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DOCUMENT TITLE
AIRCRAFT GENERAL KNOWLEDGE

CHAPTER 10 – INSTRUMENTS AND AUTOPILOT

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INSTRUMENTS AND AUTOPILOT

10.1 Engine Instruments

10.1.1 Introduction

Engine instruments are a vital element in operating an aircraft engine in a controlled and safe manner. A pilot must have constant presentation of the engine condition in order to maintain aircraft performance parameters. In addition there is the necessity to operate the engine within the manufacturer's limits and tolerances.

10.1.2 Tachometer (RPM Indicator)

This instrument enables the pilot to select the required engine speed. On an engine fitted with a fixed pitch propeller this is the only power indicator available. An upper RPM limit is critical; to exceed this limit will damage the engine.

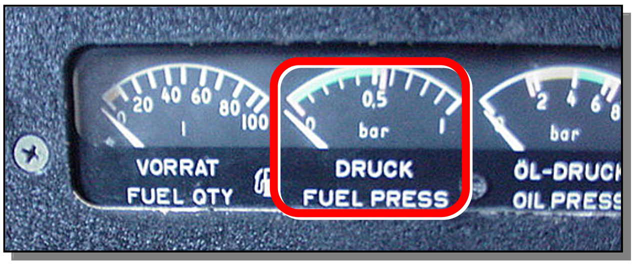
10.1.3 The Manifold Pressure Gauge

The manifold pressure gauge enables the pilot to select and maintain the required manifold pressure in order to set the desired power output from the engine. It is a measure of the air pressure within the engine intake manifold and is influenced by throttle position and RPM settings. It is usually fitted to an aircraft that has a variable pitch propeller.

10.1.4 Fuel Pressure Gauge

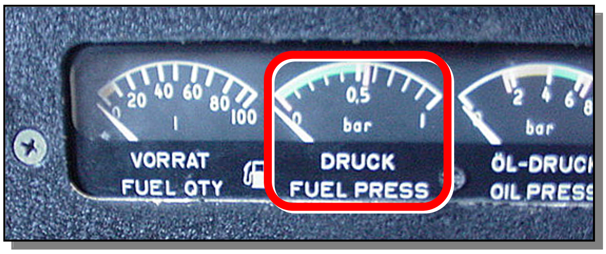
The fuel pressure gauge has different purposes depending on the type of fuel system involved. These are:

- To indicate that the fuel pump (either engine or boost) is supplying fuel in sufficient quantity to the carburettor.



- To indicate fuel pressure (fuel flow) at the discharge nozzles in a fuel injection system.

10.1.5 Fuel Quantity Gauge

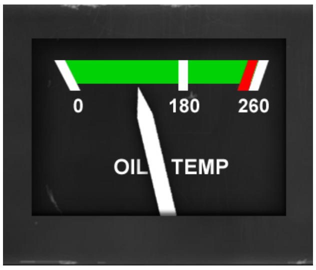


Provide the pilot with a continuous indication of the fuel tank quantities. Not considered to be entirely accurate at all times, a cross reference by visual checks is desirable before flight. Aircraft manoeuvring and attitude changes could create indicator errors.

10.1.6 Oil Pressure Gauge

An oil pressure gauge displays the regulated pressure output from the engine oil pump. Lack of indicated oil pressure is cause for concern; without lubrication an engine will soon fail. On initial engine start up positive oil pressure must be displayed within 30 seconds, if not the engine must be shut down immediately. To enable proper lubrication of the engine, power settings are limited until a minimum oil temperature is reached. This ensures that the oil has reached an adequate viscosity level before high loads are placed on the engine.

10.1.7 Oil Temperature Gauge



For the oil to perform effective lubrication and cooling functions it needs to be within a prescribed temperature range. This gauge will indicate when those conditions exist. If the oil temperature is outside the prescribed limits proper lubrication will not be achieved.

10.1.8 Cylinder Head Temperature Gauge (CHT)

A CHT gauge indicates the temperature of the cylinder head; it is the best indicator of potential detonation occurrences. Operating on the thermocouple principle, a probe is embedded in the cylinder head fins and provides a constant reading of the engine operating temperature. While ever there is heat applied to the probe it will generate a current and thus it is not dependent on the aircraft electrical system.

Temperature changes within this mass of metal are not immediate and the gauge may lag in its indication.

Maximum and minimum temperatures are set for normal operations; to exceed these is likely to result in engine damage.

10.1.9 Exhaust Gas Temperature Gauge (EGT)

The EGT gauge operates with a probe similar to the CHT, inserted in the exhaust pipe. It registers the temperature of the exhaust gases which are directly affected by the fuel air mixture ratio.

10.1.10 Carburettor Air Temp Gauge (CAT)

The carburettor air temperature gauge is useful in detecting potential engine icing conditions. Usually the face of the gauge is calibrated in degrees Celsius (ºC), with a yellow arc indicating the carburettor air temperatures at which icing may occur. This yellow arc ranges between -15° C and + 5° C.

The temperature probe is usually located near the throttle valve as this is the area most prone to icing.

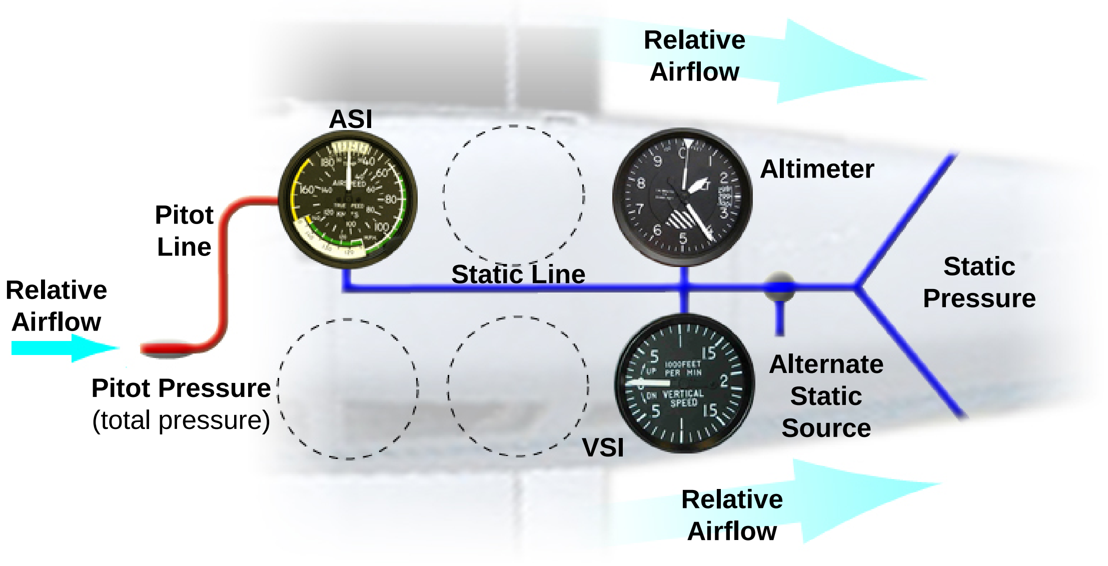
10.2 Flight Instruments

Flight instruments enable an airplane to be operated with maximum performance and enhanced safety, especially when flying long distances. Manufacturers provide the necessary instruments, but to use them effectively pilots need to understand how they operate.

10.2.1 Pitot Static (Pressure) Instruments

The three pressure flight instruments that make use of the pitot and/or static pressures are:

- The altimeter, which is sensitive to static pressure for altitude indication
- The airspeed indicator, which determines the difference between total pressure (dynamic + static pressure) and static pressure to provide indicated air speed
- The vertical speed indicator that relates the rate of change of static pressure to a rate of climb or descent.



The **Pitot Tube** senses total pressure and the aeroplane's Static Vents provide the measurement of static pressure. There are two common arrangements of the Pitot/Static sensing systems:

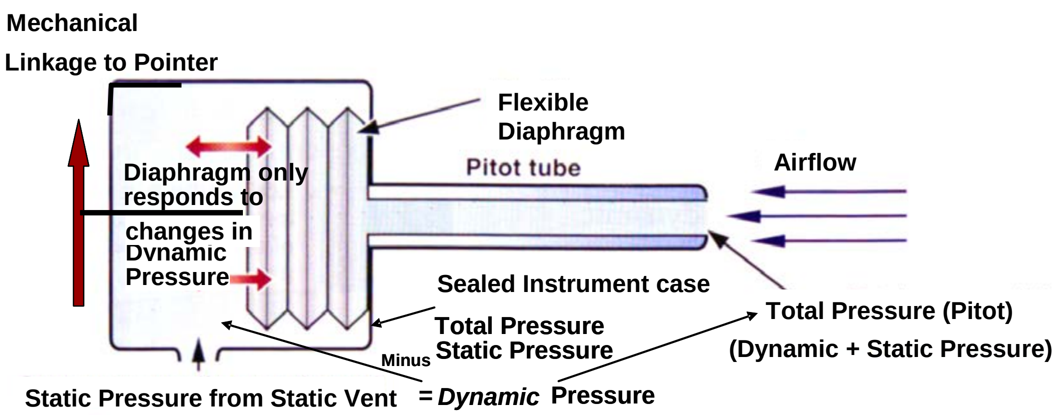
- A combined Pitot Static head
- A Pitot Tube usually on the wing and two Static Vents on opposite sides of the fuselage.

Most aeroplanes have two Static Vents, one on each side of the fuselage, so that the reading for static pressure, when evened out, is more accurate, especially if the aeroplane is slipping or skidding. This is known as a *balanced static system*.

10.2.2 The Pitot/Static Probe

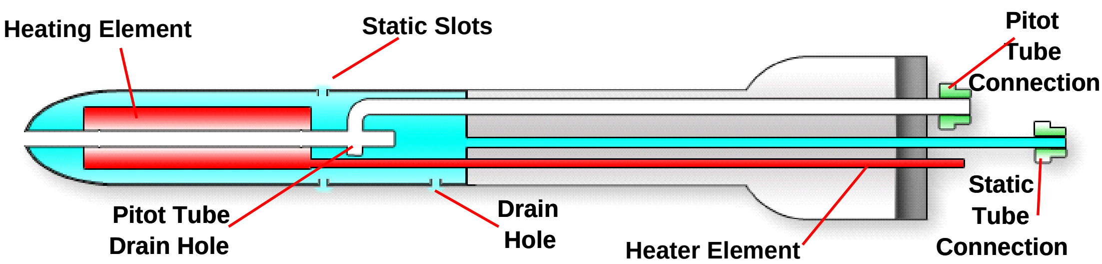
The basic Pitot-Static System probe is mounted at a position where it projects into the undisturbed airflow (along the longitudinal axis of the aircraft), and can measure the required pressure accurately, without distortion of the pressure by airflow over the probe itself, or from disturbed airflow from the aircraft structure. Generally on a single engine aircraft it is mounted under one of the wings whilst on a twin engine aircraft it is mounted on the nose of the aircraft, this ensures that it receives undisturbed airflow.

The probe measures total pressure. This is a combination of dynamic and static pressures. The value of dynamic pressure depends both on the speed of the aircraft through the air and on the density of the air. The probe therefore encounters a total pressure consisting of static plus dynamic pressures. You can feel this type of "total pressure" for yourself if you hold your hand out of a moving car with the flat of your hand facing the direction of motion. The airspeed indicator (ASI), however, is only sensitive to changes in dynamic pressure so the measured Total Pressure has to be separated into static and dynamic pressures, which is accomplished within the ASI as depicted below.



10.2.3 Pitot Heater

If the probe was to ice up during flight, airspeed indication would be lost. For this reason most probes are fitted with a heating element powered by the aircraft electrical system. A functional check of the heater is a normal pre-flight requirement. Power should be applied only briefly on the ground to avoid overheating the element.



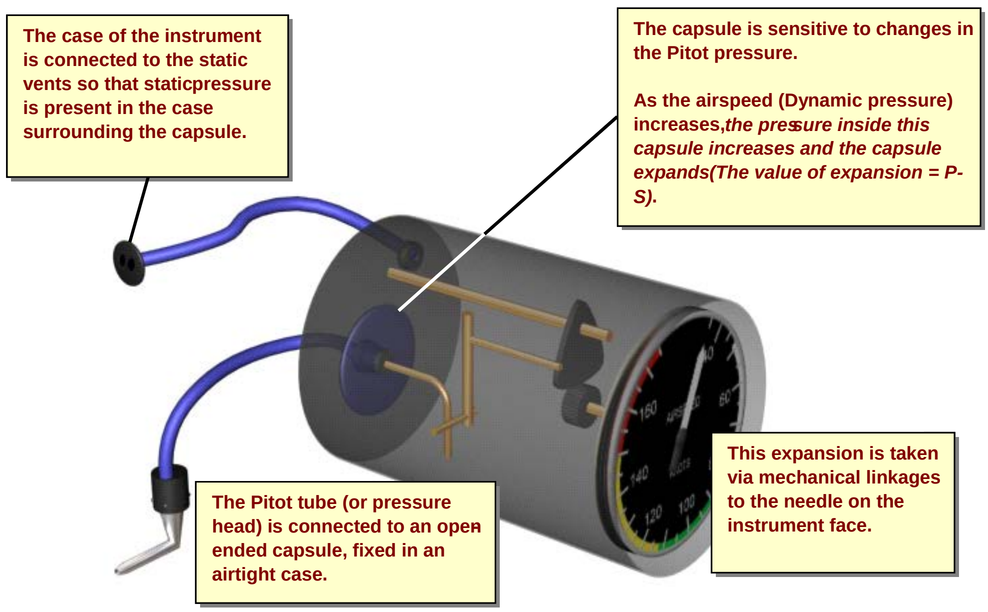
10.3 The Airspeed Indicator

10.3.1 Description and Purpose

Pilots need to know the speed at which an aircraft passes through the air because not only is it essential to air navigation, it is also vital to the safe handling of an aircraft.

The airspeed indicator (**ASI**) is basically a very sensitive pressure gauge that measures the atmospheric pressure around the aircraft as well as the pressure due to the movement of the aircraft through the air (dynamic pressure).

10.3.2 Construction



The airspeed indicator continuously subtracts the static pressure from the pitot pressure and presents this information (dynamic pressure) in terms of the aircraft's airspeed on a graduated scale in knots in the cockpit.

10.3.3 ASI Colour Coding

Colour coding on the face of the ASI highlights important speed limits which can affect aerodynamic loading on an aircraft structure.

The white arc indicates the flap operating range from stall speed at maximum all up weight in a landing configuration **(Vso**) to the maximum flap extension speed (**Vfe**).

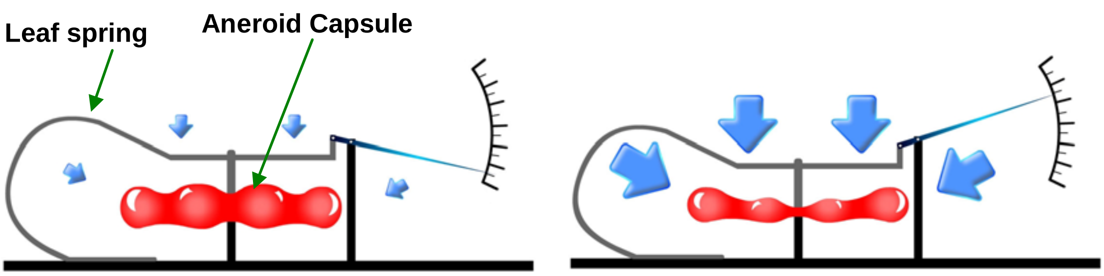
The green arc indicates the normal operating range of airspeeds from stall speed at maximum all up weight, landing gear up, flaps up and power off **(Vs1)** to maximum structural cruise speed **(Vno).**

The yellow arc indicates a caution range of speed which should only be used in smooth air extending from **Vno** to **Vne**.

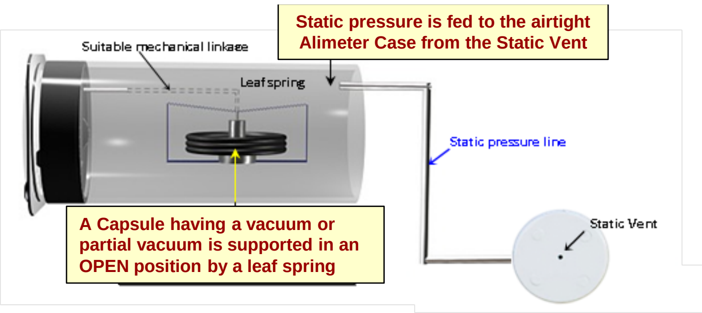
A red line marks the maximum structural speed limit and should never be exceeded. It is described as **Vne.**

10.4 The Altimeter

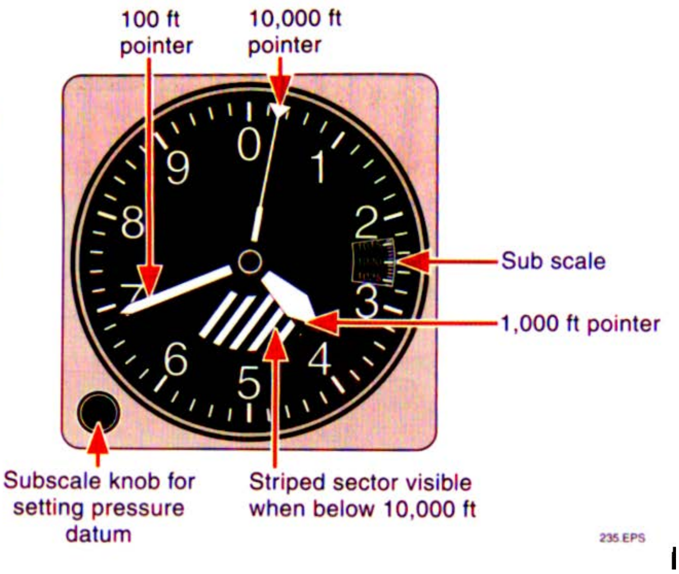
An altimeter is very similar to an Aneroid Barometer. An Aneroid is a partially evacuated metal capsule placed in an instrument casing that is completely sealed and connected to the static system. As the aircraft climbs and descends, the static pressure acting on the capsule varies resulting in expansion and contraction of the capsule which, when relayed by the mechanism, causes a change in the indication of altitude.



The dial of a typical altimeter is graduated with numerals arranged clockwise from 0 to 9. Movement of the aneroid element is transmitted through gears to the three hands that indicate altitude.



Because sea Because sea level and aerodrome pressures change with the weather, a mechanical device with a subscale is fitted to the altimeter so that a starting point (zero reference) or datum can be set. The common datum used is **mean sea level** and this datum point is known as **QNH**. In most cases QNH is used so the altimeter will indicate altitude or vertical distance from mean sea level.



10.4.1 Setting the Subscale

The altimeter is calibrated according to ISA's sea level pressure of 1013.25 hPa.

ISA is, however, only the ideal. As sea level pressure changes, a barometric error is evident. The error is corrected by the barometric setting control and the QNH (actual atmospheric pressure) is set.

The actual atmospheric pressure is obtained from Air Traffic Control and when set the airfield's elevation will be displayed on the instrument. The altitude indication also serves as an instrument serviceability check.

Whenever the pressure changes, the indication is erroneous again.

When departing your airfield, you will need to set the **actual QNH** and once en route the **Area QNH** (Forecast) is set.

Up to about 5000 ft, 1 hPa difference on the Subscale is approximately equal to 30 ft. If the QNH is set in error by 2 hPa, then the reading on the altimeter will be in error by approximately 60 ft.

For example, if flying at 5000 ft and the subscale is set to 1026 hPa instead of the true value of 1028, then the altimeter will read (5000 – 60) =4950 ft. This is known as **barometric error:**

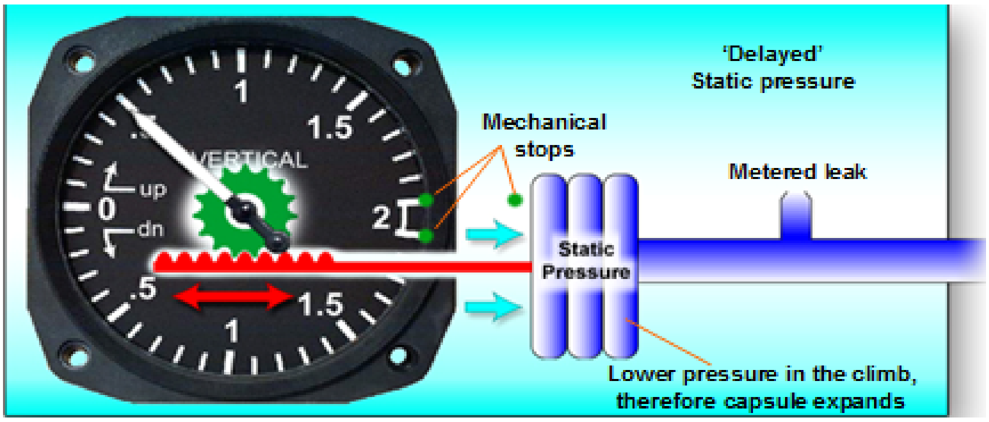
- If the subscale setting is too low, the altimeter will read low
- If the subscale setting is too high, the altimeter will read high
- The Subscale may be calibrated in either millibars Mb or hectopascals hPa.

NOTE: 1Mb = 1 hPa or, if operating in the USA, Inches of Mercury **"/Hg**

10.5 The Vertical Speed Indicator (VSI)

The purpose of the VSI is to indicate the aircraft's rate of climb or descent in feet per minute. The altimeter measures altitude from static pressure whereas the VSI measures rate of change of altitude from rate of change of static pressure.

Static pressure is directed to the VSI where it is fed to the inside of a capsule and to a metering unit. The capsule will react when the pressure inside the capsule is different from the pressure outside the capsule.



The air flows through the metering unit but the flow is restricted, causing a pressure difference between the inside and outside of the capsule. The amount of capsule expansion or contraction depends on the size of the pressure difference. If the pressure change is small (slow climb/descent), the pressure difference will be small and so the indicated rate of climb or descent will be low. However, during a rapid climb or descent the pressure change is large. The metering unit restricts the air flow and a larger pressure difference is created, keeping the indicated rate high.

10.6 Instantaneous Vertical Speed Indicator

One of the problems associated with VSI's is **LAG**, whereby it takes a few seconds for the VSI to begin to indicate a Climb/Descent after the aircraft has started to climb or descend.

An IVSI (Instantaneous VSI) contains Accelerometer pumps which act under the influence of positive or negative 'G' forces to immediately indicate a rate of Climb or Descent.

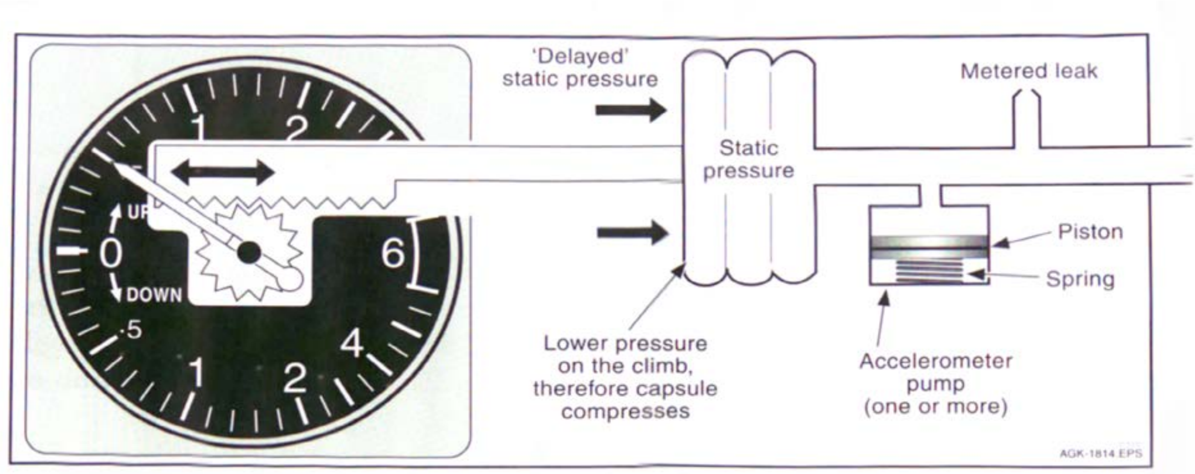
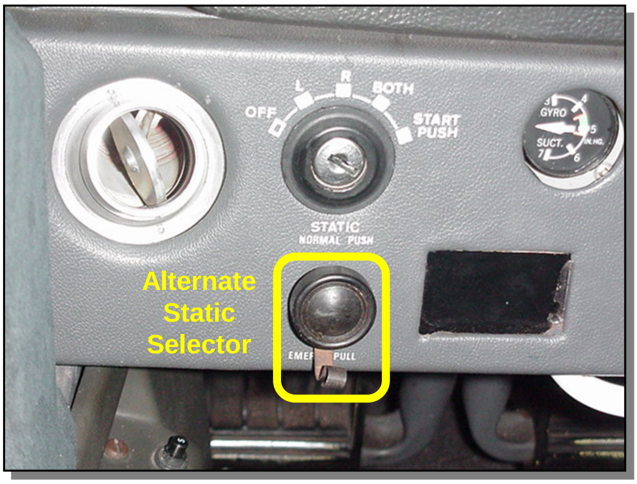


Figure 13-14 Instantaneous VSI.

10.7 Alternate static



As a protection against blockages or icing, there is often an alternate static source that can sense ambient pressure inside the cabin or engine nacelle, control of alternate static is via a cockpit mounted selector. Due to the location of the source of alternate static pressure a correction table may need to be consulted for altimeter readings. If the alternate static source is the pressure within the cockpit the pilot should be aware that as this pressure will be LOWER than the ambient Pressure, the ASI and altimeters can therefore be expected to over read when the alternate static is selected.

10.8 Blockages and Leaks

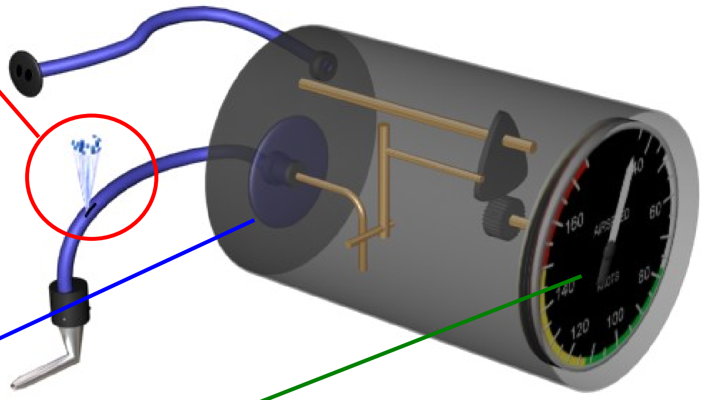
10.8.1 Leakage in the Pitot Line

If there is a leak in the pitot line from the pitot tube to the ASI capsule,

the Dynamic pressure will decrease before it reaches the capsule in the instrument.

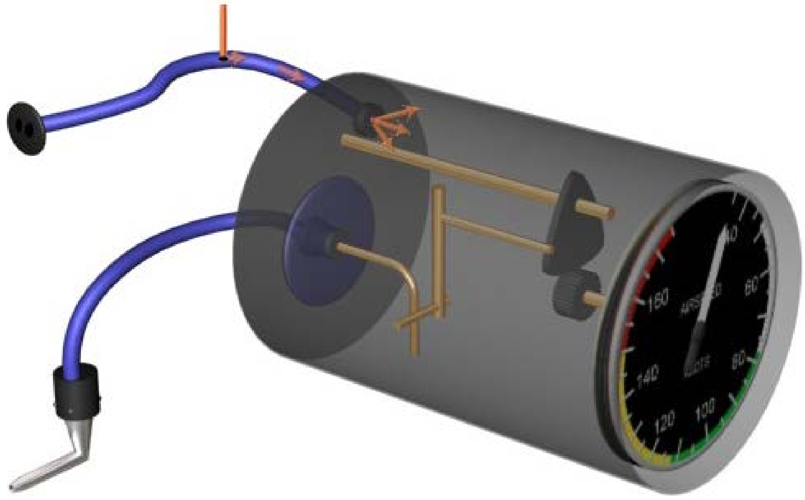
The capsule will expand less because of the reduced difference between the Dynamic - and the Static pressure,

causing the ASI to underread



10.8.2 Leakage in the static system

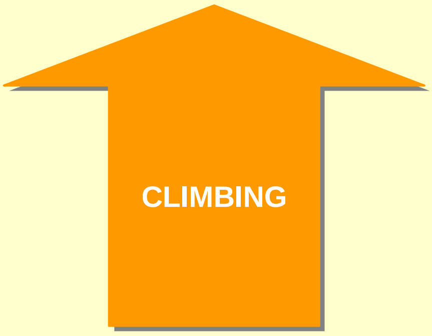
A leak in the static system would not have a great influence in unpressurised aircraft where the outside air pressure (static pressure) = pressure inside the aircraft around the instrument case.



In ***Pressurised*** aircraft, the situation differs in that the pressure inside the aircraft (that is higher than atmospheric or static pressure) enters the static system via the leak, causing the ASI to under read because of the decreased difference in the static and dynamic pressure.

10.8.3 Blockages

The effects that blocked Pitot or Static lines will have on an aircraft during climbing and descending is as follows. **Note: P** = Pitot pressure and **S** = Static pressure.

		
PITOT BLOCKED	**P** should decrease with altitude. **P** is too high - ASI **OVERREADS.** Effect: Raise nose - Aircraft Stalls. 	**P** should increase descending. **P** is too low - ASI **UNDERREADS.** Effect: Lower nose - Exceed Vne. 
STATIC BLOCKED	**S** should decrease with altitude. **S** in instrument case too high. ASI **UNDERREADS**. Effect: Lower nose - Exceed Vne. 	**S** should increase descending. **S** in instrument case too low. ASI **OVERREADS**. Effect: Raise nose - Aircraft stalls. 

A good mnemonic to memorise for ASI errors is P U D S U C:

P – Pitot blocked

U – (ASI) under reads

D – in descent (and OVER reads in CLIMB)

S – Static blocked

U – (ASI) under reads

C – in climb (and OVER reads in DESCENT)

10.8.4 Serviceability checks

The following checks are to be carried out on the ASI and pitot system before each flight:

- Ensure that the pitot cover and static vent pins (where applicable) are removed before flight.
- Check the pitot head for blockages, cracks or any other damage.
- Make sure the pitot head is not bent or misaligned with the airflow.
- The pitot heat should be turned on briefly during the pre-flight checks just to ascertain that it functions. Be aware that extended use of the pitot heater on the ground could lead to overheating of the heating element.
- As soon as possible after commencement of the take off run the airspeed indicator must be checked for a reading in order to ensure that the needle is not stuck on the dial.

10.9 The Gyroscope

A Gyroscope can be defined as "any mass that spins on its axis". Tops, wheels and aircraft propellers are but a few examples of gyros.

Even the earth itself, spinning on its axis, is a gyro.

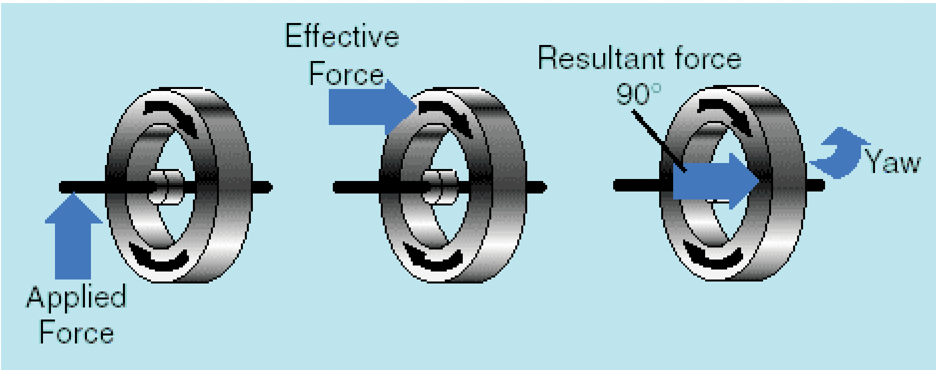
When a gyro spins on its axis, it acquires two properties, namely rigidity and precession. These properties are the key components that make them useable for the aviation industry.

10.9.1 Rigidity

Rigidity is a measure of the gyro's tendency to continue spinning in a set plane in space. This function will be dependent on the rotor mass, speed and radius.

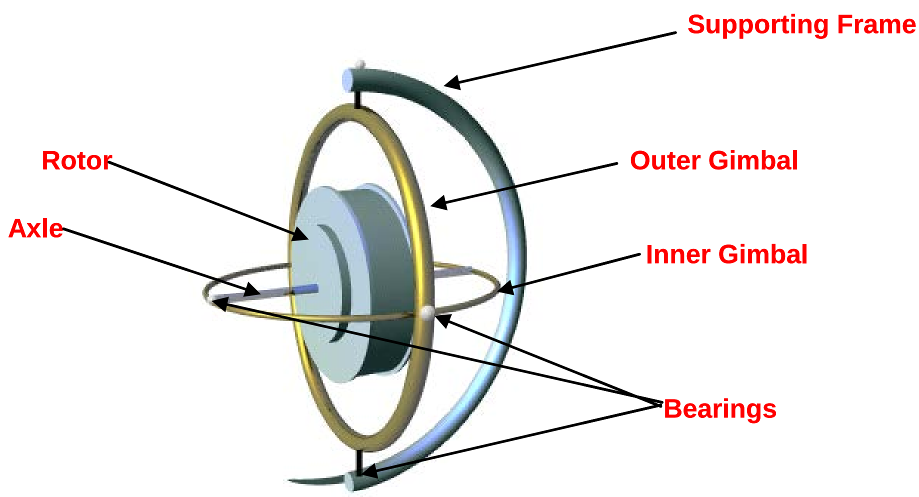
10.9.2 Precession

If a force is applied to change the direction of the gyro spin axis, the gyro will resist this force and will instead move its spin axis in a plane at 90° to the applied force.



10.9.3 Gyro Components and Types of Gyros

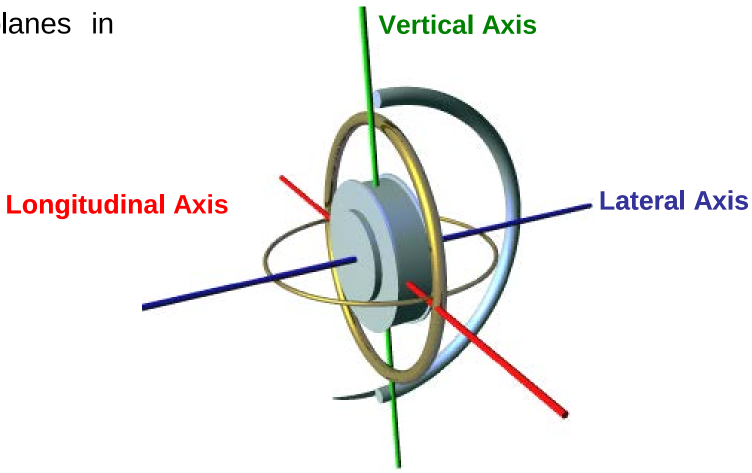
10.9.3.1 Components of the Basic Gyroscope



10.1.3.2 Types of Gyroscopes

Gyros fall into various classes determined by the number of planes of freedom the gyro is allowed to rotate. Freedom of movement is achieved by mounting the gyro in frames or rings referred to as gimbals.

The gyroscope has three planes in which it can rotate:

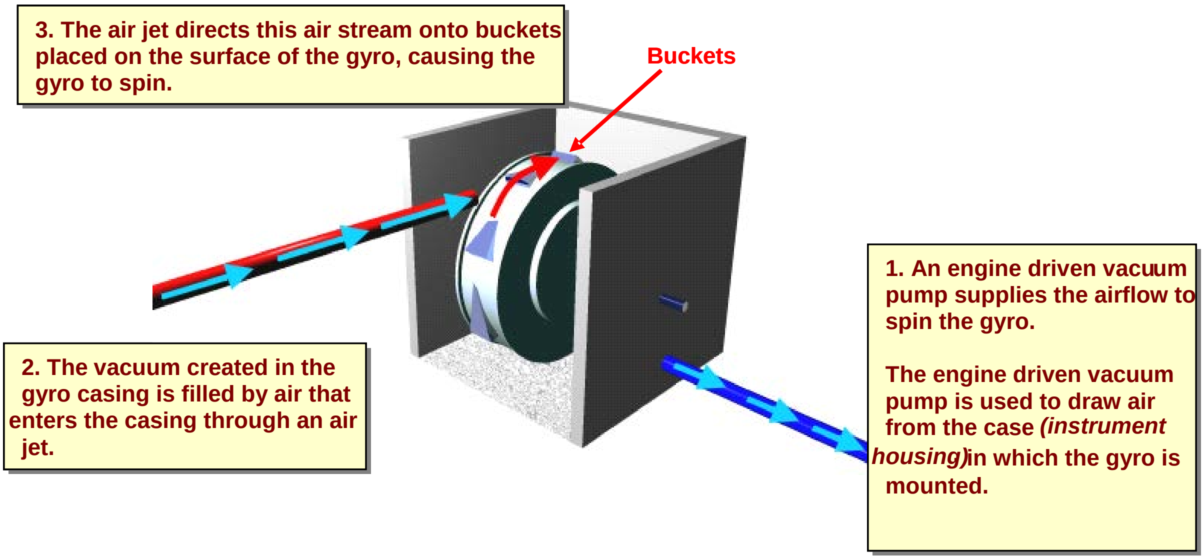


10.9.4 Gyro Driving Mechanisms

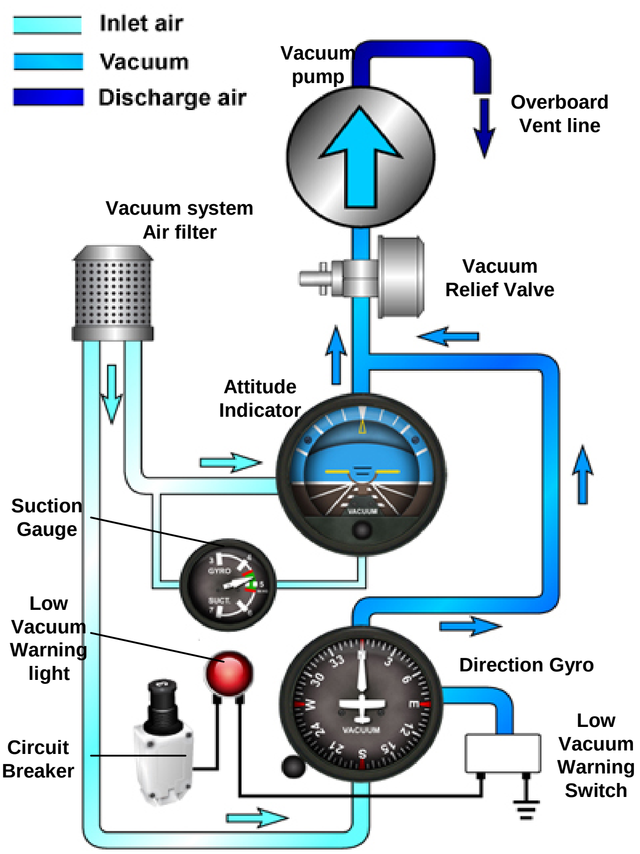
10.9.4.1 Air Driven Gyros

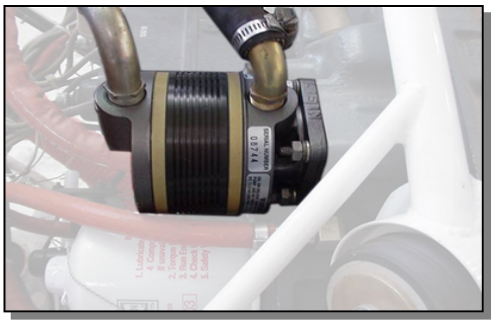
Although air driven gyros are the oldest and their rigidity decreases with increasing altitude, they are often still found in modern aircraft, especially in backup or duplicate instruments. The reason for this is twofold:

- Air driven gyros are relatively cheap to manufacture.
- Air driven gyros do not depend on an electrical supply of power and are thus not exposed to the hazards due to electrical problems such as those that can be encountered when flying in thunderstorms.



A schematic is shown of the Engine Driven Vacuum System with its various components:





Example of the engine driven vacuum pump

Example of the Suction Gauge Located in the cockpit.

10.9.4.2 Disadvantages of Air Driven Gyros

At high altitudes the reduction in atmospheric pressure causes the amount of air that the vacuum pump displaces to decrease. This in turn causes less air to enter the gyro casing through the air jet, which causes the gyro to rotate at a lower speed. The slower the speed of rotation the less the rigidity of the gyro and the less accurate the indications given by the instrument using the gyro.

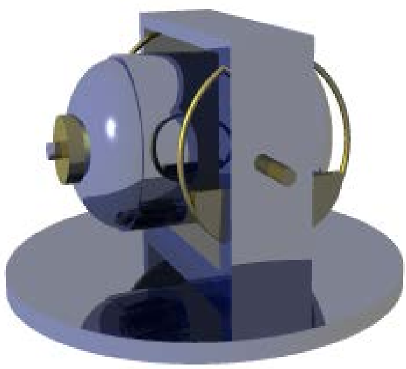
The air driven gyro takes quite a long time to attain its operational rotor speed. This is quite important in situations where aircraft have to get airborne in a minimum amount of time, such as when interceptors are scrambled in operational circumstances.

Because atmospheric air is used to rotate the gyro, moisture and dust in the atmosphere will in the long run accumulate in the instrument, impairing its efficiency and reliability.

10.9.5 Electrical Driven Gyros

Electrically driven gyros are nowadays the norm in the aviation world. The reasons for the industry preferring the electrically driven gyro to the air driven gyro are:

- Electrically driven gyros are more efficient than air driven gyros as higher rotor speeds are possible at all altitudes (with air driven gyros - high altitude - lower outside air pressure - thus less air supply to gyro suction pump). The electrically driven gyro has greater rigidity and more reliable indications at high altitudes.



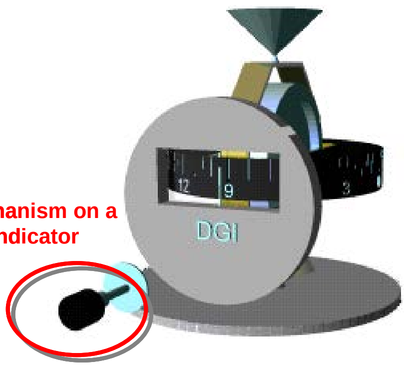
- The electrically driven gyro attains its operational rotor speed much quicker than an air driven gyro.
- The operational life of the electrically driven gyro is longer than the life of the air driven gyro since the gyro's casing can be sealed, keeping out dust and moisture.

10.9.5.1 The Comparative Advantages of Suction and Electrical Gyros

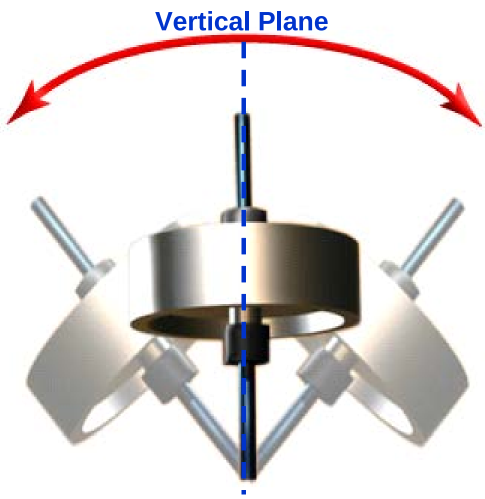
- **Suction Gyros:** Suction (vacuum-driven) gyros are independent of the aircraft's electrical power supply, but otherwise suffer from a number of disadvantages when compared to electrically driven gyros. As air must enter and leave the casing, a suction gyro cannot be contained within a sealed case. In spite of filters, dust and moisture will enter, affecting the balance off 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. The electrical gyro will run up when the master switch is turned on. Additionally, at high altitude there may be insufficient suction to maintain the correct RPM.
- **Electrical Gyros:** Electrically driven 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, **HI** and **AI**, to provide readings. Electrical gyros operate at constant speeds and this is an advantage when a predictable rate of precession is required.

10.9.6 Caging

The term caging indicates the gyro gimbals are clamped so the gyro can be re-erected or levelled. When un-caged, the gyro should be working again. The caging and realignment process can be mechanical or electromechanical but is rare in modern aircraft



10.9.7 Gyro Topple

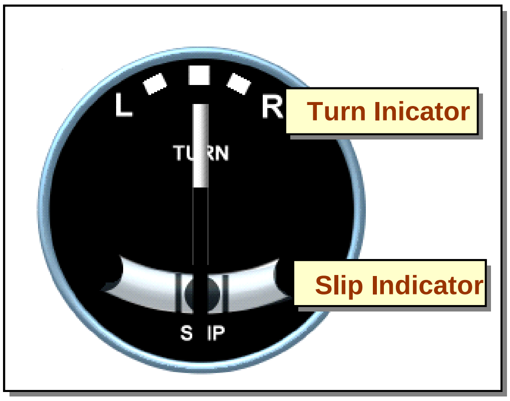


Any movement of the gyro axis in the vertical plane is called topple (tilt). The effect of topple depends on the gyro axis alignment and can also relate to latitude and earth rotation. The types of gyroscopes used in aircraft make the effects of topple less obvious than drift.

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. This could occur for example when an aircraft performs aerobatics and the extreme manoeuvring causes the gimbals to be forced against their limiting stops. The rotor is no longer isolated from the aircraft movement (instrument casing) and a rapid precession misaligns the axis.

10.10 Turn and Slip Indicator and Turn Coordinator

10.10.1 Turn and Slip Indicator



The Turn and Slip indicator was the first aircraft flight instrument to make use of a gyroscope. This instrument combined with the magnetic compass made a valuable contribution to the art of flying without external references.

Although in modern large aircraft the role of this instrument is of secondary importance, in smaller types of aircraft the turn and slip indicator is second only to the artificial horizon in importance for instrument flying.

The turn and slip indicator contains two independent instruments namely a:

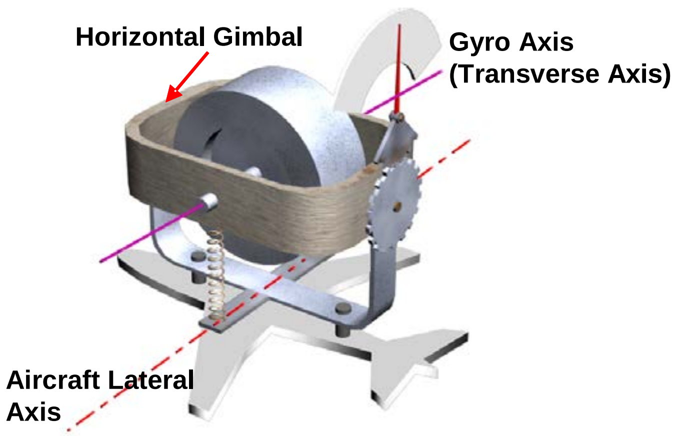
- Turn indicator
- Slip indicator.

10.10.2 Construction – Turn and Slip Indicator

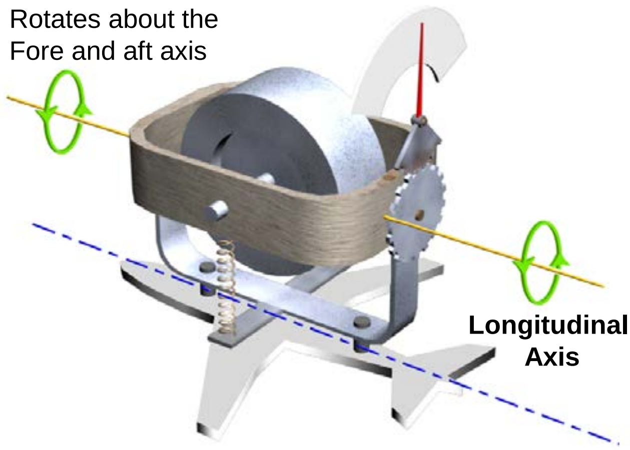
A turn indicator uses a rate gyro (horizontal axis gyro) that spins at a relatively slow speed: 9000 RPM.

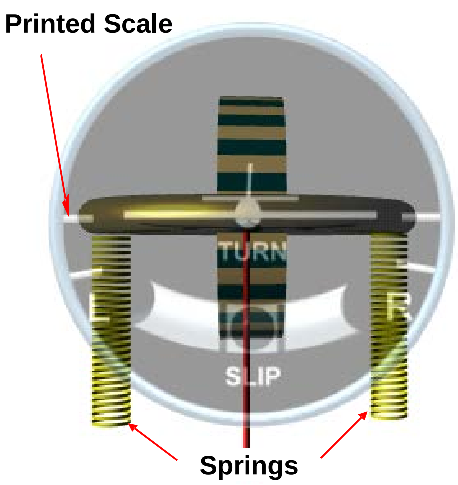
The reason the gyro spins slower than normal is to reduce the rigidity of the gyro so that the force required to precess the gyro is less. Precession is important in the instrument as it provides the measure of turn.

The gyro is mounted in a horizontal gimbal with the axis of the gyro parallel to the lateral axis (transverse axis).



Because of the way the gyro is mounted in the horizontal ring in the instrument case, the gyro has freedom of movement in one plane only - that is about the fore - and - aft axis (Aircraft's Longitudinal Axis).





The rotor of the gyro can be driven either by air or electricity.

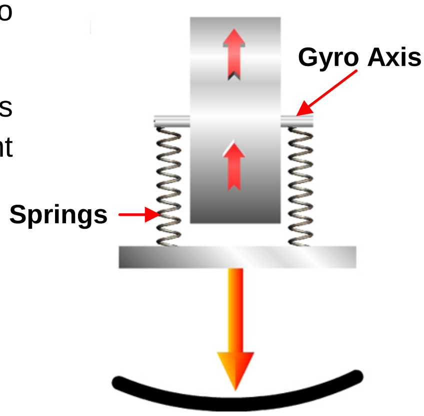
The instrument incorporates two springs, which hold the gyro axis horizontal when the aircraft is in level flight.

During normal straight and level flight, the two springs hold the gyro axis in the horizontal plane, thus preventing any unwanted precession, and the pointer attached to the vertical rotor indicates the central (or zero rate of turn) position on the printed scale.

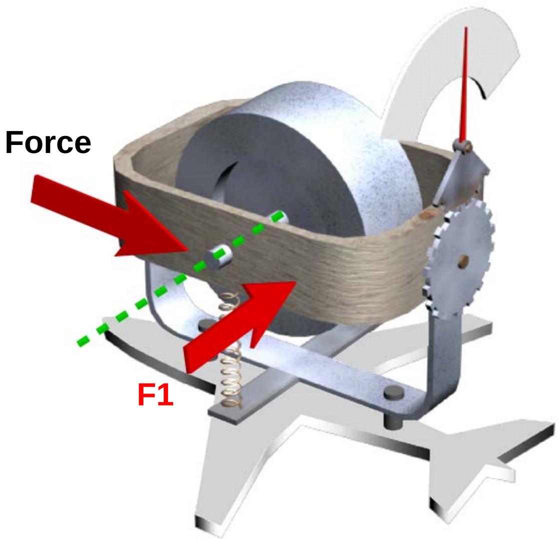
10.10.3 Principle of Operation Turn Indicator

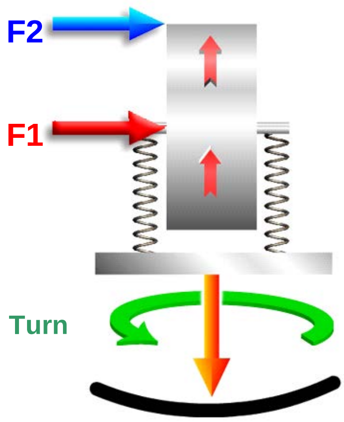
In straight and level flight the springs hold the gyro axis horizontal preventing unwanted precession.

The pointer attached to the vertical rotor indicates the central or zero position of the instrument against the printed scale.



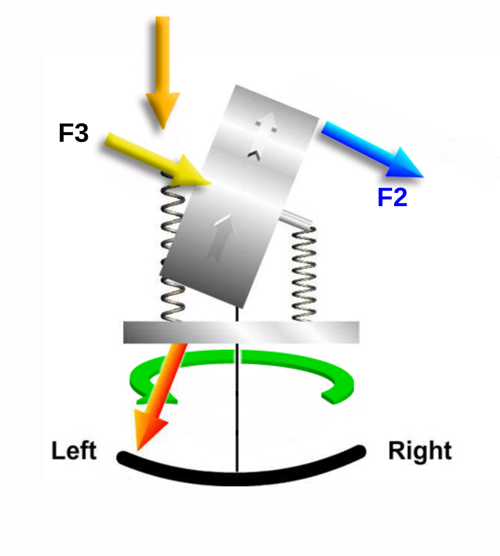
As the aircraft enters a turn the gyro axis (being rigid) opposes the turn and a force is experienced on the axis. This force can also be represented by **F1**





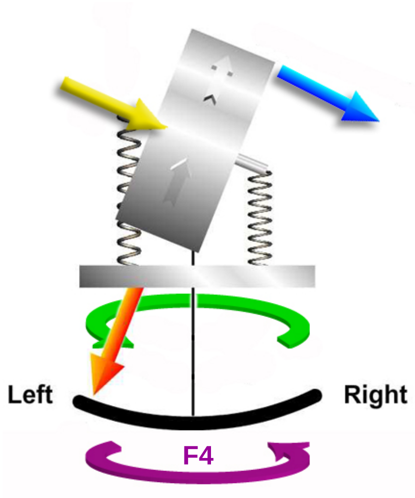
The force will precess through 90° and act at the top the rotor **F2** tilting the rotor. This tilt is called primary precession.

If no springs were attached to the rotor axis, the rotor would continue to tilt until it spun in the horizontal plane, with its axis vertical. This attitude would give no indication of the rate of turn.



However, because springs are fitted, one spring stretches and the other contracts as the rotor starts to tilt. In a left hand turn the left hand spring is stretched. This produces a force pulling down on the left hand axis or a force pushing up on the right hand axis **(F3)**.

This vertical force acting on the axis will precess the rotor in the horizontal plane in the direction shown - F4. This is called secondary precession. It will be seen that F4 acts in the same direction as that of the turn.



As the gyro continues to tilt further, the spring tension vector and consequently the magnitude of the secondary precession continue to grow. A stage will be reached where the rotor precessing under the initial force can no longer tilt any further against the spring tension. At this point the magnitude of the secondary precession is the same as the rate of turn.

Secondary Precession = Rate of Turn

Now the gyro axis that was initially reluctant to move with the aircraft because of its rigidity is precessing with the aircraft at the rate of turn. Therefore there cannot be further tilting of the rotor.

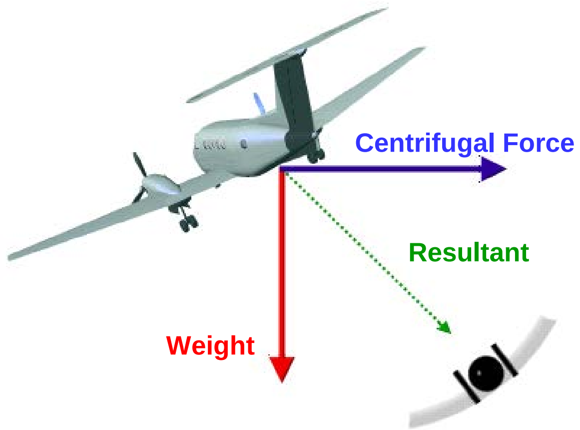
Whatever angle of inclination has been achieved during this sequence will be maintained as long as the aircraft continues turning at the same rate and no variations in the rotor speed (which affects its rigidity) occur.

10.10.4 Slip Indicator

The slip indicator is purely mechanical and depends on the forces acting on the steel ball (gravity and centrifugal force), which is in a tube filled with alcohol.

The slip indicator in a turn shows the resultant between the gravitational force and the centrifugal force acting on the aircraft.

The indication on the slip indicator will be an indication of how balanced an aircraft is flying during straight and level flight and manoeuvres such as turns.



NOTE:

a. **The steel ball rolls to the centre of the glass tube because it is the lowest part of the glass tube during level flight.**

b. **The function of the alcohol in the tube is only to create a certain amount of friction for the steel ball so that it will move slowly and not bounce from side to side when the aircraft is flying in turbulent conditions.**

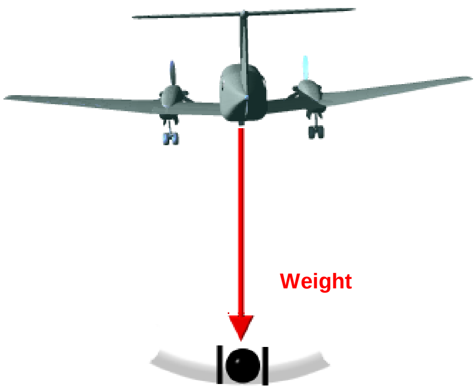
10.10.5 Indications

The following indications can be experienced during flight:

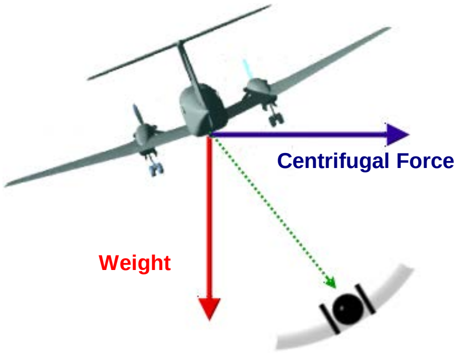
10.10.5.1 Straight and Level

During straight and level flight the four forces acting on an aircraft are in equilibrium.

In a case such as straight and level flight, the only force that will thus act on the weight of the steel ball (or the pendulous weight in the other type of indicator), will be gravity, acting in the true vertical.



10.10.5.2 Balanced Turn

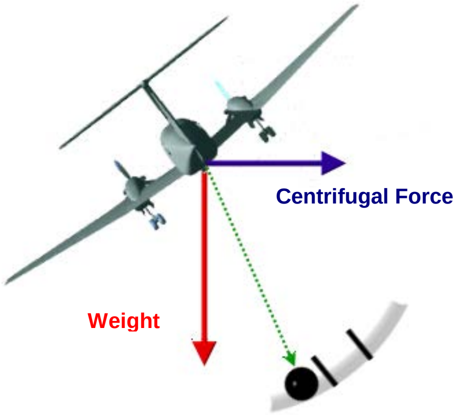


In a balanced turn the two forces, which act on the ball are gravity and centrifugal force. Gravity always vertical and CF always horizontally out of the turn. Being a balanced turn the resultant of the two forces will keep the ball in the neutral position.

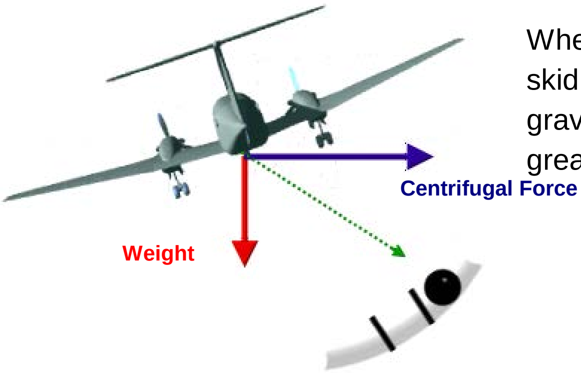
10.10.5.3 Slip or Excessive Bank

When a turn is overbanked the aircraft tends to slip into the turn. As it is slipping into the turn the horizontal CF force is reduced and the gravity force is greater.

The resultant vector of the two forces will favour the gravity vector and the ball will move in the direction of the larger force.



10.10.5.4 Skid or Insufficient Bank



When a turn is under-banked the aircraft tends to skid out of the turn. Now the CF is greater than the gravity and the ball will move in the direction of the greater force.

10.10.6 Serviceability Checks

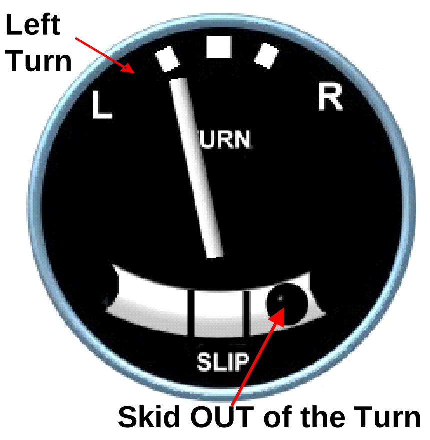
10.10.6.1 While Stationary

In the world of aviation safety is always of paramount importance. Before commencing a flight one will be expected to check and recheck most of the systems in the aircraft. Fortunately the checks for the turn and slip indicator are straightforward and easy to perform.

When the aircraft is standing on level ground, both the turn and the slip indicators should be in the central (zero) position.

It is important that the ground on which the aircraft is parked is level and that the aircraft's oleo legs are also equally compressed, so that the aircraft as a whole is level, thus the weight of the slip indicator can lie in the lowest part (the central position) of the glass tube and the springs on the axis of the gyro can keep the gyro axis in the true horizontal.

10.10.6.2 While Taxiing



The second check should be performed while taxiing the aircraft. While taxiing in a turn observe the turn and slip indicator individually: The turn indicator senses a change in direction relative to the axis of the gyro and indicates correctly as it would while the aircraft is flying. Normally while taxiing the rate of change in direction is fairly quick and the turn needle then goes to the limit of its travel on the indicator. This does not pose a problem as we are only interested to see that it indicates a turn in the correct direction.

The slip indicator senses an increase in centrifugal force due to the turn. Because the aircraft doesn't bank while taxiing, the value of centrifugal force will be high and the ball will skid out of the turn.

10.10.7 Calculating a Rate One Turn

Quite often during a flight, especially during instrument flights, a rate 1 turn is required (3º per second). The turn indicator, although designed to indicate a rate 1 turn, can prove difficult in keeping the needle of the turn and slip indicator exactly on the correct mark. A rule of thumb that can be applied to determine an angle of bank required to maintain such a turn (which can be monitored on the Artificial Horizon) is as follows:

10% of TAS + 7º = angle of bank for rate one turn.

> ***Example***
>
> If required to do a rate one turn in an instrument letdown at a TAS of 120 knots, as a rule of thumb put on 19º of bank.

10.10.8 Errors

10.10.8.1 Turn Indicator Errors

The tension of the spring is designed for a rate one turn and therefore at any other rate turns an error may be present.

The turn indicator is also calibrated for a specific rotor speed. If the rotor speed should change for any reason then an error can be expected.

Rotor speed low: lesser rate of turn indicated

Rotor speed high: greater rate of turn indicated

> **Note: the gyro of the turn indicator cannot topple as the springs hold it in the horizontal plane during level flight.**

10.10.8.2 Slip Indicator Errors

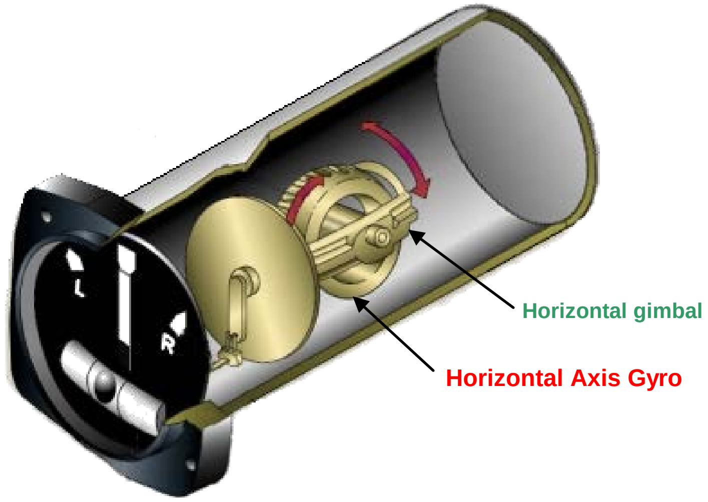
As this is an instrument that uses gravitational and centripetal forces there are no errors unless the tube in which the ball is suspended in has no fluid in it.

10.10.8.3 <u>Turn Coordinator Errors</u>

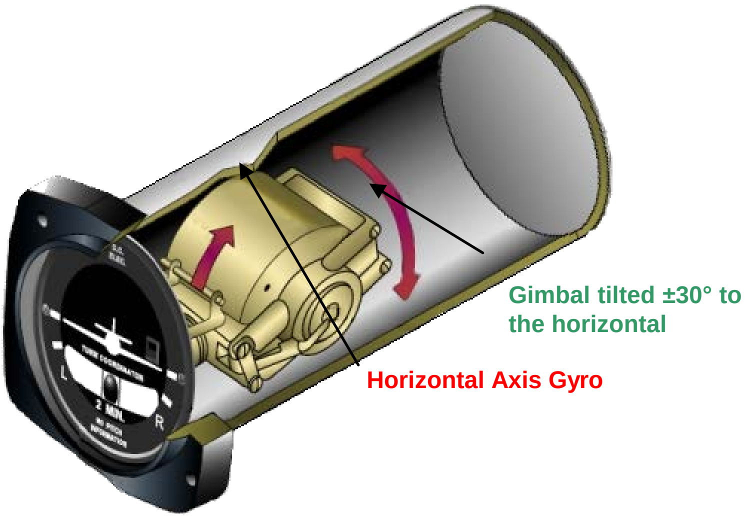
The turn coordinator is a flight instrument which displays to pilots information about the rate of yaw (turn), roll and coordination of the turn. The turn coordinator was developed to replace the older turn and bank indicator, which displayed rate of quality of turn but not rate of roll.

The turn coordinator differs from the older turn and bank indicator in that the turn coordinator has the gyro outer gimbal mounted at a 30° tilt and the turn and bank indicator has the gyro gimbal mounted horizontally. This allows the turn coordinator to respond to roll as well as turn. The TC indicator represents a sum of the roll rate and the yaw rate so it responds more quickly at the beginning and end of a turn than a turn and bank indicator. Pilots who are unfamiliar with this principle sometimes have difficulty using the turn coordinator properly, as they may see a **RATE OF TURN** indication and interpret it as **ROLL**.

Turn and Slip Indicator



Turn Coordinator



10.10.9 Turn Coordinator Indications

Coordinated turn

Slip

Skid

Unlike an Attitude Indicator, the Turn Coordinator only indicates Rate of Turn' not Roll. The Attitude Indicator indicates Pitch AND Roll. To avoid possible confusion Turn Coordinators are marked **"No Pitch Information"** on the face.

10.11 The Artificial Horizon (AH)

10.11.1 Description and Purpose

When flying in limited visibility with no reference to the outside horizon, maintaining a straight and level attitude became increasingly difficult.

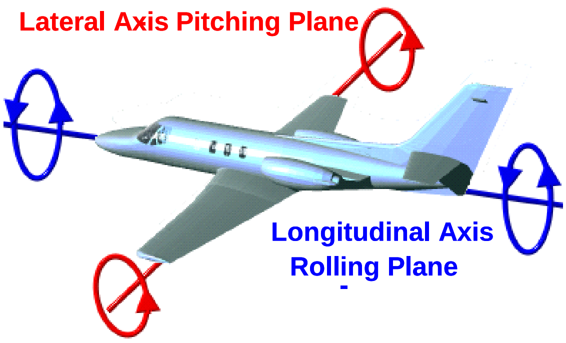
It was necessary to design an instrument that would indicate to the pilot their attitude with regards to the outside horizon. This instrument is known as an artificial horizon.

10.11.2 Principle of Operation

The artificial horizon provides a gyro-stabilised indication of the aircraft's attitude. The gyro is therefore placed in the horizontal (spin axis vertical) and has freedom in all three planes, spinning at about 15 000 RPM in the air driven models and about 20 000 to 23 000 RPM in the electrical types.

As the aircraft changes its attitude the ‘Earth gyro’ that is the basis of the AH retains its rigidity relative to the Earth’s vertical. This means the aircraft moves around the gyro of the AH. This gyro has a vertical spin axis, which is maintained vertical to the earth’s surface. The Artificial Horizon indicates the aircraft's attitude in:

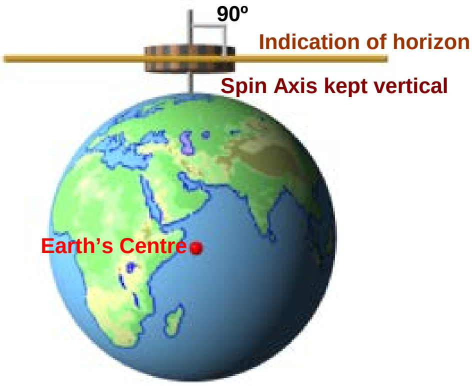
- **Pitching Plane**: Indication is given of the aircraft's nose attitude relative to the horizon.
- **Rolling Plane:** Indication is given of the aircraft's banking angle relative to the horizon.



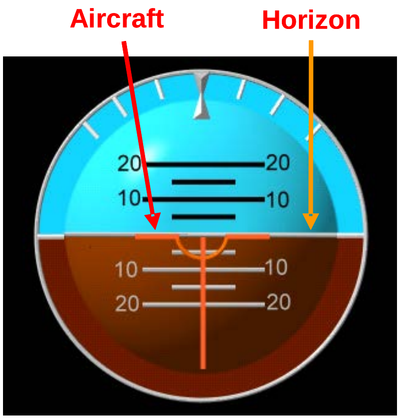
The spin axis is kept vertical with reference to the centre of the earth so that, a bar across and at 90º to the spin axis, indicates the horizon.

In flight an aircraft rolls and pitches about the gyro's axes, which remains rigid.

If the bar representing the horizon were replaced with a picture of the horizon (attached to the gyro), around which the aircraft moves, then the attitude of the aircraft with relation to the real horizon would be symbolised by the artificial horizon.



The aircraft attitude is symbolised by a small symbolic aircraft attached to the instrument dial.

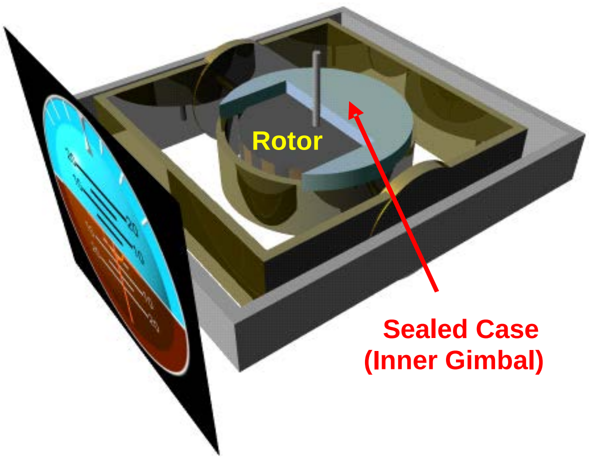


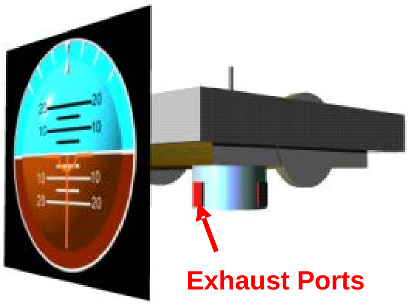
10.11.3 Construction

The rotor of the gyro is encased in a sealed case which acts as inner gimbal

Air is let in to the case under pressure; the pressure is either created by a pressure pump or by creating suction inside the case.

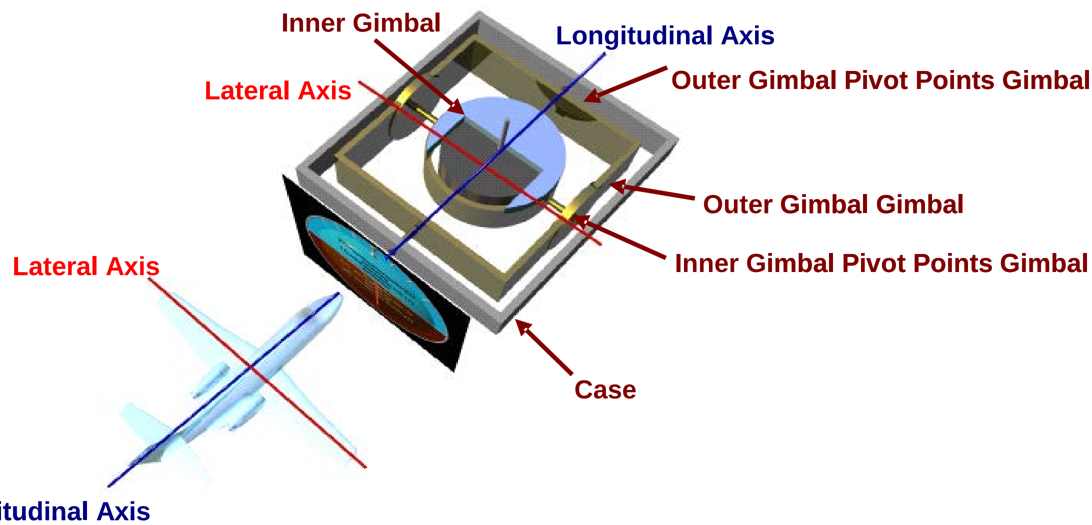
(The suction required is 4 - 5 inches of mercury).



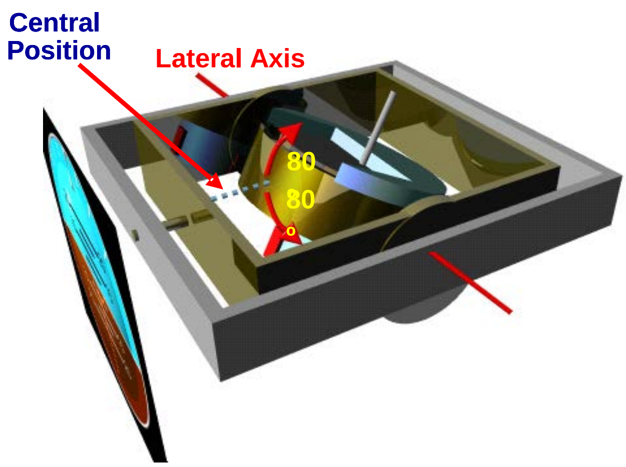


The rotor spins under pressure at the rate of approximately 15 000 RPM. Having spun the rotor, the air escapes from the case through four exhaust ports in a pendulous unit mounted at the base of the gyro.

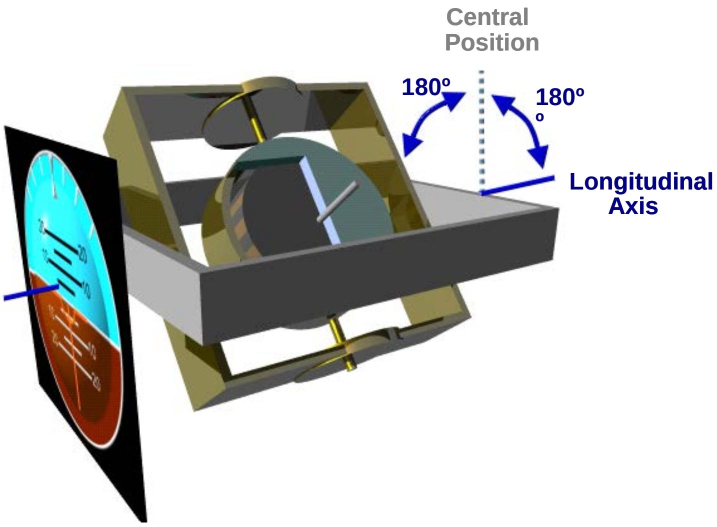
The inner gimbal is mounted in the outer gimbal with its axis lateral. The outer gimbal is mounted in the case with pivot points in the longitudinal axis of the aircraft.



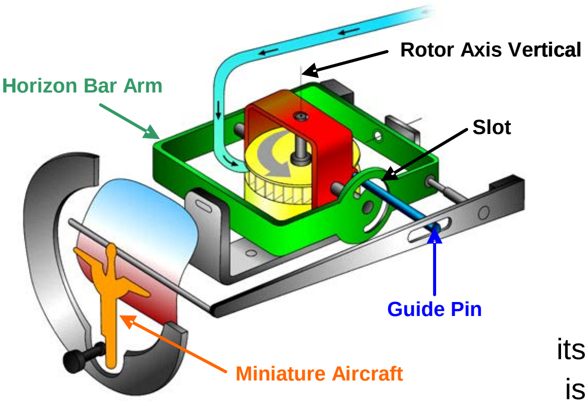
The inner gimbal having its movement about the lateral axis controls the indications in the pitch attitude. It has freedom of movement of about 80º either side of the central position depending on the model and type.



The outer gimbal controls the indications in the rolling plane bank (longitudinal axis) and has 180º freedom from the central position on either side.



Any movement relative to the inner gimbal is transmitted to the horizon bar arm through a guide pin on the inner gimbal.



During level flight the aircraft's vertical axis is parallel to the rotor axis and the guide pin is in the centre of the slot.

The horizon bar is in the centre and its extension across the face of the dial is in the centre of the miniature aircraft.

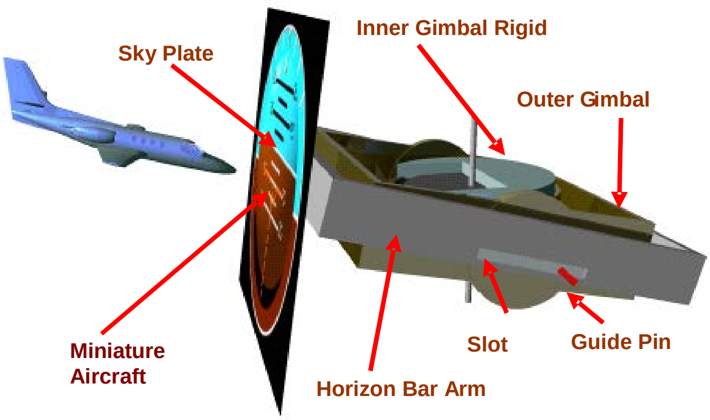
10.12 Instrument Indications

The instrument provides the pilot with visual indication of the aircraft's attitude in relation to the earth's actual horizon. These attitudes can be categorized as follows:

- Pitching
- Banking.

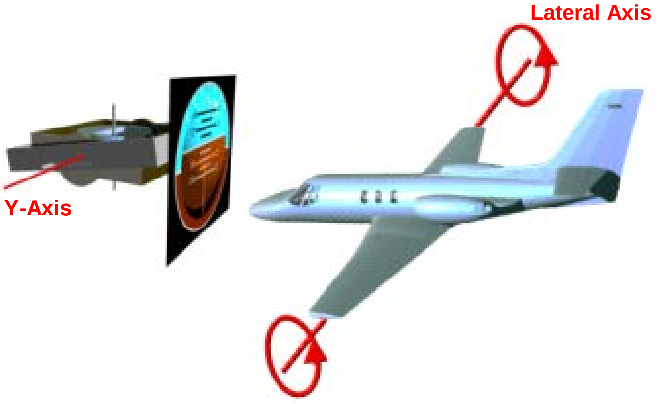
10.12.1 Pitching

When the aircraft climbs or descends the inner gimbal (rotor case) remains rigid whereas the outer gimbal and the instrument case move with the aircraft.



Due to the movement relative to the inner gimbal the guide pin gets displaced in the slot, taking the horizon bar arm with it; thus an indication of climb or descent results.

In this example the aircrafts nose is 10º below the horizon, as the miniature aircraft is below the horizon bar (in the brown portion of the skyplate).



As the aircraft pitches about its lateral axis it will pitch parallel to the Y-axis of the gyro rotor.

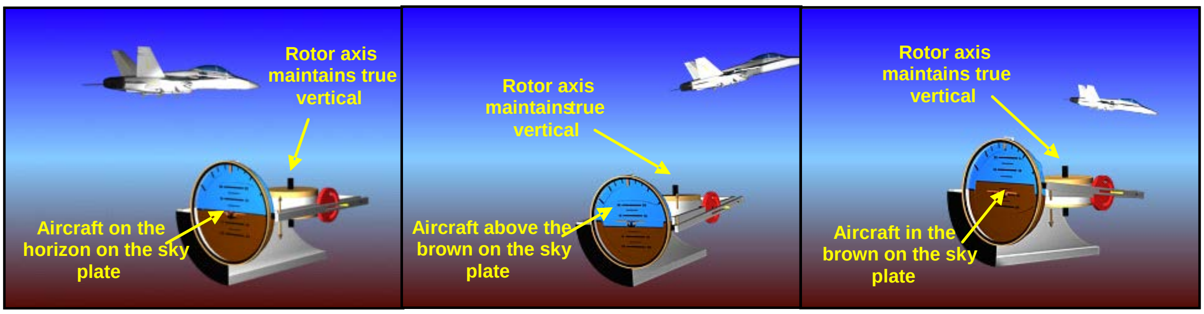
During pitching the only movement is around the Y axis of the gyro rotor.

As the aircraft pitches up and down parallel and along the Y axis of the rotor, the rotor remains in the true vertical and the outer gimbal moves up and down giving an indication of the aircraft's attitude above or below the horizon.

Note: The aircraft's movement around the axes represents the relative movement around the gyro rotor.

10.12.2 Pilot Indication

Indications of the pitching attitude are presented by the relative position of two elements: One symbolising the aircraft itself, and the other in the form of a bar (sky plate) stabilised by the gyro and symbolising the natural horizon.

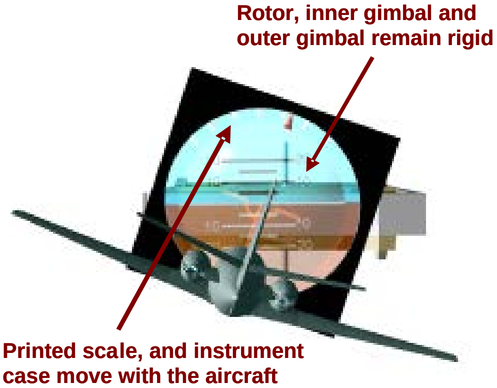


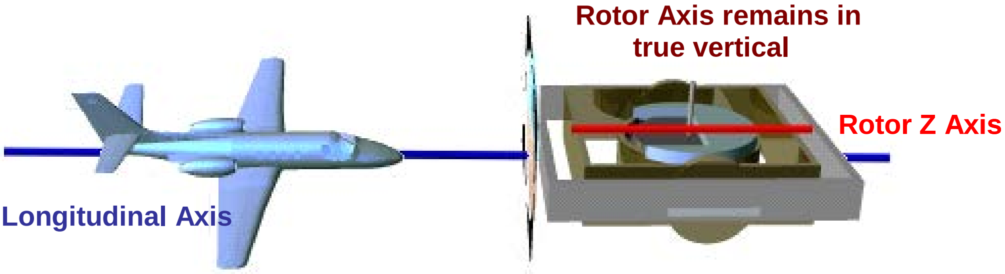
10.12.3 Banking

The bank indication is given by an index on the sky plate which is directly connected to the outer gimbal. The index reads against a scale linked to the instrument case.

In this example the aircraft is banking approximately 12º to the left.

When the aircraft banks the rotor, inner gimbal and outer gimbal remain rigid in the level position and the instrument case together with the printed scale moves with the aircraft.





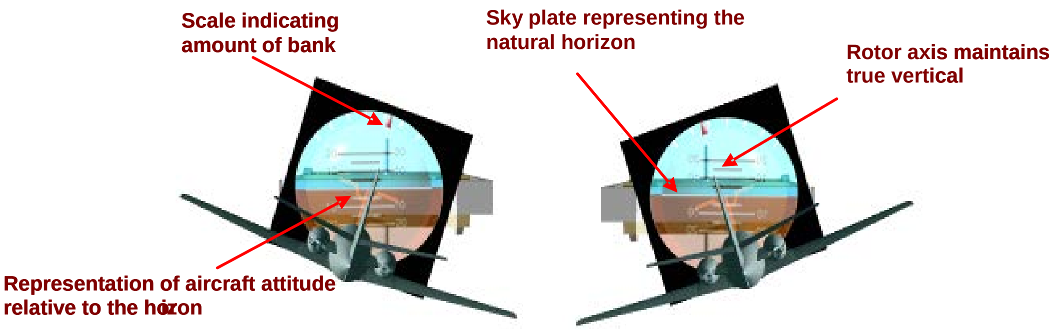
As the aircraft rolls about its longitudinal axis, it will roll parallel to the Z axis of the gyro rotor. During a level roll the only movement is along the Z axis of the gyro rotor.

As the aircraft rolls to the right or to the left parallel and along the Z axis of the rotor which remains in the true vertical, the instrument case (mounted to the aircraft) will move around the gyro giving an indication of the roll/bank.

Note: The aircraft's movement around the axes represents the relative movement around the gyro rotor.

10.12.4 Pilot Indication

Indications of the banking attitude (rolling) are presented by the relative position of two elements: One symbolising the aircraft itself, and the other in the form of a bar (sky plate) stabilised by the gyro and symbolising the natural horizon.



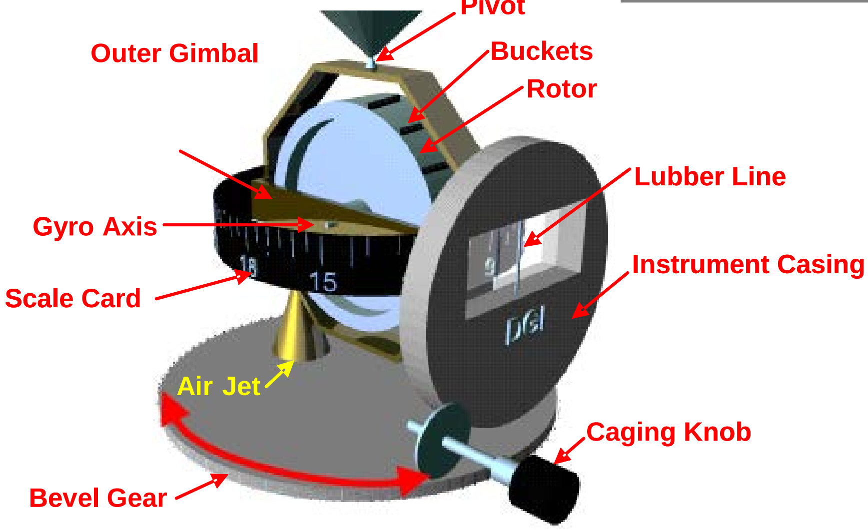
10.13 The Directional Gyro Indicator (DGI) – Technical

10.13.1 Introduction

The directional gyro indicator (DGI) makes use of a horizontally aligned gyroscope. This gyroscope is connected via gimbals to the compass card (vertical or horizontal instrument). For the purposes of this discussion the horizontal compass card will be used to describe the workings of the DGI.

Vertical Compass Card

10.13.2 Components

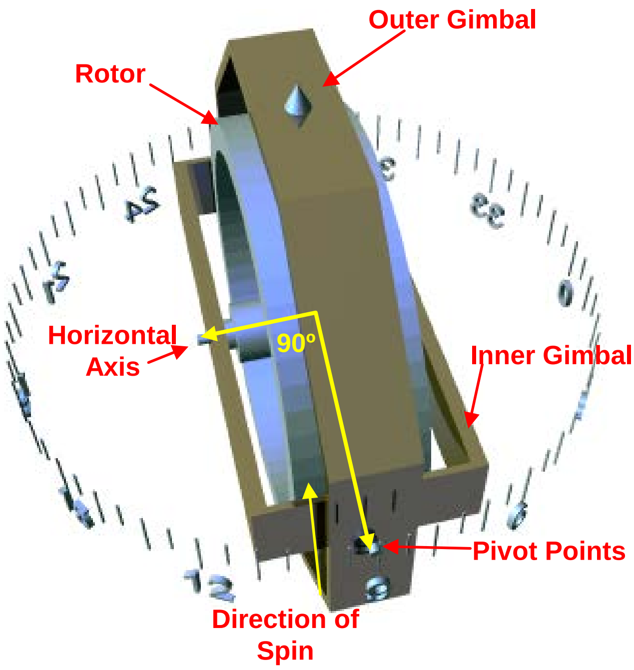


10.13.3 Construction

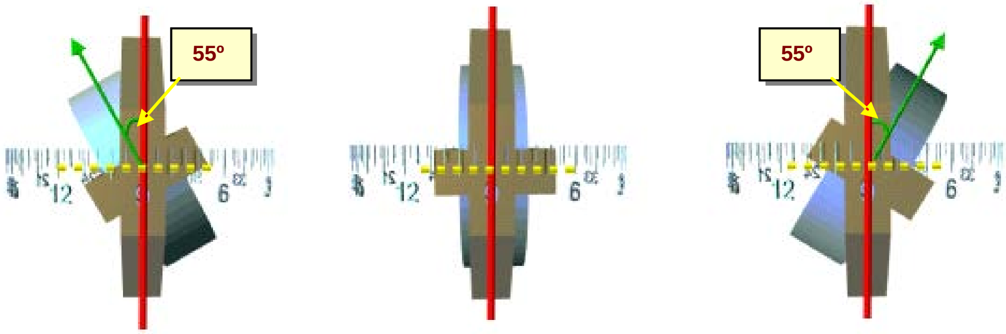
The DGI rotor is mounted in two rings, called the inner gimbal and the outer gimbal. Each gimbal has movement that is independent of the other gimbal.

The inner gimbal lies in the horizontal plane and the rotor that it holds (a horizontal axis gyro) spins in the vertical plane.

The inner gimbal is mounted in the outer gimbal on two pivot points which are 90º removed from the rotor axis.



8.11.4 Inner Gimbal

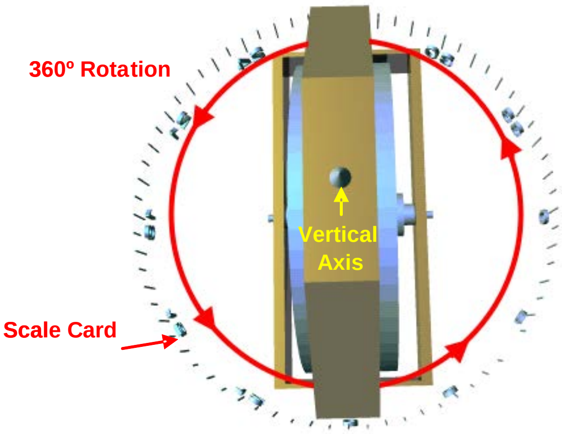


The movement of the inner gimbal on its pivot points about the horizontal axis is restricted to 110 º, which is 55 º, either side of the rotors vertical plane.

This limits the aircraft's manoeuvres in pitch and roll and if these limits are exceeded the inner gimbal will come in contact with a mechanical stop and the gyro will precess or topple.

This restriction on the old type of DGI is necessary in order to prevent the inner gimbal from coming in contact with the outer gimbal and damaging the instrument.

10.13.4 Outer Gimbal

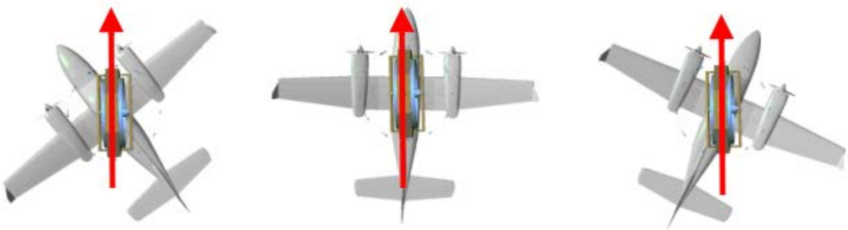


The outer gimbal (in which the inner gimbal lies), should allow movement of the rotor in the horizontal plane.

The outer gimbal is mounted in the case of the instrument and pivots around a vertical axis in a horizontal plane.

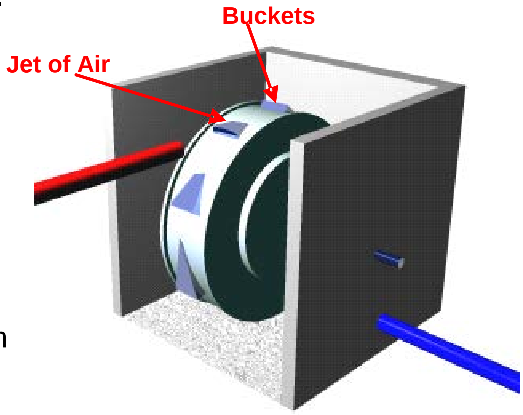
The outer gimbal has freedom in the horizontal plane of 360º and it also carries the scale card from which headings are read in the cockpit.

The case of the instrument is fixed to the instrument panel of the aircraft and during turns. The aircraft and the gyro case turn around the whole gyro assembly (the assembly maintaining a fixed direction relative to a fixed point in space).



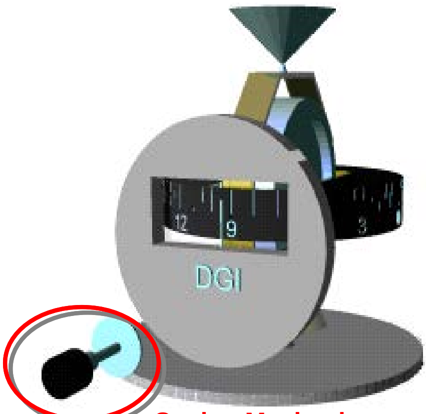
10.13.5 Gyro Driver

The rotor is driven by a jet of air from a nozzle. The jet of air is the result of a vacuum being created in the case.



The jet of air impinges on small buckets carved out of the rim and spins the rotor at about 10 000 to 12 000 RPM.

10.13.6 Pilot Control

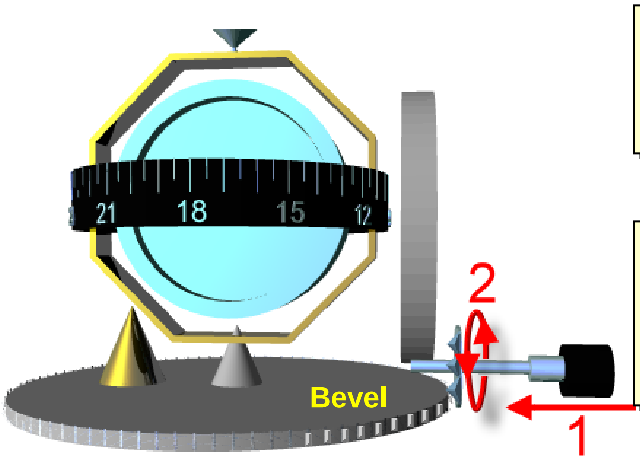


The mechanism that the pilot uses to realign or control the DGI is known as the **"Caging Mechanism".**

The initial setting of the heading as well as subsequent resetting during the flight is carried out by means of the gyro caging control.

The caging mechanism is operated by means of a knob on the face of the instrument.

In order to set the required heading on the DGI the caging knob is depressed and turned until the heading appears in the window.



1. When the caging knob is depressed, a gear on the shaft attached to the knob engages a bevel gear that is part of the outer gimbal.

2. When the caging knob is turned , it turns the bevel gear on the outer gimbal. The cylindrical scale is also attached to the outer gimbal and thus the heading display in the cockpit is also adjusted.

If we change the direction in which the gyro axis is pointing with the caging mechanism, we are actually applying a force to the gyro.

In order to prevent damage to the instrument when adjusting the heading or when executing manoeuvres that are likely to exceed the limits of the instrument, the caging knob also operates the caging mechanism that locks the inner gimbal (thereby preventing any movement of the gyro in the vertical plane).

10.13.7 Serviceability Checks

Ensure the following:

- The glass is clean
- The manual alignment functions
- It turns in the correct direction during taxi and without delay.

10.13.8 Errors and Adjustments

Because the gyro is a mechanical device it is subject to errors known as drift or topple. These errors are brought about by rotor bearing friction, unbalanced gimbals, excessive manoeuvres or even turbulence. If the gyro wanders in the horizontal plane it is known as drift. In the vertical plane this is known as topple, and in severe cases topple may cause the compass card to spin and oscillate on its axis. In these instances the instrument becomes useless and must be realigned with the magnetic compass.

As described above the DG needs a reference point when set for a directional heading, which is accomplished by aligning the compass card with the magnetic compass prior to takeoff.

For reasons just discussed, during the course of a flight the DG will drift or wander and will need to be reset on a regular basis as the flight progresses. Common practice is to realign with the magnetic compass every 15–20 minutes whilst flying wings level (unaccelerated flight) for about 30 seconds.

10.14 Automatic Flight

10.14.1 Introduction

The Automatic Pilot is designed primarily to relieve pilot workload, which allows the pilot to devote his attention to flight management, communications, systems monitoring and, most importantly, effective lookout. A simple Autopilot may only provide for 'hands free' operation but all Autopilots will generally provide the following:

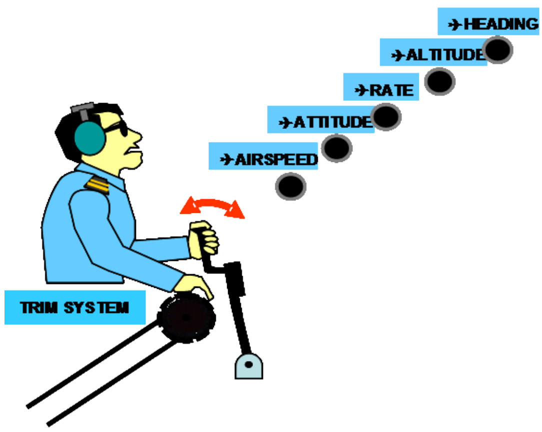
- Maintain a particular flight path
- Detect any deviations from the desired flight path
- Alter the aircraft's attitude to correct for deviations in the desired flight path.

Autopilots perform these functions by responding to deviations about a single axis (roll), about 2 axes (pitch and roll) or about 3 axes (pitch, roll and yaw).

They provide the above functions by processing attitude, performance and navigation data and then physically moving the flight controls to achieve the desired flight path.

Early Autopilots required considerable force to move the controls and were physically connected to the control column moving it as if the pilot were actually flying. Modern Autopilots are electronically signalled and typically electrically or hydraulically actuated. The Autopilot of today has become small, simple and reliable. Its modes have now become the primary means of piloting the aircraft.

Normally the pilot manually maintains the aircraft's attitude by reference to the horizon. The pilot can trim the aircraft to fly 'hands off'.



The AUTOPILOT senses and maintains attitude by reference to a ***GYROSCOPIC HORIZON*.**
The Gyros that are used to provide this reference are:

10.14.2 Attitude Indicator

The **ATTITUDE GYRO** which senses deviations in **PITCH** and **ROLL.** This would be the **ATTITUDE INDICATOR** (artificial horizon)

10.14.3 Turn Coordinator

A **RATE GYRO** which senses angular deviations in **ROLL and YAW.** This would be the **TURN COORDINATOR**

10.14.4 The Directional Indicator (DI)

Provides a high quality heading reference which may be coupled to the Autopilot to enable the aircraft to maintain a selected heading.

10.14.5 Horizontal Situation Indicator

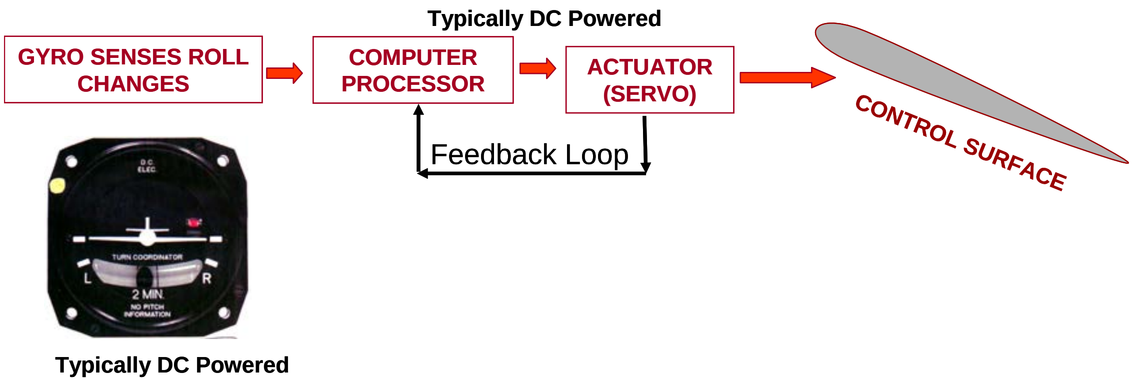
The Heading function may be vastly improved if the DI is replaced with a **HORIZONTAL SITUATION INDICATOR (HSI)** which has a selectable heading ***'bug'*** and course bars which may be coupled to radio navigation aids

10.15 Autopilot types

10.15.1 Single Axis Autopilot (Wing Leveller)

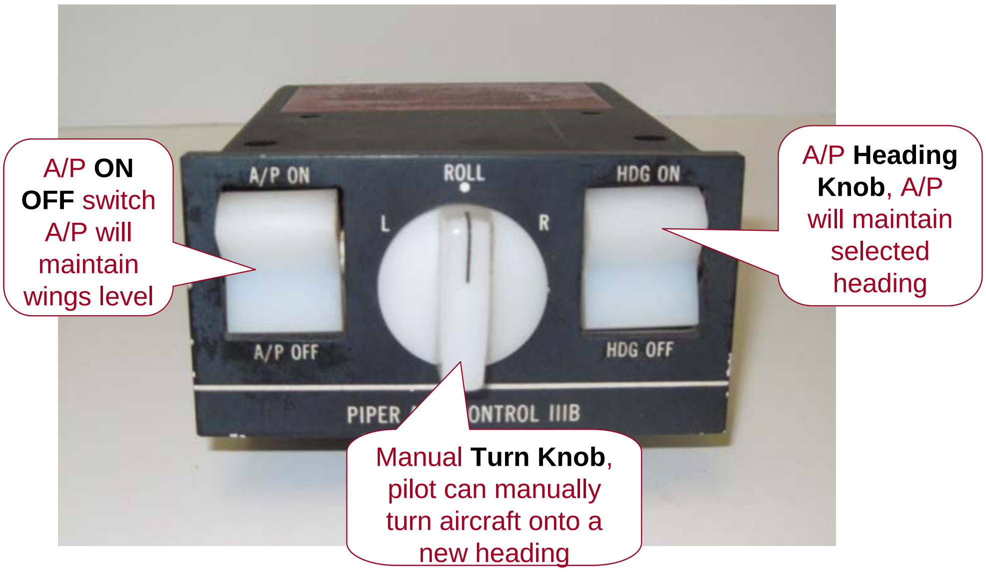
This system controls the aircraft about the **LONGITUDINAL AXIS** only (**ROLL**). It consists of **TURN COORDINATOR, COMPUTER AMPLIFIER, ACTUATOR** or **SERVO** which operates the ailerons in response to deviations in roll.

It is important that the aircraft is IN TRIM before engaging the Auto Pilot, which will prevent excessive loads on the servo units.



Simple Autopilots merely maintain the wings level. If deviations occur the ailerons operate to return the aircraft to a level attitude; however, the pilot may have to regain the desired heading by using the manual **TURN KNOB**.

10.15.2 Single Axis Autopilot Controller



10.15.3 Two Axis Autopilot

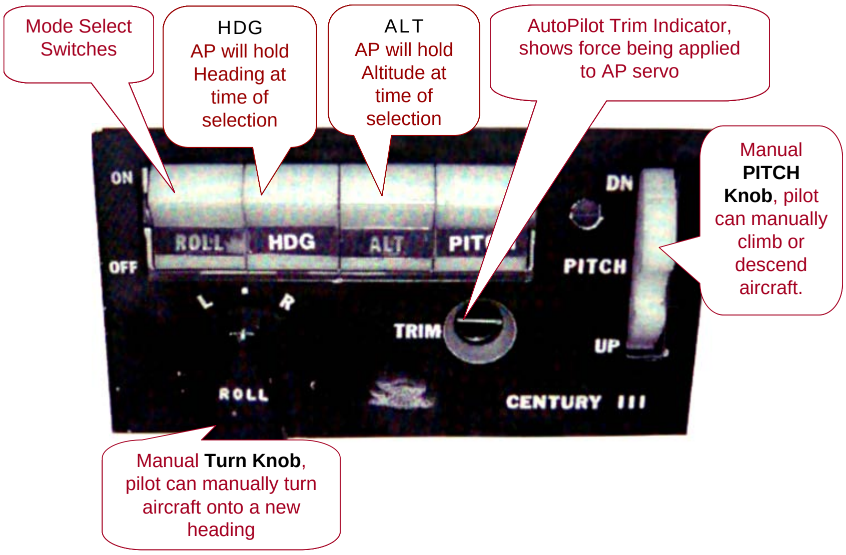
This system controls the aircraft's attitude in **ROLL** (with **AILERON** input) and in **PITCH** (with **ELEVATOR** input). If the aircraft is disturbed in **ROLL**, the AP will use **AILERONS** to return the aircraft to the selected Heading.

The AP can be commanded to adjust the **PITCH** attitude to hold a desired rate of **CLIMB** or **DESCENT**.

NOTE: The pilot must still select the appropriate power settings independently!

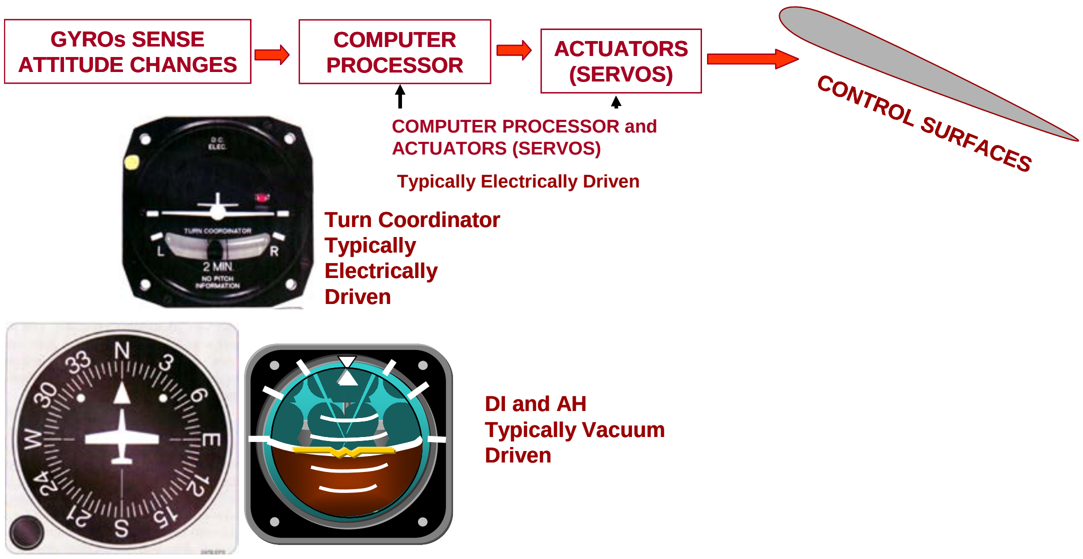
The AP can be commanded to maintain the current altitude as determined by a static pressure sensor. This is known as **ALTITUDE HOLD** and the elevators are used to make the necessary pitch adjustments. The AP may be used in conjunction with the radio Navigation aids to 'CAPTURE' and track a **VOR** radial or **ILS** localiser.

10.15.4 Two Axis Autopilot Controller



A Two Axis Autopilot controls the aircraft about the **LONGITUDINAL** and **LATERAL AXES**, (**PITCH** and **ROLL**).

System consists of **a TURN COORDINATOR, DI, AH, COMPUTER AMPLIFIER**, **ACTUATORS** or **SERVOS,** which operate the ailerons and elevators in response to deviations in roll and pitch.



10.15.5 Three Axis Autopilot

Three Axis Autopilots control aircraft around the LONGITUDINAL, LATERAL and VERTICAL AXES; however, these Autopilots are complex, multi-function devices and are only normally fitted to large commercial aircraft.

10.16 Autopilot Disconnect Switch

All Autopilots must be able to be overpowered by the pilot at all times and have provision to disengage quickly in the event of an emergency or malfunction.

An **AUTOPILOT DISCONNECT SWITCH** is often located on the control column.

Additionally a light accompanied by an aural warning is annunciated whenever the Autopilot disconnects unintentionally.