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CHAPTER 8 – GYROSCOPIC PRINCIPLES

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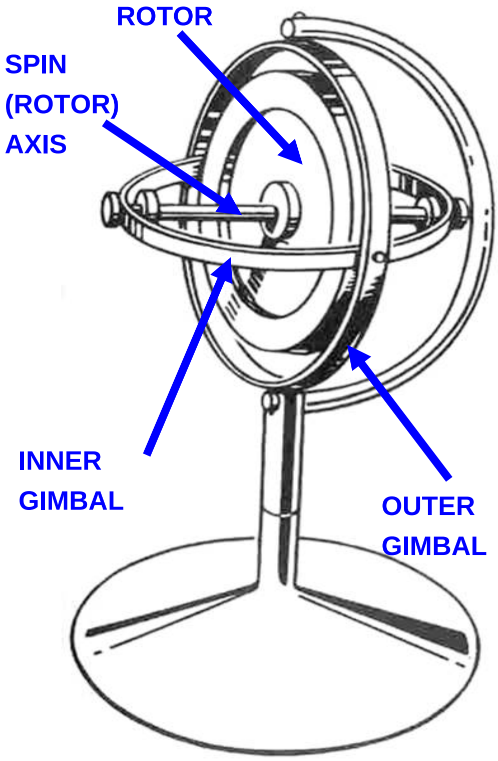
GYROSCOPIC PRINCIPLES

The mechanical gyroscope is a rotating mass supported in a frame to allow it to behave in a particular manner.



Gimbals - The frame is of 'universal design', which ideally allows the aircraft freedom of movement in all three planes without influencing the gyro rotor.

Rotor - The rotor is a mass that is wheel shaped. The mass is concentrated at the circumference of the wheel. An axle (spin axis) is supported in the inner gimbal by bearings. These rotor bearings and the gimbal bearings are very important to the function of the gyroscope.

PROPERTIES OF A GYROSCOPE

When the rotor is made to spin, the device becomes a gyroscope possessing two properties :

1. Rigidity (or gyroscopic inertia); and
2. Precession.

RIGIDITY

Rigidity is the property of a gyroscope which resists any force tending to change the plane of rotation of its rotor. As a result of rigidity, the spin axis tends to maintain a fixed direction in space. Rigidity is dependent on three factors :

(a) the mass of the rotor;
(b) the speed of the rotation (RPM); and
(c) the distance of the mass from the centre of the rotor (radius).

The mass and radius of the rotor determine its moment of inertia. Rigidity is proportional to the rotor's moment of inertia (**I**) and its angular velocity (ω).

$$\text{Rigidity} \propto I.\omega$$

Rigidity is the property of the gyro which allows the gyro to be used as an independent stable reference.

PRECESSION

Precession is the change of direction (angular change) of the plane of rotation of the rotor caused by an applied force. The amount and rate of precession is dependent on three factors :-

(a) the magnitude and direction of the applied force;
(b) the moment of inertia of the rotor and
(c) the angular velocity of the rotor (RPM).

- Rate of precession is directly proportional to the applied torque(**T**).
- Rate of precession is indirectly proportional to rigidity (**I**ω).

$$\text{Rate of Precession} \propto \frac{T}{I.\omega}$$

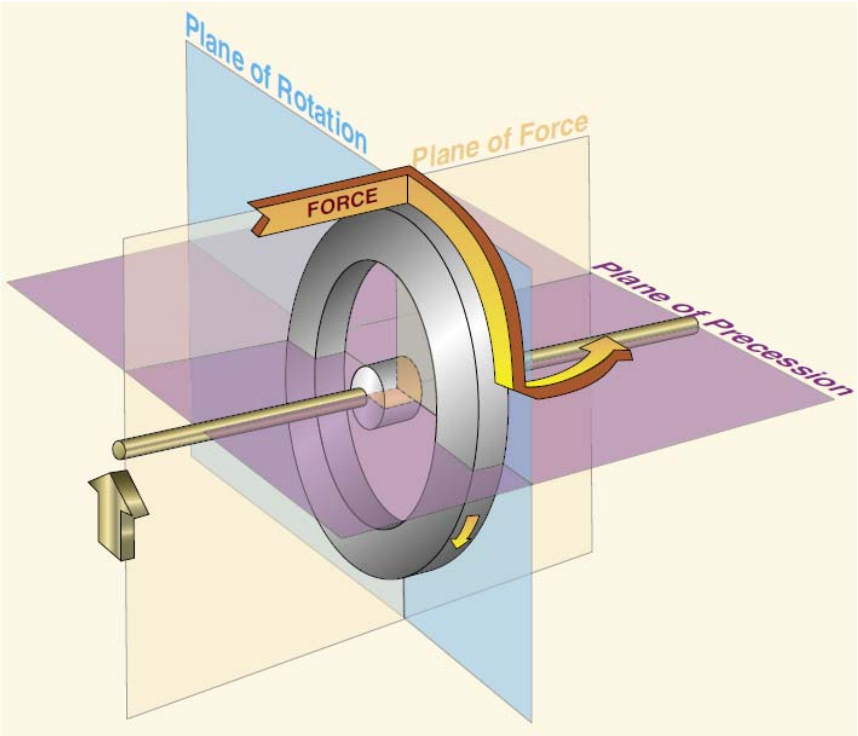
RULE OF PRECESSION

An external force acting on a gyroscope gimbal will cause a precession when it is contrary to the rotor freedom, ie. the gyroscope will react. To understand this reaction:

Transfer the applied force to the gyro rotor;

Move 90° in the direction of rotor rotation and this is the point where the applied force acts.

Note that the precession always occurs about an axis perpendicular to both the spin axis and the axis of the applied torque.



An understanding of rigidity and precession will help with the understanding of 'gyroscopic effects' relating to many areas of study, such as:

- propellers
- tail wheel aircraft
- aircraft instruments
- aircraft spinning.

TYPES OF GYROSCOPES

Mechanical gyroscopes exist in three basic forms :

a. Space or Free Gyroscopes.

b. Tied Gyroscopes, of which the Earth Gyroscope is a particular example.

c. Rate Gyroscopes.

SPACE OR FREE GYROSCOPES

The perfect gyroscope would be a unit whose rotor could be aligned in space without influences of torque, connecting wires or external forces. The rotor axle (axis) would be mounted in frictionless bearings and the inner and outer gimbals would allow complete freedom of aircraft movement without influencing the rotor. On starting, the rotor axis would be pointing to a point in space and would retain that position all the time. By definition, a space gyro is not aligned to any external datum and is free to maintain its own direction in space.

The space or free gyro is an <u>ideal gyro</u> which we use to study gyroscopic principles and effects. It is however totally impractical to make and is not used in aircraft systems, although the Earth itself exhibits many of the properties of a space gyro.

TIED GYROSCOPES

A tied gyroscope has <u>three</u> planes of freedom. However, the rotor axis is influenced to be aligned in a particular way. Examples of tied gyros are the <u>Artificial Horizon</u> - the rotor axis is kept vertical by gravity sensing devices (sometimes called an earth gyro); and the <u>Directional Gyro</u> where the axis is kept horizontal.

RATE GYROSCOPES

A rate gyroscope has only two planes of freedom. Used in the turn indicator, this unit relies on the precession reaction to provide an indication of the angular displacement that is taking place about its sensitive axis in the third plane.

GYROSCOPIC TERMINOLOGY

WANDER

The term 'wander' is used to describe any movement (real or apparent) of the gyro spin axis away from a chosen datum.

REAL WANDER

This term is used to describe the movement of the gyro spin axis relative to the chosen datum that is the result of applied forces such as friction in the gimbal bearings. It can be considered as the failure of the gyro to hold its space datum.

APPARENT WANDER

A gyro will appear to wander when the direction of its spin axis is compared with a datum which is not itself a fixed direction in space.

TOPPLE

Any movement of the gyro axis in the vertical plane is called topple (or tilt). The effect of topple depends on the gyro axis alignment and can also relate to latitude and earth rotation. The types of gyroscopes used in aircraft make the effects of topple less obvious than drift (see following notes).

The term TOPPLE may also be used, to describe the tumbling (severe and usually rapid misalignment) of a gyro that can occur when a gimbal 'limit' stop is reached. The rotor is no longer isolated from the aircraft movement (instrument casing), and a rapid precession misaligns the axis.
TOPPLE can be either real or apparent.

DRIFT

The horizontal angular change in direction of the gyroscope's axis measured in degrees/hr. Drift is considered in two forms, **real** and **apparent**.

REAL DRIFT

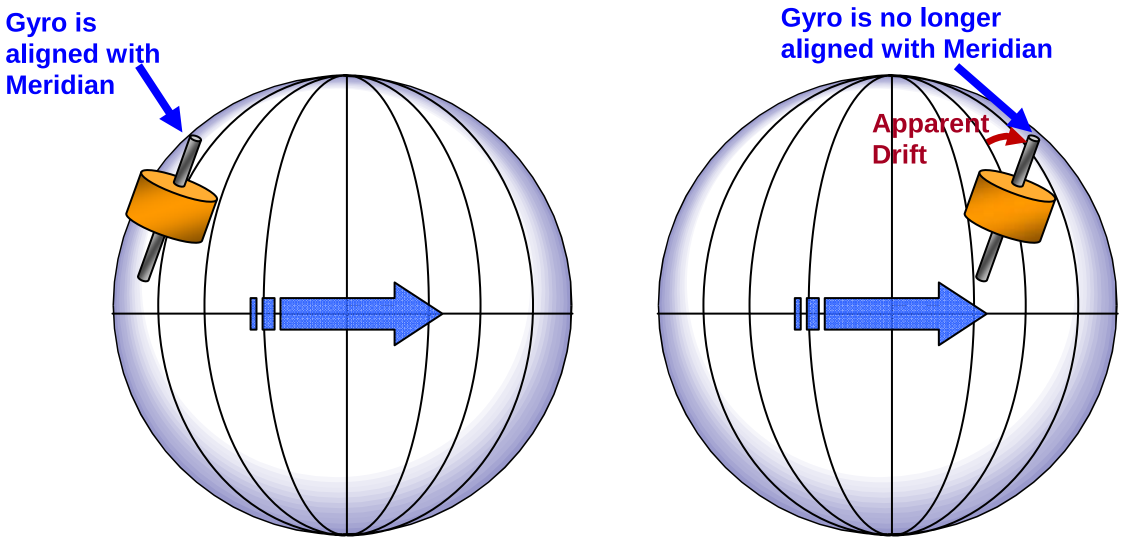
The angular change in direction of the rotor axis in the horizontal plane which has been caused by mechanical imperfections and other applied forces. Causes of real drift include:

1. Bearing Friction (gimbals);
2. Imbalance (rotor or gimbals).

NB : Both friction and imbalance cause a force or torque effect at the rotor. The effect of this force - usually very small - causes the rotor to precess away from its original alignment resulting in DRIFT (real).

APPARENT DRIFT DUE TO EARTH ROTATION

There is an angular change of the rotor axis of a horizontal gyro (when referenced to north) which is caused by the earth rotating. This drift which may be called Earth Rate is not a fault with the gyroscope or a mechanical problem. The gyro stays aligned with a point in space as the earth rotates but it 'looks like' the gyro is drifting. This is apparent drift and when a NORTH reference is used, large errors are evident at the poles but no error occurs at the equator.



NB : Directional Gyros are compensated for apparent drift due to earth rotation (which is related to latitude).

APPARENT DRIFT DUE TO TRANSPORT

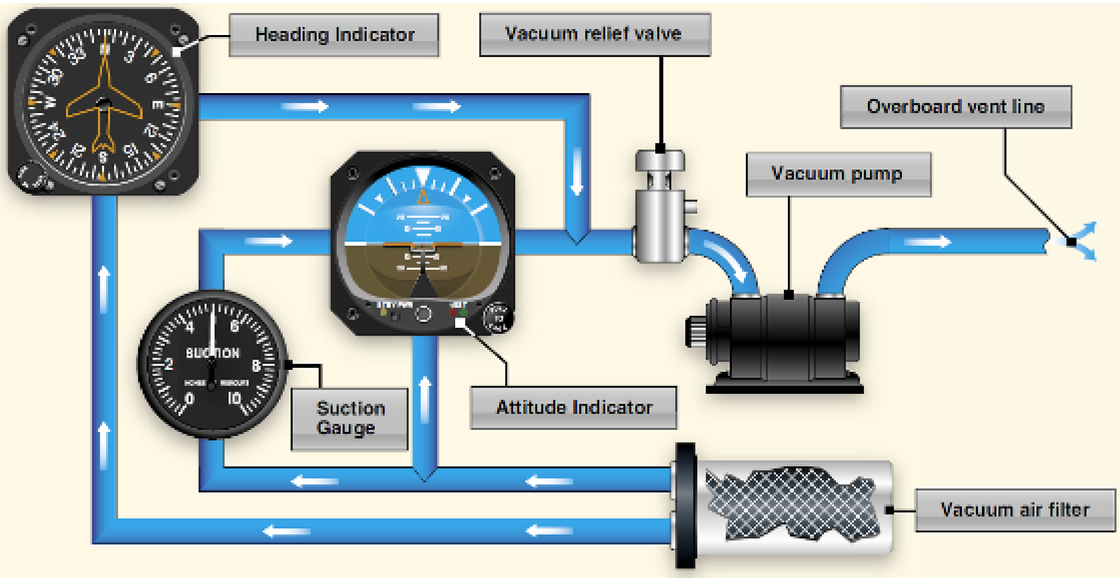
A gyro with a horizontal spin axis will appear to drift when is transported to the east or west by the aircraft. Change of longitude, described as **transport**, results in a change in the direction of the meridian and thus there is apparent drift when the gyro spin axis is compared with the meridian. In navigation, the changing direction of the meridian is referred to as convergency.

SUCTION AND ELECTRICALLY DRIVEN GYROS

The rotor of the gyro must be made to spin at a known, high RPM for the gyroscope to be useful. Originally aircraft gyros were driven by a vacuum system using suction developed by a venturi. Today the suction principle is still used (vacuum pump) but positive air pressure systems are also used. Advances in electrical systems have permitted the rotor of the gyro to be an electrical motor. Consequently, gyros can be electrically powered by either AC or DC power.

THE COMPARATIVE ADVANTAGES OF SUCTION AND ELECTRICAL GYROS

Suction gyros are not dependent on the aircraft's electrical power supply but otherwise suffer from a number of disadvantages. As air must enter and leave the casing, a suction gyro cannot be contained within a sealed case. In spite of filters, dust and moisture will enter affecting the balance of the gimbals and reducing bearing life. The suction pump is usually driven directly off the engine and so instruments cannot be run-up until the engine is started. At high altitude there may be insufficient suction to maintain the correct rpm.



Electrical Gyros can be constructed so that their rotors have a higher moment of inertia and spin speed. This is an advantage in instruments that rely on rigidity to provide readings. Electrical gyros operate at constant speeds and this is an advantage when a predictable rate of precession is required.

ERECTION AND LEVELLING SYSTEMS

Aircraft gyroscopes are **tied gyroscopes** which are slaved (influenced) to maintain their rotor axes either vertical or horizontal. The principle of erection is to maintain a rotor axis vertical. If a vertical misalignment occurs, the erection device will cause precession to re-erect the gyro.

The levelling principle is similar to erection except the levelling function maintains the rotor axis horizontal.

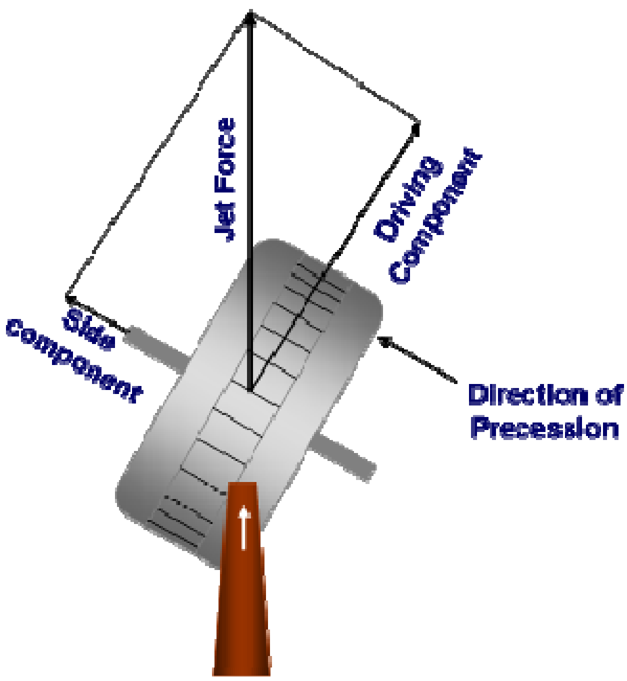
Both these systems sense a misalignment and cause a corrective action. Unfortunately, they sometimes sense or accept inputs (during accelerations or turns) that can induce errors. The errors will be discussed with each specific instrument.

The energy to operate erection and levelling systems is provided by either the vacuum or electrical systems.

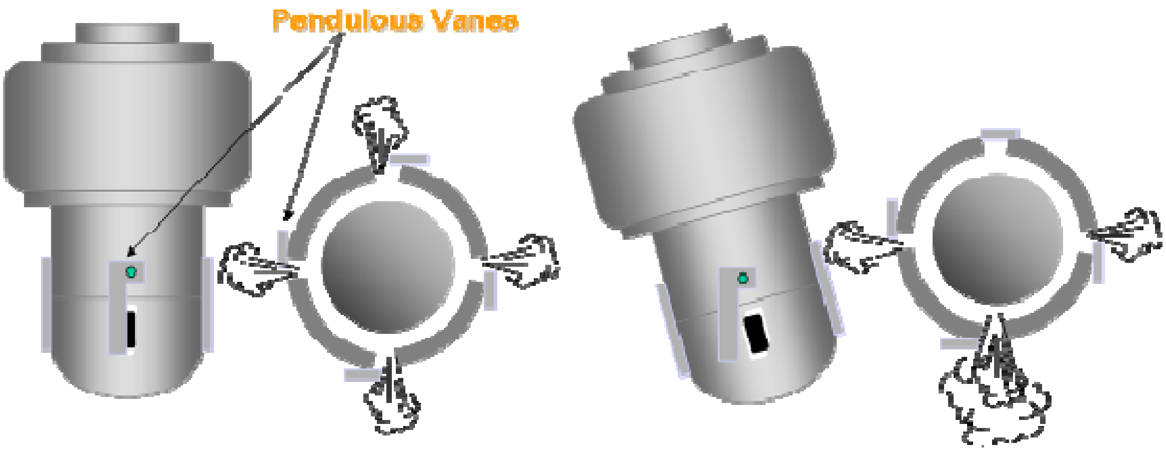
LEVELLING

An example of a levelling system is shown in the diagram to the right. The gyro spin axis would have been initially erected to the horizontal by means of a caging mechanism which locks the inner and outer gimbals at 90°. Subsequently the spin axis may have toppled due to the combined effects of real and apparent wander.

The main purpose of the air jet is to cause the rotor to spin but it also has the effect of maintaining the rotor in alignment with the vertical gimbal. If the gyro topples a component of the force from the air jet will act at right angles to the rotor, producing a precession which tends to erect the gyro.



ERECTION



An example of an erection system is shown in the diagram above. It should be assumed that when at rest the gyro unit was erected by the weight of the heavy base acting like a pendulum. Subsequently the gyro may have experienced real or apparent topple.

When the gyro is erect, the air exhausts equally through four apertures at the base of the gyro. The size of the jets is controlled by the pendulous vanes which hang vertically under the influence of gravity. If the spin axis moves away from the vertical, the pendulous vanes cause the air jets to become unequal, resulting in a force on the base of the gyro. This force results in precession which erects the gyro to the vertical.

Other erection systems make use of electrical forces but their common element is that they are gravity-sensing.