GYROSCOPES

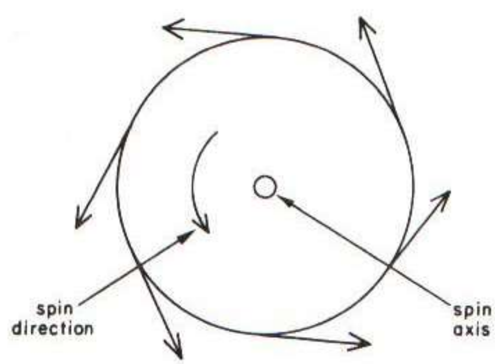
A spinning wheel / gyro has 2 properties: RIGIDITY
PRECESSION

RIGIDITY

The ability of a gyro to maintain its axis aligned with a fixed point in space.

$$\boxed{R \propto \frac{SI}{F}}$$

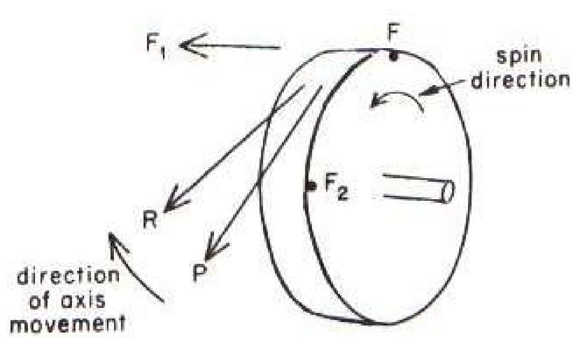
S	-	Rotational Speed (Greater speed - greater rigidity).
I	-	Moment of Inertia (Greater mass - greater rigidity).
F	-	Force (Greater force applied - less rigidity).



PRECESSION

If a force is applied to a spinning gyro, it acts at 90º to the point of application in the direction of spin.

PRECESSION TRIES TO OVERCOME RIGIDITY AND
RIGIDITY TRIES TO OVERCOME PRECESSION.



TYPES OF GYROS

Gyro types depend on the number of planes of freedom of movement. Freedom of movement is achieved by mounting the gyro in gimbal rings.

Space Gyro

Freedom of movement in all 3 planes.(Fore/aft-athwarthships and vertical). This type of gyro is of no use in aviation. We need a gyro that is fixed in at least one plane to give a reference datum.

Tied Gyro (DI)

A space gyro with freedom of movement in 3 planes, but tied to a reference point.

Earth Gyro (AH*)*

A gyro controlled by the earth's gravity.

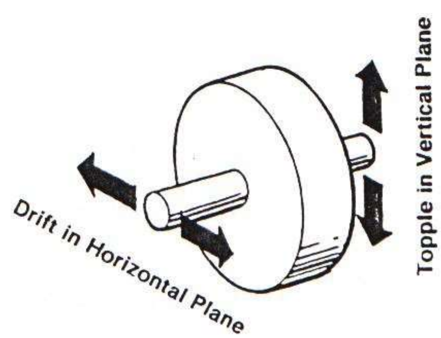
Rate Gyro (T & S)

A gyro having freedom of movement in 1 plane only.

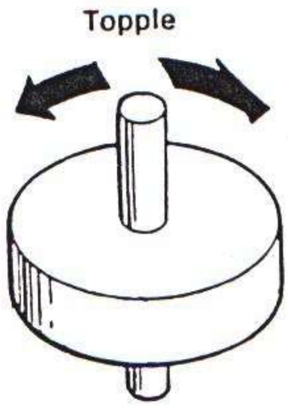
Gyroscopic Wander

Due to its rigidity, the spin axis of a perfect gyro should continue to point in a fixed direction. Any movement of the spin axis away from this fixed direction is known as gyro wander. Depending on the direction in which the spin axis moves, the gyro may be said to be drifting or toppling.

Gyro drift occurs whenever the spin axis moves in a horizontal plane,



Gyro topple occurs whenever the spin axis moves in a vertical plane,



A gyro whose spin axis is vertically mounted cannot drift, but can only topple.

Real Wander

Whenever the spin axis actually moves relative to a fixed point in space, the gyro is said to be suffering real wander, that is to say real drift, real topple or a composite of both.

Such real wander may be deliberately induced or may be due to mechanical imperfections in the gyro assembly, for example:

a) An imperfectly balanced gyro wheel.

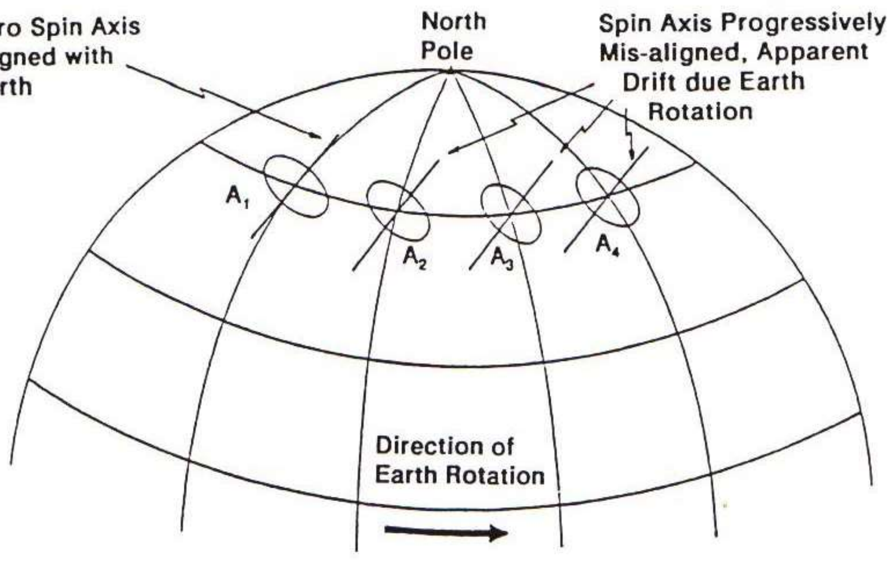
b) Imperfectly balanced gimbals.

c) Uneven friction loadings at the bearings.

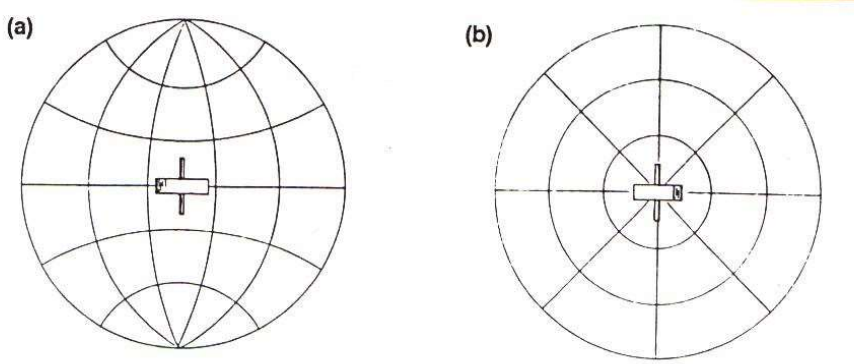
Apparent Wander

Whenever the spin axis of a perfect gyro (with no real wander) appears to an Earth bound observer to be changing direction, the gyro is said to be suffering from apparent wander.

The diagram on the next page shows apparent drift. The spin axis of a perfect gyro is aligned with true north at time A. The gyro continues to remain perfectly rigid relative to a fixed point in space, however with the passage of time (A2, A3, A4) the spin axis appears to an Earth bound observer to be drifting away from true north. Appreciate that the gyro is stationary on the Earth, it is the Earth which is moving about its own spin axis.



Apparent drift does not occur at the equator, since the meridians are parallel. At the poles the rate of apparent drift is equal to the rate of Earth rotation (15º per hour),



Zero Drift at Equator

Maximum Drift at Poles

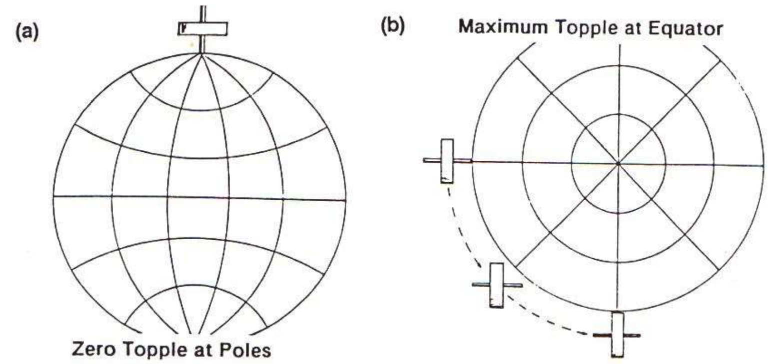
The formula for the apparent drift (due to Earth rotation) is:

RATE OF APPARENT DRIFT = 15° x THE SINE OF THE LATITUDE °/HOUR

Conversely apparent topple is calculated using the formula:

RATE OF APPARENT TOPPLE = 15° x THE COSINE OF THE LATITUDE °/HOUR

Since it is zero at the poles, but occurs at the maximum rate of 15° per hour at the equator,



Apparent wander (either drift or topple) also occurs whenever the gyro is transported east or west across the surface of the Earth. This apparent wander is specifically termed transport wander.

Gyros can be air driven but electrically driven gyros are more advantageous due to:

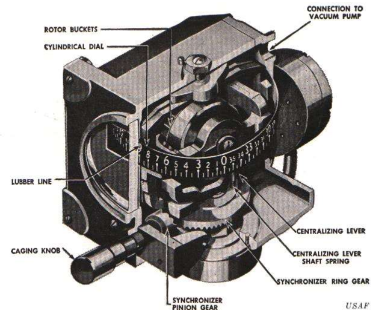
More efficient - higher speeds at all altitudes.

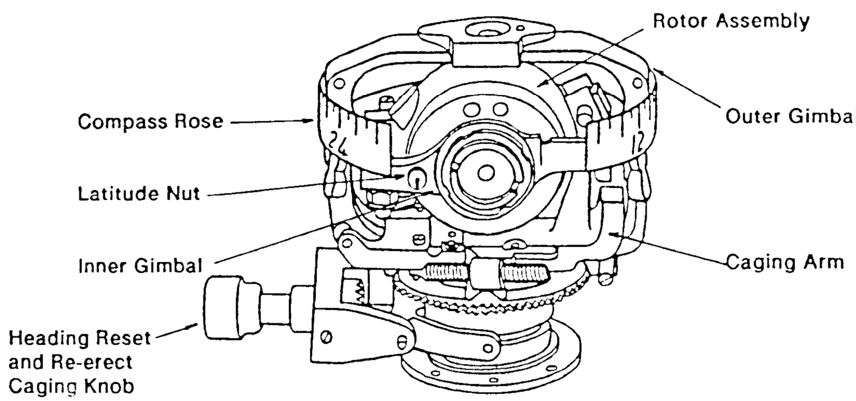
Operational speed is attained much quicker.

Case can be sealed so no impurities to clog gyro.

Heat generated by the motor, maintains a stable operating temperature, thus increasing the useful life of the bearings.

THE DIRECTION GYRO (DGI)





TIED GYRO

Tied to North

HORIZONTAL AXIS N/S

The gyro has freedom of movement of 360º in the horizontal plane, but is restricted to 55º freedom of movement either side of the vertical plane. This is to prevent damage to the gimbal rings.

HIGH RPM

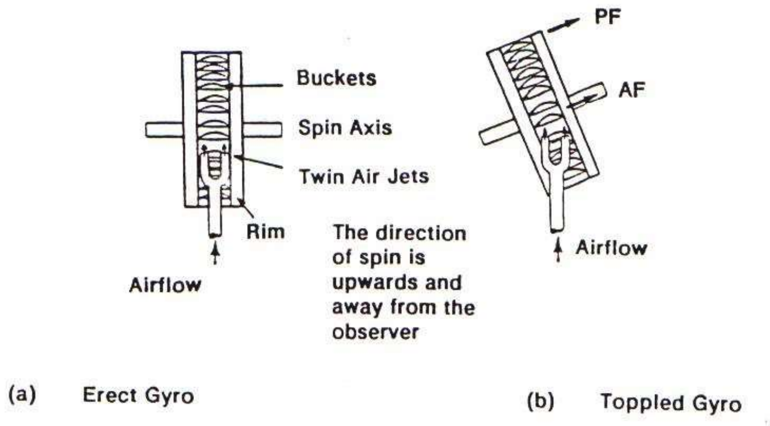
The gyro spins at ± 12000 RPM because:

PRINCIPLE OF OPERATION = RIGIDITY

The A/c turns in the horizontal plane. The gyro assembly and gimbals remain directed at a fixed point in space. So the A/c turns about the rigid gyro and heading is indicated.

PRINCIPLE OF CONTROL = PRECESSION

To give a reference for change of heading, the gyro must always be maintained in the A/c horizontal axis. (not true horizontal). Therefore, to indicate a change of heading in a banked turn, the gyro must be precesses back into the A/c horizontal axis. Also if the A/c flies from the equator to the pole, its horizontal axis changes by 90º, so the gyro will have to be precessed by 90º.



GYRO WANDER

The DGI suffers from 4 factors that cause TOTAL DRIFT.

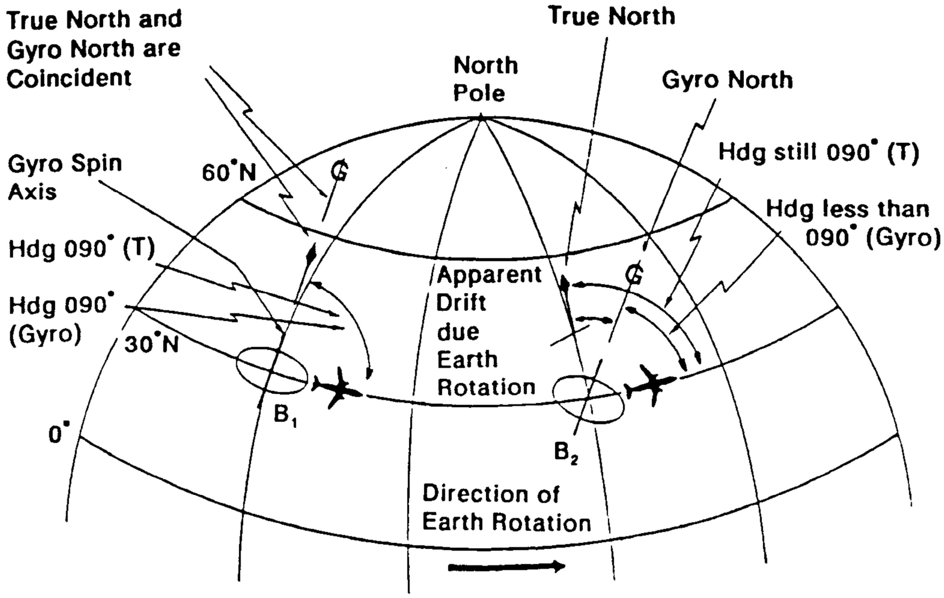
REAL WANDER
EARTH ROTATION WANDER
LATITUDE NUT CORRECTION
TRANSPORT WANDER

TOTAL DRIFT

Real Wander

Nothing can be done about this because it is due to asymmetric friction etc.

Earth Rotation Wander

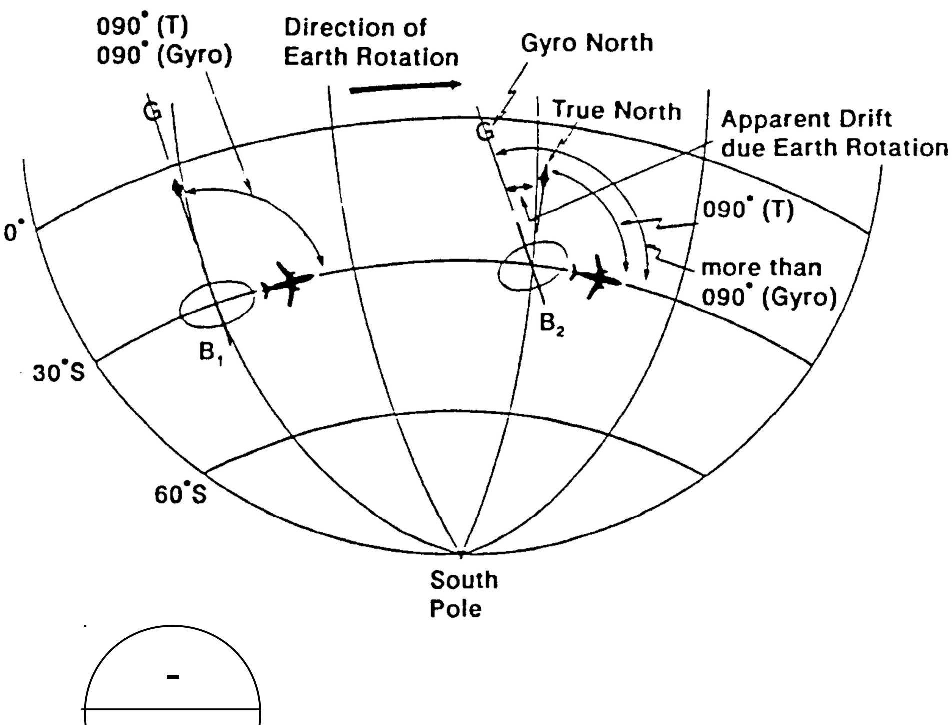


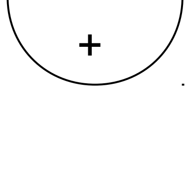
NORTHERN HEMISPHERE

DGI READING DECREASE AT
15º Sin Lat/HR

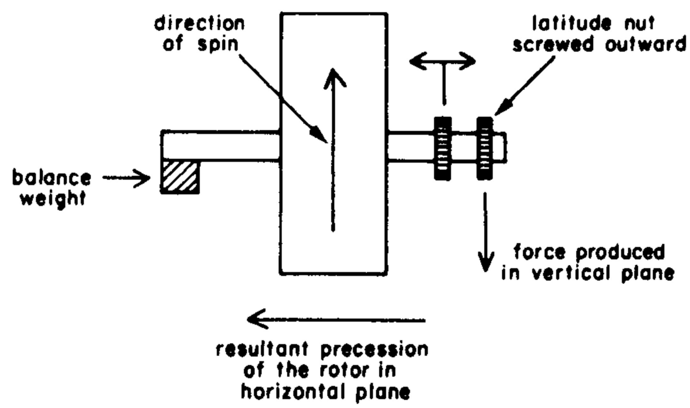
SOUTHERN HEMISPHERE

DGI READING INCREASE AT
15º Sin Lat/HR





Latitude Nut Correction



To counteract the effect of EARTH ROTATION WANDER, we use a LATITUDE RIDER NUT. It imposes a precessional force on the DGI which is equal and opposite to ERW at that latitude. This continually lines up the fixed point in space with magnetic North, effectively making the Earth stand still.

NORTHERN HEMISPHERE : NUT SCREWED INWARDS
SOUTHERN HEMISPHERE : NUT SCREWED OUTWARDS

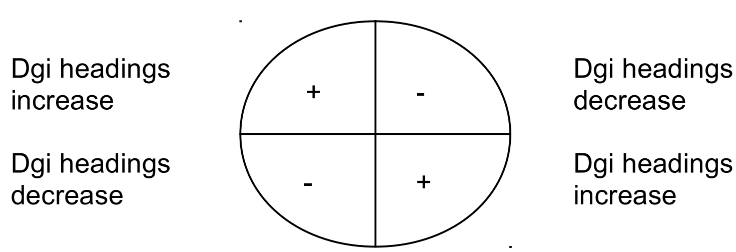
It must be remembered that because APPARENT WANDER changes with latitude, the latitude rider nut is set for a specific latitude only. Any departure from this latitude and precession will not equal wander and headings will increase or decrease.

TRANSPORT WANDER

The latitude rider nut has cancelled out ERW and basically stopped the earth from turning. However, if an A/c flies from one meridian to another, (TRANSPORT), the fixed point in space will not coincide with the Magnetic North and the result will be TRANSPORT WANDER.

The magnitude of Transport Wander will equal the magnitude of Convergency.

Therefore an A/c flying along the equator will experience zero transport wander.



If travelling EXACTLY east or west:

$$\text{Transport wander} = \frac{\text{Groundspeed Kt} \times \tan \text{latitude} \ {}^\circ/\text{hr}}{60}$$

Any other track:

$$\text{Transport wander} = \frac{\text{d long}^\circ \times \text{Sin mean lat}}{\text{Flight time}}$$

TOTAL DRIFT = REAL DRIFT + APPARENT DRIFT

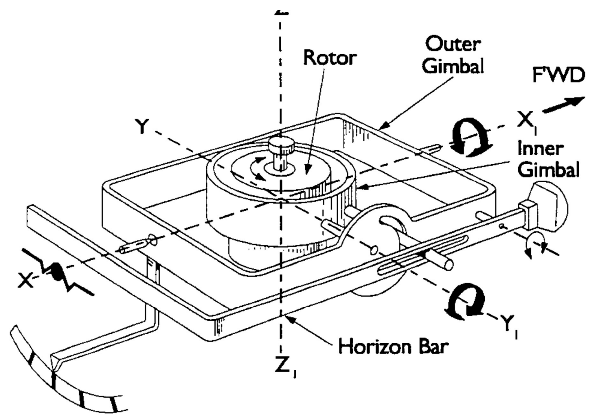
* These factors are all calculated in DRIFT PER HOUR.

* If a problem is over several hours, remember to multiply the degrees of drift by the number of hours.

RING LASER GYRO

The ring laser gyro (RLG) is just about as different from a conventional gyro as it is possible to get. The RLG operates on the principle of the relative movement of two beams of laser light, whereas a conventional gyro operates on the principle of stored mechanical energy (inertia). RLGs are a solid state alternative to the conventional rate integrating gyro.

ARTIFICIAL HORIZON



The (AH) is an EARTH GYRO

VERTICAL AXIS
HIGH RPM
PRINCIPLE OF OPERATION - RIGIDITY
PRINCIPLE OF CONTROL - PRECESSION

EARTH GYRO

It is controlled by earth's gravity.

VERTICAL AXIS

And has freedom of movement in all 3 planes

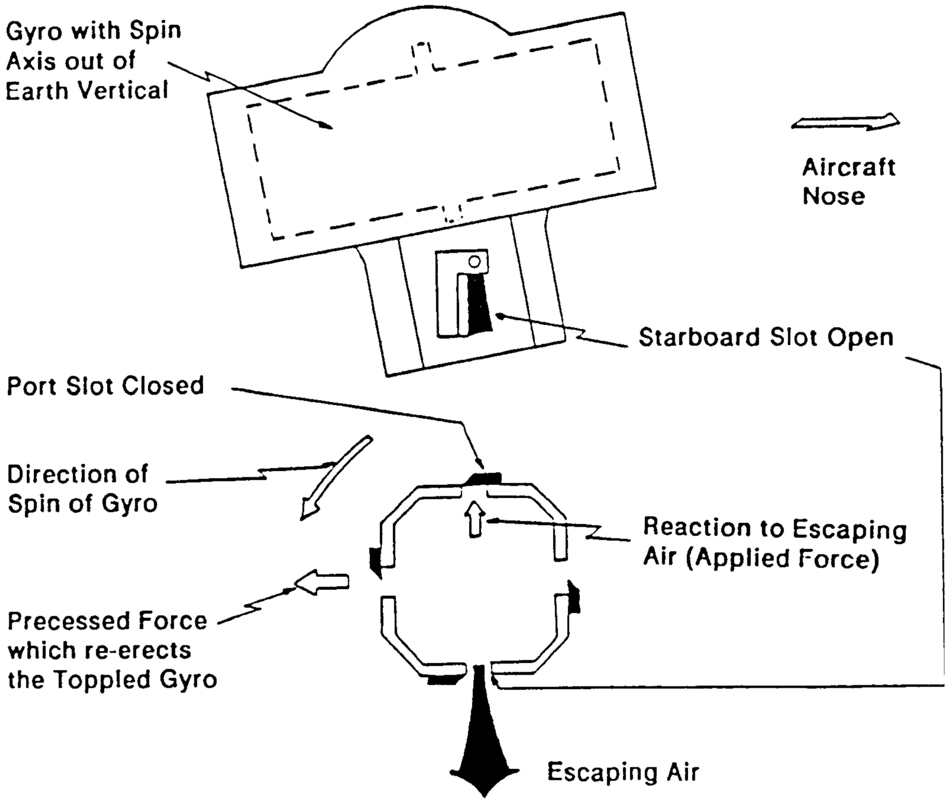
HIGH RPM

$\pm$ 15000 RPM for air models.
It has this high RPM because: PRINCIPLE OF OPERATION IS RIGIDITY

The A/c pitches and rolls around the gyro system which is rigid, giving instantaneous reference to pitch and bank.

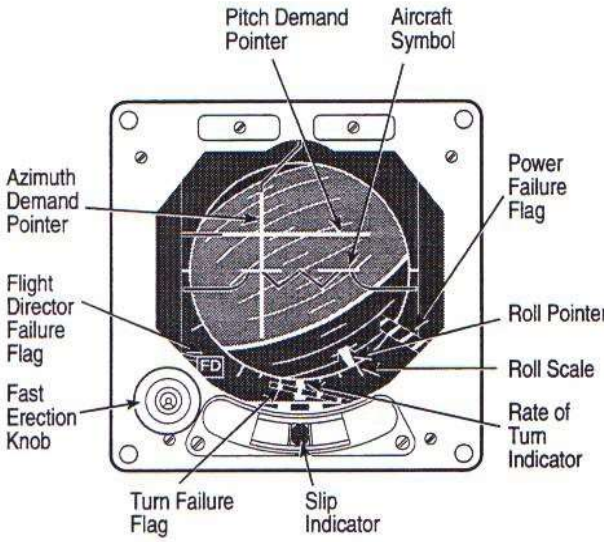
PRINCIPLE OF CONTROL IN PRECESSION

The gyro axis is kept in the vertical (true vertical) plane by the PENDULOUS VANE UNIT which provides the necessary precessional force if the gyro has toppled.



The pendulous unit has 4 exhaust ports. Air exits here after spinning the gyro. Each port is half closed by a vane which lies to the left as you look at the port. After the gyro topples, the vanes remain in the vertical. One of the vanes will cover its port, and no air escapes here. There is a pressure force here which is precessed through 90º and erects the gyro. The rate of precession is kept low so that when the vanes are disturbed by turbulence, the precessional force on the gyro is negligible.

AH INDICATOR



The miniature A/c is fixed to the outer gimbal. The horizon bar, through the guide pin is linked directly to the gyro (inner gimbal). If the A/c descends, the horizon bar moves up causing our little A/c to appear below the horizon and vice versa for climbing. A similar thing occurs when the A/c banks and the horizon bar, linked to the gyro, rotates around the little A/c.

GYRO ERRORS

The Gyro suffers from 2 errors:

(a) Acceleration Error.
(b) Turning Error.

The causes of these errors are:

(a) PENDULOSITY. (bottom of unit heavy)
(b) ERECTION (precession by vanes)

PENDULOSITY

In acceleration (and deceleration). The pendulous unit makes the rotor bottom heavy, and the bottom of the unit is subject to inertial forces generated by acceleration and deceleration.

In a turn, the pendulous unit suffers from centrifugal force which provides a processional force to the gyro.

ERECTION

In acceleration (and deceleration), The vanes should remain in the true vertical and keep the gyro axis vertical. During acceleration both longitudinal side vanes are thrown back, with the result that the right side opens and the left side closes. Reaction is a force which provides an erectional force which precesses the gyro.

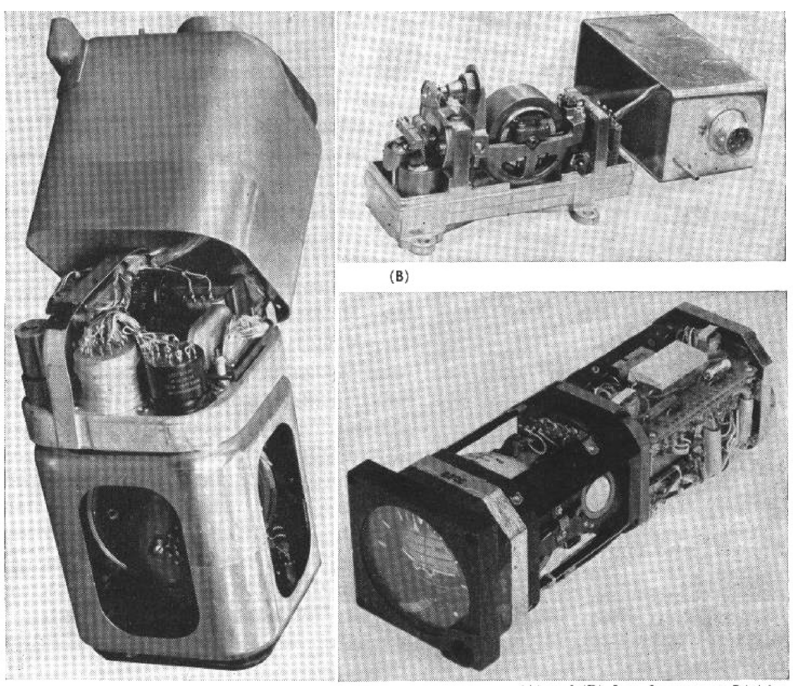
In a turn, the vanes suffer from centrifugal force which causes an erectional force, which precesses the gyro.

ACCELERATION ERROR	- CLIMBING RIGHT BANK
DECELERATION ERROR	- DESCENDING LEFT BANK
TURNING ERROR TO LEFT	- REDUCTION IN LEFT BANK
TURNING ERROR TO RIGHT	- REDUCTION IN RIGHT BANK

NOTE: The effect of pendulosity and erection increases the error to a maximum at 180º turn, thereafter reducing to zero.

The reason is because the effect of pendulosity opens and closes the opposite two vanes which erection error opens and closes. This causes an erectional force which is correct and nullifies the 2 errors after a while.

THE ELECTRICAL ARTIFICIAL HORIZON



(A) (B) (C)

(A) and (B) Lear Instrument Division
(C) Bendix Corp.

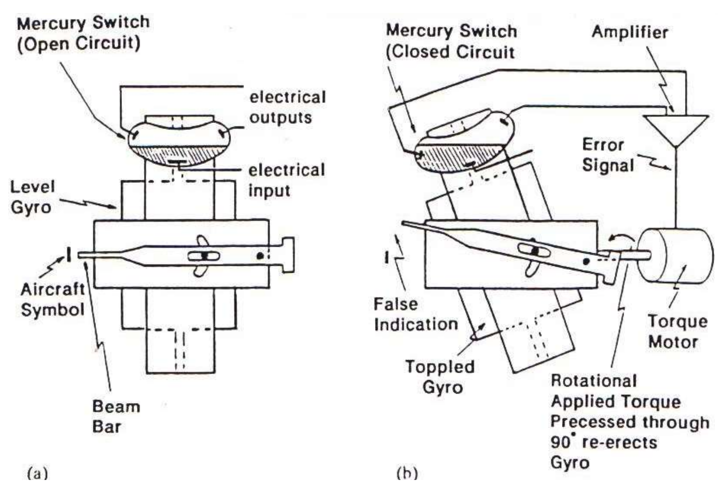
Once again, the gyro is controlled through _precession. This precessional force is achieved by levelling switches and a torque motor.

The levelling switches are at 90º to their respective axis and the torque motor applies a correcting torque at 90º to the respective axis.

e.g. GYRO DISPLACEMENT IN PITCH

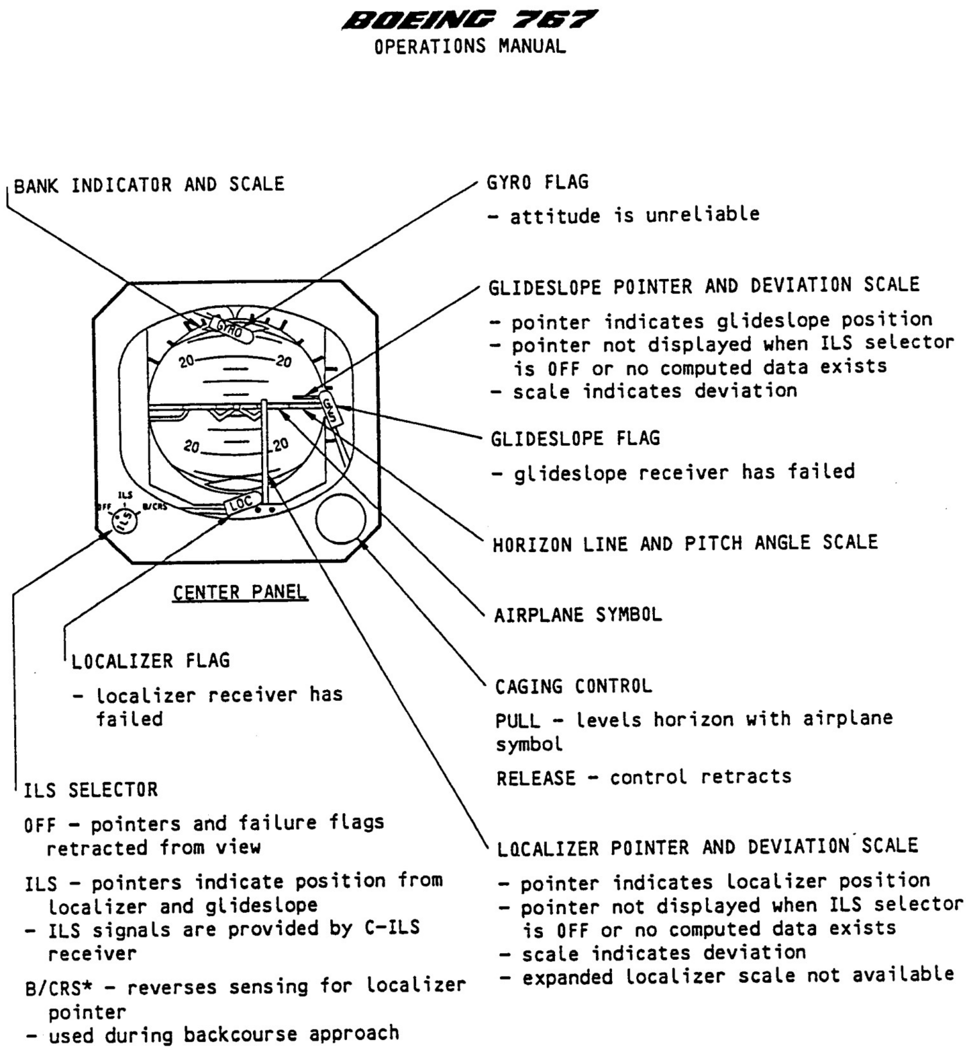
Levelling switch on roll axis (90º to Pitch Axis).
Torque motor on roll axis (90º to Pitch Axis).

The opposite applies to gyro displacement in roll.



Mercury switches and their placements and use

THE STANDBY AH



Major airlines today do not use the conventional AH, but instead, they all have Flight Directors. It is controlled by a remote gyro or inputs from the INS. Now in case of an electrical failure, a STANDBY AH is employed.

It is an electrically driven gyro that is powered by 115 volt - 3 phase AC from a static invertor. It is guaranteed of electrical power because it is linked to the 28 Volt DC Battery Busbar (Hot Bus).

TURN AND SLIP INDICATOR

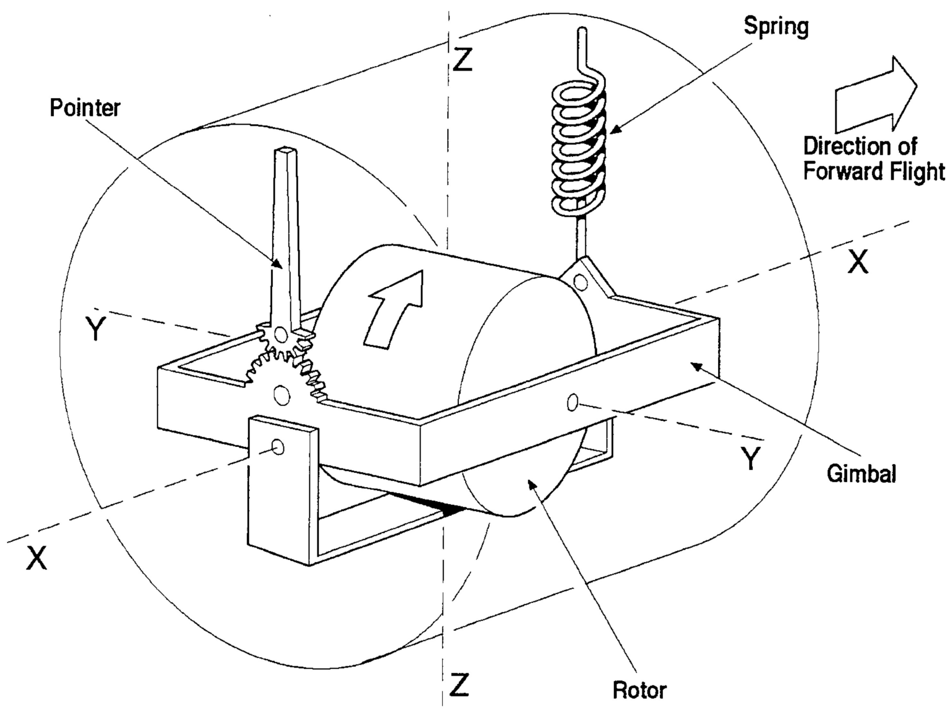
The Turn and slip indicator are 2 separate instruments:

Turn Indicator - Gyroscope
Slip Indicator - Mechanical

Turn Indicator is a : RATE GYRO

HORIZONTAL AXIS
LOW RPM
PRINCIPLE OF OPERATION - PRECESSION

RATE GYRO:



Freedom of movement is in one plane only - Rolling Plane.

Some books say it has freedom of movement in a second plane - plane of rotation. The instrument measures the rate of turn in the 3rd plane at right angles to the other 2.

HORIZONTAL AXIS:

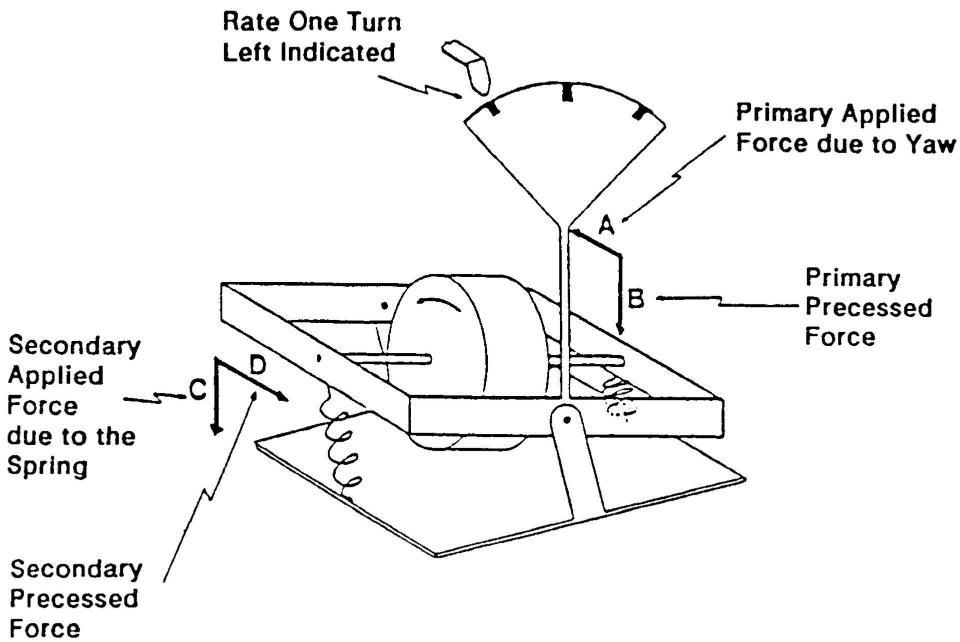
The axis of the gyro is mounted athwartships.

LOW RPM:

The gyro spins at 9000 RPM. This low RPM because:

PRINCIPLE OF OPERATION IS PRECESSION

The instrument measures the precessional rate of the gyro and indicates it as a turn.



OPERATION

As the A/c turns, the gyro wants to remain in the horizontal, but is forced to remain in the A/c athwarthsips axis. This force is precessed and causes the gyro to tilt.

GYRO TILT IS DUE TO PRIMARY PRECESSION CAUSED BY THE A/C TURNING. The gyro now experiences a secondary precessional force from the springs. When primary and secondary precessional forces are equal, a steady turn is indicated.

The secondary precessional force returns the gyro to its original position once the turn is stopped.

The turn indicator is usually electrically driven to provide a back up in case of AH and DGI failure resulting from loss of suction.

TURN INDICATOR ERRORS

Springs

The springs are adjusted to a rate one turn. Any other rate will provide inaccuracies.

Rotor Speed

The turn indicator is calibrated for a given rotor speed only.

ROTOR SPEED TOO LOW

Primary precession less than secondary precession - LESSER RATE OF TURN INDICATED.

ROTOR SPEED TOO HIGH

Primary precession greater than secondary precession - GREATER RATE OF TURN INDICATED.

TO CALCULATE THE RADIUS AND ANGLE OF BANK OF A TURN

TAS 240 Kts
RATE 1 TURN
RATE 1 TURN = 2 mins.

a) What is the radius of the turn?

b) What is the bank angle required?

Answers

a) Circ = $240 \times 6080' \times \frac{2}{60}$

Circ = 48640'

Circ = $2 \pi r$

r = $\frac{\text{circ}}{2 \pi}$

r = $\frac{48640}{2 \times \pi}$

r = 7741'

b.

$$\tan \theta = \frac{V^2}{gr}$$

$$\tan \theta = \frac{405.33^2 \text{ (ft/sec)}}{32.2 \times 7741}$$

$$\tan \theta = 0.66$$

$$\theta = 33.39°$$

or 10 % of TAS + 7

$$\theta = \frac{TAS}{10} + 7$$

$$\theta = 24 + 7$$

$$\theta = 31°$$

V = speed
G = gravity 32.2 ft/sec^2
r = radius

THE TURN INDICATOR IS THE ONLY INSTRUMENT THAT CAN ACCOMMODATE UNLIMITED PITCH WITHOUT TOPPLING.

SERVICEABILITY CHECK*:*

While taxing, check: Needle in direction of turn.
Ball out of turn.

Questions

1. The rigidity of a spinning wheel is directly proportional to:

   a) the speed of rotation and indirectly proportional to the mass of the rotor; CAA
   b) the moment of inertia and inversely proportional to the speed of rotation;
   c) the speed of rotation and inversely proportional to the moment of inertia.

2. Errors in both pitch and bank indication on an attitude indicator are usually at a maximum as the aircraft rolls out of a:

   a) 90 degree turn;
   b) 180 degree turn;
   c) 270 degree turn.

3. When an aircraft is rapidly accelerated in straight and level flight, or at take-off, what inherent precession characteristic will be displayed on the attitude indicator?

   a) The miniature aircraft would indicate a descent.
   b) The miniature aircraft would indicate a climb.
   c) The miniature aircraft would indicate a climb and bank.

4. What is the approximate angle of bank for a rate one turn at 110 knots?

   a) 18 degrees
   b) 25 degrees
   c) 30 degrees

5. The Turn and Slip indicator pre-flight check consists of:

   a) Aircraft level, ball central, turn needle central.
   b) Aircraft level, turn needle central, ball central, fluid in tube.
   c) Aircraft not level, turn needle and ball displaced.

6. What indications should you get from the Turn and Slip indicator during taxi?

   a) The needle and ball should move freely in the direction of the turn.
   b) The ball moves opposite to the turn and the needle deflects in the direction of the turn.
   c) The ball deflects opposite to the turn and the needle remains central.

7. The effect of decreasing rotor speed in the turn and slip indicator will cause:

   a) the turn indicator to over-read and the slip indicator to under-read;
   b) the turn indicator to under-indicate the angle of bank but will not effect the slip indicator;
   c) the turn indicator to under-read the rate of turn.

8. The angle of tilt of the rate gyro in a turn indicator is due to:

    a) the force in the horizontal plane generated by secondary precession balancing the tilt caused by primary precession;
    b) the tension of the control spring opposing the angular tilt of the gyro;
    c) primary precession which is generated by an aeroplanes rate of turn.

9. To complete a 360° turn using the Turn Co-ordinator, takes 131 seconds. The rotor speed is:

    a) High
    b) Low
    c) Correct

10. The rigidity of a gyro is directly proportional to:

    a) Rotor speed and inversely proportional to rotor mass.
    b) Gyro inertia and inversely proportional to rotor speed.
    c) Gyro inertia and rotor speed.

11. If the rotational speed of the Turn and Slip gyro rotor is below the calibrated speed the:

    a) Turn indicator overreads.
    b) Turn indicator and Slip underreads.
    c) Turn indicator underreads, slip not affected.

12. A warning flag appears on an electrical Turn and Slip indicator, this means:

    a) Total instrument failure.
    b) Turn indicator failure. Slip indicator serviceable.
    c) Turn indicator underreads, slip not affected.

13. The principle of rigidity is used for the operation of the following gyroscopic instruments:

    a) Directional Gyro and Artificial Horizon.
    b) Directional Gyro and Turn indicator.
    c) Artificial Horizon and Turn indicator.

14. An Artificial Horizon employs a;

    a) Tied gyro
    b) Earth gyro
    c) Rate gyro

15. One characteristic that a properly functioning gyro depends upon for operation is the:

    a) Resistance to deflection of the gyro rotor.
    b) Ability to resist precession at 90 degrees to an applied force.
    c) Position of the gyro axis relative to the Earth's axis.

16. The Latitude Rider nut of a DGI compensates for:

a) Real wander.
b) Earth rotation wander.
c) Transport wander.

17. The Latitude Rider nut of a DGI is set to give zero drift due to the Earth's rotation at 30ºS. The gyro readings will:

a) Increase when flying North from 30 S.
b) Increase when flying South from 30 S.
c) Remain correct when flying East or West along the 30 S parallel.

18. The rotor of the DGI spins up and away from the pilot when 090 is indicated. The latitude compensation nut situated on the near right hand side of the inner gimbal from the gyro axis, has been set to give zero drift on the ground at the equator. To compensate for earth rotation at 30 S the latitude compensating nut:

a) must be adjusted outwards;
b) must be adjusted inwards;
c) is not adjusted since the latitude nut can only be used to correct for apparent wander in the northern hemisphere.

19. What is earth rotation wander at 30 degrees S?

a) +7.5 degrees per hour.
b) +7.5 degrees per minute.
c) -7.5 degrees per hour.

20. If a vacuum gauge indicates the pressure to be lower than the minimum limit, the air-operated instruments that would be affected, are:

a) pressure altimeter;
b) heading indicator (DGI);
c) vertical-speed indicator.

21. The air driven Artificial Horizon erection error is due to:

a) Centrifugal Force acting at the bottom of the pendulous unit.
b) Centrifugal Force displacing the vanes.
c) Wear and tear of the gimbal bearings.

22. The DGI, Artificial Horizon and Turn indicator are:

a) Rate, Earth and Tied gyros respectively.
b) Tied, Rate and Earth gyros respectively.
c) Tied, Earth and Rate gyros respectively.

23. Erection errors in an air driven Gyro Horizon Indicator are due to:

a) Loss of gyro rigidity due to the reduction in rotor speed at high altitudes.
b) The movement of the pendulous vanes during aircraft accelerations and manoeuvres.
c) The displacement of the pendulous gyro casing during acceleration or a turn.

24. In an electrically driven artificial horizon, the axis wander about the pitch axis is controlled by:

a) A mercury switch at right angles to the pitch axis inducing torque about the roll axis.
b) A mercury switch parallel to the pitch axis inducing torque about the pitch axis.
c) A mercury switch at right angles to the roll axis inducing torque about the pitch axis.

25. During a stabilised climbing turn at a constant rate, the instruments which indicate the correct pitch and bank are the:

a) vertical-speed indicator and turn-and-slip indicator;
b) altimeter and turn-and-slip indicator;
c) attitude indicator and turn-and-slip indicator.

26. A RMI (Radio Magnetic Indicator) displays a warning flag which indicates a compass failure. The radio bearing pointers:

a) are not to be used;
b) can be used to home to an NDB;
c) can be used to home to an NDB and a VOR station.