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FLIGHT INSTRUMENTS

CHAPTER 14 – THE DIRECT INDICATING COMPASS

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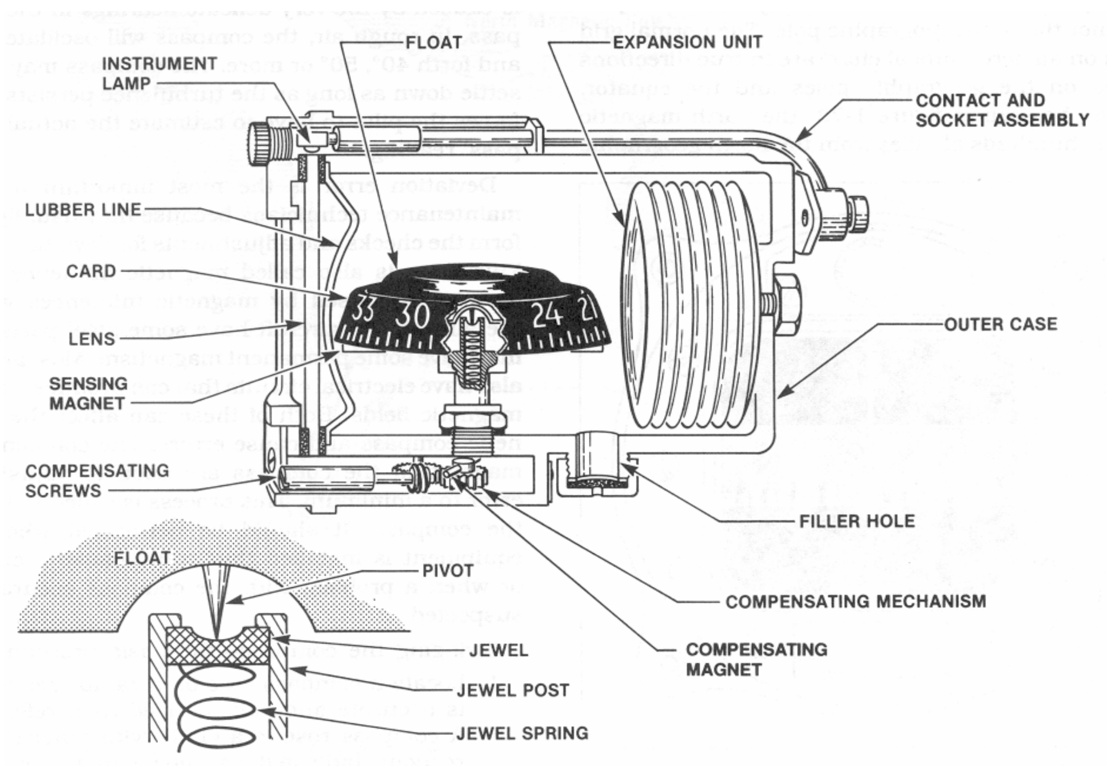
THE DIRECT INDICATING COMPASS

The Direct Indicating Compass (also known as a Stand-by Compass) is a simple independent compass which is powered by only the Earth's magnetic field. It is normally centrally mounted on top of the instrument panel, away from most aircraft magnetic (and electric) influences, where it can be read by both pilots. Some parallex error is evident.

The direct indicating compass is a north seeking device, i.e. It has the ability to find its datum (magnetic north). However, it is an unstable reference and is difficult to use accurately. A good understanding of this compass is necessary because if the aircraft DG failed, the pilot must be able to recover the aircraft to a suitable airfield.



CONSTRUCTION

The principle of the Direct Indicating Compass is similar to any other magnetic compass. It is important to remember that the compass needle, or in this case, the 'suspended sensing system' is the reference. A vertical compass card is mounted on the sensing system which ideally stays stationary (seeks magnetic north). It is the instrument casing on which the lubber line is marked, which rotates about the magnet system and the vertical compass card.

COMPASS REQUIREMENTS

The direct reading compass comprises of a pivoted magnet able to align itself and remain aligned with the horizontal component of the Earth's field. For the compass to succeed, certain requirements must be satisfied. The most important of these are that the magnet system must be:

(a) Horizontal
(b) Sensitive, and
(c) Aperiodic.

Horizontality - High Pivot & Low C of G

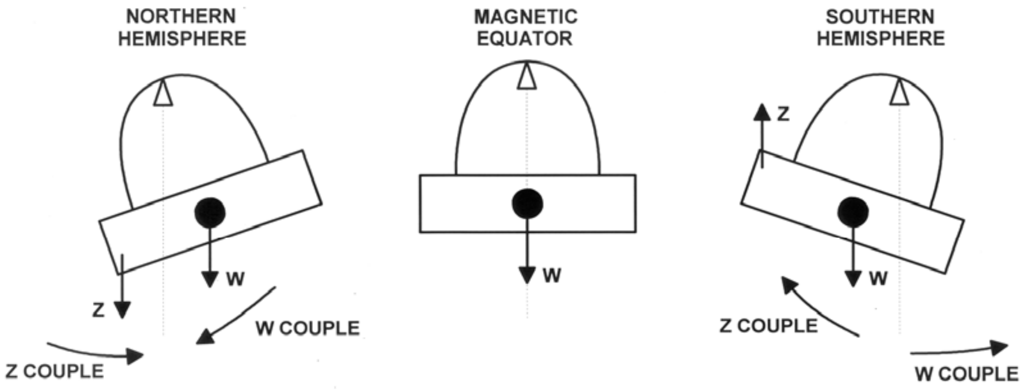
Sensitivity - Multiple Magnets (field strength) &
Liquid immersion (reduces friction)

Aperiodic - Short magnets (assembled near centre)
Liquid interacts with assembly providing damping.

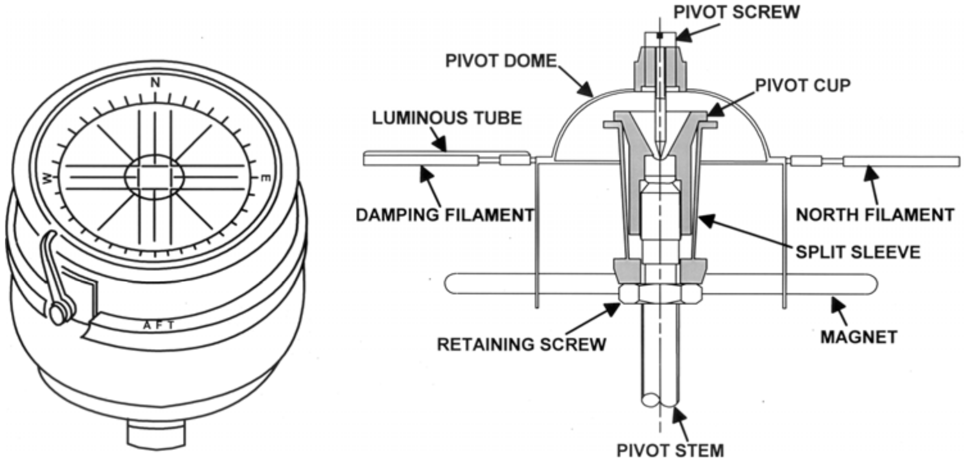
HORIZONTALITY

In order to measure direction in the horizontal, the magnets (normally two or four) must lie as nearly as possible in the horizontal plane during normal straight and level flight. A freely suspended magnet assembly would align itself with the earth's total field so that the magnets would only be horizontal at the magnetic equator. To achieve horizontally, therefore, the magnet assembly is 'pendulously suspended', the centre of gravity of this assembly being lower than its supporting pivot.

In this way, the tilting effect caused by the vertical component of the Earth's field is opposed by the weight of the magnet assembly, this equilibrium being achieved at the cost of only a slight residual tilt of the magnet's South-seeking end points down by about 2° at mid latitudes in the Southern hemisphere, North-seeking end points down in the Southern hemisphere.



EFFECT OF PENDULOUS SUSPENSION



THE P.11 COMPASS

THE MAGNET SYSTEM

COMPASS CONSTRUCTION

SENSITIVITY

The compass sensing system responds to the horizontal component of the Earth's field in all areas except near the magnetic poles where the horizontal component is inadequate. The compass sensitivity therefore depends on the strength of the external field and on the magnetic moment of the magnet. The magnetic moment also depends on the magnet's length and the pole strength. The pole strength is increased by using two or four or six short magnets made of an alloy which will accept and retain the high degree of magnetism required. Friction is reduced by using a jewelled pivot and immersing the assembly in a liquid, a clear light oil.

APERIODICITY

The magnetic assembly is required to be aperiodic (or 'dead-beat') which means that it should settle down quickly again on a steady North indication after being displaced from the meridian by turbulence or manoeuvres. Any tendency to oscillate must be quickly 'damped out'. The desired aperiodicity is achieved as follows :-

- Several short magnets are used instead of one longer one. This keeps the mass of the assembly near the centre, so reducing the moment of inertia and consequently making any oscillations easier to damp out. The sensing assembly is constructed of a light alloy - this also reduces the effects of inertia.

- The whole assembly is immersed in a liquid which has a natural damping effect. Additional damping wires are fitted to the assembly of some direct indicating compasses to interact with the liquid.

The use of this liquid causes other problems. Errors occur in sustained turns as a result of 'liquid swirl'. During a turn, the liquid in contact with the inside of the bowl tends to be dragged round with the bowl, so producing in the liquid small eddies which drift inwards from the circumference and deflect the magnet assembly in the direction of turn. This effect is due to viscosity, so the liquid chosen should have a low viscosity to minimise the liquid swirl error.

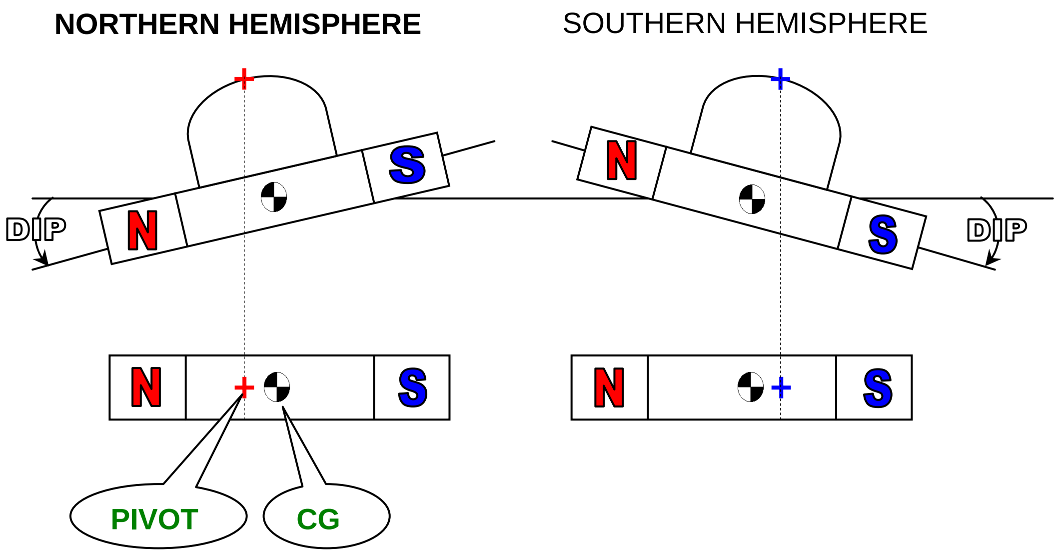
The main properties required of a compass liquid are listed below :-

Low coefficient of expansion.
Low viscosity.
Transparency.
Low freezing point.
High boiling point.
Non-corrosiveness.
Good lubrication

TURNING AND ACCELERATION ERRORS

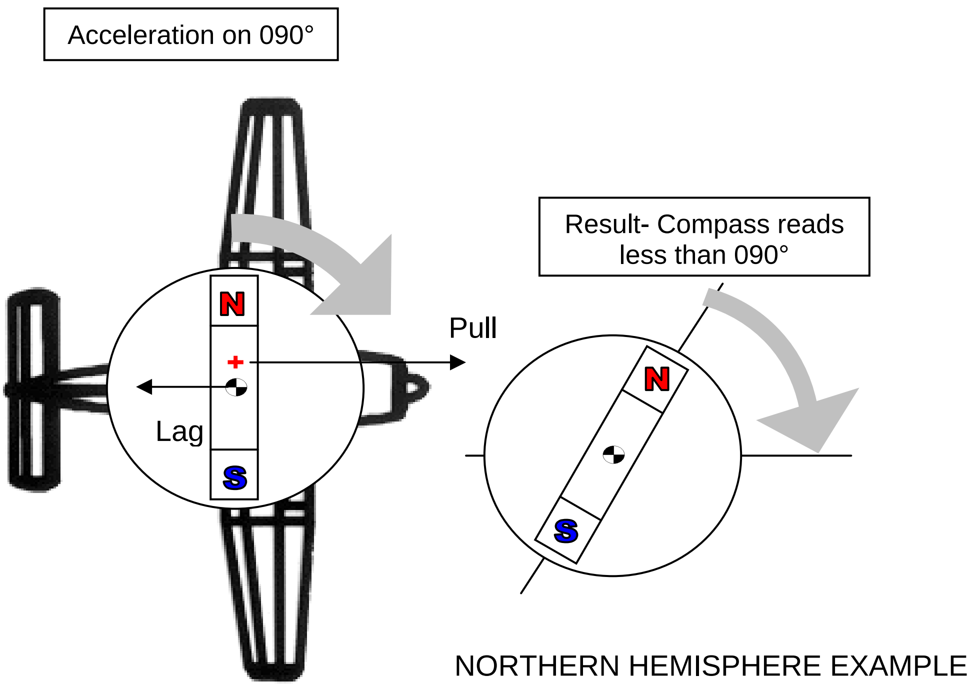
The direct reading compass has been constructed with a pendulous suspension system (high pivot point) to ensure horizontality where possible. However, as the latitude increases, the 'dip' has an increasing effect and this causes a misalignment between the pivot point and the centre of gravity of the compass.

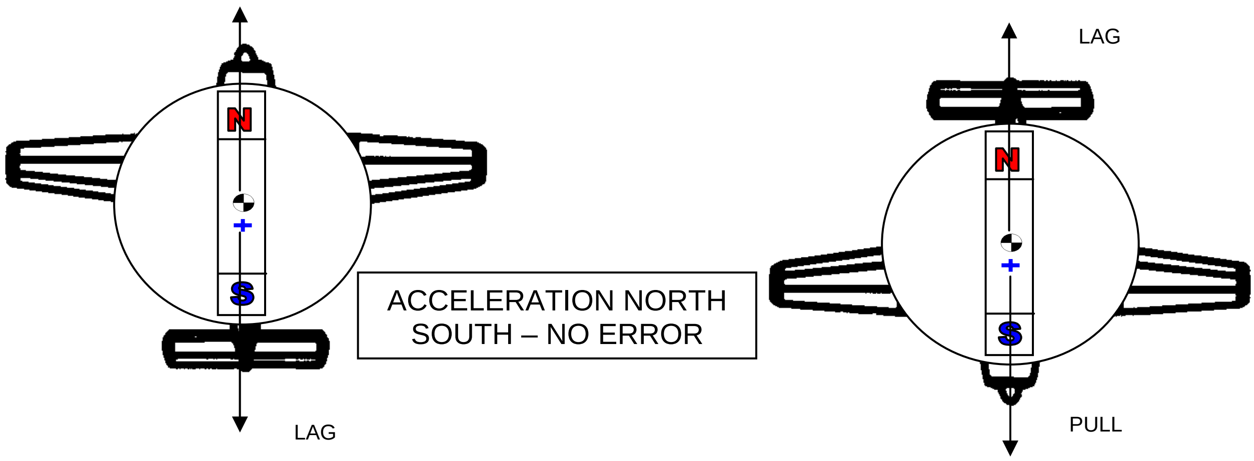
When the compass is viewed from above the pivot point and centre of gravity are displaced. Note that irrespective of hemisphere, the centre of gravity is always displaced to the equatorial side of the pivot.



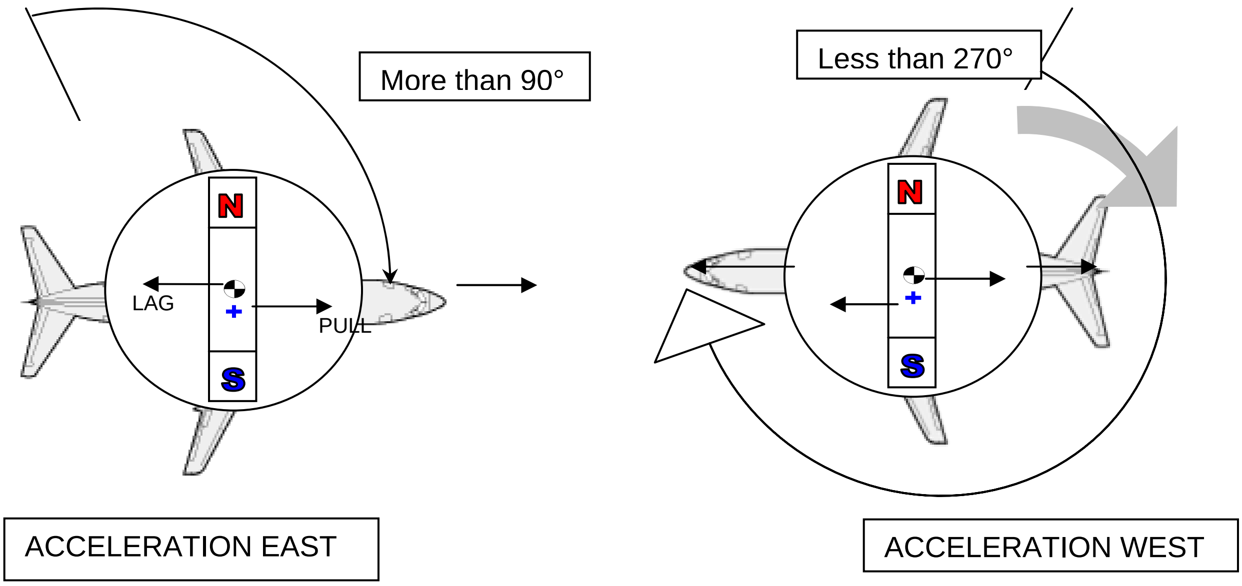
ACCELERATION ERRORS

When accelerating EAST or WEST, the displacement of the pivot and the CG causes there to be a couple between the pull of the acceleration acting through the pivot and the lag (inertia) acting through the C of G.





SOUTHERN HEMISPHERE EXAMPLE



RESULT - APPARENT TURN TO SOUTH IN SOUTHERN HEMISPHERE
APPARENT TURN TO NORTH IN NORTHERN HEMISPHERE

NOTE :

1. There is no acceleration error when heading NORTH or SOUTH as the pivot and the C of G are in line.
2. The size of the acceleration error depends on:
   - (a) the aircraft heading,
   - (b) the magnitude of the acceleration and
   - (c) the magnetic latitude.

3. The errors are maximum near the magnetic poles, decreasing to zero at the magnetic equator.
4. The direction of the errors is opposite in Northern and Southern Hemisphere.
5. Deceleration has the opposite effect to acceleration. For example, deceleration in the Northern hemisphere causes an apparent turn to South.

TURNING ERRORS

The direct indicating compass relies upon the assumption that the magnet assembly always remains aligned with the magnetic meridian. Hence, contrary to appearances from the cockpit, the compass card should not move in azimuth. Instead, changes of heading should be registered solely by the rotation of the aircraft (with the compass lubber line attached) about the magnet assembly.

We have seen how acceleration errors cause actual rotation of the compass card resulting in erroneous heading indications. Turning errors have the same effect, although the causes are more complex and the errors are usually more serious.

Like acceleration error, the primary cause of turning error is the displacement of the centre of mass of the card assembly away from the pivot. As the aircraft turns, the centripetal force that pulls the card assembly around the curved path, acts through the pivot. The reaction to this turning force - the centrifugal force (or inertia) of the card- acts through its centre of mass and since this is not aligned with the pivot, a couple is established that tends to rotate the card about the pivot.

In addition, in level flight the vertical component of the earth's field tends only to tilt the card slightly (blue pole down in the southern hemisphere), as previously described. However, in a balanced turn the compass card moves from the horizontal through an angle equal to the aircraft's angle of bank, allowing the magnetic force that pulls the blue pole downwards to form a couple about the pivot. This causes further rotation of the card away from the magnetic meridian.

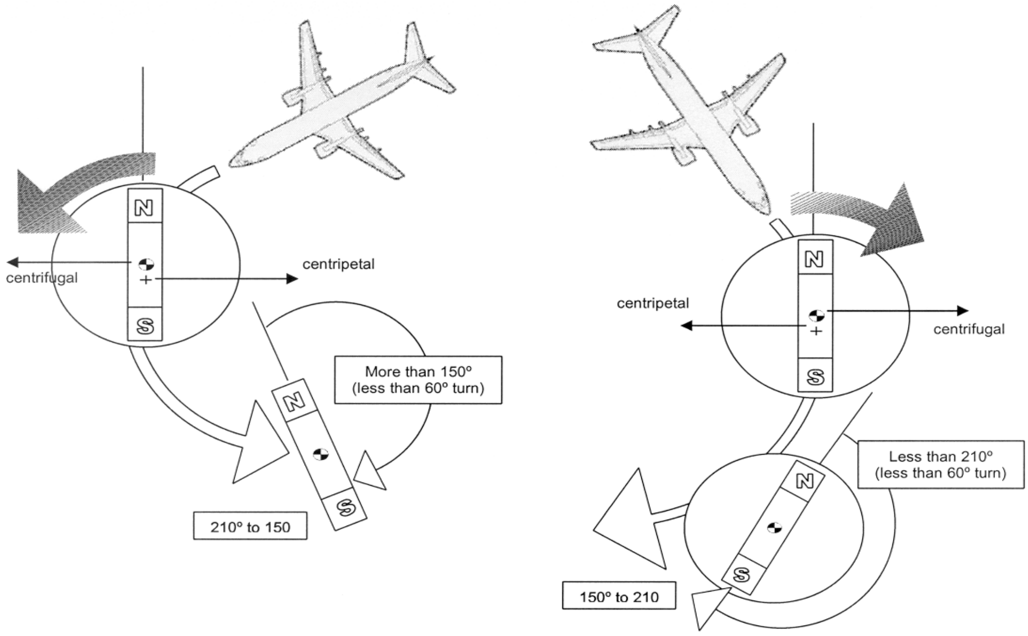
Finally, in a prolonged turn, the liquid in the compass bowl tends to turn in the same direction as the turn, and to carry the magnet assembly with it. This is known as "liquid swirl".

The effects of the various error sources may be additive, or may tend to cancel each other, depending of the particular circumstances. Due to the number of variables involved, e.g:

instantaneous heading,
rate of turn and its duration,
bank angle,
hemisphere and local angle of dip, and
characteristics of the particular compass,

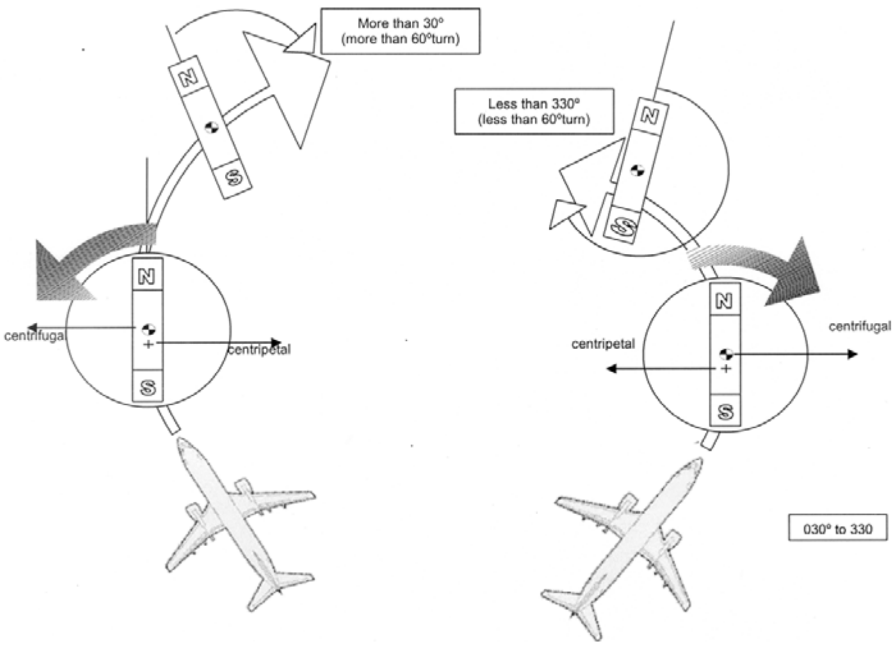
It is difficult to estimate the precise magnitude of turning errors. However, when considering relatively gentle manoeuvres in light aircraft at low to mid latitudes, the centripetal effects tend to dominate. These are considered in more detail in the following pages.

Consider a turn through South in the Southern Hemisphere.



When turning through South the card tends to turn with the aircraft causing an under-read. i.e. The compass is slow on South.

Consider turns through NORTH in the Southern Hemisphere.



When turning through North the couple turns the card opposite to the turn. The turn appears faster than it really is and the card tends to lead the aircraft causing an over-read.

During a turn through North or South the rotational couple is maximised. In the Northern Hemisphere the card moves with a turn through north. The card moves opposite to the turn through south.

Consequently - In the Northern Hemisphere **U**ndershoot the indication of **N**orthern turns and **O**vershoot the indication on turns through **S**outh.

UNOS (Undershoot North Overshoot South).

Application : When applying a correction for turn error, consideration must be given to the rate of turn and the size of the heading change through north or south. The correction normally applied is 15° to 30°.

A good compass turn is difficult to achieve. If the turn indicator is available, a 'timed turn' at rate one (3° per second) is more efficient.

Similar to acceleration error, the Magntiude of Turn Error depends on :-

a. heading change through which turn is made.
b. rate of turn.
c. magnetic latitude.

Turning errors are usually more significant than acceleration errors for the following reasons :

(a) They are inherently of greater magnitude because greater displacement of the magnet assembly is likely in turns.

(b) Turns occur more often and are likely to be more prolonged than linear accelerations.

The basic theory of turning errors is much the same as that for acceleration errors. It helps to remember that the magnet system is a pendulum. In a turn, this pendulum swings outwards to take up a position determined by the speed of the aircraft and its rate of turn. It is no longer in the true vertical but is aligned more or less with the aircraft vertical (precisely aligned in a balanced turn, the magnet system taking up the same angle of bank as the aircraft). As soon as the rotational axis of the magnet assembly swings out of the vertical plane through the pivot, there is a turning couple about this axis and the assembly rotates causing a turning error.

SUMMARY

Turn errors can be fairly complex as the rate of turn and the latitude (dip) are significant factors. In the Southern Hemisphere, when turning through the North, the compass appears over sensitive (lively). The pilot needs to overshoot the turn and should roll out 15° - 30° after the desired heading is passed. The opposite is true for turns through South. The compass appears sluggish and the pilot needs to stop the turn (wings level) about 15° before reading the desired heading. The only error occurring at the magnetic equator is due to liquid swirl and this is usually very small.

Note: in the Southern Hemisphere - **O**vershoot **N**orth, **U**ndershoot **S**outh.

CONCLUSION

These compass errors provided the incentive for the development of the Directional Gyroscope, an instrument which gives stable indications during turns, turbulence and linear accelerations. The DG, having no magnetic sensing capability and being subject to gyroscopic drift, is always associated with the magnetic compass with which it must be regularly synchronised. The two instruments are therefore complementary, the North-sensing compass being used to reference the stable gyro indications. The Remote Indicating Compass is a combination of these two instruments, providing automatic synchronisation and the advantages of both.

CAUTIONS

Keep magnetic material well clear of the compass to prevent the risk of interference with the magnetic sensing assembly.

SERVICEABILITY

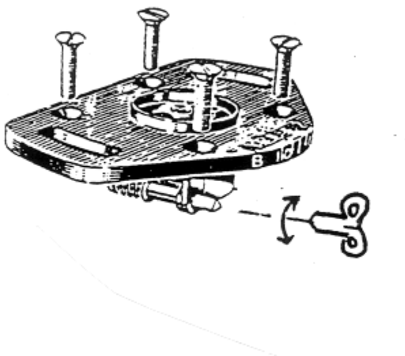
- Glass clean.
- No discolouration of the fluid.
- No bubbles visible.
- Indicators within 5° of a known heading (runway).

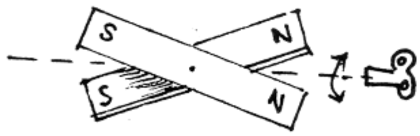
SUMMARY OF TURNING AND ACCELERATION ERRORS

	Northern Hemisphere		Southern Hemisphere
(1)	Acceleration on westerly headings and turns to the West cause the compass system to rotate anti - clockwise.	(1)	Acceleration on westerly headings and turns to the West cause the compass system to rotate clockwise.
(2)	Acceleration on easterly headings and turns to the East cause rotation clockwise.	(2)	Acceleration on easterly headings and turns to the East cause rotation anti - clockwise.
(3)	Acceleration causes an apparent turn to the North.	(3)	Acceleration causes an apparent turn to the South.
(4)	Turns through North causes the compass to under - indicate the turn.	(4)	Turns through North causes the compass to over - indicate the turn.
(5)	Turns through South cause the compass to over-indicate the turn.	(5)	Turns through South cause the compass to under-indicate the turn.
(6)	Liquid swirl increases turning errors around North.	(6)	Liquid swirl increases turning errors around South.

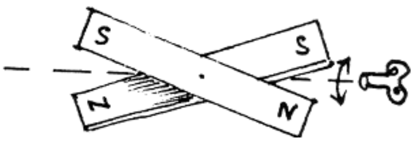
COMPENSATION FOR DEVIATION

As the result of the compass swinging procedure (described in the previous chapter), the deviation affecting the compass is analysed into its separate causes. Coefficients B and C represent the maximum values of deviation due to aircraft magnetism on the fore/aft and athwartships axes of the aircraft. These coefficients are corrected by introducing at the compass position magnetism in the opposite direction. For example, Coeff. +B resulting fom magnetism towards the nose of the aircraft, is corrected by introducing compensating magnetism towards the tail. The compensating magnetism is varied by means of a' micro-adjuster', an example of which is illustrated below. In current models of direct reading compasses, the micro-adjuster is an integral part of the compass (see diagram on page1 of this chapter).





ALMOST
NO
EFFECT



ALMOST
MAXIMUM
EFFECT

The small magnets are moved to vary their field strength by means of key put into key-ways marked B and C. By turning the key, the angle between the magnets can be varied so that their combined field strength varies between zero and maximum.

Coefficient A is corrected by rotating the whole compass to realign the lubber line with the aircraft's fore/aft axis.

THE DEVIATION CARD

On completion of the compass swing, a deviation card is drawn up to present to the pilot a record of the residual deviation. Part of such a card is illustrated below. Further information about the application of deviation will be provided in Navigation classes.

DEVIATION CARD

FOR (HDG°M)	N	030	060	E	120	150	S	210	240	W	300	330
STEER (HDG°C)	002	031	060	089	118	148	179	210	241	272	303	332

7/9/01