Basic Instruments

Instruments:

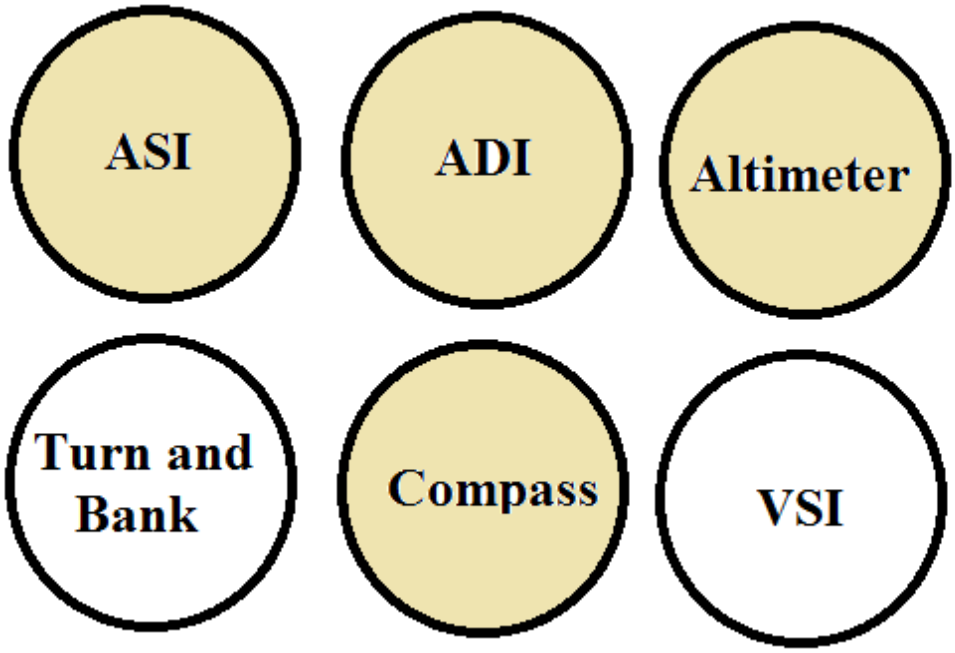
LRU – Line Replaceable Unit – Box containing equipment, easily taken out and replaced. Cooled, rackable, heavy and located generally under the cockpit.

Basic 6 Instruments:

- Airspeed Indicator (ASI)
- Attitude Directional Indicator (ADI)
- Altimeter
- Directional Gyro / Compass
- Turn And Bank/Slip Indicator
- Vertical Speed Indicator (VSI)

Pressure Instruments – Airspeed, Altimeter, VSI.

Electomechanical Instruments – ADI, Directional Gyro, Turn and Bank Indicator.



“T” Instruments – ASI, ADI, Altimeter, Compass.

Analogue – Comparative data – Pointer against a scale.
Best for spotting anomalies, rate of change and approximating values.

Digital – Quantitative – Numerical Read Out.
Best for finding exact values. However, very hard to estimate rate of change.

Ideal is a combination of both types.

A number drum is a mechanical system (not electronic) but it is still a digital readout.

Green - Normal
Yellow - Caution
Red – Warning

Pressure Sensing:

Presure = Force / Area

1 Pascal = 1 N/m^2; 1hPa = 1millibar.

Sea Level Pressure = 1.01325 bar = 1013.25 hPA = 29.92 inHg.

Sensing Devices:
- Bellows
- Capsules (used in most flight instruments)
- Diaphragm (allows separation of liquids whilst transmitting pressure)
- Bourdon Tube (used for very high pressure systems).

Static Pressure – aka ambient, atmospheric.

Aneroid Capsule – expands with decreasing relative external pressure. Partially evacuated = some air removed to increase accuracy, causing it to be slightly compressed at MSL. No flow = sealed unit. Made from naturally springy brass.

The change in size is proportional to the change in pressure.
By using multiple capsule, you increase the overall change in size, and therefore increase accuracy.

In compressible flow, dynamic pressure is also known ans impact pressure.

Pitot Pressure = stagnation pressure = static + dynamic

Dynamic Pressure is found by using pitot – static.

Pitot pressure is measure parallel to the airflow. Static pressure is measured at 90 degrees to the airflow.

A combination pressure head contains both pitot and static probes.

Location – Large aircraft – Nose; Small aircraft – Underwing.
They are placed in areas of minimum airflow interference.
Static ports are often found in pairs to help eliminate errors.

Errors – IMP
Instrument – Resistance and Hysteresis (the property of metal that causes a delay in the deformation).
Manoeuvre – Changes in air distribution due to manoeuvring.
Position – Predictable changes due to AoA.

REMEMBER TO REMOVE BUNGS AND PLUGS.

Vertical Speed Indicator (VSI)

aka Ratiometer, Variometer, Rate of climb/descent indicator, 'a special gauge'.

Uses a logarithmic scale, and therefore has greater accuracy at lower rates of climb/descent.

Principles of Operation:

- The instrument is fed solely by the static feed system.
- Air is fed directly into an aneroid capsule.
- Air is fed into the case by a metering unit, which delays it using a combination of laminar and turbulent flow (with a knife edge and capillaries).
- By doing this, in climb or descent a differential is produced between aneroid pressure and case pressure, leading to aneroid expansion/compression that can be measured.

In the climb, due to the delay valve, the capsule pressure will be LOWER than the case pressure, and therefore the capsule will be compressed.
In the descent, capsule pressure will be higher than case pressure, and therefore the capsule will expand.
The difference between present and recent pressure gives rate.
Present = external reference, Recent = internal reference.
The case is gas tight.

Errors:

- IMP
- Time Lag – Due to resistance of the instruments, there is a time lag in the instrument. Therefore, the instrument always lags behind the actual descent rate.

IVSI – Instantaneous Vertical Speed Indicator

Contains an accelerometer (aka dashpot) made up of a sealed weight and a spring. When accelerating downwards (descent), this forces more air into the capsule, increasing the capsule pressure. When starting a climb, it creates negative pressure, reducing the capsule pressure. This has the effect of reducing the lag.

However, this introduces some new errors:

Turning Error – Dashpot leads to errors when turning (usually indicating a climb).

Turbulence – Dashpot is displaced by turbulence leading to errors in vertical speed indication.

Blockages – Static blockage will cause the VSI to slowly move to 0.

Leaks:
Outside Pressure hull – Functional but less accurate. Shows instantaneous climb due to suction effect.
Inside pressure hull – Only measures cabin altitude. Shows instantaneous descent.

Altimeter

Works purely off static pressure. Consists of a gas tight case, with a partially evacuated aneroid capsule held open by a leaf spring (increasing accuracy). On climbing, the capsule will expand, and on descending, it will contract.

The instrument compares the pressure difference between "pressure surfaces" (e.g. MSL and current altitude) to calculate an altitude difference.

Rate of change of pressure with altitude is not constant. As altitude increases, a 1 hPa change in pressure represents a greater change of altitude. Therefore, altimeters become less accurate as altitude increases. The pressure altimeter is therefore designed to give a linear presentation of non linear changes, by means of a variable magnification lever system and specially designed capsules.

If an airfield is uneven, then a runway QFE or touchdown QFE may be used.

If we know the height above MSL, and the QFE, then we can calculate the QNH:

QNH = QFE + (Height above MSL/27)

Errors:

IMP

Temperature – Decreased temperature gives you an increased indicated altitude. Can be corrected either by calculation (0.004 x altitude x ISA DEV) or by temperature correction tables.

Barometric – Incorrect QNH setting in use.

"High to Low, Look out Below".

Time Lag – Hysteresis and friction of gears and linkages.

Blockages – It static line becomes fully blocked, the display will be frozen.

Leak – Pressurised – Under read (Increased Pressure).
Unpressurised – Over read (decreased pressure due to cabin suction effect).

Simple Altimeter – Single aneroid, coarse intervals usually from 0 to 10,000ft.

Sensitive Altimeter – Multiple aneroid (stack), with increased accuracy. Contains a vibrator to decrease lag by preventing sticking of gears and linkages. It can be set to a reference pressure using a knob to adjust the subscale. It also has multiple pointers, usually in 100ft, 1000ft and 10,000ft increments. Often contains jewelled bearings in order to further reduce friction, and therefore lag.

Servo Assisted – Contains a vertical I bar, and an E bar. The E bar is electified ,creating a magnetic field, that is felt in the I bar. When the capsule moves, it moves the I bar, causing a change in the magnetic field, and therefore a change in the charge of the 'prongs' of the E bar. This is amplified and sent as a signal to an electric motor. This motor then moves the instrument gauge.
Advantages – Increased accuracy (especially at high altitudes), friction and manufacturing imperfections are greatly reduced (as there are less parts), digital readout and altitude warnings can be easily incorporated.

Air Speed Indicator

- Fed by pitot and static pressure.
- Pitot Pressure is fed into the capsule.
- Static Pressure is fed into the case.
- Therefore the expansion of the capsule is caused by the difference between pitot and static pressure – the dynamic pressure.

The scale numbers are white. The white arc is the flap arc, and runs from V_{S0} to V_{FE}. The green arc is for normal operation and runs from V_{S1} to V_{NO}. The yellow arc is the caution arc and runs from V_{N0} to V_{NE}. The red mark is at V_{NE}. Light twins may also have marks for $V_{Y\,SE}$ and V_{MCA}.

Approximate TAS scale – There is a scale at the top that allows you to input approximate pressure altitude against OAT. This then moves a TAS scale.

Calibration – The ASI is calibrated so that IAS and TAS are equal at ISA MSL (Density 1.225 kg/m^3).

Errors:

- IMP – I and P may have a correction card.
- Compressibility – For speeds greater than 300 kts.
- Density error – Due to decreased air density at higher altitude.

Speeds:

ICE Tea **I**s a **P**retty **C**ool **D**rink

IAS
CAS/RAS – Corrected for Instrument error and Position error.
EAS – Corrected for Compressibility error.
TAS – Corrected for Density error.

Pitot Blockage – IAS will remain constant, and the instrument acts like an altimeter.
PUD – Pitot Under reads in Descent.
POC – Pitot Over reads in Climb.

Static Blockage – Shows changes in speed but is highly inaccurate.
SUC – Static Under reads in Climb.
SOD – Static Over reads in Descent.

Pitot Leak – Under Reads.
Static Leak (pressurised) – Under Reads.
Static Leak (unpressurised) – Over Reads.

CRP 5:

When converting TAS to IAS (TAS>300kts), you still adjust for compressibility in the same direction (left), as this INCREASES the IAS.

Temperature:

Kelvin = Celsius + 273.

Fahrenheit = (Celsius – 32) / 1.8

Types of Air Temperature Thermometers:

Direct Reading / Thermal Expansion – Consists of a strip made of two different metals (bimetallic), usually copper and iron. An increase in temperature will cause the two strips to expand, but at different rates. This leads to bending of the strip. This bend can then be shown against a scale. Often, the strip is coiled to amplify the effect.

Remote Indicating:

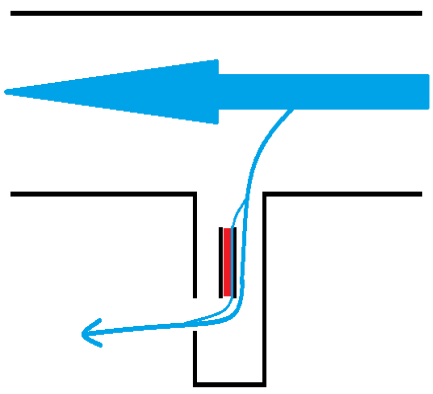
Electrical Resistance – Some metals change resistance based on their temperature. Therefore, by measuring the resistance of a circuit, you can measure temperature. This is generally used for OAT probes. It is best for small ranges, as the change in resistance is non linear. By the nature of the device, the probe and the indicator can be in separate places.

Electrical Thermocouple – When two different metals are in physical contact, a small voltage is produced proportional to the temperature difference between them. This is generally used for engine temperature measurement.

- A “Hot Junction” is at the measurement point. This is at the rearmost piston for a prop (lowest airflow for cooling), and usually at the exhaust on a jet.
- The “cold junction” is at the monitor, which acts as a voltmeter to show the temperature.
- No power supply is required.
- By using multiple hot junctions in parallel, the voltage can be amplified. This is useful for jets where increased EGT may require fuel flow to be reduced automatically.

Radiation – An object emits a different frequency of light depending on its temperature. The higher the temperature, the higher the frequency. Therefore, temperature can be sensed at a distance. This is useful for fire detection systems.

TAT Probe:



Air flow is diverted into two streams. Most of the airflow goes straight through. However, some of the airflow slows down and moves through 2 90 degree turns. Ice and water cannot make the turn.

There is a sensor in this slowed air to measure the temperature. However, due to the slowing of the air, it has become heated, and so the temperature measured is Total Air Temperature, NOT static air temperature.

The sensor is surrounded by a heat shield, to ensure that it only samples air from the centre of the flow.

The probe itself is usually on the inner forward fuselage, on a stalk so as to take it outside of the boundary layer. It is made of nickel plated beryllium copper, and has its own anti-ice system (only heats the case, not the sensor). The sensor itself is a pure platinum wire resistance sensor. This has a high rate of conductivity, rapid response and a linear change in resistance.

The probe only works when the aircraft is moving. An aspirator may be fitted to improve flow, and to allow sensing when stationary.

Errors:
Icing (environmental).
Radiated Heat (environmental, from sun heating).
Boundary Layer (stalk location).

Measured ram rise is either given as "ram rise" on its own, or with a recovery factor. In this case, measured ram rise = ram rise x recovery factor. Recovery factor is the amount of error in the temp bulb as given by the manufacturer.

SAT = TAT – (Ram Rise x Recovery Factor)

When air is decelerated, Kinetic Energy is converted mostly to pressure energy, with some converted to Thermal Energy (Adiabatic heating).

Aspirated TAT probe – Induces an air flow using bleed air fed into the end of the TAT probe. As the bleed air is pressurised, it draws air through the probe. It is positioned after the probe so that the heat of the bleed air does not interfere with the probe readings. This increases the accuracy on the ground and in slow taxi.

Alternate SAT Calculation:

SAT = RAT (kelvin) / (1 + (0.2 x K_R x M^2). Where K_R is recovery factor and M is Mach no.

Mach meter:

Requires Pitot and Static pressure.

Has an Altitude capsule - Upper capsule attached with a spring, partially evacuated.
And an Airspeed capsule – Lower Capsule at back end. Has pitot feed.

LSS depends purely on temperature, and increases with increasing temperature.

LSS = 38.96 x √(Temperature in Kelvin)

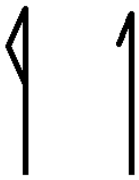
Compass:

Field lines emerge from the Earth's magnetic south pole and descend back into the north pole.
Blue = North pole, Red = South pole.
On a compass, the Red pole is the north seeking pole (as it is magnetically south).
A freely suspended magnet will seek its nearest pole. Therefore, in the northern hemisphere the primary pointing force is the red pole pointing at the north pole. In the southern hemisphere, the primary force is from the blue end seeking the south pole.

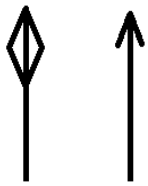
Components : Z (Vertical) – Causes dip, and is strongest at the pole.
H (Horizontal) – Causes seeking, strongest at the magnetic equator.

The magnetic poles move around 10 miles a year.
Secular Changes – Every 450,000 years the magnetic poles flip.
Predictable changes – Annual – Due to the Earth's orbit.
Diurnal – Due to ionospheric changes during the day/night cycle.
Unpredictable changes also occur as a result of solar winds.

Magnetic North:



True North:



Variation – Westerly when the magnetic north pole is west of true north.
Changes in variation can result in runway designations changing.

Aircraft Magnetism:
Occurs due to certain components and materials within the aircraft. 'Soft' components are those that are not inherently magnetic, but become slights magnetic in the presence of a magnetic field. 'Hard' components are those that can have their own magnetic field. They cause more of an issue than soft components. Electronic systems also produce a magnetic field when they are switched on.

You get more deviation when moving at 90 degrees to the magnetic field lines than you do when going directly along them.

Compass swinging is required to find deviation at various headings. There are a number of reasons that you would need to do this : Change of base latitude, major equipment change, lightning strike, parked in the same direction for a long duration (changes magnetism of hard components), new compass, any reason for doubt in readings, when scheduled.

Direct Reading Compass:

E Type compass:
A magnet, or series of magnets, mounted on a compass card, that is hung from a pivot inside an oil filled casing. It is read visually, and used as a standby instrument as it has no electronic parts (except for a light). A lubber line is used against the card in order to read off heading. The back of the compass is the part that is read. Therefore, it will appear to move left when you move right, and therefore can be hard to interpret.

When dip occurs, the compass moves on its pendulous mounting. Therefore, the CG is displaced and the compass becomes vulnerable to various errors.

Horizontality – How horizontal the compass is. Achieved by supporting the compass pendulously, allowing the magnet to align with the H component, and opposing the Z component through movement of the CG. This also causes it to quickly find equilibrium.

Sensitivity – Improved by using 2, 4 or 6 high quality magnets. A precision bearing is created using an iridium tipped bearing in a jewelled cup. Immersing the assembly also improves sensitivity by allowing the compass to float.

Aperiodicy (Liquid damping) – Needs to settle down quickly after a disturbance (aperiodicy or dead beat). This is accomplished by keeping the CG close to centre (using short magnets), and by using a damping fluid.

The oil in the compass has to have certain characteristics – low viscosity, transparent, remains liquid over full range of operating temperatures, non corrosive, does not expand or contract excessively (may have an expansion chamber (siphon tube)).

Pre Flight Checks – Intact, secure, not leaking, sensible indication (check grossly against runway / known directions, and cross-check against other instruments).

Manoeuvring Errors – All manoeuvres cause displacement of the CG of the compass. This is known as tilt.

Acceleration Errors:
Worst on direct East/West headings. The acceleration displaces the CG forward or backwards, and this forms a couple with the magnetic dip that is already present. On direct N/S headings, the dip and tilt work on the same plane and therefore no turning moment occurs.
Remember that the compass is suspended from the top, and therefore acceleration forwards will cause the card to rotate backwards, with the forward end moving downwards.

NANDS – **N**orthern hemisphere – **A**ccelerate → **N**orthwards displacement, **D**eceleration → **S**outh.

SSAND – **S**outhern Hemisphere – **S**outh when **A**ccelerating, **N**orth when **D**ecelerating.

Turning Errors:
Maximum when turning through North or South.
Liquid swirl occurs in the direction of the turn. This may either dampen or worsen the error.

NUNOS – Northern Hemisphere – **U**ndershoot if turning through **N**orth. **O**vershoot if turning through **S**outh.

Opposite applies for the southern hemisphere.
Overshoot or Undershoot is what you must do in order to roll out at the correct heading. e.g. Turning through north in the northern hemisphere – if turning to 045 you should actually turn out on an apparent heading of 025, and this will lead you to be on an actual heading of 045 once the compass stops moving.

Swirl always worsens an overshoot, and always improves an overshoot.

You always UNDERSHOOT when turning through the direction of your hemisphere (e.g. North in the Northern hemisphere, South in the Southern hemisphere).

If you are undershooting then your compass is moving in the same direction as the aircraft.

You always undershoot or overshoot by 20 degrees.

Gyroscopes:

Properties:

Rigidity – Rotating objects maintain their position in space. A space gyroscopes has a design that allows it to retain its orientation in space regardless of any movement around it.
3 Requirements – High Density material, Mass biased towards outer rim, High RPM (15,000-25,000).
Factors – rotational speed, gyro mass, mass distribution, radius of rotation.

Precession – Force applied has a resultant at 90 degrees in direction of the spin from the original point. The turn indicator uses precession in order to indicate rate of turn. The lateral turn causes a force that rocks the gyroscope to one side, which moves the instrument needle.

Gimbals are supporting frames that allow free movement in one axis. The rotor is the mass.
Gimbal lock occurs when 2 gimbals line up (and effectively form 1).

Spin Bearing Only – Can only move in one axis, without disturbing the gyroscope.

1 Gimbal (Rate Gyro) – Can now move in 2 axis without disturbing the gyroscope. This is used in the rate of turn indication. This is 1 degree of freedom (spin axis not counted as always present).

2 Gimbals – Now has 2 degrees of freedom. This is a space gyro.

The number of degrees of freedom is the same as the number of gimbals.

Spin Axis Vertical = Vertically Tied. The attitude indicator is vertically tied.
Spin Axis Horizontal = Horizontally Tied. The DI is horizontally tied.

A classic instrument is one that rotates anticlockwise as seen from above.

The Directional (Gyro) Indicator (DI/DGI) gives short term accuracy for heading after being synchronisation with the magnetic compass. Every 10-15 minutes it must be caged and reset.

However, no magnetism is required within the instrument for it to function.

Extreme manoeuvres can lead to “gimbal lock” where the gyroscope is displaced.

Gyroscope Power Sources:

Pneumatically Driven – Vacuum pump removes air from the casing. Air at atmospheric pressure rushes in to replace it, and in doing so turns the gyroscope. As part of this system there is a vacuum gauge and vacuum warning light (if vacuum failing). This design is cheap and simple. However, it becomes quickly unreliable if the pump fails. The RPM is also dependent on atmospheric pressure. Finally, the air must be filtered or it risks fouling the system.

Electrically Driven – DC motor can be used directly with DC battery power. If an AC motor is used, then it will require an inverter to run off the DC supply. An AC motor also requires constant AC frequency, as wild frequency AC will lead to RPM changes. RPMs of up to 24,000 are achievable, and thus the gyro can be smaller.

Wander:
Topple – Axis movement from the vertical.
Drift – Axis movement in the horizontal.

Real Wander – Actual topple or drift of the gyro in space.

- Random Wander – due to mechanical imperfections. This is inevitable.
- Latitude Compensation (gimbal inputs) and other intentionally induced wanders.

Apparent wander – due to the rotation of our own reference compared to the gyroscope.

- Transport Wander – Moving the gyroscope around the earth.
- Earth Rotation – Movement of the earth under the gyroscope.

The earth rotates eastwards at approximately 600kts. This relates to 15.04 degrees per hour at the pole. It varies with the sine of the latitude for a vertical gyro.

Poles – Maximum Drift, Minimum Topple.
Equator – Maximum Topple, Minimum Drift.

Vertically Tied Gyroscopes:
Equator - Maximum topple but no drift.
Poles – No topple or drift (Earth spins under it around its rotational axis.)

Horizontally Tied Gyroscopes:
Alignment refers to the direction that the spin axis is pointing. The 'edge' of the gyroscope will be pointing at 90 degrees to this.

North/South aligned at the equator – The edge of the gyroscope points E/W. When moving around the equator (or as the earth rotate), the edge 'rolls' along the equator. As the only displacement would be in the spin axis (that is already rotating), there is no drift.

Moving up a meridian, you get increasing drift, due to the fact that the Earth's rotation is no longer in line with the spin axis, but is now at an angle.

At the pole, this reaches a maximum. The rotation is now at 90 degrees to the spin axis, and so the

drift is now at a maximum (15.04 degrees per hour).

For the directional gyroscope, we are interested in the drift elements of wander, as topple is dealt with by the erection system. To counter the drift, the latitude nut is used to induce synthetic real wander. This nut can be adjusted based on the aircraft's latitude on the ground by an engineer.

At the North pole, the gyro appears to rotate clockwise, and the heading decreases by 15.04 / hour.
At the South pole, the gyro appears to rotate anticlockwise, and the heading increases by 15.04/hr.

The DGI is horizontally tied, has 2 gimbals and 2 degrees of freedom. It compares aircraft axis with the gyro axis. Its function is to provide a heading with short term accuracy, after being aligned with the magnetic compass. It does not replace a magnetic compass, but supplements it. Generally, it must be caged and re-aligned every 10 minutes.

Maintaining Erection – compensates for random wander, as well as earth rotation and transport runway. It does this through a small rate of precession.

Pneumatically:
Coarse Erection is via an Air Jet (acting on the spin axis).
Fine Erection is via a Wedge plate (acting on the inner gimbal).

Air Jet – The gyroscope has a water wheel pattern upon it. There is airflow directed from the case onto this. When the gyroscope topples slightly, this airflow now hits the side of the “wheel”. This produces a sideways force, that is precessed into re-aligning the gyroscope with the aircraft.

Wedge Plate – Air is exhausted from a casing around the inner gyroscope onto a wedge plate located on the outer gimbal. When the gyroscope is in line, the airflow is equal on both sides, and there is no motion. When the gyroscope is leant, the airflow goes more to one side, and produces a force on the outer gimbal. This is precessed through 90 degrees, and causes the gyroscope to tilt back to the aircraft's axis.

Electrically:
Electronically detects topple by means of a switch, with a torque motor to re-align it.

Directional Indicator:

Total Drift:
Earth Rate/Rotation – 15.04 x Sin (Latitude).
Latitude Nut is the same equation, but opposite sign.

Transport Drift only occurs when moving E/W not on the equator.

Perfect Gyroscopes have no random drift (from mechanical imperfections).

In the Northern Hemisphere – ER -ve, LN +ve.
In the Southern Hemisphere - ER +ve, LN -ve.

Total Drift = Earth Rotation + Transport Drift + Random Drift + Latitude Nut.
= ED + TR + RD + LN.

Roll Limits – Pneumatic – 55 degrees in pitch and roll.
Electrical – 85 degrees in pitch and roll.

Attitude Indicator:

aka Artificial Horizon. Interested in roll and pitch. Measures angular displacement from the vertical and horizontal.

2 Gimbals – Displacement Gyroscope. The rotor is kept level with the horizon.

The aircraft symbol on the instrument is attached to the aircraft. The card is attached to the gyroscope.

Erection System (Pneumatic)
Pendulous – Large weight attached to the base, performs coarse erection.
Pendulous Vane – 4 slots each ½ blocked by vane. When level, all of the holes are equally blocked, and exhaust an equal amount of air. As soon as the instrument pitches or yaws, one of the vanes is blocked. This leads to an imbalance of forces that is precessed around the gyroscope so that it re-erects. This is fine erection.

Errors:
Pneumatically driven attitude indicators are vulnerable to any acceleration in the horizontal plane. These are known as acceleration and turning errors. Due to precession, they affect more than one axis.
Accelerating – Pitch Up, Right Roll. Note that this is only for classic (anticlockwise) instruments, the yanks have backwards ones and these do the opposite.
Decelerating – Pitch Down, Left Roll.

Turning:

Total Turn	Angle Of Bank	Pitch
90	Under Reads	Over Reads
180	Correct	Over Reads
270	Over Reads	Over Reads
360	Correct	Correct

Electrical:
Mercury switches that activate torque motors when displaced.
Acceleration errors are reduced by having a limit on the switches and motors.

Limits – Pneumatic – +/- 60 in pitch, +/- 110 in roll.
Electrical - +/- 85 in pitch, unlimited in roll.

Turn Indicator – Needle pointing to rate.
Turn Co – Ordinator – Aircraft symbol.

Both contain a gyroscope fixed along the fore and aft axis. There is a single gimbal (therefore it is a rate gyro) that is attached to a spring to erect it.

On turning, the yaw is precessed into topple, and this topple is measured to give the rate of turn. Therefore, this indicator is designed to have a lower RPM to allow the topple to occur. The gyroscope is then re-erected by the spring once the turn stops.
The turn becoming topple is primary precession.
The spring re-erection is secondary precession.

The rate of turn indicator is only exactly correct for one TAS. However, it remains reasonably accurate outside this.

Errors:
TAS
RPM – Too high causes an over read, too low causes an under read.
Pitch – Up – Over Read ; Down – Under Read.

Note, if everything else has toppled, then the turn indicator remains accurate, as it is designed to topple. Therefore, it can be used to aid recovery – you know you are not turning and can then use altimeter to correct any climb/descent.

The Turn indicator has the gimbal horizontal, and generally shown many rates of turn.
The Turn co-ordinator has the gimbal tilted to 30 degrees from the longiudinal axis. It is therefore immediately directly sensitive to roll. Therefore small amounts of roll are easily detected.
The errors are the same for both.

Turn Rates:
Rate 1 = 3 Degrees / second; Rate 2 = 6 Degrees / s; Rate 3 = 9 Degrees / s.

Radius of turn = ((Speed/60) x Time for turn) / 2 ∏

Balance Indicator:

Consists of a tube of glass with a ball in it. The ball falls towards gravity. There is also a rear tube to allow fluid to move out of the way of the ball.

Balanced turn – 'Gravity' acts directly down, parallel to lift.

Skid Out – Under Banking.
Slip In – Over Banking.

Angle of bank calculation (for rate 1 turn) = (TAS/10) + 7

Turn Radius – Skidding – Turn radius decreased.
Slipping – Turn radius increased.

Remote Indicating Compass / Gyromagnetic Compass / Slaved Gyro Compass / Magnetic Heading Reference System (MHRS):

Combines the long term accuracy of the compass with the short term accuracy of the directional indicator. Basic composition is essentially the same as the directional indicator, but extra systems are used to maintain magnetic alignment. The system requires electrical power to function.

Slaving refers to the detection and correction of wander by the magnetic system.

Flux valves are placed on the underside of the wingtips, far from any source of electrical interference. They are connected by a Hookes joint, that allows free movement in pitch and roll, but is fixed in yaw. There is a 25 degree maximum pitch and yaw deviation beyond which the system hits the side of the casing and becomes disturbed.

The flux valve itself consists of 3 detector legs, each attached to their own curved horn. The horns form almost a complete circle. The horns collect magnetic field lines and channel them into the legs, where they are detected.

Stator – Signals from the flux valve are sent to the stator. This is a set of 3 windings that appears similar to the flux valve. The electromagnetic fields collected at the flux valve are mirrored here, in an orientation reflecting the orientation of the field lines of the Earth.

Slaving Circuit – A detector coil is mounted on a shaft connected to the outer gimbal, that passes through the stator. When the gyro is magnetically aligned, the shaft is at 90 degrees to the stator and no signal is produced. If it deviates, a current is induced (maximum when perfectly aligned). This signal is sent to a precession motor via 3 steps. These are Amplification, Phase Comparison and Rectification.

Errors – Attitude – Due to the 25 degree limits of the Hookes joint, Deviation, Acceleration and Turning, gimbal errors. These are all generally very small as the 2 systems correct each other.

Components:

- Detector Unit
- Heading Indicator
- Signal Amplifier (3 degrees per minute correction)
- Rapid Synchronisation Unit – Usually for starting the system up. Manual caging, or automatic system (high gain amplifier) at 60 degrees per minute.

Annunciator – Shows signal that is being sent to precession motor. May be able to switch from FREE (DGI) to SLAVED (RIC).

AHRS – Modern systems in large aircraft use IRS position and lookup tables for finding magnetic variation. Some light aircraft may use a flux valve to provide this information instead.

Basic principle of using coils and a stator can be used in SelSyn (Self Synchronising) systems that allow instruments to be replicated.