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FLIGHT INSTRUMENTS

CHAPTER 12 – TERRRESTRIAL MAGNETISM

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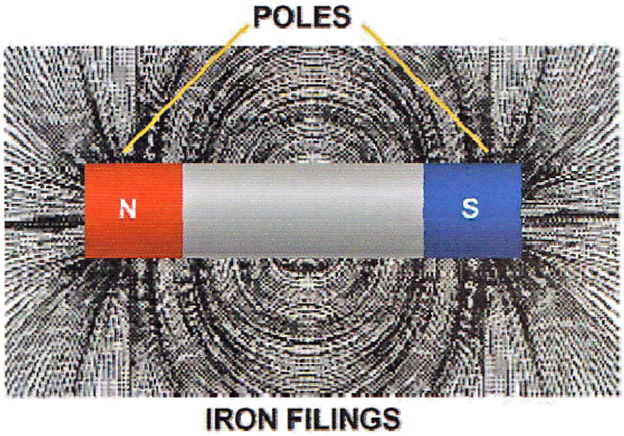
TERRESTRIAL MAGNETISM

INTRODUCTION

For thousands of years the oxide of iron called magnetite has been observed to attract small pieces of iron. This property is known as 'magnetism'. Another property for which magnetite was known was its North-seeking capability: If mounted on wood and floated in water it would swing round and align itself in a roughly North-South direction, so acting as a primitive compass. In more recent history it was found that some metallic elements and alloys (mainly 'ferrous' - iron and steel) could be given these properties, bars of such magnetised material are now known as 'magnets'.

MAGNETIC FIELD

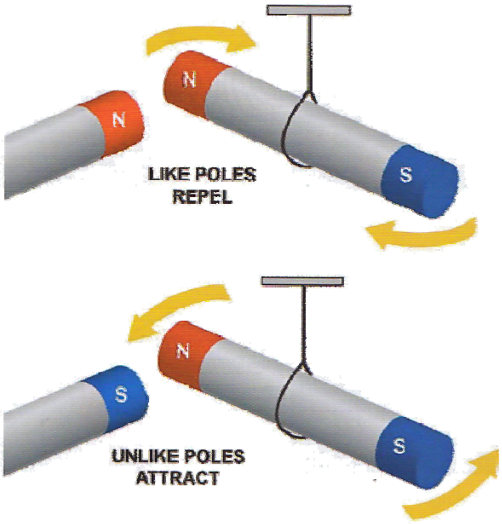
The field of a magnet is the space around it in which its magnetic influence is felt. This may be illustrated by placing a card over a bar magnet and scattering iron filings on it. When the card is shaken or tapped the filings will take up the field pattern as shown below.



Magnetic Field

POLES OF A MAGNET

From the diagram it can be seen that the 'lines of force' traced by the iron filings converge towards small areas near (but not exactly at) the ends of the magnet. These two areas are called the 'poles' of the magnet and are where the properties of magnetism are most strongly displayed. Magnets are made in various shapes but each magnet always has two poles. By convention these poles are described as RED and BLUE. If a magnet is cut into two pieces, each piece will have two poles, RED at one end and BLUE at the other. If two such magnets are placed close together, it is found that:



Like poles repel each other
RED repels RED

Unlike poles attract each other
RED attracts BLUE

INVERSE SQUARE LAW

When two bar magnets are brought close together, end to end, and then moved apart again, it is most noticeable that the forces of attraction or repulsion strengthen rapidly at short range. This is because magnetic forces behave according to an inverse square law, in other words, the force exerted between two magnetic poles is inversely proportional to the square of the distance between them, or:

$$F \propto \frac{1}{d^2}$$ F = force, and d = distance

The repulsive force between two like poles also depends on the strength of these poles. For instance, if the strength of one of the poles is doubled, then the repulsive force is doubled.

Therefore we can say that the force between two poles is directly proportional to the pole strengths m1 and m2 (and, as stated before, inversely proportional to the distance^2 between them) or :-

$$F \propto \frac{m_1 \times m_2}{d^2}$$ m = strength of each pole

MAGNETIC MOMENT OF A MAGNET

The term magnetic moment is used to express the strength of a magnet by indicating how strongly a magnet tries to align itself with a magnetic field.

The magnet system in a compass must be very sensitive for it to be responsive to the earth's weak field. This requirement is met by using a 'strong' magnet or magnets - in other words magnets with high magnetic moments. This is preferable to increasing the magnet's effective length which, though increasing the magnetic moment, would also increase the moment of inertia, (as mass is increased) making the system mechanically sluggish.

Ferromagnetic material can be broadly divided into two classes, hard iron and soft iron. The words hard and soft do not refer to the physical properties of the material but to their magnetic characteristics. A strong magnetising field is required to produce magnetic saturation in hard iron. Hard iron magnetism is said to be 'permanent', meaning that the material, typically steel containing cobalt or chromium, remains magnetised for an indefinite period after it has been removed from the magnetising field. Such a substance is suitable for permanent magnets.

Soft iron magnetism is called 'temporary' (or 'transient' or 'induced') the substance being easy to saturate magnetically with only a weak magnetising field but retaining little or no magnetism when the field is removed. Nearly pure iron behaves in this way.

Some materials exhibit magnetic characteristics which lie somewhere between those of hard iron and soft iron. The substance can be magnetised but this 'sub-permanent' magnetism is lost partly or wholly over a period of time.

In summary, hard iron requires greater energy to be magnetised but a permanent magnet is formed. Soft iron is easy to magnetise but quickly loses its magnetic properties. These facts are important as they will help us understand how the combined magnetism of aircraft components forms a magnetic field which interferes with the earth's magnetic field at the compass position. This causes the compass needle to be displaced from the magnetic meridian by an angle referred to as Deviation (see Chapter 13).

MAGNETISATION

Magnetism may be induced in an unmagnetised bar of iron by one of the following methods :-

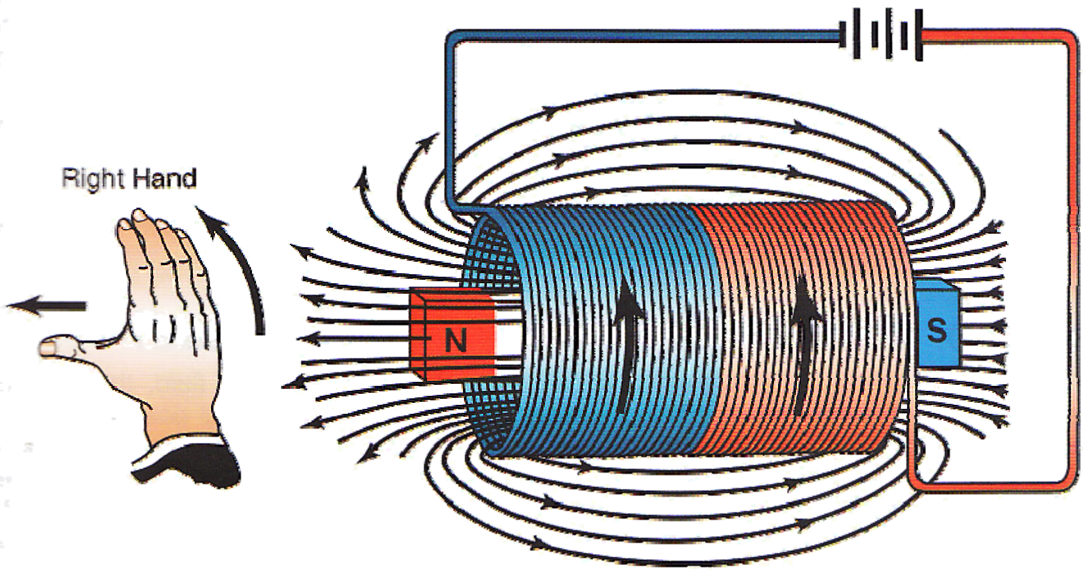
(a) By stroking an iron bar repeatedly in the same direction with one end of a magnet, a slow process which will result in magnetisation of the iron bar.

(b) By aligning the iron bar with the lines of force of a magnetic field and subjecting it to vibration or hammering. Such agitation during manufacture (in the earth's magnetic field) is the main cause of aircraft magnetism. An aircraft being assembled on a Northerly heading in the earth's field will acquire a permanent magnetic polarisation.

(c) In the case of soft iron simply by subjecting it to a magnetic field, magnetic polarisation is induced.

(d) By placing the specimen within a solenoid (a cylindrical coil of wire) carrying a Direct Current. This is the most satisfactory method as the current flowing in the coil produces a concentrated magnetic field along the axis of the coil so that a high degree of magnetism can be induced in the iron. (Note that the amount of magnetisation which can be induced is not unlimited because, at a certain level, the iron becomes magnetically 'saturated').

The diagram below shows the polarity of the magnetism induced in the bar inside the solenoid. (If the current flow were reversed, the induced magnetic polarity would be reversed.)



Magnetisation by Solenoid

DEMAGNETISATION

Three ways of removing most or all of the magnetism from a magnetised item are listed below.

(a) Shock. A magnetised bar of iron can be placed at right angles to the earth's magnetic field and hammered.

(b) Heat. If the specimen is heated to about 900°C, it loses its magnetism and this does not return as the specimen cools.

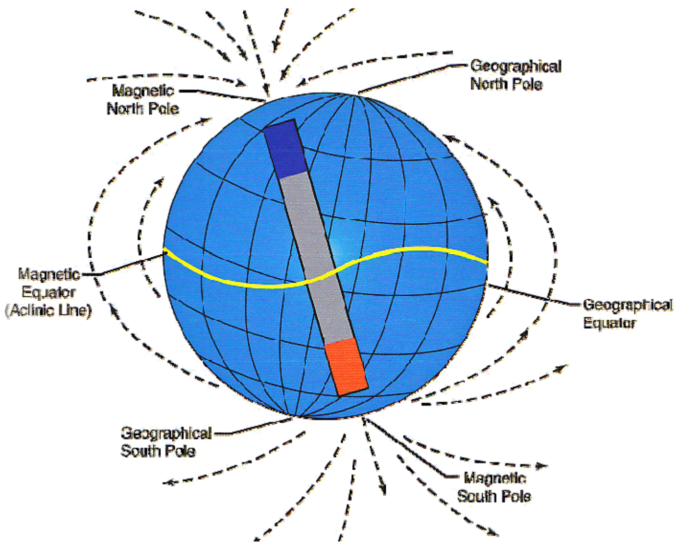
(c) The two somewhat drastic methods above could obviously not be used to demagnetise a delicate aircraft component. Instead, the component is placed inside a solenoid carrying alternating current, the amplitude of which is gradually reduced to zero. The strong alternating magnetic field produced by the alternating current keeps reversing the direction of magnetisation (that is the polarity of the magnetism) in the specimen. Not only is the polarity being reversed, but the intensity of magnetisation is being reduced as the current is reduced. Very quickly the specimen's magnetism is reduced to zero or very nearly zero.

MAGNETIC AND NON-MAGNETIC MATERIALS

The important magnetic materials are the 'ferrous' metals, iron and steel, steel being iron alloyed with substances such as carbon, cobalt, nickel, chromium and tungsten. These metals are called 'ferromagnetic' and in an aircraft they may be magnetised and produce deviation in the aircraft's compasses.
Many materials used in aircraft construction are non-magnetic and do not affect the compass. Examples of such non-ferrous substances are aluminium, duralumin, brass, copper, plastic and paint.

THE EARTH'S MAGNETIC FIELD

The Earth behaves as though a huge permanent magnet were situated near the centre producing a magnetic field over the surface. Of the many theories put forward to explain this magnetism, none has met with universal acceptance. The poles of this hypothetical earth-magnet do not lie on the earth's spin axis (this unfortunate lack of symmetry giving rise to magnetic variation). The Earth's magnetic North Pole lies at present beneath Northern Canada in the area around 70°N 95°W, the magnetic South Pole being below Antarctica at about 72°S 155°E. By convention, the North magnetic pole is BLUE and attracts the RED pole (north -seeking end) of the compass needle.

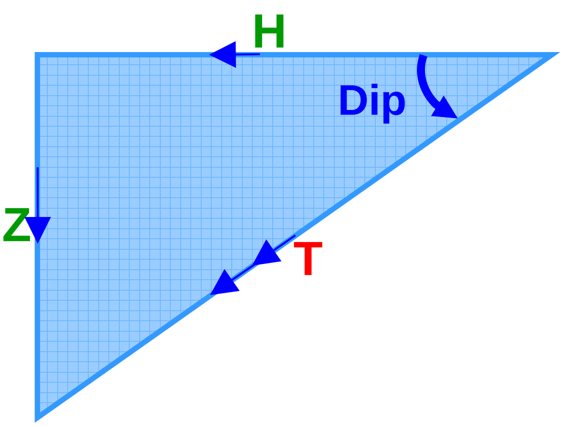


MAGNETIC VARIATION

The direction of the Earth's field at any given point can be indicated by a freely suspended magnet. Such a magnet will align itself roughly in a North-South direction. (Except in some polar regions where the direction of the Earth's magnetic pole can be up to 180° removed from that of the geographic pole.) The magnetic meridian is the direction of the horizontal component of the Earth's field at a point on the Earth's surface. The angle, measured in the horizontal plane, between the magnetic meridian at a point and the true meridian at the point is known as the magnetic variation. Variation is designated West or East depending on whether the magnetic meridian lies to the West or to the East of true North. Variation can have any value from zero to 180°, the latter occurring on the true meridian linking North geographical with North magnetic poles. The application of variation to headings and bearings is detailed in the Navigation lectures.

FIELD STRENGTH

The total force T exerted at a point by the Earth's field acts in the direction taken up by a freely-suspended magnet influenced only by the Earth's field. (The total force, angle of dip, and magnetic variation at a point are sometimes known as the 'magnetic elements' for that place.) It is convenient to resolve this total force T into its horizontal and vertical components H and Z respectively. The diagram below demonstrates this resolution and should help in checking the relevant trigonometric relationships listed alongside.



$$\frac{Z}{H} = tanDip$$

$$Z = T\ sin\ Dip$$

$$H = T\ cos\ Dip$$

DIRECTIVE FORCE

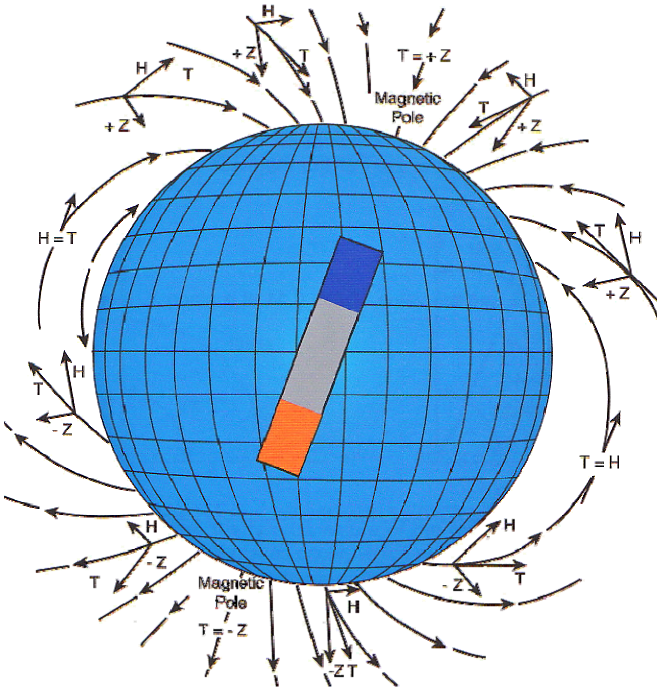
The horizontal component H of the Earth's field is known as the directive force because it is the component which aligns the magnetic compass needle with the magnetic meridian, so providing a directional reference. When either of the Earth's magnetic poles is approached, this component approaches zero strength (while the value of Z approaches that of T). Over the pole, with dip 90° and zero directive force H, the magnetic sensor (compass) becomes useless. In the region of the magnetic equator, the strength of the directive force H approaches the value of T (directive force is maximum), while Z approaches zero as does the angle of dip. The directive force decreases as the angle of dip increases and vice versa, consequently near the equator and to about 70° North or South a compass system works fairly well.

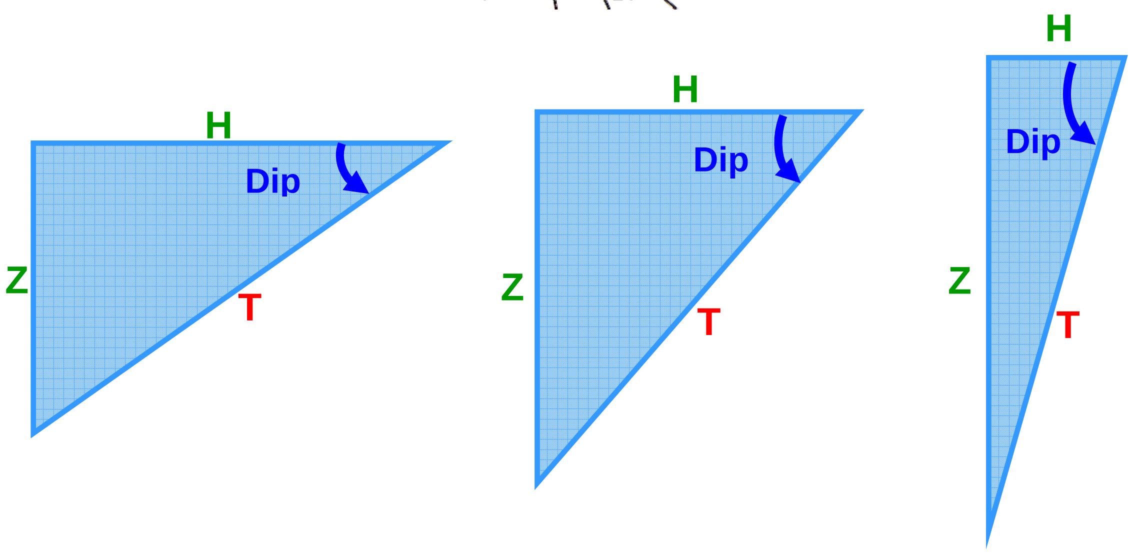
MAGNETIC DIP

Except near the 'magnetic equator' where the lines of force are parallel to the surface, one end of the freely-suspended magnet will dip below the horizontal, pointing to the nearer pole. To the North of the magnetic equator, the magnet's North seeking pole will be lower, whereas to the South the magnet’s south seeking pole will be lower. The angle, measured in the vertical plane, between the axis of the magnet and the horizontal is called the 'angle of dip'.

The 'Magnetic Equator' is represented by a line on a chart where the magnetic dip is zero. The magnetic equator is within 10° of latitude of the geographical equator.

If the freely suspended magnet is moved either North or South of the magnetic equator the dip gradually increases, reaching about 66° in the United Kingdom (latitude 50°00N) and about 52° at Adelaide in South Australia (latitude 35°00S). Over the Earth's magnetic poles, the dip is 90° and the magnet is then vertical.





Lower Latitude **Medium Latitude** **High Latitude**

MAGNETIC MAPS

The values of the 'magnetic elements' vary over the surface of the earth. These values can be measured and the information obtained can be displayed as lines plotted on 'magnetic maps'.

ISOGONALS

These are lines joining places having the same magnetic variation. They are printed on most navigational charts. It is important to remember that they do not represent the direction of the magnetic meridian - a mistake sometimes made, especially in countries like the UK, where the isogonals lie roughly North / South. It should be noted that the isogonals show the general pattern of magnetic variation over the surface of the Earth, but local anomalies exist. It is quite common for magnetic materials near the surface to cause the actual magnetic variation from a small area to be several degrees different from that shown by the charted isogonal. Magnetic deposits in an area of about one square mile in Alaska are reputed to cause compass errors of up to 60°, the effect reducing rapidly with increased altitude.

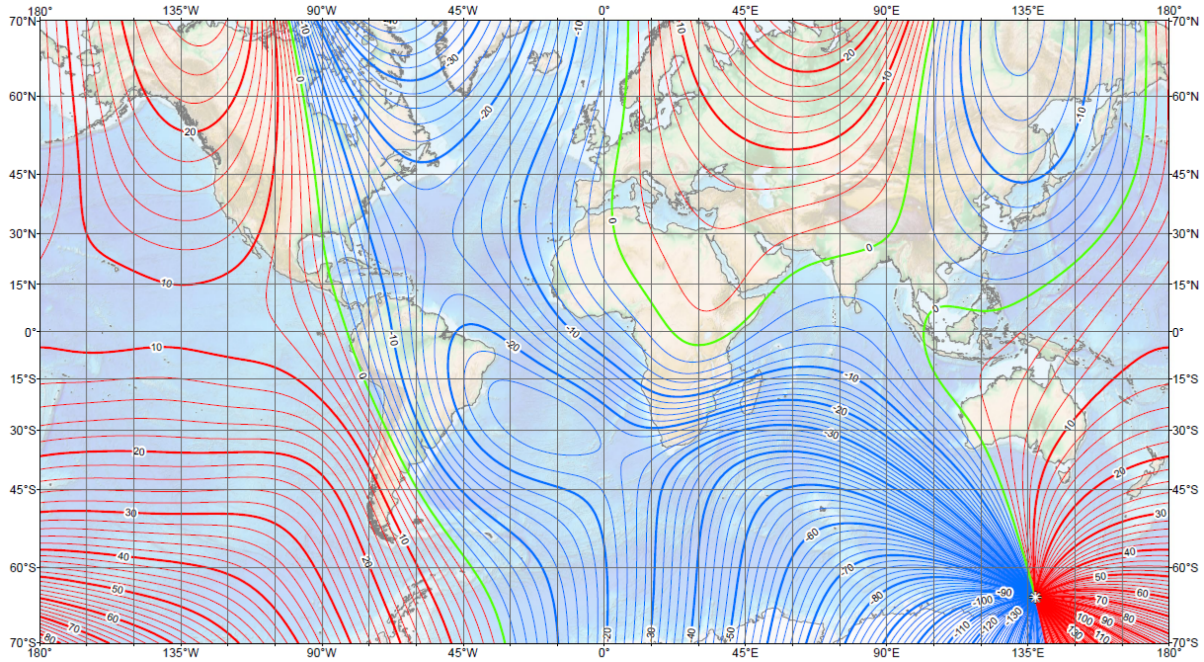
AGONIC LINES

These are lines joining places where the variation is zero. There are two agonic lines, one runs roughly North / South down the American continent. The other curves down through Europe, the Near East and Aden, then northwards through Pakistan, Russia, round Siberia and Japan and back south again through Malaysia, Singapore , Indonesia and Western Australia.

ISOCLINALS

These are lines joining places having the same magnetic dip and in general they follow the geographic parallels of latitude. The isoclinal of zero dip is the magnetic equator and is sometimes called an **aclinic line**.

US/UK World Magnetic Model -- Epoch 2010.0
Main Field Declination (D)



ISODYNES

These are lines joining places where the directive force (H) has the same value.

REGULAR CHANGES IN EARTH MAGNETISM

The Earth's field lacks symmetry and is also subject to several known periodic changes. Of these, the secular changes are the most significant and are produced by the slow movement of the magnetic poles about the geographic poles, the period of this cycle is apparently about 960 years. The North magnetic pole is moving slowly westward, this movement mainly affecting magnetic variation.

In Australia, this change means that the Agonic Line through Western Australia is slowly moving West. The current variation in Perth is 3W, this will reduce to zero over the next 20-30 years. The variation in Adelaide (7E) and Sydney (12E) will increase at about at the same rate. The annual rate of change of variation is shown on navigation charts so that the variation printed against the isogonals can be readily up-dated.

Other regular changes occur diurnally, annually, and over an eleven year period, this latter cycle apparently being related to the eleven year cycle of sunspot activity. These changes, unlike the secular type mentioned earlier, are not of sufficient magnitude to affect normal navigation.

UNPREDICTABLE CHANGES IN EARTH MAGNETISM

Magnetic 'storms' of varying intensity and lasting for as long as three days, occur at irregular intervals. They are always accompanied by auroral displays in the upper atmosphere of polar regions. The propagation of radio waves is also affected. All these phenomena appear to be produced by radiation or particle emissions from unusually large sunspots.

The main effect of these magnetic storms is a temporary but significant change in magnetic variation. The alteration is unlikely to exceed 2° in Australia, even in the most intense magnetic storms, but in the Antarctic and Arctic the change may exceed 5° and last for as long as an hour. The value of the directive force H can also change and in high latitudes may fall below the minimum required for efficient compass operation.