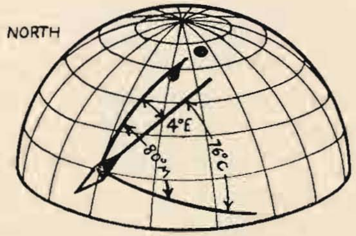


Fig. 11.

Problems: (Fill in blanks below).

Direction (M)	*Deviation*	*Direction (C)*
235°	5° E	?
163°	4° W	?
092°	?	096°
358°	?	002°
?	2° E	359°
?	3° W	002°

It is quite obvious now that a direction given by a particular Compass needle may be expressed as a True direction if the Deviation and Variation are known. Since Variation and Deviation may change during a flight, all calculations and plotting are usually in True directions.

Example: Fig. 12.

The True direction in which you wish to travel is known to be 230°. If the Variation is 15°W (–) and the appropriate Deviation is 7°W (–) what compass direction should your compass indicate.

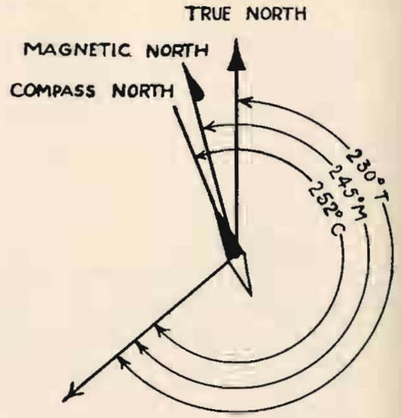


Fig. 12.

True direction	230°	
Apply Variation	15°W (–)	
Magnetic direction	245°	Magnetic best
Apply Deviation	7°W (–)	
Compass direction	252°	Compass best

NOTE—It is obvious that the Variation and Deviation signs (+) and (—) can only be used algebraically when changing from Compass to Magnetic or Magnetic to True directions.

Problems: (Fill in the blanks).

Direction (T)	*Variation*	*Direction (M)*	*Deviation*	*Direction (C)*
030°	6°W		5°E	
	10°E	352°		357°
252°		240°	4°W	
070°	13°E			056°
156°			3°E	140°
358°		007°		003°
	3°E	000°	1°W	
	15°W	011°		117°

Course (Co.)

The direction in which an aircraft is pointing or heading is called its *Course* i.e. the angle measured clockwise

between the meridian and the longitudinal axis of the aircraft. The course of an aircraft may, therefore, be expressed in three ways, namely:—

(a) True Course, abbreviation: Co. (T)
(b) Magnetic Course " Co. (M)
(c) Compass Course " Co. (C)

The True Course is found by calculation and plotting. It is converted to Magnetic Course by applying Variations. The Magnetic Course is converted to Compass Course by applying Deviation. The Compass Course is the one used to steer the aircraft. From the definition of Course, we see the rules for converting True to Magnetic to Compass directions also apply in converting True to Magnetic to Compass Courses.

Example: Fig. 13.

Example:

A pilot wishes to steer a Course of 080° True, in a locality where the Variation is 21°E (+) and the appropriate Deviation is 6°W (–). What Course should he steer by his Compass.

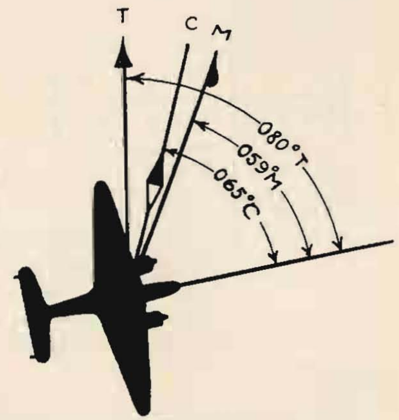


Fig. 13.

True Course	080°	
Variation	21°E (+)	Magnetic least
Magnetic Course	059°	
Deviation	6°W (–)	Compass best
Compass Course	065°	

Problems: (Fill in the blanks).

Course (*T*)	*Variation*	*Course* (*M*)	*Deviation*	*Course* (*C*)
007°		358°		003°
154°			3°W	142°
	15°E	295°		297°
069°	14°W		4°E	
	9°E	140°	2°W	
260°		254°		257°
359°		009°	2°E	
	12°W	348°		336°

For Magnetic Course	Steer by Compass	Dev.
N 0°	002	-2
NE 45°	045	0
E 90°	089	+1
SE 135°	135	0
S 180°	182	-2
SW 225°	224	+1
W 270°	269	+1
NW315°	315	0

Fig. 14.

Deviation Card.

It is possible to eliminate excessive deviation of an aircraft compass by means of a corrector device which, when adjusted properly, produces a magnetic field which will balance out part of the magnetic field of the aircraft. The aircraft is lined up on a compass base which has the magnetic directions marked on it. A definite procedure is followed in adjusting the corrector. This is called "Swinging" the aircraft. However, as the deviation can not be entirely eleminated, the remaining deviations are tabulated on a Deviation Card. (Fig. 14). In order that the pilot may convert magnetic courses to compass courses he is supplied with a Deviation Card. This card is usually mounted on the instrument panel beside the compass.

Bearing

The direction of one place from another is called its *Bearing*. Like directions, it may be expressed with reference to three different Norths, and is accordingly called,

(a) A True Bearing
(b) A Magnetic Bearing
(c) A Compass Bearing

A more formal definition of True Bearing of an object from an observer, is, the angle at the observer between his meridian (i.e. the direction of True North) and the line joining him to the object. Bearings are always measured clockwise, that is, from North through East, South and West, and are expressed in three figures i.e. 009°, 027°, 152°, etc. The line joining the observer to the object may be along the great circle or along the rhumb line. The former is called a Great Circle Bearing and the latter a Rhumb Line Bearing.

Example: Fig. 15.

An observer in an aircraft finds the Compass bearing on a lightship is 068°. The appropriate deviation is 3°E (+) while the local variation is 11°W (–). What is the True bearing of the lightship?

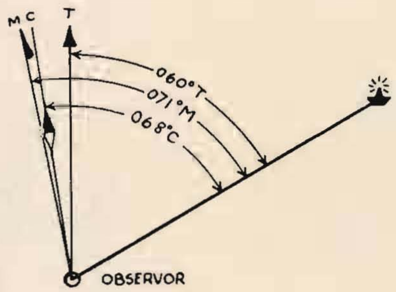


Fig. 15

Compass Bearing	068°	
Deviation	3°E	Compass least
Magnetic Bearing	071°	
Variation	11°W	Magnetic best
True Bearing	060°	

Compass Bearings are taken in the air by means of a special observer's type compass. A separate deviation card is used with this compass. Magnetic bearings may be taken only on the ground by means of a Landing compass, which is a special type of compass mounted on a tripod.

Problems: (Fill in the blanks).

Bearing (*T*)	*Variation*	*Bearing* (*M*)	*Deviation*	*Bearing* (*C*)
086°	6°W		3°E	
001°		350°		358°
	7°E	248°	4°W	
358°			1°E	346°
221°	12°W			236°

Relative Bearing

A *Relative Bearing* is a direction measured clockwise from the heading of an aircraft from 0° to 360°. Added to the True Course it becomes a True Bearing (–360° if necessary).

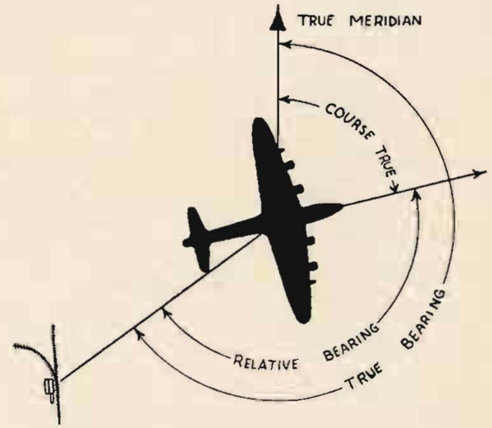


Fig. 16.

Examples: Fig. 16.

An observer in an aircraft which is flying a course of 077° True uses a Bearing plate to find the Bearing on a railway station to be 167°R. What is the True Bearing of the railway station.

True Course	077°
Relative Bearing	157°
True Bearing	234°

Should the True Bearing of the aircraft from the railway station be desired, we must take the reciprocal (±180°) of the above i.e. 234°–180° = 054°T.

Problems:

Bearing (*R*)	*Course* (*T*)	*Bearing* (*T*)
255°	080°	
325°	057°	
090°	278°	
116°	244°	

Vectors

Any student of elementary physics learns that there are some qualities which have more than just magnitude alone. These quantities besides having magnitude also have direction. A quantity of this type having both magnitude (amount) and direction, is called a *Vector*. Velocity, acceleration, momentum and force are examples of quantities having the characteristics of a Vector. These quantities can not be added by simple arithmetic as can mass, area, volume, etc.

The Vector which we are concerned with in Navigation is Velocity. A Velocity is a rate of change of position in a given direction. It s not sufficent to say that an aircraft has a velocity of 200 m.p.h. The direction must also be given so that 200 m.p.h. in a direction of 100°T would completely describe the velocity.

Vectors may be illustrated graphically by straight lines. The direction of the line is referred to an arbitrary datum line. The datum line is usually drawn from top to bottom of the page, the direction of True North is taken as being at the top of the page, and South at the bottom. The datum line corresponds, therefore, to our True meridian.

The length of the vector line is determined by an

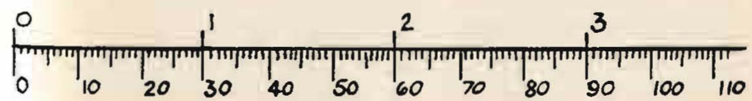


Fig. 17

arbitrary scale. The scale is indicated either by a statement such as, 1 inch=30 m.p.h., or by drawing a scale line from which the speeds are measured. (Fig. 17.)

For example, if an aircraft has a velocity of 160 m.p.h. in a direction 045° this may be represented vectorially by A.B. in figure 18.

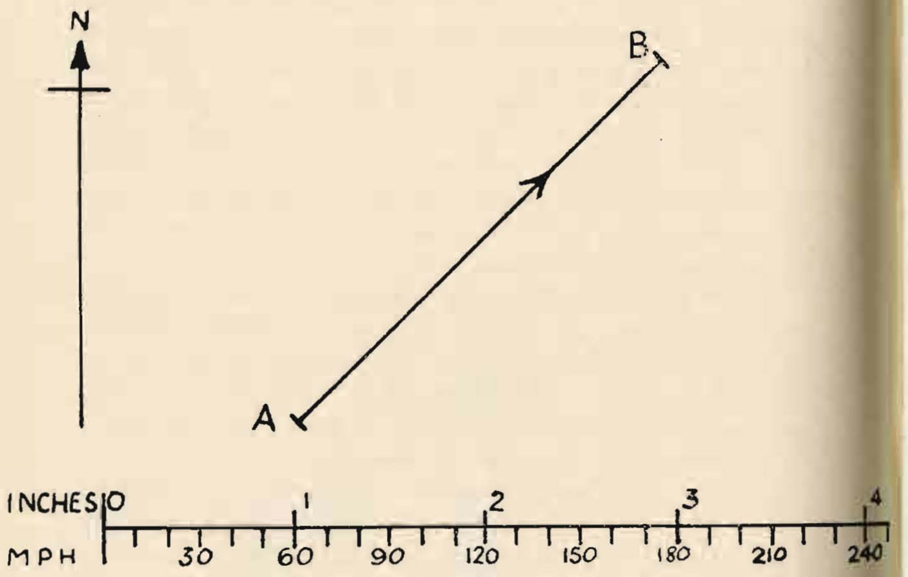


Fig. 18.

Vector Parallelogram and Triangle

A body may be subject to two or more velocities at the same time. For example, if we consider a boat steaming up a stream, the boat may have a velocity of 8 m.p.h. while the stream has a velocity of 2 m.p.h. The boat has two velocities at the same time, and its progress, in relation to a person standing on the bank of the stream, will be the result of the two velocities, i.e. 6 m.p.h. up the

stream. The single velocities of the boat and the stream are called *component* velocities and the velocity of the boat in relation to the observer on the bank is called the *resultant velocity*.

If the component velocities do not act along the same line the resultant will act in a direction between the two. There are many simple experiments in physics which show us that the resultant of two vector quantities may be found by constructing a vector diagram in the form of a parallelogram. If the two sides of the parallelogram are drawn to scale and in directions corresponding to the two component vectors the resultant is represented by the diagonal of the parallelogram. The length of the diagonal represents to scale the magnitude of the resultant while the direction of the diagonal represents the direction of the resultant vector.

For example, a ship is steaming East at 6 m.p.h., in a tide running at 2 m.p.h. from 030°T.

The figure shows AB as component vector representing the ships velocity while AC is the component vector of the tides velocity.

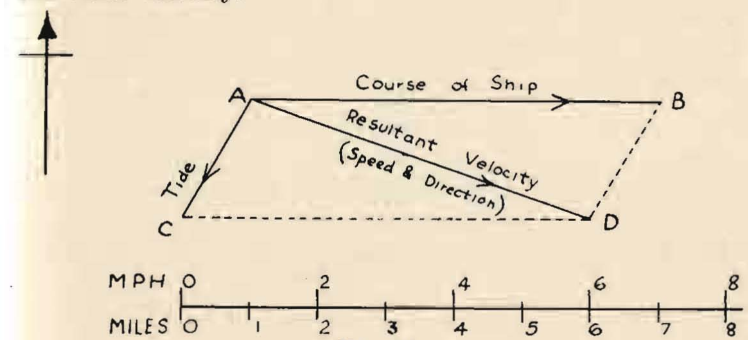


Fig. 19.

The parallelogram is completed as shown by the broken lines and the diagonal AD is drawn. AD then represents the resultant velocity of the ship which is found on measuring to be 5.3 m.p.h. in a direction of 109°T.

It is possibly easier to understand the results obtained from the parallelogram if we consider distances instead of velocities.

If we let the scale used be a distance scale, the ship would travel from A to B in the water in one hour. In the same hour the water has travelled a distance from B to D. Therefore, after one hour the ship is at D. Thus, the ship must move along the line joining A to D and arrive at D in one hour. Therefore, the speed is AD m.p.h.

Vector Triangle

It is easily seen from Fig. 19 that the side BD is equal in length and has same direction as AC. Therefore AD the resultant may be found by constructing only a triangle with the two component velocities as sides. It must be noted, however, that the two component velocities must follow one another around the triangle. The resultant velocity will oppose the direction of the components around the triangle. If we place a single arrow on each of the components and a double arrow on the resultant the result will always be as shown: Fig. 20.

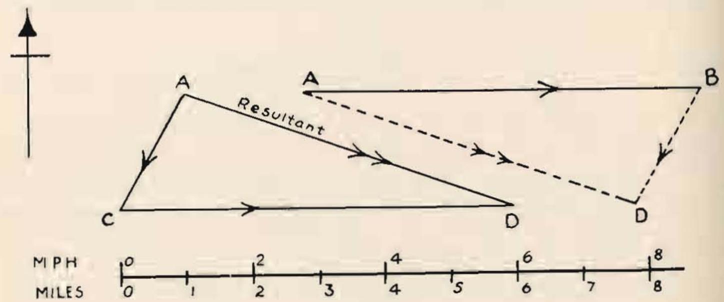


Fig. 20.

Problems

Find the resultant velocity when the following two component velocities are acting on a body.

1. 090/10 mph and 030/15 mph.
2. 350/18 mph and 260/ 7 mph.
3. 200/30 mph and 280/28 mph.
4. 160/25 mph and 340/16 mph.

Simultaneous Velocities Relative to Aircraft

When an aircraft leaves the ground it is pulled through the air by the airscrew in the direction of its longitudinal axis, i.e. the direction it is pointing (heading). The air itself is moving with a definite velocity. Therefore, the aircraft will have a resultant velocity with respect to the ground entirely dependent on these two components. We have already defined the direction the aircraft is pointing (heading) as the Course of the aircraft and measure this direction by means of the compass. The speed which the airscrew pulls the aircraft through the air is called the Air Speed and is measured by an indicator called the Air Speed Indicator. This Indicator is subjected to several errors and so the indicated Air Speed must be corrected to give us True Airspeed.

To find the actual path of the aircraft with respect to the ground we construct a vector triangle using the wind velocity as one component, the direction (course) and speed of the aircraft as the other component. The direction of the resultant is called the *Track* of the aircraft while the magnitude of the resultant is called the *Ground Speed,* because it is the speed of the aircraft relative to the ground.

It follows that in the vector triangle constructed there are six variables, each of which has its effect upon the other five. The variables are, 3 directions and 3 magnitudes. The six factors and their abbreviations are:

Directions		*Magnitudes*	
Course	Co.	True Airspeed	T.A.S.
Wind Direction	W/D.	Wind Speed	W/S.
Track	Tr.	Ground Speed	G/S.

Wind Speed and Direction are usually combined and called Wind Velocity (W/V).

Example:

An East wind of 30 m.p|h. is written W/V=090°/30 m.p.h.

If we know any four of the above factors we are able to find the remaining two by completing the vector diagram.

A single arrow is always placed on the Course and Wind vectors and a double arrow is placed on the Track vector. Fig. 21 (a).

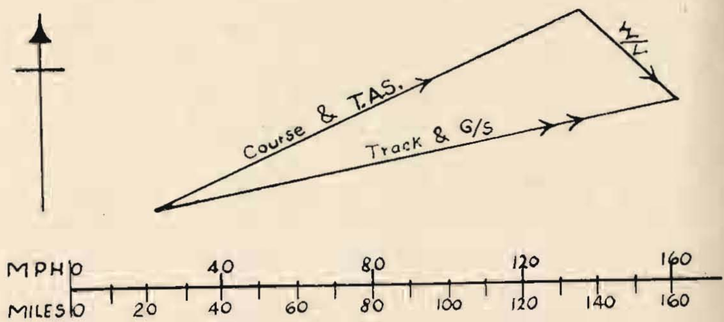


Fig. 21 (a)

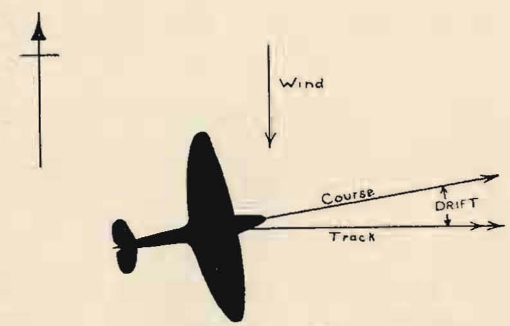
Fundamental Navigation Problems Based on Triangle of Velocities

Although there are six parts of the triangle of velocities all of which are variable, the Navigator is usually only concerned with three problems because certain variables are usually known. For example, the Airspeed is usually given in all problems because in practice each aircraft has its particular cruising speed. Also if the points from, and to which, the aircraft is flying are known, the Track would be known. Wind velocity cannot be adjusted but varies at different altitudes so a definite Wind velocity may be given. It must be remembered in all navigation plotting problems that the Wind always blows the aircraft from the direction of its course toward the direction of its Track. Also the Wind Direction is always that *from* which the Wind blows i.e. East wind blows *from* the East.

Drift

In practice a great deal of use is made of the angle between the Course of an aircraft and its Track. This angle is called the angle of Drift. Drift is measured in degrees to Port (P) left, or Starboard (S) right, from the aircraft's nose.

In Fig. 21 (b) a drift of 10° Starboard is shown. The aidcraft Course is 080°T and the Trick is 090°T. The wind is from North (000°T).



(Fig. 21 (b)

Problems: (Fill in the blanks).

Course (T)	*Track (T)*	*Drift*
085°	068°	
359°	007°	
001°	349°	
240°		5°P
358°		3°S
009°		2°P
	006°	7°S
	354°	8°P
	152°	11°S

The three fundamental problems of Navigation will now be considered in detail.

Finding the Track and Ground Speed of an Aircraft knowing Course, True Airspeed and Wind Velocity

Example:

An aircraft on a Course of 090°T has an Airspeed of 100 m.p.h. It is experiencing a wind of 025/25 mph.
What is its Track and Ground Speed?

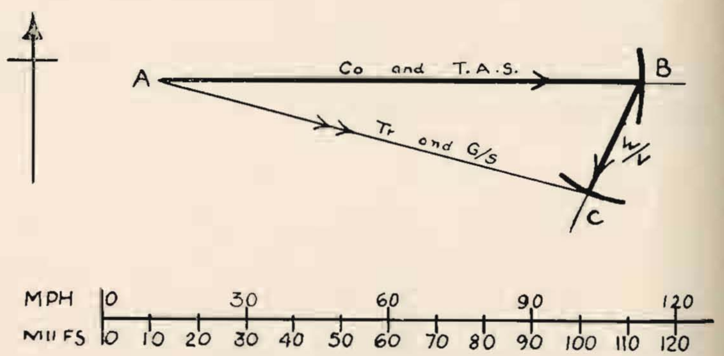


Fig. 22.

Draw a line AB in the direction of the Course of the aircraft and cut its length off to scale to represent the True Airspeed of the Aircraft. From B draw BC to represent the Wind, also drawn to

scale. The wind must be drawn downwind so that the two arrows follow in order around the triangle. The direction of line joining A to C represents the Track of the aircraft and the length of the line represents the Ground Speed of the aircraft to scale. The Track is found to be 105°T and Ground Speed 93 mph.

This problem may be more easily explained if we take the scale as a distance scale. B would then be the position of the aircraft after flying for one hour with no wind. However, in that same hour the wind would blow the aircraft downwind to the position C. AC would, therefore, represent the distance travelled by the aircraft in one hour while being subjected to the wind, and the direction of AC would represent the Track of the aircraft.

Problems:

Find Track and Ground Speed.

Given

	Course	*Air Speed*	*W/V*
1.	247°T	88 m.p.h.	305°/25 m.p.h.
2.	288°T	90 "	025°/22 "
3.	353°T	87 "	105°/28 "
4.	030°T	92 "	210°/20 "
5.	079°T	91 "	015°/18 "

Finding the Course and Ground Speed of an Aircraft, given Track Required, True Airspeed and Wind Velocity

This problem is used much more than the preceding problem since a navigator usually knows the Track required.

Example: Fig. 23.

An aircraft is required to make good a Track of 080°T. The W/V is 020/30 m.p.h. and the True Airspeed is 200 m.p.h. What is its Course and Ground Speed?

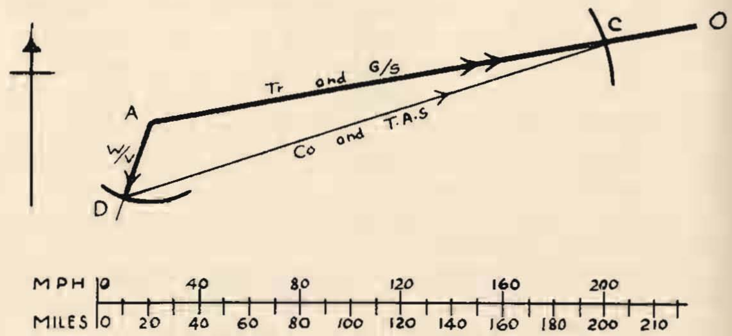


Fig. 23.

Draw a line AO in direction 080°T to represent the required Track. From A draw AD to represent to scale the Wind Velocity. The wind is drawn downward to observe the rule of the arrows around the triangle. With centre D and radius the True Airspeed cut AO at C. Join DC. DC then represents the Course in direction and is found to be 072°T. The length AC represents the Ground speed to scale, 182 m.p.h.

In this problem we have actually used the opposite triangle of the parallelogram to that used in the previous problem.

This problem may also be more clearly explained by considering a distance scale. If we consider the Track AO as before and the aircraft starting from A; if the wind alone acted on the aircraft for one hour it would blow it downward a distance of 30 miles to position D. DC is the distance the aircraft would travel with no wind in one hour. In order that the aircraft be on Track in the same hour DC must cut the Track at its extremity C. That is, the aircraft must steer the Course DC. The distance AC is that covered by the aircraft in one hour, i.e. the Ground Speed.

Problems:

	Track	*W/V*	*T.A.S.*	*Co*	*G/S*	*Drift*
1.	088°T	025°/30 m.p.h.	85 m.p.h.			
2.	116°T	186°/25 "	87 "			
3.	330°T	045°/18 "	90 "			
4.	210°T	160°/15 "	83 "			
5.	175°T	260°/20 "	91 "			

Finding Wind Velocity knowing Course and Airspeed, Track and Ground Speed of an Aircraft

Example: Fig. 24.

An aircraft is steering a Course of 090°T and its True Airspeed is 220 m.p.h. The Track is 079°T and the Ground Speed is 240 m.p.h.

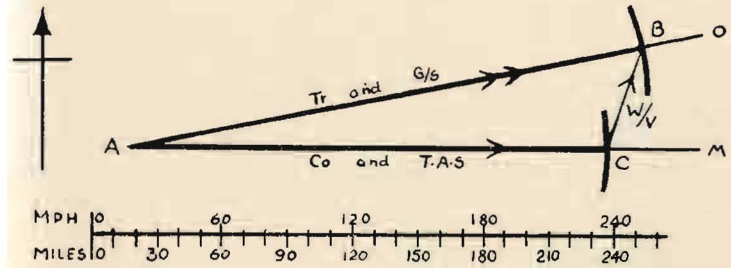


Fig. 24.

Draw AO in the direction of the Track, 079°T and AM in the direction of the Course. Cut off AB on Track to represent the Ground Speed 240 m.p.h. to scale. Cut off AC on Course to represent Airspeed 220 m.p.h. to scale. Join BC. BC is therefore the wind vector and represents a velocity of 199°/48 m.p.h.

This problem may also be illustrated using a distance scale. If there had been no wind the aircraft would travel distance AC in one hour. The actual position of the aircraft in one hour is at B. The wind must have been in the direction from C to B and the distance from C to B must be the effect for one hour, and therefore represents the Wind Velocity.

Problems:

Find the Wind Velocity (W/V).
Given

	Co.	*T.A.S.*	*Tr.*	*G/S*	*W/V*
1.	112°T	90 m.p.h.	119°T	82 m.p.h.	
2.	261°T	88 "	270°T	76 "	
3.	092°T	84 "	087°T	78 "	
4.	105°T	110 "	111°T	103 "	
5.	316°T	98 "	308°T	108 "	

The actual Track and Ground Speed of the aircraft are measured in practice by observing the time the aircraft passes over two particular points while flying a constant Course. Measuring the distance between the points and using time to pass between them we are able to calculate actual Ground Speed. The line joining the two points is the actual track which is usually called the "Track Made Good" (T.M.G.).

Examples: Fig. 25.

An aircraft is cruising at a True Airspeed of 180 m.p.h. on a Course 120°T. It passes over a point Y at 0920 hours and a point X at 0950 hrs. X bears 110°T from Y and the distance between the two points is 75 miles. ∴ The Ground speed is 150 m.p.h. and T.M.G. = 110°T.

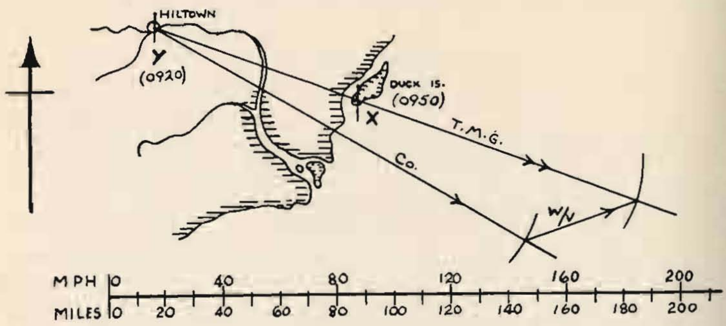


Fig. 25.

We have the four variables necessary to complete the triangle and so find W/V = 252/41 m.p.h.

It will be remembered that the angle of drift is the angle between Course and Track. Therefore given either Course or Track, we are able to calculate the other. That is, Course ± Drift = Track.

There are various methods of measuring drift while the aircraft is in flight and so, knowing the Course, we are able to apply Drift to find T.M.G.

In practical navigation there are several terms which are very essential.

(a) The time the navigator sets course (S/C) over his own aerodrome.

(b) The estimated time of arrival (E.T.A.) at his destination.

(c) The estimated time to carry out the flight.

Problems:

1. A place P bears from a place Z 200°T, and their distance apart is 25 miles. An aircraft flies from Z to P in 15 minutes with a True airspeed of 125 m.p.h. and Course 191°T.
Find: T.M.G., G/S and W/V.

2. A place P bears from a place Z 210°T, and their distance apart is 90 miles. An aircraft flies from Z to P with a True airspeed of 125 m.p.h. W/V is 090°/25 m.p.h. Variation 12°W.
Find: G/S, Co. (M), Drift, and estimated time to go from Z to P.

3. A place P bears from a place Z 010°T, An aircraft flies from Z to P a distance of 62 miles with a True airspeed of 95 m.p.h. W/V 200°/30 m.p.h. Variation 10°W S/C at 0100 hrs.
Find: Co. (M), G/S, Drift, E.T.A.

4. A place M bears from a place N 054°T. An aircraft flies from N to M a distance of 182 miles with a T.A.S. of 85 m.p.h. W/V 300°/27 m.p.h., Variation 9°W, S/C at 0913 hrs.
Find: Co. (M), G/S, Drift, E.T.A.

5. A place R bears from a place S 317°T. An aircraft flies from S to R with a T.A.S. of 150 m.p.h. W/V 090°/30 m.p.h. Variation 12°E, Deviation 3°W.
Find: Co. (C), G/S, Drift.

6. The bearing of London from Toronto is 225°T. An aircraft S/C at Toronto at 1132 hrs. for London. The wind is from NW at 30 m.p.h. The mean variation is 5°W and the Deviation is 4°E. Distance from London to Toronto is 80 miles. T.A.S. is 125 m.p.h.
Find: Co (M), and Co. (C), G/S, Drift, E.T.A.

(See page 374 for answers to all problems in this Section)