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DOCUMENT TITLE
# FLIGHT INSTRUMENTS

# CHAPTER 13 – AIRCRAFT MAGNETISM

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# AIRCRAFT MAGNETISM

## THE CAUSES OF AIRCRAFT MAGNETISM

Aircraft permanent 'hard iron' magnetism and temporary 'soft iron' magnetism distort the field of the earth at the compass position giving rise to deviation. Although an aircraft is constructed mainly of non-magnetic material, it is fitted with engines, instruments and electrical circuits etc., any or all of which may produce magnetic fields. The resultant of all these fields comprises the aircraft's magnetic field, due in part to hard iron magnetism and in part to magnetism induced in soft iron. Significant effort is required to analyse and compensate the aircraft compass, this occurs during a compass swing. The study of aircraft magnetism considers each individual component of aircraft HARD IRON and SOFT IRON magnetism.

For the purposes of analysis, HARD IRON(HI) magnetism is considered permanent and any magnetism, such as that produced by electrical circuits, which is not induced by the earth's magnetic field is classified as HARD IRON. SOFT IRON (SI) magnetism is by definition temporary magnetism induced by the earth's magnetic field. HORIZONTAL SOFT IRON (HSI) is induced by the horizontal (H) component of the earth's magnetic field. VERTICAL SOFT IRON (VSI) is induced by the vertical (Z) component of the earth's field. Deviation caused by HSI magnetism is not corrected in the normal compass swing procedure.

## DEVIATION

Deviation can be defined as the angular difference between a heading measured from the magnetic meridian and the same heading measured by the compass. Deviation is caused by mechanical faults within the compass system as well as by the aircraft's magnetic field.

Deviation is named Easterly or Westerly depending on whether the North-seeking end of the compass needle lies to the East or West of the magnetic meridian. Deviation East may be given a positive (+) sign and deviation West a negative (-) sign, indicating the correction to compass heading to obtain magnetic heading.

## THE COMPASS SWING

The term "compass swing" is used to describe the procedure for the calibration of the compass. The procedure is designed to:

(i) determine aircraft deviation on a series of headings.
(ii) correct for deviation (compensation) and
(iii) record residual deviation.

The basic method of determining deviation is to compare the aircraft's heading as defined by the aircraft compass with its magnetic heading as defined by a high quality datum compass placed well clear of the aircraft.

The compensation procedure requires the aircraft to be positioned in an area that is free of local magnetic interference, away from buildings, machinery, powerlines, etc. The aircraft systems should be as near as practical to a normal operating state (engine running above alternator threshold, radio, navaids on).

The procedure for analysing the deviation into separate causes for subsequent compensation is described later in this chapter.

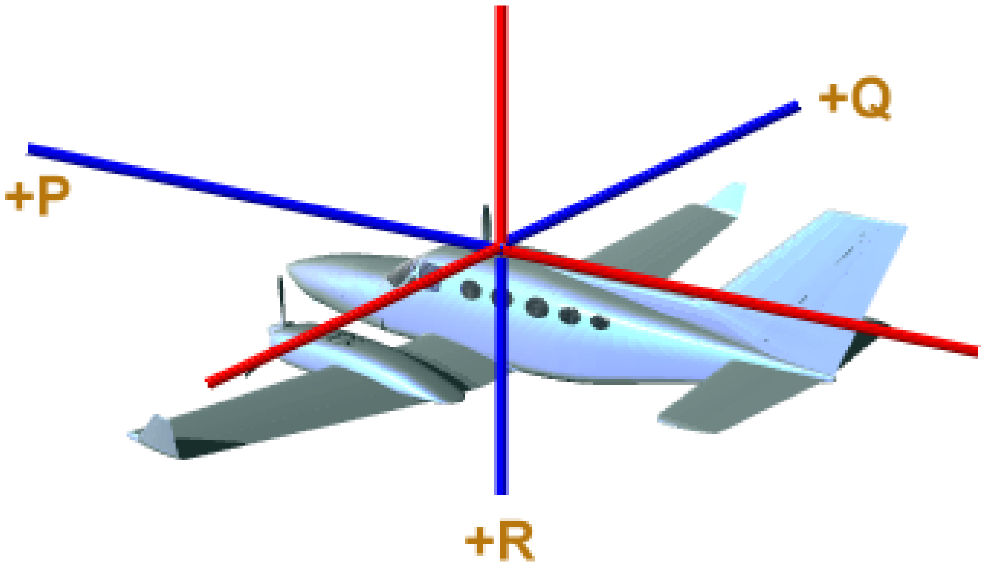
## OCCASIONS FOR COMPASS SWINGS

As the residual aircraft magnetism can change, it is common for aircraft to be swung at least once a year. Some occasions when a compass swing is considered necessary are as follows:-

a. Replacement of the compass or compass system component.
b. When the accuracy of compass is in doubt.
c. As required by maintenance schedules.
d. Aircraft modification, engine change, electrical re-wiring, significant avionics changes.
e. Lightning strike.
f. A large change of magnetic latitude.
g. After aircraft has been in long term storage.
h. When carrying ferro magnetic loads

## ANALYSIS OF DEVIATION

All the magnetism in the aircraft contributes to a total magnetic field and the associated lines of magnetic force may arrive at the compass position in any direction.




It is useful for the purpose of compensation to consider the deviation effect of the vector of magnetic force at the compass position in terms of its fore/aft and athwartships (lateral) components.

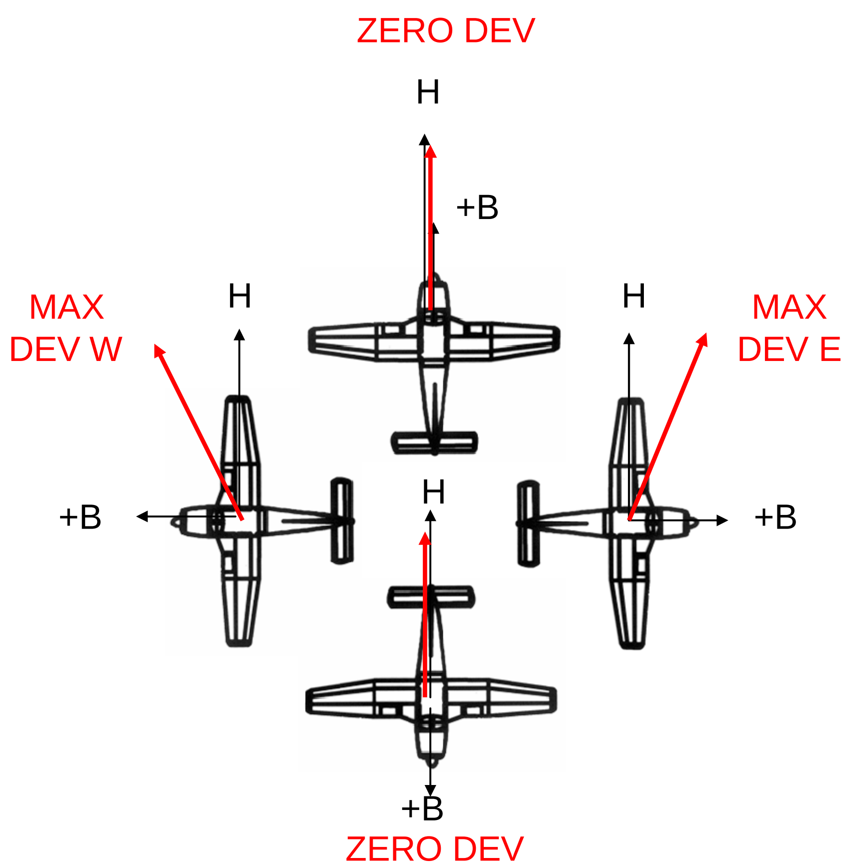
The maximum value of deviation due to the fore/aft component is termed
COEFFICIENT B and for the athwartships component, it is termed COEFFICIENT C. Mechanical faults (and Horizontal Soft Iron) cause COEFFICIENT A. Having obtained values for A, B and C, separate compensations can be made for each so as to reduce deviation in the compass.

## CHANGE OF DEVIATION WITH CHANGE OF HEADING

### FORE / AFT MAGNETISM

Magnetic force pulling towards the nose of the aircraft will cause a positive Coefficient B, towards the tail causes a negative Coefficient. B.

The following diagram illustrates how magnetism resulting in Coefficient +B causes deviation that has maximum values on the headings of East and West and zero values on the headings of North and South.

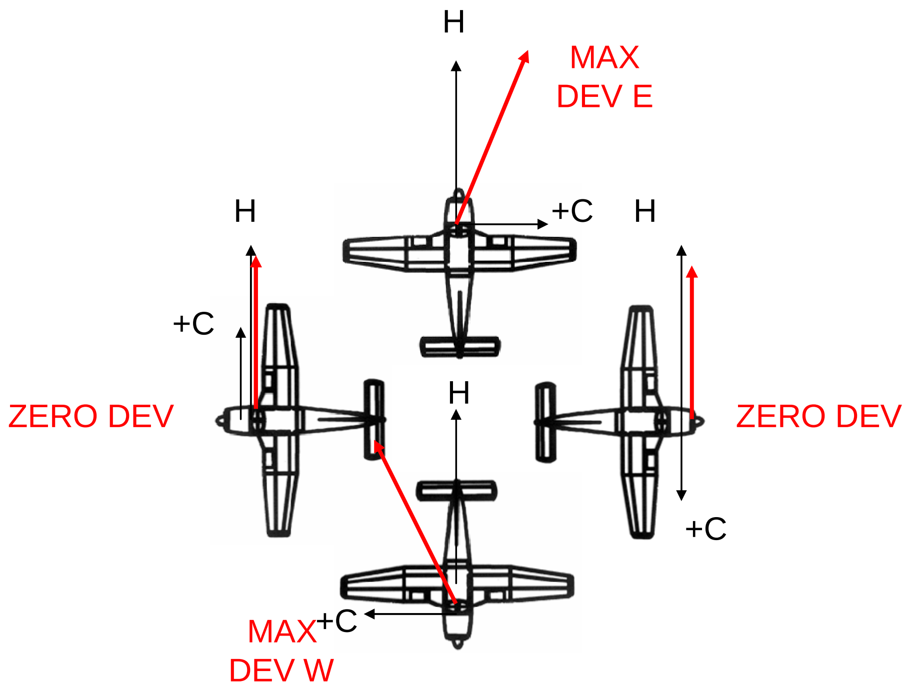



It can be seen that deviation due to fore / aft magnetism on compass heading θ will be B Sine θ.

## ATHWARTSHIPS MAGNETISM

Magnetic force pulling towards the right wing will cause a positive Coefficient C, towards the left wing causes a negative Coefficient C.

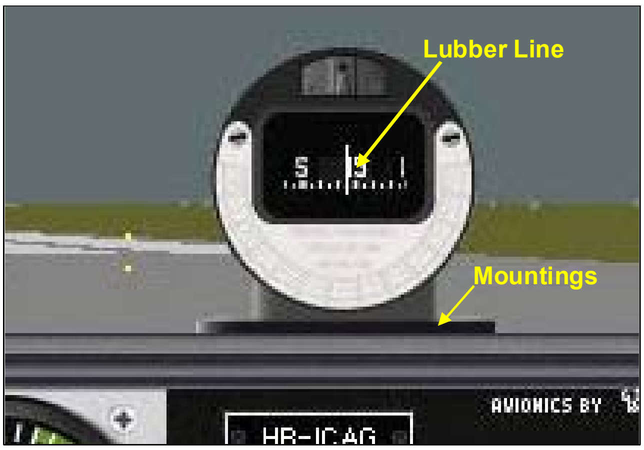
The following diagram illustrates how magnetism resulting in Coefficient +C causes deviation that has maximum values on the headings of North and South and zero values on the headings of East and West.




It can be seen that deviation due to athwartships magnetism on heading θ will be C Cosine θ.

### Mechanical faults

Mechanical faults contributing to Coefficient A include misalignment of the compass with the fore/aft axis of the aircraft, transmission faults between components of a gyro-magnetic compass and faults within the heading indicator. Some of these faults may produce random errors but generally their characteristic will be that the error is the same on all headings.




The following diagram illustrates error due to compass misalignment. It can be seen that the deviation, given by the value Coefficient A, is the same on all headings.

## GENERAL FORMULA FOR DEVIATION

The previous statements about Coefficients A, B and C can be combined into a general formula for deviation:

Deviation on heading $\theta$ = A + B Sin $\theta$ + C Cos $\theta$.

## FINDING THE VALUES OF THE COEFFICIENTS

From the general formula, the causes of deviation on the cardinal headings can be seen to be as follows:

| DEV ON HDG | +A | +B SIN$\theta$ | +C COS$\theta$ |
|---|---|---|---|
| NORTH | +A | ZERO | +C |
| EAST | +A | +B | ZERO |
| SOUTH | +A | ZERO | -C |
| WEST | +A | -B | ZERO |

Note:

- Coefficient A is the same on all headings
- The + and - signs for Coefficient B and C indicate a change of sign on reciprocal headings. For example Coefficient +B caused by a force towards the nose of the aircraft would cause + deviation on East but - deviation on West.

## COEFFICIENT A

Coefficient A is found by adding all the deviations and then dividing by the number of readings. The positive and negative values of B and C cancel out and so are eliminated from the total.

$$\text{Coefficient A} = \frac{\text{sum of deviation on 'n' headings}}{n}$$

For this formula to be used, deviations must be measured evenly through 360°.

## COEFFICIENT B

Coefficient B is found by subtracting the deviation found on West from the deviation on East with the result then divided by two. In this way, A which is the same on all headings is eliminated.

$$\text{Coefficient B} = \frac{\text{Dev on E} - \text{Dev on W}}{2}$$

## COEFFICIENT C

Coefficient C is found by subtracting the deviation found on South from the deviation on North, with the result then divided by two. Again, A is eliminated from the result.

$$\text{Coefficient C} = \frac{\text{Dev on N} - \text{Dev on S}}{2}$$

**Example:** Find Coefficient A, B and C given the following readings:

| AIRCRAFT COMPASS | DATUM COMPASS | DEVIATION |
|---|---|---|
| 356°C | 002°M | +6 |
| 090°C | 089°M | -1 |
| 185°C | 183°M | -2 |
| 266°C | 271°M | +5 |

Remember that the deviation is the <u>correction</u> to the aircraft compass to make it agree with the datum compass.

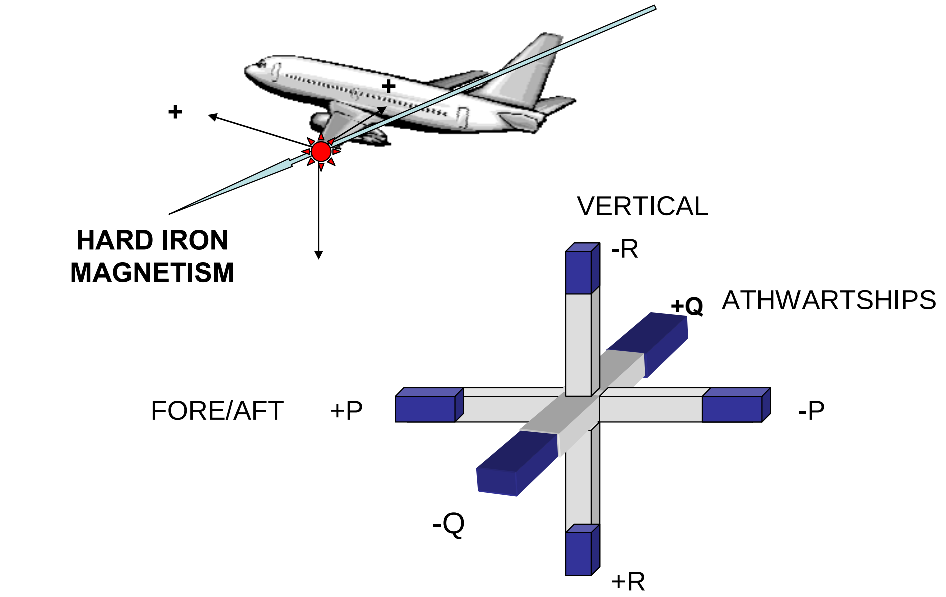
$$\text{Coefficient A} = \frac{\text{sum of deviation on 'n' headings}}{n} = \frac{+8}{4} = +2$$

$$\text{Coefficient B} = \frac{\text{Dev on E} - \text{Dev on W}}{2} = \frac{-1 - (+5)}{2} = -3$$

$$\text{Coefficient C} = \frac{\text{Dev on N} - \text{Dev on S}}{2} = \frac{+6 - (-2)}{2} = +4$$

## COMPONENTS OF HARD IRON MAGNETISM

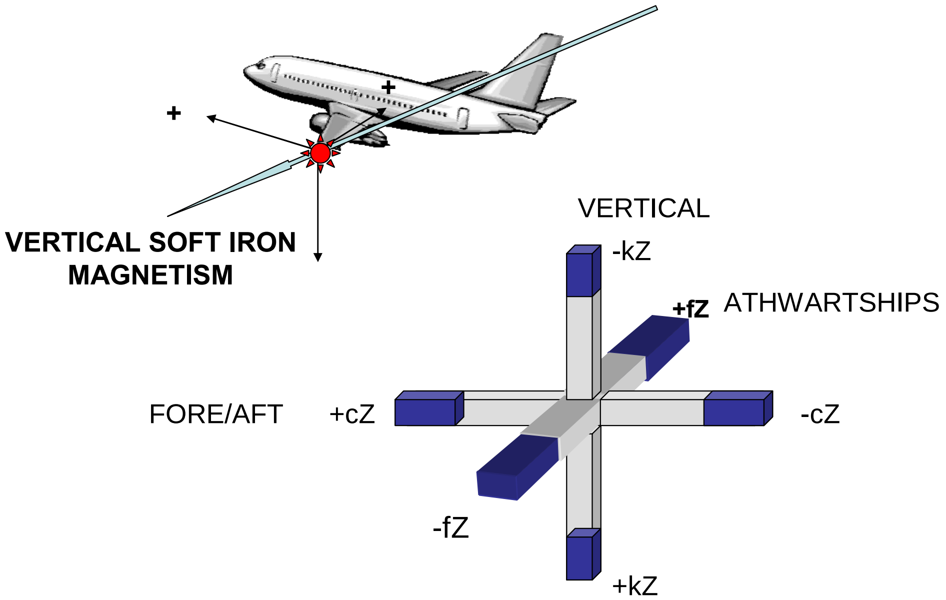
The vector of magnetic force due to Hard Iron can be resolved into Fore/Aft and Athwartships components.




The vertical component R can be ignored as it has no effect on deviation in level flight.

## COMPONENTS OF VERTICAL SOFT IRON MAGNETISM

Similarly the vector of magnetic force due to Vertical Soft Iron can be resolved into Fore/Aft and Athwartships components.




The vertical component kz can similarly be ignored.

## RELATIONSHIP BETWEEN HARD IRON AND SOFT IRON MAGNETISM AND THE COEFFICIENTS

Components P and c*Z* lie on the fore / aft axis and cause Coefficient B.

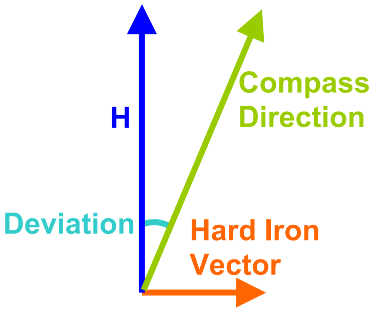
**Coeff B is caused by P and c*Z***

Components Q and fZ lie on the athwartships axis and cause Coefficient C.

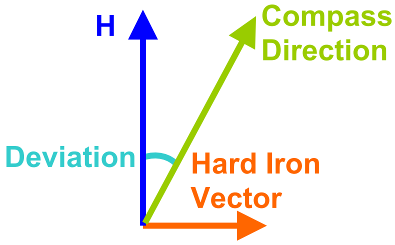
**Coeff C is caused by Q and f*Z.***

## EFFECT OF CHANGE OF MAGNETIC LATITUDE ON DEVIATION

### DEVIATION DUE TO HARD IRON (HI)




**HI Deviation at 30°N**

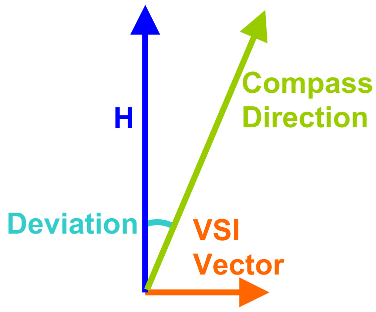



**HI Deviation at 70°N**

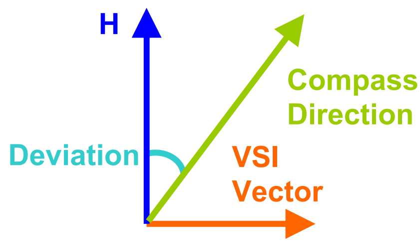
- Hard Iron magnetism is considered permanent and so does not change with latitude.
- The Horizontal (H) component of the earth's magnetic field becomes weaker in high latitudes.
- Deviation due to HI is proportional to $^1/_H$ and so increases with increase in latitude.
- Given values of H and the value of deviation due to HI at one latitude, the value of deviation at a second latitude can be found using the formula:

$$\frac{DEV_2}{DEV_1} = \frac{H_1}{H_2}$$

## DEVIATION DUE TO VERTICAL SOFT IRON (VSI)




**HI Deviation at 30°N**




**HI Deviation at 70°N**

- Vertical Soft Iron magnetism is induced by the vertical (Z) component of the earth's magnetic field. As latitude increases so does Z and VSI magnetism.
- The Horizontal (H) component of the earth's magnetic field becomes weaker in high latitudes.
- Deviation due to VSI is proportional to $^{Z}/_{H}$ and so increases with increase in latitude.
- Given values of H and Z and the value of deviation due to VSI at a second latitude can be found using the formula:

$$\frac{DEV\ 2}{DEV\ 1} = \frac{H_1}{H_2} \times \frac{Z_2}{Z_1}$$

Compensation for Coefficient B and C is made by introducing Hard Iron magnetism in an opposite sense. For example, Coefficient + B which results from +P or +cZ components towards the nose of the aircraft is compensated by introducing HI magnetism towards the tail. If the deviation magnetism is entirely HI, the compensation will remain valid when latitude is changed. If on the other hand, the deviation is caused by VSI, the compensation will not be valid and deviation will increase as latitude is changed.

**NOTE:** Horizontal Soft Iron magnetism (induced by H) changes in strength and polarity with change of heading as well as with change of latitude, unlike Vertical Soft Iron magnetism which only changes with latitude. It results in Coefficients D and E but corrections for these are not applied.

## FINDING THE DEVIATION ON A GIVEN HEADING.

From a knowledge of Coefficients A ,B and C, deviation can be calculated on any heading by using the general formula:

Deviation on hdg $\theta$ ° = A $\pm$ B Sin $\theta \pm$ C Cos $\theta$

For example:

If A = +2, B = -3, C =+1,

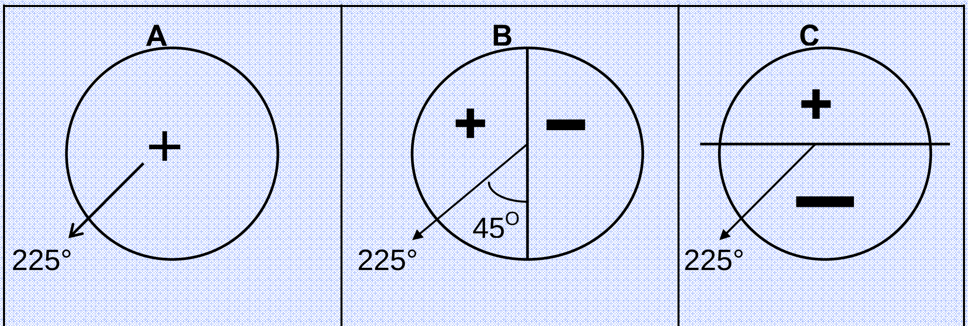
Find the deviation on 225°.

[Assume Sin 45 = .7, Cos 45 = .7]

**Working**

Note

- A applies on all headings.
- B which is negative is the value of deviation (due to fore / aft magnetism) found on East. On Westerly headings, deviation from this cause will be positive.
- C which is positive is the value of deviation (due to athwartships magnetism) found on North. On southerly headings, deviation from this cause will be negative.




| | | |
|---|---|---|
| +2° | +3 Sin45° | -1 Cos 45° |
| +2° | +2.1° | -0.7° |

**TOTAL +3.4°**

## CALCULATING RESIDUAL DEVIATION

Residual deviation is the deviation that is unexplained by known values of Coefficients A, B and C. It is the deviation that remains after correction.

For example given:

(i) Deviation found on hdg 045° (prior to correction) is +1
(ii) The Coefficients are found to A = +2, B = -3 and C = +1

Find the residual deviation on hdg 045°.

**Working**

The total correction is the deviation explained by the known coefficients:

$$A \pm B \sin\theta \pm C \cos\theta.$$

$$\text{or } +2 - 3 \sin 45 + 1 \cos 45$$

$$\text{or } +2 - 2.1 \quad + 0.7 \quad = +.6$$

Residual Deviation = Original deviation less the total correction

Residual Deviation = +1 - (+.6) = + .4°

## BCAR / JAR COMPASS REQUIREMENTS

British Civil Airworthiness Requirements (BCARs) and European Joint Airworthiness Requirements (JARs) state requirements in terms of the compass installation and its accuracy.

JARs require that from each pilot's position a non-stabilised magnetic compass and a direction indicator (gyroscopically stabilized, magnetic or non-magnetic) must be visible. For the non-stabilised (direct-reading) compass, JARs specify that its installation must be such that 'its accuracy is not affected by the aeroplane's vibration or magnetic fields'. It may not have a deviation after compensation, in normal level flight, greater than 10° degrees on any heading.

For the Direction Indicator (gyroscopically stabilized, magnetic or non-magnetic) JARs specify that they must have an accuracy adequate for the safe operation of the aeroplane. Adequate accuracy is defined as follows:

(1) After correction the deviation on any heading should not exceed 1° except that:

(a) on aeroplanes with a short cruising range, the limit of 1° may be extended after consultation with the National Authority.

(b) a change in deviation due to the current flow in any item of electrical equipment and its associated wiring is permissible but should not exceed 1°. The combined change for all such equipment , with all combinations of electrical load, should not exceed 2°.

(c) a change in deviation due to the movement of any component (e.g. controls or undercarriage) in normal flight is permissible, but should not exceed 1°.

(2) The change in deviation due to the proximity of any item of equipment containing magnetic material should not exceed 1°, and the combined change for all such equipment should not exceed 2°.

BCARs state that the residual deviation.............................

(1) of a direct reading compass shall not exceed 3° on any heading, and

(2) of a remote indication compass shall not exceed 1° on any heading.