INSTRUMENTS INTRO – BASIC COCKPIT INSTRUMENTS

BASIC T

Airspeed	Attitude	Altimeter
	DI	

BASIC 6

Airspeed	Attitude	Altimeter
Turn Cord	DI	VSI

PRESSURE

- $Pressure\ (Pa) = \frac{Force}{Area}$
- Can be measured in:
    - hPa (1 hPa = 100 Pa)
    - Bar (1 mbar = 1/1000 bar)
    - PSI (Pounds per square inch)
    - In Hg (Inches of mercury)

ATMOSPHERIC VARIATIONS

- Pressure
- Density
- Humidity
- Temperature

- ISA gives us a datum point from which we can measure.

INSTRUMENTS 1 – PITOT STATIC SYSTEMS

ISA

- **Pressure MSL** = 1013.25 hPa / 1013.25 mb / 29.92 In.Hg / 14.7 PSI
- **Density MSL** = 1.225 Kg / m^3
- **Temperature MSL** = 15 ^{0}C

- All instruments are calibrated to ISA.

STATIC PRESSURE

- Exerted **in all directions, all the time.**
- Located on **side** of fuselage.
- A static port can be fitted **on each side:**
  - Balance out errors from side-slipping
  - Removes need for a standby vent
  - Reduced the effect of turbulence and crosswinds.

PITOT PRESSURE

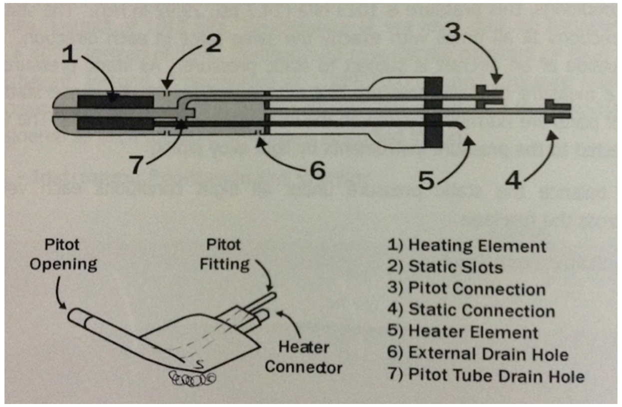
- **PITOT = STATIC + DYNAMIC**
- Called **total pressure.**
- Dynamic can be calculated by **total – static.**
- **Dynamic Pressure =** $\frac{1}{2}\rho\, v^2$
  - v^2 is TAS

BLOCKS AND LEAKS

- Pitot-static system can become **blocked** through ice, debris, insects etc.
- A blockage will **trap the pressure** in the system.
  - Exception if the blockage is forward of the drain hole = pressure dissipates.
- **Leaks** can also occur if the light alloy piping network fractures or becomes detached from bulkhead mountings.

COMBINED PITOT-STATIC HEAD

- Not often used as **turbulent air** can form around the static opening.



GENERAL ERROR TYPES

- Applies to all instruments.
- **Instrument –** Due to imperfections in the mechanical construction / limitations.
- **Manoeurve** – Due to constantly changing position. (Unpredictable)
- **Position –** Due to location of sensors. (Predictable)

PITOT-STATIC ERRORS

- **Position Error**
  - Disturbance from airflow around aircraft.
  - Will vary with angle of attack and airspeed.
- **Manoeuvre Error**
  - Disturbance of airflow around the ports during and shortly after manoeuvres.

REDUNDANCY

- Commercial aircraft have 3 sets of pitot-static ports:
  - Captain
  - F/O
  - Emergency (Located on tail)

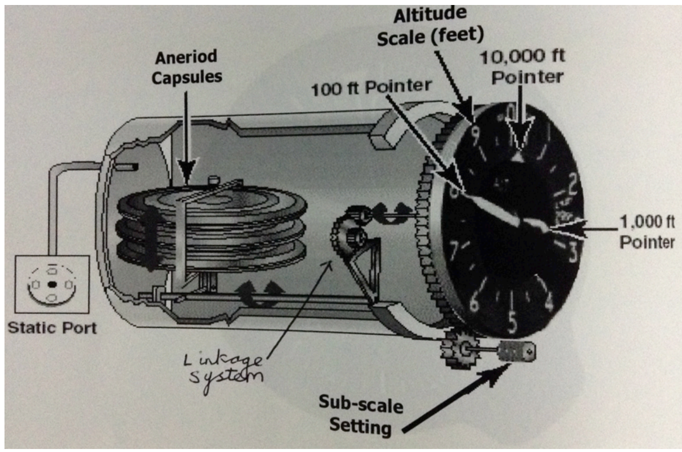
INSTRUMENTS 2 – PRESSURE ALTIMETER

PURPOSE

- Measures **vertical distance**.
- Ensures **separation** from other aircraft.
- Ensures **clearance** from terrain.

ANEROID CAPSULE

- **Sealed** and **partially evacuated.**
- When climbing, static pressure outside is less than inside capsule and it expands.
- A **linkage system** converts this movement into a display on the altimeter.
- **Multiple capsules** can be used to amplify the expansion and contraction, giving greater sensitivity.
- **'D spring' / 'Leaf spring'** used to correct for cockpit temperature variations.



PRESSURE CHANGES

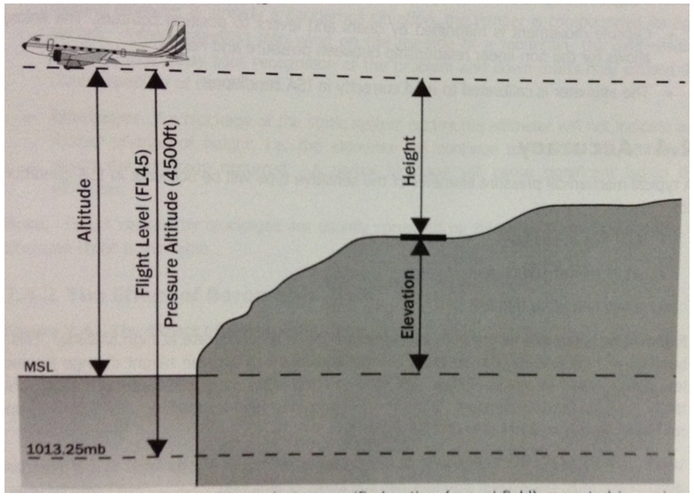
- Altimeter is calibrated for a **non-linear** decrease in pressure with height.
- A change in the sub-scale however will **always vary by 30'** as the datum being changed it at 'sea level'.

DATUMS

- Altimeter indicates vertical distance **from a selected datum**.

- **Height**
- **Altitude**
- **Flight Level**

- Indicated altitude and true altitude are only the same when everything is perfect (ISA).

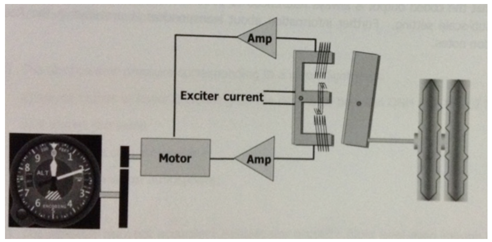


ALTIMTER ERRORS

- **Instrument** – Due to mechanical imperfections. Larger with height as capsule changes become smaller.
- **Pressure** – Includes maneuver and position error. Due to error in sampling of static air.
- **Temperature –** Corrective calculus needed
- **Barometric –** Minimised by ensuring correct datum is set.
- **Lag / Hysteresis** – Most dangerous during a rapid descent.
- **Orographic –** Pressure variation in vicinity of high ground. Lower pressure on leeward side compared and higher on winward side.
- **Blockages / Leaks** of static system.

SERVO ALTIMETER

- Removes some of the time lag and instrument error.
- **More sensitive** (especially at higher altitudes)
- Easier to **digitalise**
- Capsule Expands → Asymmetry between E & I bars → DC Flow to servo-motor → Digital Reading → Cam driven to realign bars



INSTRUMENTS 2 – PRESSURE ALTIMETER

ALTERNATE STATIC SOURCE

- Cabin pressure is slightly **lower than outside** in an unpressurised aircraft.
  - Due to low pressure on the outside creating a suction effect within the cabin.
- Use of alternate static source will therefore cause a slightly increase in altimeter reading.

PRESSURISED AIRCRAFT LEAK

- Higher static pressure will enter the system and cause altimeter to decrease to cabin pressure level.

MECHANICAL (SENSITIVE TYPE)

- Seal Level: ± 50 ft
- 10,000 ft: ± 175 ft
- 40,000 ft: ± 600 ft

SERVO ALTIMETER ACCURACY

- Seal Level: ± 30 ft
- 20,000 ft: ± 50 ft
- 40,000 ft: ± 100 ft

STATIC BLOCKAGE (DUAL PORTS)

- A blockage of the left static port will cause an over-read when side slipping left.
  - The right port is reading a lower than normal pressure (higher air velocity)

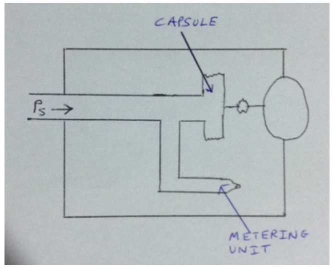
INSTRUMENTS 5 – VERTICAL SPEED INDICATOR

THE VSI

- Measures the **rate of change of static pressure.**
- Can use either a **linear** or **logarithmic** scale.

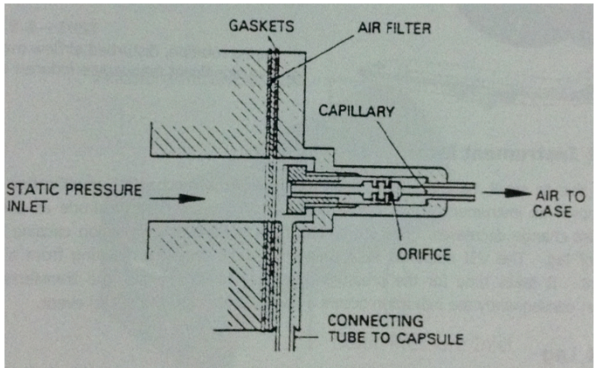
CONSTRUCTION

- **Metering unit** creates a lag in static pressure entering the case.
- Climb = Capsule contracts
- Descent = Capsule expands



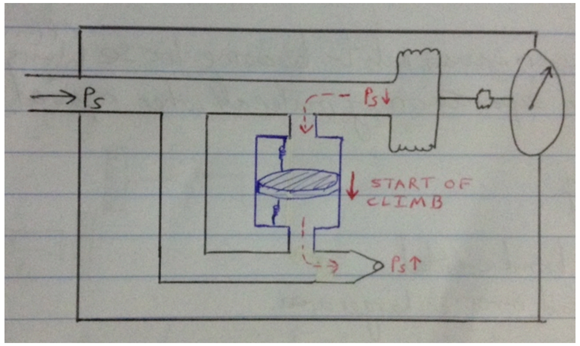
METERING UNIT

- An **orifice and capillary device** compensate for changes in viscosity (due to temperature and density changes).



INSTANTANOEUS VSI (IVSI)

- A.K.A Inertia Lead VSI
- Small accelerator pump (**dashpot)** is fitted.
- Creates an artificial pressure change **immediately** when vertical acceleration occurs.
- EG/ At start of a climb, P_S is decreased from within capsule and increased within casing.



- Lag has been practically **eliminated.**
- **Steeply banked turns** could create a false reading as the dashpot is displaced however.

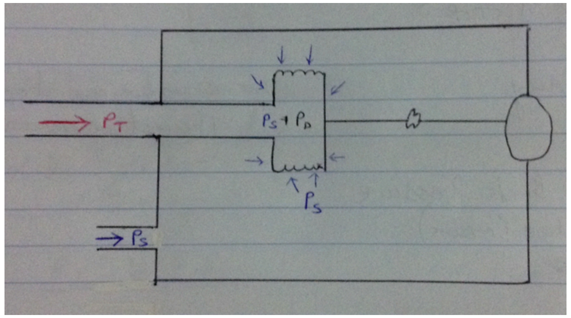
ERRORS

- **Instrument Error**
  - Error increases with altitude
  - Hysteresis and friction contribute to lag within the VSI.
- **Pressure Error**
  - Manoeuvre – Sudden change in attitude disturbs airflow around static port. Gives large, short lived errors.
  - Position – Change of speed may cause temporary error in VSI.
- **Time Lag (VSI)**
  - Takes time for a pressure difference to occur between capsule and case.
  - VIS is slow to respond at start or end of a climb or descent.
- **Temperature Error**
  - Causes rigidity and elasticity.
- **Blockage**
  - VSI returns to zero.
  - IVSI may fluctuate with dashpot
- **Leakage**
  - Pressurised – Rapid descent indicated as higher pressure enters.
  - Unpressurised – No problems.

INSTRUMENTS 3 – THE AIRSPEED INDICATOR (ASI)

CONSTRUCTION

- ASI measures dynamic pressure.
- Static pressure in the casing cancels out the static within the capsule to give dynamic.



ASI ERRORS

- **Instrument Error**
- **Pressure Error** (Manoeuvre + Position)
- **Compressibility Error**
- **Density Error**

AIRSPEED CORRECTIONS

- **Indicated (IAS) –** Shown on the ASI
- **Calibrated (CAS / RAS)–** IAS corrected for:
  - Position error (due to location of pitot head and static)
  - Instrument error (due mechanical workings of ASI).
- **Equivalent (EAS) –** CAS corrected for:
  - Compressibility Error (when TAS>300kts or ALT>10,000ft).
  - Not applicable less than this as air assumed incompressible.
- **True (TAS) –** EAS corrected for:
  - Density error
- **ICE - T**

TAS VS EAS RELATIONSHIP

$$V_{TAS} = V_{EAS} \times \sqrt{\frac{\rho\ ISA\ msl}{\rho\ ambient}}$$

BLOCKAGES

- **Pitot Block**
  - Under-read during descent (PUD)
- **Static Block**
  - Over-read during descent (SOD)

PRESSURISED LEAKAGES

- **Pitot Leak**
  - Capsule expands and over-reads
- **Static Leak**
  - Capsule contracts and under-reads

UNPRESSURISED LEAKAGES

- **Pitot Leak**
  - Capsule contracts and under-reads
- **Static Leak**
  - No change

ASI MARKINGS

- **White Arc**
  - V_{SO} = Stall Speed Full Flap
  - V_{FE} = Max Flap Extension Speed
- **Green Arc**
  - V_{S1} = Stall Speed Clean
  - V_{NO} = Max Normal Operating Speed
- **Yellow Arc –** Calm Operating Range
- **Red Line** - V_{NE} Never Exceed Speed

OTHER V SPEEDS

- **V_{RA} =** Max Speed Turbulent Air (Not on ASI)
- **V_{LO} =** Max gear operating speed (< V_{LE})
- **V_{LE} =** Max speed with landing gear down

INSTRUMENTS 4 – MACHMETER

MACHMETER FORMAULAS

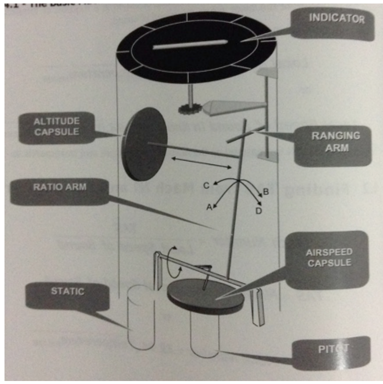
$$M = \frac{TAS\ (True\ Airspeed)}{LSS\ (Local\ Speed\ of\ Sound)}$$

$$LSS\ = 38.95 \times \sqrt{Temperature\ (Kelvin)}$$

$$M = f\sqrt{\frac{P_T - P_S}{P_S}}$$

CONSTRUCTION

- It can be seen the Machmeter essential uses the **ASI** components (P_T – P_S) and those of the **Altimete**r (P_S).
- Mach speed is unitless.
- Climbing at a constant IAS means the ASI capsule remains constant and the Altimeter expands, thus increasing the mach number.
- Contains two diagraphams with only that of the Altimeter part being of the aneroid type (sealed and partially evacuated)



ERRORS

- Compressibility, density and temperature errors are all cancelled out by the ratio calculation.
- **Instrument Error** – Tolerance should not exceed M.01
- **Pressure Error** – Inaccurate sampling of static pressure.

CLIMB / DESCENT WITH CONSTANT M

- Climbing with constant mach means IAS (P_T – P_S) must decrease as P_S decreases.
- Descending with constant mach means IAS must increase as P_S increases.

CRITICAL MACH NUMBER

- Free stream mach number when **the local mach number first becomes sonic** anywhere on an aircraft.
- Local mach is different as **air is accelerated** over the wing for example.
- Flight above $\mathbf{M_{CR}}$ is possible.
- $\mathbf{M_{MO}}$ (Max Operating Mach Number) will be slightly higher and is an absolute limit.

MAX TAS

- Occurs at CAS = V_{MO} & M = M_{MO}
- “Changeover point”

PITOT / STATIC ERRORS

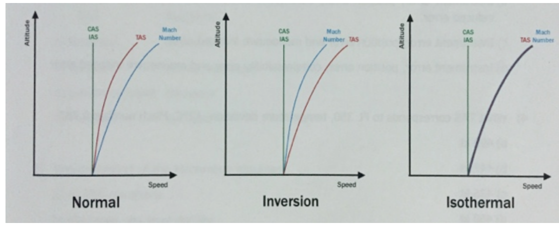
- Same as the ASI

OAT EFFECTS

- Mach & CAS not affected by temperature. Only TAS varies with temperature changes.

CAS, TAS & MACH RELATIONSHIP

- Cover up the one that stays constant. If the line is to the left then it decreases in a climb and increases in a descent.
- If line is to the right, it increases in a climb and decreases in a descent.



INSTRUMENTS 6 – GYROSCOPES

PRINCIPLE 1: RIGIDITY IN SPACE

- Maintains a **fixed orientation**
- **Rigidity is dependent** on:
  - Mass
  - Mass Distribution (Radius)
  - Speed of Rotation (RPM)
- Rigidity $\propto I\ (Inertia)\ \omega\ (Angular\ Velocity)$
  - Inertia = Radius x mass

CONSTRUCTION

- **Bearings**
  - Normally 5
- **Gimballs**
  - DOF = Degrees of freedom (excludes the basic plane of rotation)
  - X 1 = 1 DOFs (2 Planes)
  - X 2 = 2 DOFs (3 Planes)

TYPE 1 - DISPLACEMENTS GYRO'S

- **2 gimballs & 2 degrees of freedom**
- **Space Gyro's**
  - Free to maintain their own direction
  - Not aligned to an external datum
  - Not useful for aviation
  - **"Perfect with no influences of torque, or other external forces"**
- **Tied Gyro's**
  - Fixed orientation
  - Horizontal Gyro (DI)
  - Vertical Gyro / Earth Tied (AI)

TYPE 2 - RATE GYRO'S

- **1 gimball & 1 degrees of freedom**
- Turn Indicator

WANDER

- Movement of the gyro spin axis **away from the chosen datum.**
- Wander can be **real** or **apparent.**
- Wander in **horizontal plane = Drift**
- Wander in **vertical plane = Topple**

REAL WANDER

- Movement of axis **due to an actual force.**
- **Friction**
- **Mechanical Imperfections**
- **Instability of gimbals**
- **Hard manoeuvres / turbulence**
- **"We did it"** (Intentional)

APPARENT WANDER

- Movement of axis **due to earth's rotation and shape**
- **Earth Rotation**
- **Transport** (Gyro is moving)

APPARENT (EARTH) WANDER

- **Max Drift:** Polar Horizontally Tied
- **Max Topple:** Equator Vertically Tied and Equator Horizontally Tied (With Parallel)

APPARENT (TRANSPORT) WANDER

- **Greatest effect when travelling east** (with direction of the earth's rotation)

AIR DRIVEN (PNEUMATICAL) GYRO

- **Suction Pump** provides main drive
- Only requires **1 power source** (engine)
- **Relatively complex** and requires lots of construction parts.
- Depends on **air density**
- Has a **longer start-up time**

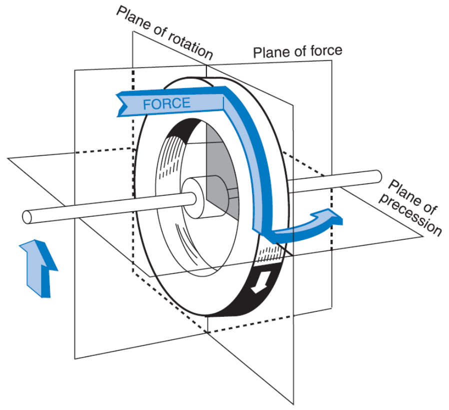
ELECTRICAL GYRO

- **Electric motor** provides main drive
- Requires **2 power sources** (engine + gen)
- **Relatively simple**
- Can achieve a **higher rpm** (more rigidity)
- Although better than air driven, both types are used for **redundancy.**

INSTRUMENTS 6 – GYROSCOPES

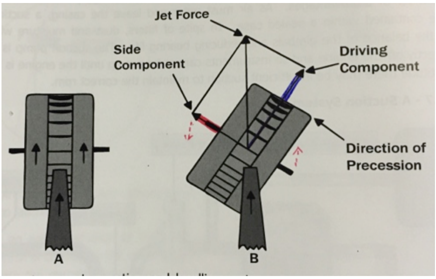
PRINCIPLE 2: PRECESSION

- Change of direction (angular change) of the plane of rotation of the rotor cause by an applied force.



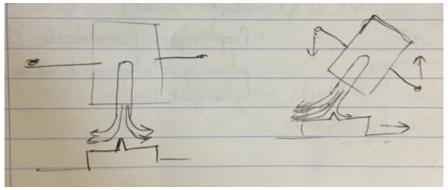
ERECTION JET METHOD

- The basic mechanism for driving the gyro will cause it to **self-level.**
- A component (red) of the air jet will act at right angles to the rotor.
- A **precession** is induced which will erect the gyro.



ERECTION PLATE METHOD

- Since the wedge is in a fixed position, a precession will act on the gyro.



ELECTRICAL DRIVEN ERECTION

- **Torque motor and commutator motor** are mounted on an outer gimball.

CAGING KNOB

- Allows for the **initial erection**
- Locks inner and outer gimbals at $\mathbf{90^0}$

ROTATION SPEEDS

- Air Driven = 9,000 – 12,000 rpm
- Electrical = 22,000 rpm

ERECTION VS LEVELLING

- **Erection**
  - Used on AI
  - Maintains the rotor axis vertical
  - Aligns rotor with horizontal gimball
- **Levelling**
  - Used on DI
  - Maintains the rotor axis horizontal
  - Aligns rotor with vertical gimball

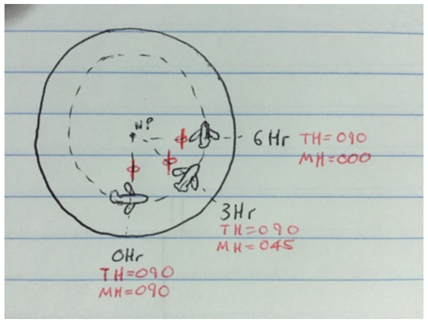
INSTRUMENTS 7 – DIRECTIONAL GYROSCOPE

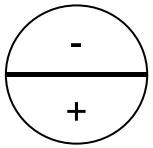
RANDOM DRIFT (REAL)

- **Mechanical Imperfections**
  - Friction in gimbal bearings and imbalances.
- **Gimballing Error**
  - When aircraft's heading is aligned with the gimbals (90 degrees), maneuvers can take place without disturbing gyro.
  - When on any other heading (not 90 degrees), maneuvers cause forces that result in small amounts of real drift.
- A "mechanically perfect" DG can be assumed to have to random drift.

EARTH ROTATION (APPARENT)

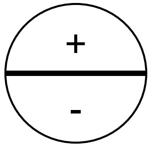
- Drift is max at the poles and zero at EQ.
- It is assumed the earth rotates at 15.04^0 / hr which is a combination of the earth's rotation and the orbit round the sun.
- **ER (^{0}/hr) = ± 15.04 x sin(lat)**
- Subtract if NH / Add if SH





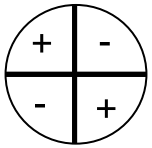
LATITUDE NUT (REAL)

- This is the **"intentional"** real error.
- Latitude nut can be calibrated to apply a torque to the **inner gimbal.**
- Through precession, this will act in opposite direction of the expected apparent drift.
- **LN (^{0}/hr) = ± 15.04 x sin(lat)**
- Opposite signs compared with ER formula.



TRANSPORT DRIFT (APPARENT)

- Will cause indicated heading to decrease (like ER in NH) when travelling to east in the NH (direction of earth rotation).
- Results from **convergence of meridians.**
- **TD (^{0}/hr) = ± GS / 60 x tan (lat)**



TOTAL DRIFT

- **Total Drift = RD ± ER ± LN ± TD**

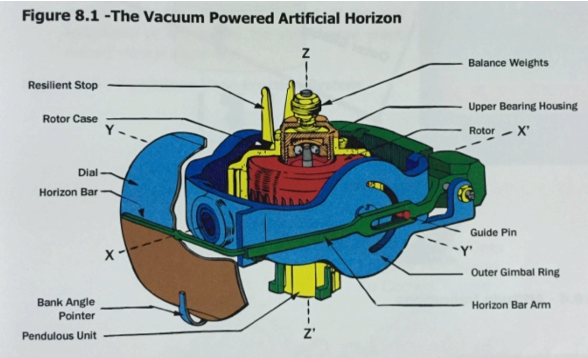
"LONGITUDINAL ACCELERATION"

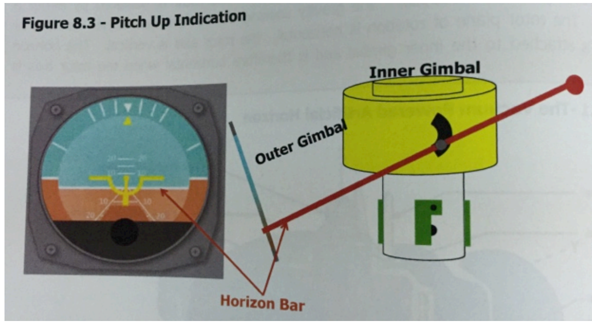
- Longitudinal acceleration **does not affect a DG** as you are travelling with the meridians.

INSTRUMENTS 8 – ATTITUDE INDICATOR

BASIC CONSTRUCTION

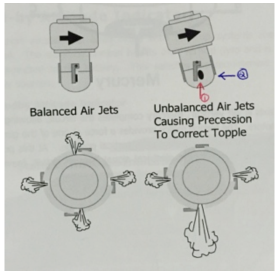
- **Casing** mounted to the **outer gimbal**.
- For roll, the aircraft symbol and scale move around the fixed horizon bar and pointer.
- For pitch, the outer gimbal pitches with the aircraft and the horizon bar moves.
- A pendulous unit allows outflow of suction air from casing.





PENDULOUS VANE ERECTION SYSTEM

- Air flows from Outer Gimbal ---> Inner Gimbal (rotor) ---> Pendulous Unit
- When vertical, all vanes are **half covered** and the forces are **balanced.**
- When toppled, some are closed and some open so the force is **unbalanced.**
- Force is applied to the pendulous unit (1) and will erect gyro through **precession** (2).
- The pendulous vane also has a **slightly shifted CoG** so gyro rests in the vertical axis (Aids in start-up orientation).

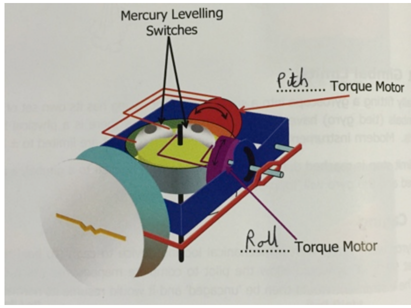


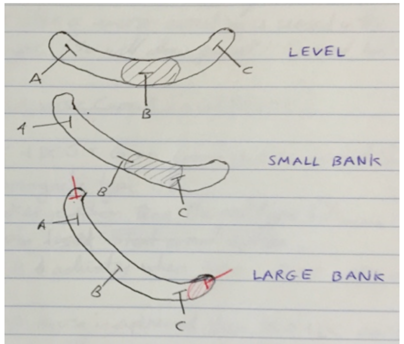
TORQUE MOTOR ERECTION SYSTEM

- Used on an **electrical AI** where there is no pendulous unit.
- **Mercury switches** are used to control two **torque motors.**
- When the gyro topples, multiple contacts are made on the switch (eg/ B + C) and the torque motors are operated.
- **Precession** causes them to act in the ‘opposite sense’

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv

^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^





- During **steep turns**, the mercury may pool at the ends and no contact is made, thus **preventing erection if required.**
- **Secondary contacts** are installed on some AIs to provide a **fast erection** should the AI topple in steep turns.
  - Should not be activated for more than 30 – 60 secs due heat build up.
  - Normal erection = 2 – 4^0 / min
  - Fast erection = 60 – 120^0 / min

- **Low angle of bank turns should be avoided** as the torque motors will cause an overcorrection.

INSTRUMENTS 8 – ATTITUDE INDICATOR

ACCELERATION ERROR

- **Pitch error** is caused by a lag in the **lateral vanes.**
    - They swing back towards the pilot and close the port slot whilst opening the starboard slot.
    - Precession causes the base to move towards the pilot and results in a **pitch up indication.**
- **Roll error** is caused by a lag in the **weighted base due to interia.**
    - Precession causes the gyro base to move to the right, causing a **roll right indication.**

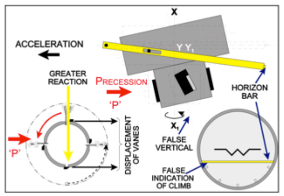


Figure 12.8 Pitch Error Due to Acceleration

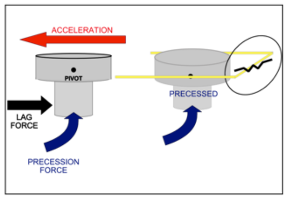


Figure 12.9 Roll Error Due to Acceleration

- So, **Acceleration = Pitch Up & Roll Right** Indication (Approx 2-3 degrees)
- **Deceleration = Pitch Down & Roll Left**
- The above assume an anti-clockwise gyro.

TURNING ERROR

- In a turn, a **centripetal force** exists towards the centre of the turn.
- The **centrifugal reaction** acts on the **vanes and weighted base** causing pitch and roll errors.
- **Magnitude of errors** varies with speed, rate of turn and length of turn.

8.5.3 Summary of Turning Errors

TURN	PITCH INDICATION	BANK INDICATION
START 0°	CORRECT	CORRECT
AFTER 90°	OVER PITCH	UNDER BANK
AFTER 180°	OVER PITCH	CORRECT
AFTER 270°	OVER PITCH	OVER BANK
AFTER 360°	CORRECT	CORRECT

ELECTRICAL VS AIR DRIVEN ERRORS

- Errors present in both types although **minimised with electrical type.**
    - Absence of heavy base
    - High rotor speeds
    - Cut out switches

GIMBALL LIMITS

- **Old Designs: $\pm$ 111^0 Roll & $\pm$ 60^0 Pitch**
- **New Designs: 360^0 Roll & $\pm$ 85^0 Pitch**
- Gyro will topple when these are exceeded
- Unless a fast erect is present, **gyro will take 10 - 15 mins to re-erect itself.**

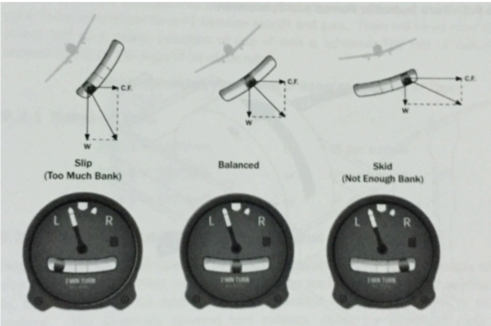
REMOTE VERTICAL GYRO

- Uses a **syncro system** to convert pitch and roll data into a **digital output.**
- Displayed on a Attitude Director Indicator
- Can be used by multiple systems.

INSTRUMENTS 9 – TURN AND BALANCE INDICATOR

BALANCE INDICATOR

- For **slip**, think banking but with no turn
  - Centrifugal force not enough
  - Ball falls to the inside of the turn
- For **skid**, think turning without bank
  - Centrifugal force too great
  - Ball pushes to outside of turn
- **Step on the ball to correct**
- A **fluid** is present within the glass case:
  - Damping agent
  - Reduces friction



TURN INDICATOR

- **Horizontally tied rate gyro**
- Situated **parallel to the lateral axis**
- One gimball & **one DoF**
- **Denied freedom in yaw axis**
- Measurement is accurate for the **yaw rate at low bank angles.**
- **Does not drift or topple**

RATE ONE TURN

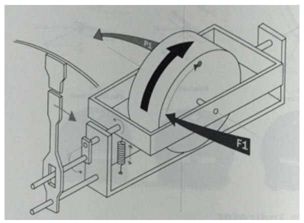
- **180^0 / Min = 3^0 / Sec**
- Angle of bank required for rate one turn:

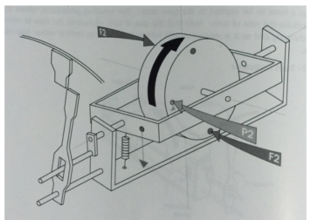
$$AoB = \frac{TAS}{10} + 7$$

- Turn indicator is **calibrated to a fixed airspeed.**
- Above formula can also be used if given IAS.

PRIMARY AND SECONDARY PRECESSION

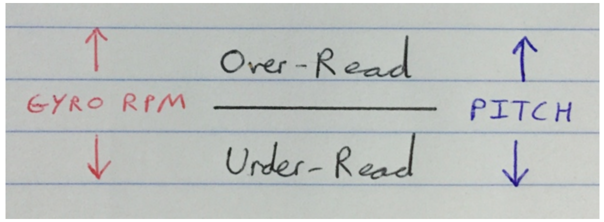
- The gyro is **denied movement in the yawing plane.**
- When a yaw to the right occurs, a force F1 is applied to the gyro which results in a precession P1 causing the gyro to tilt left.
- The spring force now causes a force F2 to be applied which results in precession P2 **acting in the direction of yaw.**
- Gimball continues tilting until spring force produces precession equal to rate of turn of the aircraft.
- When balanced, tilt stops and a steady indication of turn rate is provided.





TURN INDICATOR ERRORS

- Any TAS different to the calibrated TAS will result in an under-read.
- There is also **rotor speed** and **loop (pitch) error** that is present.



TURN COORDINATOR

- **Gimball is tilted upwards by 30^0 – 40^0**
- Now sensitive to both **yaw and roll**
- Can be difficult to determine however whether indication is due primarily to bank or yaw.

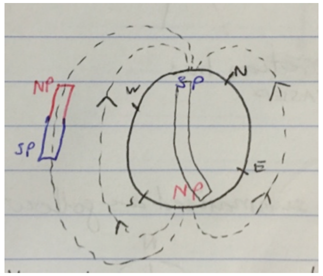
INSTRUMENTS 10 – TERRESTRIAL MAGNETISM

MAGNETIC FIELD

- **Space around the magnet in which magnetic influence is felt.**

EARTH'S MAGNETIC FIELD

- The **magnetic meridian** is the horizontal component of the earth's field.
- A freely suspended magnet will align its north seeking pole with the magnetic meridian.
- To keep our convention of flux flowing North to South, it can seen we must imagine the magnet to be turned upside down within the earth.
- The "earth's magnet" is slightly curved at the true south pole => **not anti-podal**



TERRAIN EFFECTS

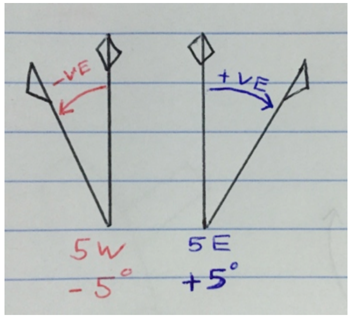
- Due to terrain magnetism, magnetic north is **not in a fixed direction.**

MAGNETIC FIELD CHANGES

- **Long Term (Secular) Changes**
  - Moves approx 10 nm / yr
  - Poles swap positions every 10,000 yrs
- **Short Term Changes - Predictable**
  - Earth's orbit around the sun (annual)
  - Ionosphere height changes (daily)
- **Short Term Changes - Random**
  - Solar activity

VARIATION

- Westerly variation described as – ve
- Easterly variation described as + ve
- **Isogonal** joins places of equal variation
- **Agonic** line shows zero variation



MAGNETIC DIP

- **Total Field = Horizontal + Vertical Component**
- The Horizontal component is the "**directive force"**
- The **vertical component causes dip**
- Dip is greatest at the poles where the horizontal component is least and the vertical at max.
- **Isoclinals –** Lines of equal dip
- **Aclinic –** Line of zero dip (magnetic equator)
- When the horizontal component drops **below 6 micro tesla**, the compass becomes too unreliable.
  - Occurs above 70 N/S

B/E TYPE DIRECT READING COMPASS

- Circular compass card attached directly to the magnet assembly.

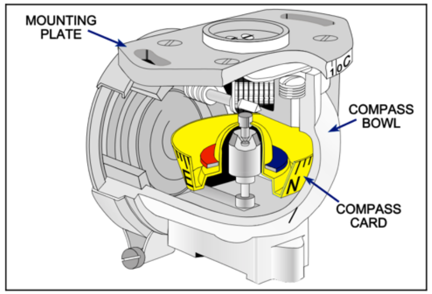
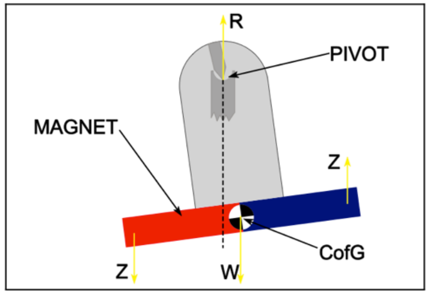


Figure 9.1 A Vertical Card Compass

INSTRUMENTS 10 – TERRESTRIAL MAGNETISM

REQUIREMENT 1 - HORIZONTALITY

- Compass is kept horizontal by means of **pendulous suspension.**
- Centre of gravity of assembly is lower than the supporting pivot.
- When magnetic dip (force Z) occurs, the weight of the assembly will oppose the dip moment due to the **offset CoG.**
- The result of this is that **residual dip** (actual dip experience by compass) is less than the dip due to the magnetic vertical component.



REQUIREMENT 2 - SESNSITIVITY

- Improved by **using more magnets**
- Improved by keeping **pivot friction to a minimum.**
- **Must be within ± 10⁰**

REQUIREMENT 3 - APERIODICITY

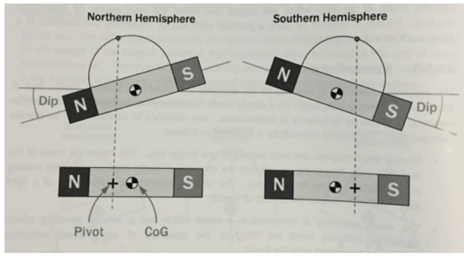
- **Use of fluid to dampen oscillations.**

COMPASS LIQUID PROPERTIES

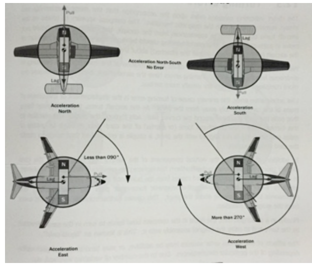
- Low coefficient of expansion
- Low viscosity
- Transparency
- Low freezing point
- High boiling point
- Non-corrosiveness
- Good lubrication

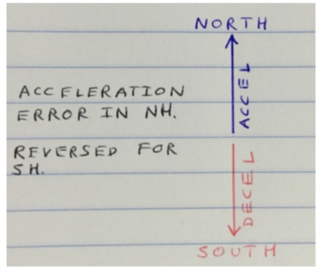
ACCELERATION ERROR

- Due to magnetic dip, the **CoG is always displaced towards the equatorial side of the pivot.**
- **Inertia** causes the magnet to swing around it's pivot point.
- In NH, **acceleration results in an apparent turn towards north.**
- In NH, deceleration results in an apparent turn towards south.
- Reserved for SH.
- Acceleration in north / south results in no error however due to no turning around pivot.



ANDS – Accelerate North / Decelerate South

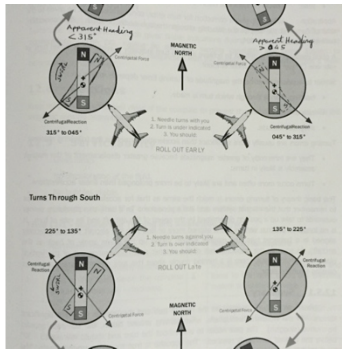




- **Size of error** depends on:
  - Heading
  - Magnitude of acceleration
  - Design of magnet system
  - Magnetic latitude

TURNING ERROR

- **Centripetal force** acts on **pivot**
- **Centrifugal force** acts on **CG**
  - Pull GC towards outside of the turn
- Error is max when turning through N / S
- Error is min when turning through E / W
- Error increases with magnetic latitude



INSTRUMENTS 10 – TERRESTRIAL MAGNETISM

LIQUID SWIRL

- Will increase turning error when turning through the nearer pole.
- Will decrease turning error when turning through the further pole.
- Liquid in compass bowl will tend to **swirl in the same direction of the turn.**
    - Like turning a glass full of water

TURNING ERROR – NORTHERN HEMIS

U - Underead => Undershoot
N - North
LIQUID SWIRL INCREASES ERROR

O - Overread => Overshoot
S - South
LIQUID SWIRL DECREASES ERROR

LIMITATIONS

- Errors
- Closeness to sources of deviation
- Self contained unit
    - Cannot be used to feed readings to other equipment.

INSTRUMENTS 11 – AIRCRAFT MAGNETISM

DEVIATION

- Difference between compass north and magnetic north.
- Easterly deviation is expressed + ve
- Westerly deviation is expressed - ve

CAUSES OF DEVIATION

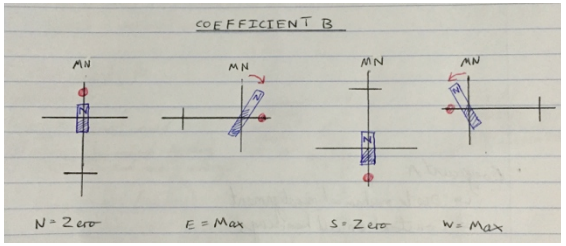
- **Hard Iron Magnetism (Permanent)**
  - Permanently present throughout the flight
  - Not affected by heading / latitude
  - EG/ Electrical circuits
  - Can be resolved separately on the longitudinal (coefficient B) and lateral (coefficient C) axis.
- **Soft Iron Magnetism (Temporary)**
  - Temporary by nature
  - Induced from flying through the earth's

COEFFICIENT A

- Due to mechanical misalignment
- Error the same on all headings

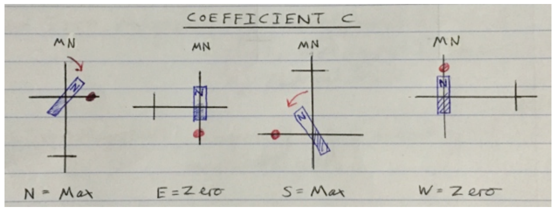
COEFFICIENT B

- Component of permanent deviation resolved on the **longitudinal axis**
- Maximum on East / West Headings
- Zero on North / South Headings
- **B = B_{MAX} x sin (HDG)**



COEFFICIENT C

- Component of permanent deviation resolved on the **lateral axis**
- Maximum on North / South Headings
- Zero on East / West Headings
- **C = C_{MAX} x cos (HDG)**



CALCULATING THE COEFFICIENTS

- An initial compass swing takes places in order to calculate the coefficients.
- A **datum compass** is used to align the aircraft with N / E / S / W.
- The readings of the aircraft compass are then noted and the coefficients are calculated as follows:

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

Aircraft Compass	Datum Compass	Deviation
356°C	002°M	+6
090°C	089°M	-1
185°C	183°M	-2
266°C	271°M	+5

Remember that the deviation is the correction to the aircraft compass to make it agree with the datum compass.

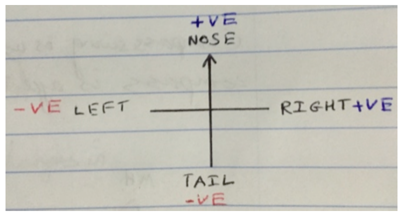
$$\textit{Coefficient A} = \frac{\textit{Sum of Deviations}}{n} = \frac{+8}{4} = +2$$

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

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

POSTIVE / NEGATIVE COEFFICIENTS

- Coefficient A is positive if the longitudinal component is towards the nose.
- Coefficient B is positive towards the right.



INSTRUMENTS 11 – AIRCRAFT MAGNETISM

DEVIATION ON GIVEN HEADING

$$A + B_{MAX} \sin(HDG) + C_{MAX} \cos(HDG)$$

CORRECTING THE COMPASS

- **Coefficient A** is corrected for by physically realigning the compass.
- **Coefficient B & C** are corrected by introducing a compensating magnetism at the compass.

RESIDUAL DEVIATION

- Even once A, B and C have been 'factored out' by correcting the compass there will still be some **unexplained deviation.**
- A second compass swing takes place with the aircraft being turned through 30^0 heading intervals.
- A **compass deviation card** is then created which summarises the residual deviation.

INSTRUMENTS 13 – REMOTE INDICATING COMPASS (RIC)

REQUIREMENT

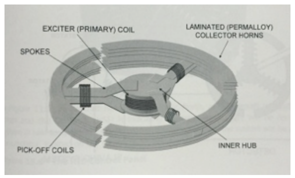
- The RIC is an attempt at taking the best of both worlds from a DIC and DG.
- **Long term accuracy of the DIC** – retaining alignment with magnetic north.
- **Short term accuracy of the DG** – unaffected by short term maneuvers.

LOCATION

- Installed on the **wings / tail section** where interference from aircraft is at a minimum.
- **Compensation circuit** can be fitted to counter any magnetism that may remain even once it has been remotely located.

DETECTION UNIT (FLUX VALVE)

- Consists of **three flux valve legs.**
- The **primary coil** is excited with an AC current and a magnetic flux is induced in both the A and B legs.
- The flux in each leg will be equal in magnitude but opposite in direction, so the resultant flux is zero.
- **No current** is induced in the secondary pick-up coil due to zero resultant flux.



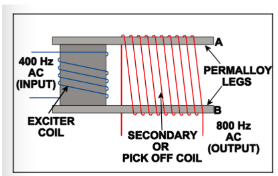


Figure 16.6 A single leg of a Flux Valve

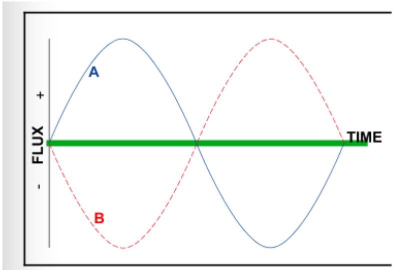
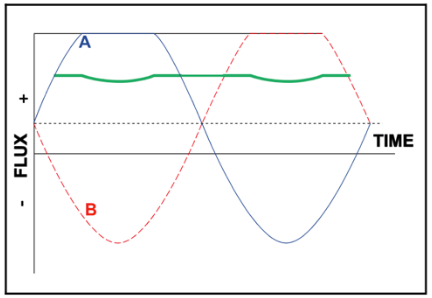


Figure 16.7 Flux fields at A and B and resultant

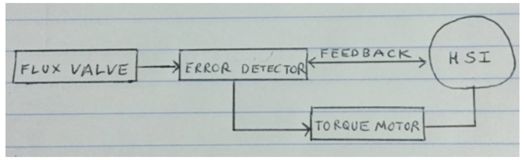
- The AC frequency used is carefully chosen to bring both legs **just short of saturation.**
- When the earth's magnetic field is present, it will cause one of the legs to become saturated.
- There is now a resultant flux present.
- An EMF is now induced within the secondary pick-up coil at the points where the **resultant flux changes** (dips in green line). In accordance with Faraday's law.



- The flux valve remains stationary when the aircraft turns.
- When aircrafts heading changes, different EMFs are induced within each of the 3 secondary windings.

SYNCHRONISATION

- EMF changes from the flux valve are transferred to coils on a **selfsynchronous (selsyn) unit** which forms part of the **error detector**.
- This essentially **replicates** the flux detectors output.
- The error detector checks the position of the HSI.
- If it detects the HSI is not aligned correctly, it operates a **torque motor** to re-align the gyro as required.



PENDULOUS COMPENSATION

- The detection unit is suspended from a **Hooke's joint.**
- Allows **freedom of 25^0 in pitch and roll.**
- It is suspended within a liquid base to provide damping and reduce the tilt that results from maneuvers.

DEVIATION

- **Max deviation: ± 1^0**

INSTRUMENTS 13 – REMOTE INDICATING COMPASS (RIC)

MODES

- **Slaved**
  - Uses the remote indicating compass
  - Torque motor and leveling switches will automatically precess the gyro at a rate of 2 -4 degrees per minute.
- **DG Mode**
  - Used as a reversionary mode or when operating close to magnetic poles.
  - A slew switch is used to align the HSI manually every 15 mins. A precession rate of 60 – 120 degrees per minute is used.

SLEW SWITCH

- As well as using the slew switch when in DG mode, it can be used in slaved mode as a **fast erect method**.
- This is used when manually re-aligning the gyro in case of gross misalignment / toppling after maneuvers or on start-up for example.

ANNUNCIATOR

- Deviates from vertical alignment when HIS is not aligned with selsyn unit.
- Auto-alignment occurs in slaved mode.

ADVANTAGES

- Reduced deviation
- Reduced turning and acceleration errors
- Improved presentation
- Power output of heading

DISADVANTAGES

- AC power required
- Heavier
- More expensive
- More complex to maintain

INSTRUMENTS 14 – AIR DATA COMPUTER & SENSORS

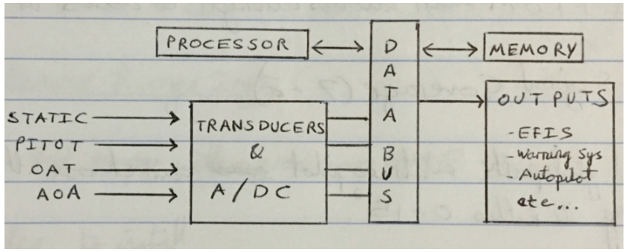
TRANSDUCER

- Device that **converts mechanical / physical changes into an electrical signal.**

ANALOGUE / DIGITAL CONVERTER (A/DC)

- Device that **converts an electrical signal into a digital output.**

AIR DATA COMPUTER ARCHITECTURE



ADC REDUNDANCY

- Captain and F/O have a **separate ADC** each.
- Each ADC is fed by a separate set of probes.
- In case of discrepancy, readings can be checked against the **standby instruments** to confirm which ADC is functioning correctly.
    - Selector can then be changed from BOTH to either ADC 1 or ADC 2 as appropriate.

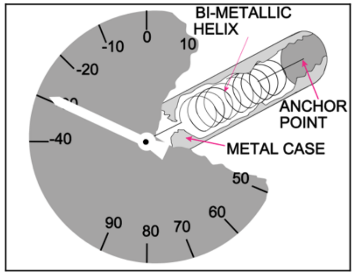
ADC ADVANATGES

- Improved displays
- Reduced instrument and lag error
- Error correction
- Central source for other systems
- Clean design / less maintenance
- Failure warning
- Modular replacement is possible

TEMPERATURE SENSING

HELICAL BI-METALLIC SENSOR

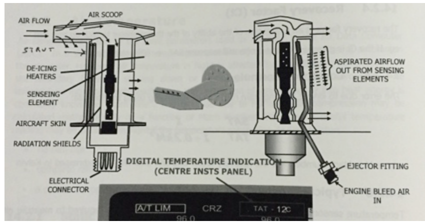
- One metal will expand more than the other when temperature increases.
- When wound into a coil and fixed at one end, a temperature change will cause it to rotate.
- Used on small aircraft that do not need to take into account ram rise.



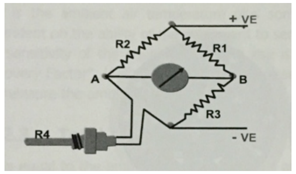
TAT PROBE

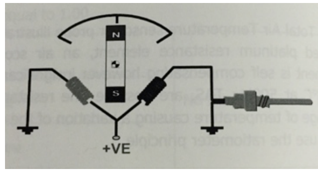
- **Sensing element** acts as a transducer.
- **Radiation shield** stops heating from the sun.
- **De-Icing Heaters** prevent icing effects.

- When stationary, **engine bleed air** is used to induce an airflow into the probe.



- The electrical output could be interpreted using a Wheatstone Bridge design but this **requires a constant supply voltage.**
- Instead, a **ratiometer thermometer** is used.
    - Supply voltage variations affect both coils
    - Output from probe will change magnetic field around the right coil thus causing the magnetic indicator to move.
    - Subject to small vibrations in flight





INSTRUMENTS 14 – AIR DATA COMPUTER & SENSORS

SAT, TAT AND RAT

- SAT (Static Air Temperature) is the temperature of the **free stream air** that we want to measure.
- Due to **compressibility** at high speeds, there is an increase in temperature due to **adiabatic heating.** This is known as the **Ram Rise (RR).**
- **TAT = SAT + RR** (Where TAT = Total Air Temp)

- Imperfections in probe mean it does not pick up all the ram rise however. The amount picked up by the probe is the **MMR (measured ram rise)**
- **The Recovery Factor (K_r)** is the ability of the probe to pick up ram rise.
- **MRR = K_r x RR** (Where K_r < 1 | Usually 0.8)

- The temperature as sensed by the probe is called the **Ram Air Temperature (RAT):**
- **RAT = SAT + MRR**

RAM RISE RULE OF THUMB

$$RR \approx \left(\frac{TAS}{100}\right)^2$$

CORRECTION FORMULA

$$\frac{SAT}{TAT} = \frac{1}{1 + (0.2\,M^2)}$$

$$\frac{SAT}{RAT} = \frac{1}{1 + (0.2\,K_r\,M^2)}$$

Temperature must be in Kelvin (K)

ERRORS IN TEMPERATURE MEASURING

- **Instrument Error**
  - Manufacturing imperfections.
- **Environmental Errors**
  - Solar heating / ice accretion.
- **Heating Errors**
  - Ram Rise or frictional effects of being too close to aircraft skin.

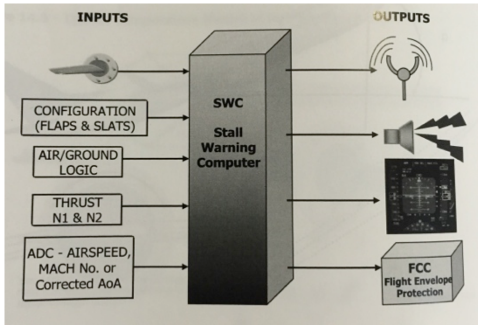
ANGLE OF ATTACK SENSORS

ERRORS IN TEMPERATURE MEASURING

- **Vane Type**
  - Orientates freely with relative airflow
- **Pressure Differential Type**
- **Conical Probe Type**
  - Cone will rotate in order to equalize pressure

STALL WARNING

- **Activates when within 5% of stall speed or 5 kts, whichever is greater.**



STALL WARNING SYSTEM

- **Warns flight crew of an impending stall.**
  - Stick Shaker
  - Audible Warning
  - Warning Display

STALL PROTECTION SYSTEM

- **Prevents the stall from occurring.**
- Operates on **activation of the stall warning system.**
- **Manual Flight / Autopilot System**
  - Stick Push
  - Auto deployment of leading edge devices
- **Fly By Wire System**
  - AP + AT used to maintain appropriate pitch attitude and keep speed above stall speed.

INSTRUMENTS 15 – RADIO ALTIMETER

PURPOSE

- Measures the **height / distance of aircraft above the ground.**
- By comparison, the pressure altimeter measures distance from a set datum and not the ground.
- Can be used to provide AGL height and rate of height change to other aircraft systems.

PULSE VS CONTINOUS RADAR

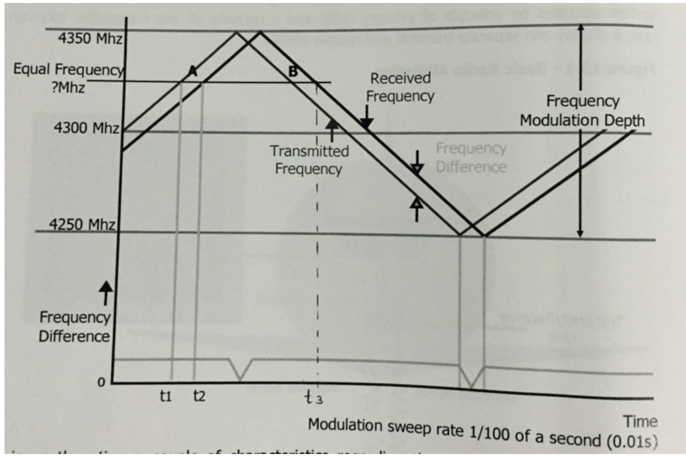
- Pulse radar has **one antenna** for both receiving and transmitting. It cannot do both at the same time.
- At low altitude, a reflection may return to the aircraft before it has switched to RX mode, thus missing the return.

- Continuous radar uses **two antenna** (one to TX and one to RX), thus overcoming this problem.

FMCW OPERATION

- As a continuous transmission is used, some method of distinguishing between returns is required.

- Radio altimeter transmissions are of the **frequency modulated continuous wave** type.
- **Carrier Wave = 4300 MHz (SHF)**
- **FM Modulated with 50 MHz**
    - Produces a 100 MHz bandwidth
    - 4250 – 4350 MHz
- The **time difference** between the transmitted and received frequency is measured to give distance.



MODULATION SWEEP RATE

- If t_1 is the time a particular frequency is transmitted, this will be returned to the aircraft at both t_2 and t_3
- An **equal frequency** is said to exist.
- The time gap between t_2 and t_3 needs to be prevented from coming too close otherwise ambiguity as to the correct signal will exist.

- The **modulation sweep rate** is essentially the time taken to complete one cycle
- A low sweep rate (longer time period) is used to increase the distance between t_2 and t_3
- **Typically a sweep rate of 0.01s is used.**

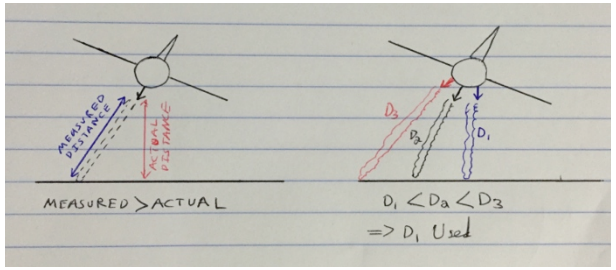
DEPTH OF MODULATION

- This is the bandwidth that results from frequency modulation.
- A **large depth of modulation** is used to prevent apparent changes in frequency due to the **Doppler effect.**

CONE EMISSION

- In a turn, if only one vertically aligned antenna is used the distance measured will be greater than in reality and an over-read will occur.

- Multiple antennas are used to sense the return that provides the lowest height.
- This cone emission provides accurate readings up to **± 40⁰ bank and ±25⁰ in pitch**



INSTRUMENTS 16 – INERTIAL NAVIGATION

INTRODUCTION

- Allows navigation **independent of any external aids.**
- **INS = Inertial Navigation System**
- Given a known starting point plus the distance and direction travelled, our position can be obtained.
- **Accelerometers** measure the distance and direction travelled.
- **IRS = Inertial Reference System**
    - INS + Attitude & Heading Info + Display

REDUNDANCY

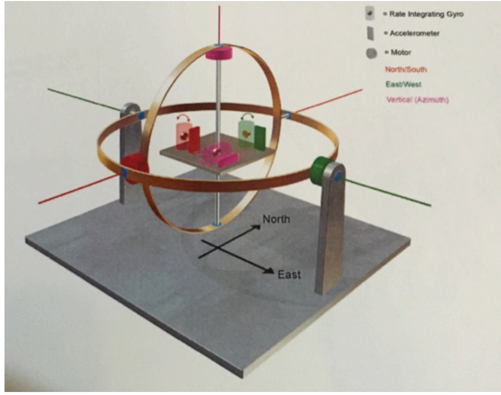
- 2 IRSs are installed for redundancy.
- Left IRS utilised by left FMC.
- Right IRS utilised by right FMC

1ST GENERATION INS

STABILISED PLATFORM

- **3 Accelerometers aligned:**
    - N/S
    - E/W
    - Vertical
- **3 Rate Integrating Gyro's**
    - Sense displacement and drive torque motors as required to ensure accelerometers remain aligned.
- **3 Torque Motors**

- Stabilised platform is orientated to **true north**



RATE INTEGRATING GYRO (RIG)

- A normal gyro (as fitted in a turn indicator) measured the rate of movement.
- Rate integrating gyro **measures amount of movement.**
- 2 cylinders are separated by a **viscous fluid**

VISCOUS FLUID

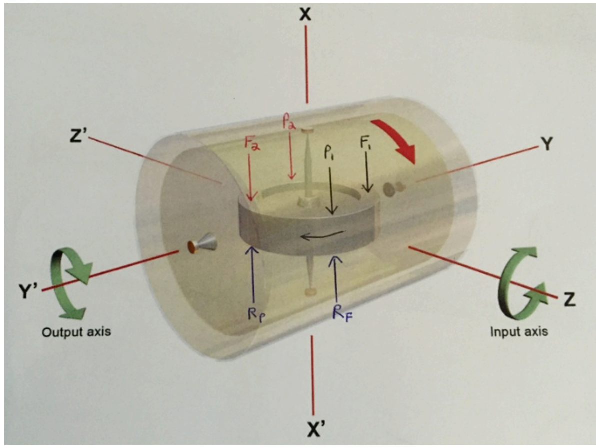
- Allows for **cylinder rotation**
- Provides a **calibrated resistance** (like the spring in a turn indicator)
- The viscous fluid is only calibrated when at the **correct temperature.**
    - When the gyro's are spun up, friction force heats the fluid to the correct temperature.

GAIN EFFECT

- The movement in the input axis is **amplified** and a large movement in the output axis results.
- This is **transferred to the torque motors** which ensure the platform remains stabilised.

RIG PROCESS

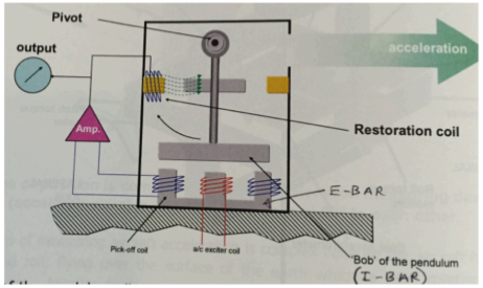
- Force applied (F_1)
- Precession Occurs (P_1)
- Reactionary force from viscous fluid (R_F)
- Reactionary precession (R_P)
- Gyro cannot tilt but can only roll to an equal and opposite force must be applied (F_2)
- This is precessed and gyro movement is stopped (P_2)



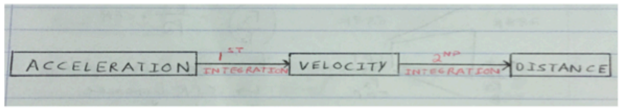
INSTRUMENTS 16 – INERTIAL NAVIGATION

ACCELEROMETER

- I-BAR movement causes an **electromagnetic induction** within the pick off coils on the E-BAR.
- **Sent to INS computer + restoration coils**
- Amount of feedback is directly proportional to the acceleration.



- **Integrating** acceleration gives us:
  - Velocity (1st Integration)
  - Distance (2nd Integration)



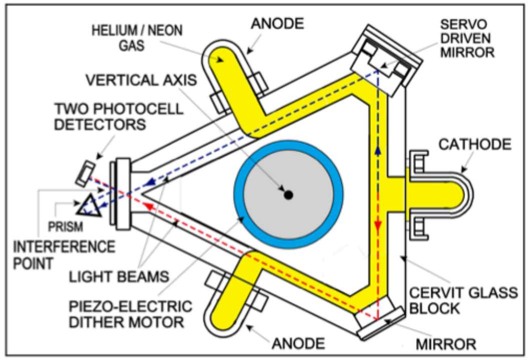
ALIGNMENT PROCESS

1. **Caging**
   - "Grabbing of the gyro and getting it roughly level"
   - Allows the gyro to spin up
2. **Levelling**
   - N/S & E/W accelerometers sense gravity via displacement of the I-BAR.
   - Torque motors level the platform until there is no displacement.
3. **Gyro Compassing**
   - Aligning with True North
   - Torque motors adjust platform as required until there is no topple on the E/W axis
   - This topple occurs due to earth rotation
4. **Position Enter**
   - Input LAT / LONG to tell INS where we are starting from.

- Aircraft **must remain stationary during stages 2 & 3.**

RING LASER GYRO

- Used primarily to **reduce spin up time**
- A laser beams are created between each anode and the cathode => **2 beams are produced.**
- **Angular movement** will cause one beam to reach the detector before the other.
  - When upright, they arrive at the same time.
- The **difference in frequencies** between the two beams is proportional to the angular movement.
- **Laser lock** is prevented by a **dither motor.**



RING LASER GYRO ADVANTAGES

- Reduced spin up time
- Insensitive to G-Force
- Small Size
- Lower power consumption
- Greater MTBF (Mean time between failures)

RING LASER GYRO DISADVANTAGES

- Laser lock (prevented with dither motor)
- Drift caused by imperfections in mirror

INSTRUMENTS 16 – INERTIAL NAVIGATION

STBY CONTROL

- This is the caging stage of the alignment process.
- Only present on systems with RIGs.
- RLGs do not need to be caged.

LATITUDE LIMITS DURING ALIGNMENT

- Topple is greatest at the equator (due to greater earth rotation) but negligible at the poles.
- **Alignment not possible above 70 N/S** as gyro compassing is ineffective.

POSITION ENTER 'DOUBLE CHECKS'

- When shutdown, the INS remembers it's last position.
- If on next alignment a LAT / LONG is input that differs from this, it will ask you to re-enter the LAT / LONG as a double check.

- The gyro's can sense topple and compute the aircraft's latitude.
- If a different latitude is entered, it will ask you to re-enter the LAT / LONG.
- If the latitude still differs on the second input, the system will not enter NAV mode.

ALIGNMENT TIMES

- INS = 15 Minutes
- IRS = 10 Minutes

2ND GENERATION – WANDER PLATFORM

WANDER PLATFORM

- The 1st generation INS suffers from errors when operating near to the poles.
- Near the poles, the stabilised platform will be continuously re-aligned with true north.
- This results in gimballing errors.

- The initial displacement from true north can be calculated during the alignment.
- Instead of continuously re-aligning the platform, the initial 'error' can be factored into the outputs and the correct readings obtained.
- Requires more computing power but allows more reliable navigation in polar regions.

3RD GENERATION – STRAPDOWN PLATFORM

STRAPDOWN PLATFORM

- This above principle is taken one step further and used to correct for platform 'tilt'.
- There are now **no torque motors or platform required.**
- A box containing **3 accelerometers and 3 RLGs** is strapped down to the aircraft.

INTERTIAL REFERENCE SYSTEMS

- This 3rd generation marks the beginning of the IRS system.
- INS = Stabilised / Wander Platform + RIGs
- IRS = Strapdown System + RLGs

INTERTIAL REFERENCE SYSTEM

REDUNDANCY

- **2 IRS units** are installed to redundancy.
- Should the axis in one IRS fail, the axis from the other IRS can be used.
- Failure of the same axis in both units can be overcome by tilting the unit 45^0

IN-FLIGHT RE ALIGNMENT

- Aircraft fitted with GPS can re-align to IRS in flight if required.

ADIRU

- **Air Data Inertial Reference Unit**
- ADIRU = IRS + ADC

- The IRS provides HDG, TRK & G/S Inputs
- The ADC provides TAS
- Wind can now be calculated be the ADIRU and the complete set of components in the wind triangle is obtained.

LONGITUDE CALCULATION

- Since our distance is obtained via the 2nd integration, **the departure formula is used by the IRS** to calculate the change in longitude and obtain the correct LAT / LONG at any given moment in time,
- CH Long = Departure / cos (lat)

INSTRUMENTS 16 – INERTIAL NAVIGATION

IRS CORRECTIONS

- **Coriolis Effect**
  - Adjusting for the different rotational velocities at different latitudes.

- **Centripetal Effect**
  - Without adjusting for the centripetal effect (as the aircraft follows the curvature of the earth) the IRS will think the aircraft is higher than it really is.

- **Schuler Oscillation**
  - The IRS position is adjusted for oscillation which occurs with a period of 84.4 mins.

- **Transport Wander**
- **Earth Rotation**

IRS ERRORS

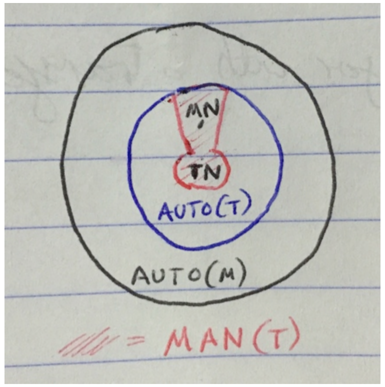
- **Total Error = Bounded + Unbounded Errors**

- **Bounded** (Remain constant with time)
  - Initial Leveling Error
  - 1st Integration Error
  - Faulty Accelerometers

- **Unbounded** (Get worse with time)
  - Initial Alignment Error
  - 2nd Integration Error
  - Gyro Drift

TRUE / MAGNETIC HEADING

- An **AUTO / MAN** switch is provided to select between true heading or magnetic heading output from the IRS.
- In AUTO mode, magnetic heading is used operating away from the poles. The IRS uses a **variation database** to convert from True to Magnetic.
- When within a certain radius of true north, heading output is automatically changed to true.
- When within an inner 'key hole', MAN mode should be selected to force true heading.

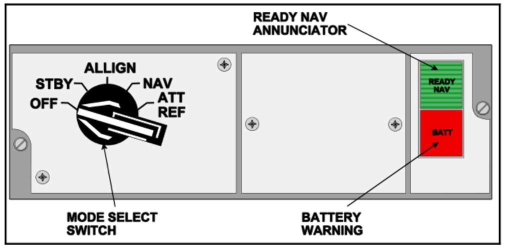


ADIRU CONTROLS

MODE SELECTOR UNIT (MSU)

- **STBY** – Caging and POS ENTER
- **ALIGN** – Levelling & Gyro Compassing
- **READY NAV** illuminates once align complete
- **NAV –** Selected after alignment and system now ready to use.

- **ATT –** Uses the gyro's to provide attitude information only to instrumentation. Used if IRS computers fail preventing full normal NAV functioning.
- **BATT –** In event of electrical failure, IRS will use it's own battery. Illuminates when the IRS battery is about to die.



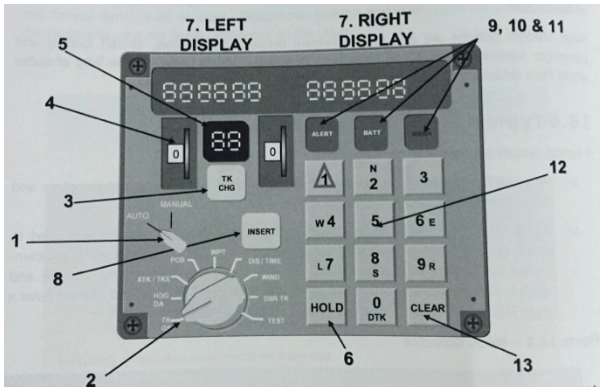
INSTRUMENTS 16 – INERTIAL NAVIGATION

CONTROL DISPLAY UNIT (CDU)

- **TK/GS** – Track & Groundspeed
- **HDG / DA –** Heading & Drift Angle
- **XTK / TKE** – Cross Track Dist & Track Error Angle
- **POS –** Present LAT / LONG
- **WPT –** Waypoint Display
- **DIS / TIME –** Distance & Time (To next WP)
- **WIND**
- **DSR TK / STS –** Desired TRK (To next WP) & System Status Code

- **AUTO / MAN** – Toggles between automatic waypoint advancing or manual.
  - MAN used to overfly a waypoint
- **TK CHG** – Allows manual selection of next WP

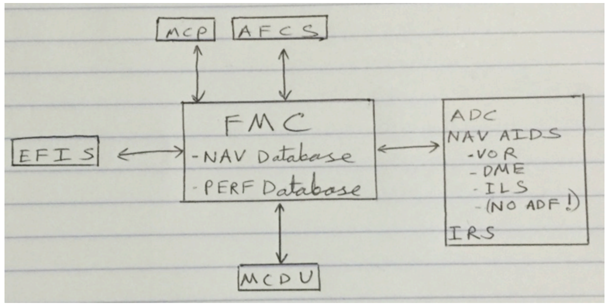
- **ALERT** – Illuminates 2 mins before next WP
- **BATT** – Illuminates when running on BATT
- **WARN** – Illuminates when a fault exists



INSTRUMENTS 17 – FLIGHT MANAGEMENT SYSTEM

INPUTS AND OUTPUTS

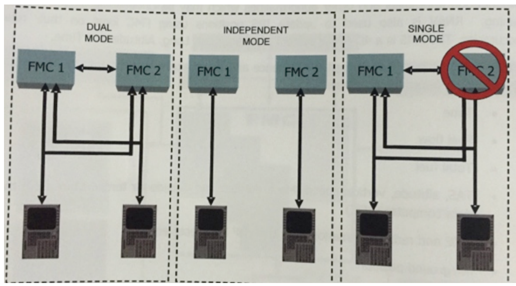
- **At the heart of the FMS is the FMC** (Flight Management Computer)
- The FMC **communicates with multiple other systems** as in the diagram below.



FMS ARCHITECTURE

- The FMS is comprised of two FMCs for redundancy.

- The FMS can operate in several modes.
- **DUAL –** FMC's are in sync.
- **Independent –** No communication between FMCs
- **Single –** Only one FMC operational



COMPOSITE FIX

- The FMC will compute the position of the aircraft by taking inputs from the IRS, GPS, DME and VOR fixes.
- IRS position is very accurate initially but then decreases with time.
- For the other inputs, GPS is the most accurate, followed by DME then VOR.
- During earlier stages of the flight, more weight is given to the IRS and GPS position and in latter stages more weight is given to the GPS, VOR and DME positions.
- A **kalman filter** is used to apply the correct weightings and derive a **composite fix.**
- The system will also indicate the accuracy of the aircraft position at any moment in time. This is knows as the **ANP (Actual Navigation Performance)**

- IRS + GPS + DME + VOR ---> Kalman Filter ----> Composite Fix ----> ANP

AREA NAVIATION (R-NAV)

- Area navigation is navigation that is not restricted to flying from ground based aid to ground based aid.
- **Ghost waypoints** can be created via LAT / LONG, VOR/VOR or VOR/DME fixes.

REQUIRED NAVIGATION PERFORMANCE

- Each block of airspace will have a published RNP value.
- To operate within the airspace using area navigation, the **ANP must be less than the RNP.**

B-RNAV & P-RNAV STANDARDS

- **B-RNAV (Basic Area Nav)** = RNP of 5 miles
- **P-RNAV (Precision Area Nav)** = RNP of 1 mile

COST INDEX

- Fuel vs Everything Else (Flight Time)
- Cheap Fuel = High CI = Fly Fast
- Expensive Fuel = Low CI = Fly Slow

- Low CI for max range

EFIS DISPLAYS

- Boeing = EADI & EHSI
- Airbus = PFD & ND

FLIGHT DIRECTORS

- V Bar (Single Cue)
- Cross Bar (Split Cue)

INSTRUMENTS 17 – FLIGHT MANAGEMENT SYSTEM

EHSI MODES

- **MAP** (TRK / HDG Up)
- **EXP NAV** (CDI + MAP)
- **PLAN** (North Up)
- **FULL NAV** (HSI)

EFIS COLOURS

- **GREEN –** Low Priority
- **WHITE –** Scales & present status info
- **MAGENTA** – Command Information
- **CYAN –** Off Route Waypoints
- **RED –** Warnings
- **YELLOW** – Cautions
- **BLACK** – Blank Areas

INSTRUMENTS 1 – INTRODUCTION TO AFCS

AFCS

- **Automatic Flight Control System**
- AFCS = A/P + A/T + FD

CONTROL LOOPS

- Closed loops have **feedback**

- **Outer Loop = FD**
  - Controls flight guidance
- **Inner Loop = Autopilot**
  - Controls attitude (pitch + roll)

- The flight director essentially decides on the target attitude and the autopilot actually flies the target attitude.

CLOSED VS OPEN LOOPS

- Closed loops have **feedback**
- **Outer Loop = FD**
  - Controls flight guidance
- **Inner Loop = Autopilot**
  - Controls attitude (pitch + roll)

Loop Combinations

Inner	Outer	Mode
✗	✗	Hand Flying
✗	✓	HF with FD
✓	✓	Autoflight
✓	✗	CWS

FMA's

- GREEN = Active
- WHITE = Armed
- Once made active, the FMA is boxed for 10s

MODE ENTRY

- **Manually** – MCP Selection
- **Automatically** – ALT AQR -> ALT HOLD
- **Pre-Arming** – Manually armed then automatically engaged (VOR LOC)

MODE EXIT

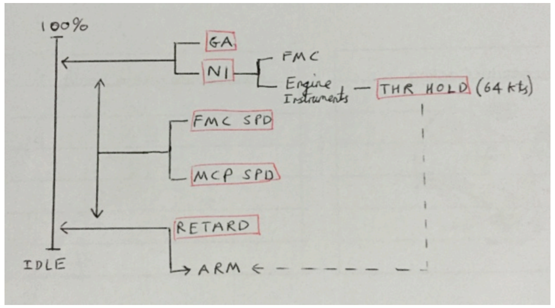
- Press mode select a second time
- Enter a different mode

FD FUNCTIONALITY

- FD Display
- FD Control Panel
- FD Computer

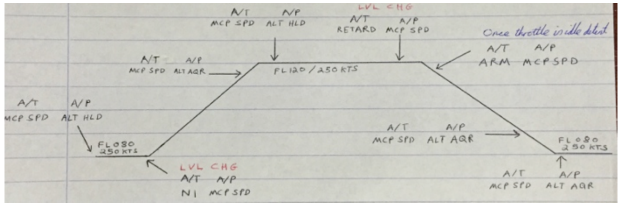
AUTOTHROTLLE

- Controls **speed and thrust**
- At 64 kts, servos disengage and THR HOLD is entered in order to prevent servo's moving throttle in case of RTO.

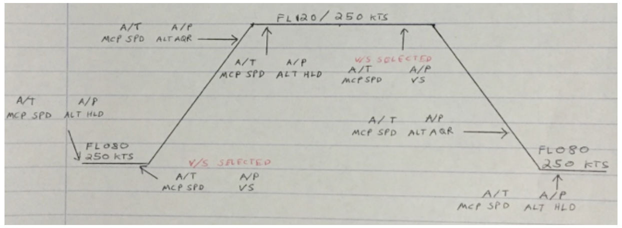


INSTRUMENTS – AUTOPILOT MODES

LEVEL CHANGE



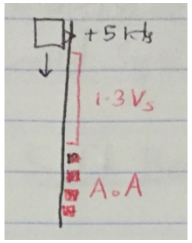
VERTICAL SPEED



SPEED REVERSION

- **Speed too low**
- Can occur during a VS climb with a too high ROC selected.

- **Cautionary Range** – Yellow speed range on speed tape. Top of range is 1.3 V_S



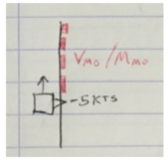
- **Red Bricks** – Critical angle of attack

- Speed reversion is triggered when airspeed falls into the cautionary range.
  - Speed box turns amber
  - MCP speed window shows flashing 'A'
  - A/T = N1 | A/P = MCP SPD
  - Aircraft will pitch to give **5 kts above the cautionary range**
  - Once pilot has intervened and aircraft accelerates **15 kts clear** of the cautionary range, the flashing A disappears.

SPEED LIMITING

- **Speed too high**
- Can occur during a VS descent with a too high ROD selected.

- **Red Bricks** – V_{MO} / M_{MO}



- Speed limiting is triggered when airspeed falls into the cautionary range.
  - Flashing block in MCP
  - MCP speed window shows flashing block
  - Clacker sounds
  - A/T = RETARD | A/P = MCP SPD
  - Aircraft will pitch to give 5 kts below the red bricks

INSTRUMENTS – AUTOPILOT

AXIS CONTROL

- Controls the **pitch and roll axis**
- Yaw damper (separate system) controls yaw

SINGLE PILOT IFR

- Requires a minimum of:
    - Altitude Hold
    - Heading Hold

AUTOPILOT TYPES

- **Standard -** In the event of failure, full control is handed back to the pilots.

- **Operational** – Built-in redundancy

PREVENTING CONTROL RUNWAY

- **Biggest danger** with a **single autopilot** system

- **Authority Weighting**
    - Manual inputs are given more weighting than autopilot inputs so it can be forcefully overcome if required.

- **Comparators**
    - If sensors feel a movement in a plane that is opposite to the actuator movement, the system is disconnected.

- **Rate Triggers**
    - System disconnected when a too rapid change in aircraft attitude is sensed.

OTHER AUTOPILOT SYSTEM TYPES

- **Duplex System**
    - Not possible to determine whether AP1 or AP2 has failed.

- **Duplex System (With Cross Coupling)**
    - AP1 monitors AP2's actuators and vice-versa.
    - When runway is sensed, the system in that axis can now be disconnected.
    - Since control is handed back to the pilot in that axis this is a standard autopilot.

- **Triplex System**
    - Contains AP1, AP2 and AP3
    - Allows a majority vote to be cast and the faulty autopilot disconnected

- **Pseudo-Triplex**
    - Adding a third autopilot is very heavy and expensive however.
    - A computer is added which can determine the faulty autopilot and disconnect it from the system.

SERVOMECHANISM

SERVOMECHANISM

- **Sense a small movement and create a large output by applying gain.**

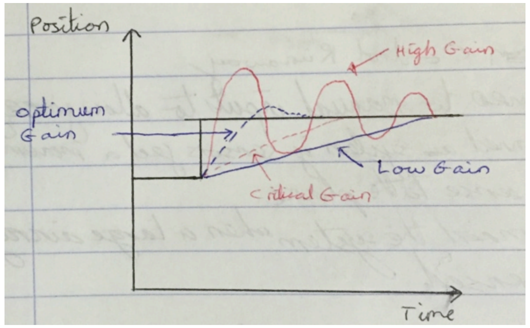
RESPONSE TIME

- **High Gain = Fast Response (Lightly Damped)**
    - Oscillates too much

- **Low Gain = Slow Response (Heavily Damped)**
    - Takes too long

- **Critical Gain**
    - Balance of high and low gain
    - Highest gain that results in no oscillation

- **Optimal Gain**
    - Critical gain is still too slow
    - Optimal allows a slight but acceptable overshoot



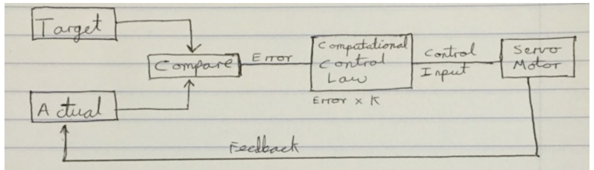
INSTRUMENTS – AUTOPILOT

GAIN CONSTANT

Error x K = Input

- K is the constant set by the system to determine to gain applied.

- If K does not vary = **Constant System**
- If K varies = **Variable System**
  - Used to reduce gain when near to VOR for example.



SERVO-ACTUATOR TYPES

- Pnuematic
- Mechanical
- System

TRIM SYSTEM

TRIM RUNAWAY

- Prevented by use of **two switches**

STAB CUT-OFF SWITCHES

- Can be used to disconnect the pitch trim in the event of runaway occurring.

AUTO-TRIM

- When autopilot is in operation, auto-trim takes place in **pitch only**

- **Reduces control surface deflection** thus increasing efficiency
- Prevents **control snatch** when A/P disconnected

- Fitted in **parallel** to servo control and actuators
- If manual pitch trim is used whilst A/P is engaged the autopilot will be disconnected

MACH TRIM

- Helps prevent **mach tuck**
- As mach number increases, a small amount of pitch up trim is gradually applied.

AUTOPILOT SYNCRONISATION

- Allows for **smooth engagement** of the autopilot
- Prevents control snatching

INTERLOCKS

- Set of **required parameters** needed for autopilot engagement and continued operation.

AUTOPILOT SELECTION

- Selection of AP2 will disengage AP1 unless in approach mode.

TOUCH CONTROL STEERING (TCS)

- AFCS **remains syncronised during maneuvers** unlike CWS.

INSTRUMENTS – GPWS

Purpose	Warnings
Excessive Descent Rate	SINK RATE / WOOP WOOP PULL UP
Excessive (Rising) Terrain Closure	TERRAIN / WOOP WOOP PULL UP
TOGA Height Loss	DON'T SINK
Terrain Clearance (Not in landing config)	TOO LOW GEAR (4A) & TOO LOW FLAPS (4B) / TOO LOW TERRAIN
Glideslope Deviation	GLIDESLOPE
Advisory Callouts	ONE THOUSAND / MINIMUMS / BANK ANGLE
Windshear	CAUTION WINDSHEAR / WINDSHEAR

WARNING TYPES

- Mandatory Aural Warnings
- Optional (Additional) Visual Warnings

SYSTEM INPUTS

- Received from ADC

GPWS RANGE

- Ground – 2500 ft

INSTRUMENTS – AUTOLAND

AUTOPILOT FAILURES

Fail Operational

V

Fail Passive

V

Manual Flight

AUTOLAND PROCEDURE