Principles and Sensors

The Basic T:

- **Airspeed indicator**
- **Attitude indicator**
- **Altimeter**
- **Compass / Gyro Driven DI**

This 6 Pack:
Includes:

- **Turn co-ordinator**
- **VSI**

Electronic Flight instrument Systems: (EFIS)
Modern AC use LCD screens which allow selective displays.
But retain standard displays in case of electric failure.

Temperature:
"Comparative measure of hot and cold'.
Hot body = + molecular activity.
Abs zero = -273.15 C

Degrees Celsius:
Based on water = 0C is freezing and 100C is boiling. Abs zero = -273C

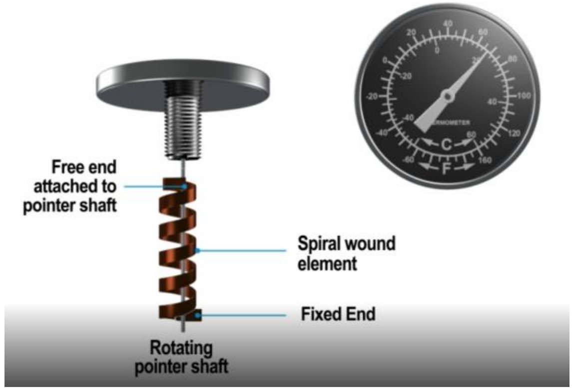
Kelvin:
Same as Celsius.
0K = -273C

Fahrenheit:
Freezing = 32F, Boiling = 212F.
Use Wizz-wheel to convert
Or F = (Cx9/5) +32.

Temperature Sensing:
4 Types:

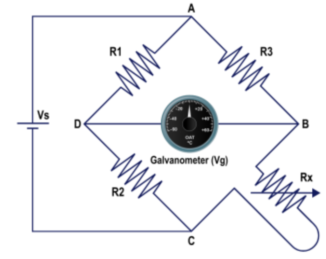
- **Bimetallic Sensor**
- **Resistance thermometers**
- **Thermocouples**
- **Radiation Pyrometers.**

Bimetallic Sensor



Two diff metals bound, when heated one metal expands.

Resistance Thermometers:

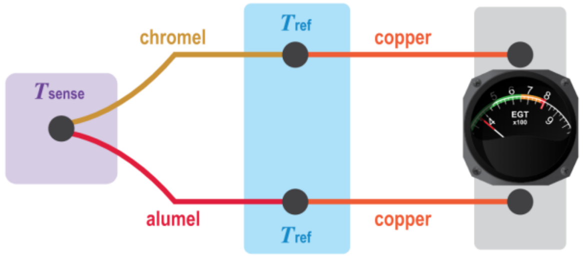


A Wheatstone bridge indicates temperature changes through through a galvanometer

Resistive sensor or Resistance Temperature Detector (RTD), Relies on **change of electrical resistance** of a pure metal such as **Platinum, nickel, or copper. Operate Typically -200 to 600c.** Simply, measures voltage to a proportional resistance.

Robust sensor, NEEDS DC current.

Thermocouples:



Used for **HIGH** temp sensing i.e., engine.
'Two dissimilar metals which create an electrical potential at their junction which is proportional to the temp'. also known as Thermo EMF.

E = K x Th.
E = Emf, Th = hot junction temp, K = Constant.

Parallel wiring, to ensure redundancy.
Temps from -200 to 1250C.
Not very accurate.

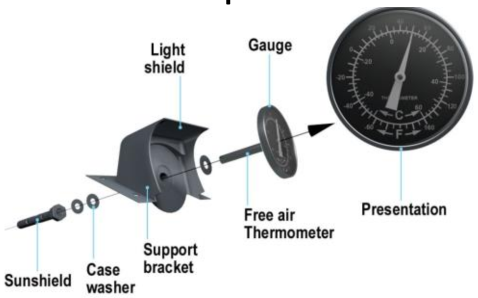
Radiation Pyrometers:
Used for Higher temps. Optical or radiation pyrometer can be used. Measures the frequency of the emitted radiation from the area examined, used for turbine blades/inlet.

Air temperature probes:
2 Types used:

- Expansion type, Uses Bimetallic strip **(Direct reading probe)**
- Electrical wire/resistance type, relies on change of resistance with temp. **(Remote reading type)**

Light aircraft temperature sensors:
For light AC, probe normally **bimetallic types.**
Probe mounted through windshield, indicator inside, sensor outside.

No icing protection.
Accurate for low-speed AC.



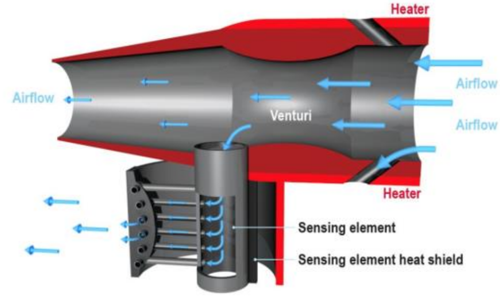
Issue with speed:
Faster AC create temp sensing problem.
If air temp measured as it flows past, frictional heating will distort the result.
This increase called **'Kinetic heating', 'Ram Rise' or Ram rise in temp due to adiabatic compression.**

Faster AC describe temp as:
Static Air Temp (SAT) = temp you would sense if you were in a basket of a balloon with a thermometer.
Or Total Air Temp (TAT) = The higher temp sensed by fast moving AC.

SAT sometimes called outside air temp (OAT) or corrected OAT (COAT).
TAT = Measured impact temp.

Increase in temp can be calculated:
TAT = SAT (1+0.2 k M^2) [K] (k = 0.9 fudge factor).
Sensor gives TAT

Temp sensors on faster AC:
Many names, 'Total head thermometer'.



Rosemount Probe.

Temperature Measurement Errors:
3 Error sources:

- **Instrument error** (calibrations etc)
- **Environmental Error** (Solar heating, Icing) No correction
- **Heating error** (Ram rise or frictional heating) can be corrected.

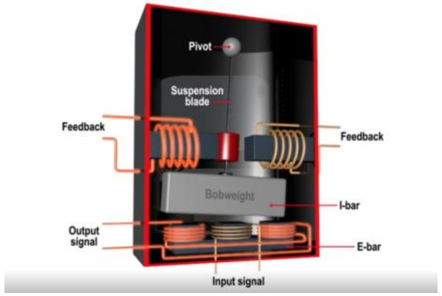
Time measurement:
Time standard = UTC (GMT)
Modern AC use electronic clock called 'System Clock' which provides 'System time' as the on-board reference for anything needing a time ref. E.g. engine hours run, voice recording etc.

Tach time = 1 hour of running at datum RPM.

Hobbs meter:
Measures running time:
Activated by:

- Electrically from AC power up
- Oil pressure (shows engine running)
- Weight on wheels switch
- Airspeed sensing vane.

Accelerometers:



More sophisticated: consist of a weight suspended on a thin metal blade. Acceleration in on axis only will move the wight off centre.

MEMS Accelerometers:
Modern Inertial Reference System (IRS)

3 Accelerometers mounted at right angles. To sense in all planes.

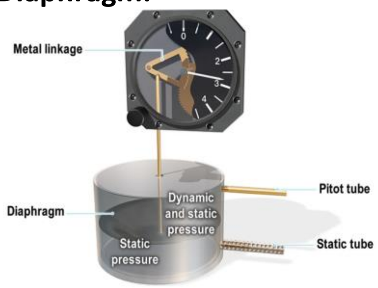
Pressure Sensing

Pressure
Units:
- **Force per unit area.**
- **Lb/fr^2**
- **Lbin^2** PSI
- **N/m^2 (Pa)**
- **inHg (Bar)**

Conversions
1 Bar = 100,000Pa
1 Bar = 1000 hPa.
1 Bar = 14.5 PSI

Absolute and Differential Pressure sensors:
Differential pressure sensors:
- **Diaphragm**
- **An Aneroid Capsule**
- **A Pressure Capsule**
- **Bellows**
- **A Bourdon Tube**
- **Pressure Transducer**

Diaphragm:



Simplest = Diaphragms/Membranes.
Thin discs, fixed at an edge, distort under pressure.
Rarely used, due to small scale deflections.

Aneroid Capsules:

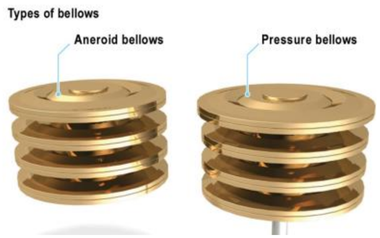
Aneroid capsule

CSA.

Aneroid = 'Without fluid'
In a vacuum
Measure absolute pressure
Measure only a small range due to their limited ability to expand and contract.

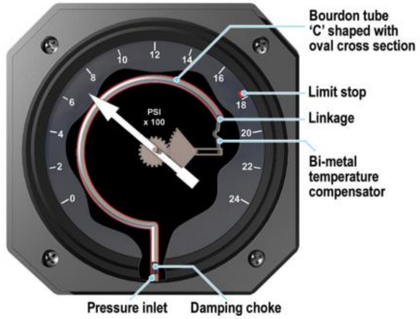
Pressure Capsules:
Like Aneroid, but not sealed.
Fed with pressure to be sensed.
Distortion = a measure of extra pressure being sensed, over and above atmos. (Direct differential pressure).

Bellows:



To increase movement, stacks of capsules can be joined to make a bellow.
Completely sealed, aneroid bellows or open to a pressure feed, pressure bellows.
Increased expansion therefore medium range of pressure. (Engine manifold pressure).

Bourdon Tube:



Curved like a 'C' fixed at one end with an oval cross section.
Pressure being measured is fed at one end with a tendency to straighten the tube, therefore deflecting it.
Large range of pressure (more used for high pressure application i.e. Engine oil pressure)

Pressure Transducers:
Transducer = Changes input parameter such as temp or pressure to a diff output i.e. electrical signal.

Like a strain gauge. Resistive element wired to a Wheatstone bridge.

No risk of leaks/hazards.

Pitot Static system:
AC on ground has pressure from all directions ‘Static pressure’.
As it moves through the air it encounters wind resistance that is in effect a pressure acting on the front of the aeroplane.
Dynamic pressure is proportional to the aircrafts speed.
Dynamic pressure = $\frac{1}{2}P\ V^2$
P is rho, Density
V = true velocity of AC.

Dynamic pressure represents the pressure of air flowing over the AC which in turn creates lift.

Static pressure is atmospheric pressure. Dynamic Pressure is the kinetic energy of the air changed to pressure energy.

Pitot Tube:
Pitot Senses Static and Dynamic pressure.

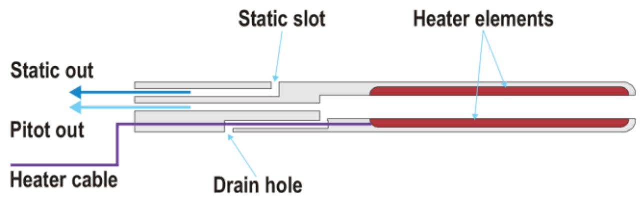
Finding dynamic pressure:

Total Pressure = Dynamic + static.
Dynamic = Total pressure – static. (Bernoulli’s)

Static pressure can also give us an indication of height, and rate of climb/descent.

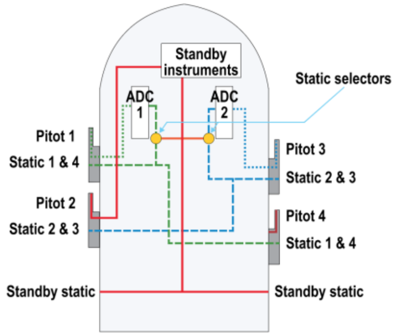
Static Ports:
Placed at right angles to the airflow so it doesn’t detect dynamic pressure.

The combination pressure head:
Pitot and static pressure can be kept separate but are more often combined into a single pressure head.



Essentially a 2 in 1.

Large AC Systems:
Errors in pitot or static pressure will bring errors in: Speed, height, VSI, Mach.

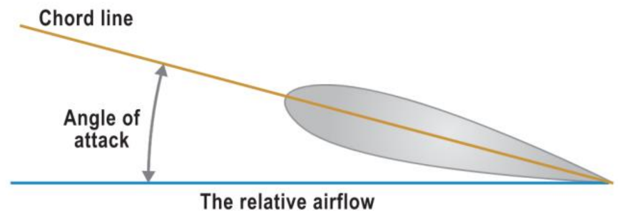


Large AC have redundancy.

Position error:
‘If static pressure is giving false indication.’
Position error includes predictable configuration error and unpredictable manoeuvre error.

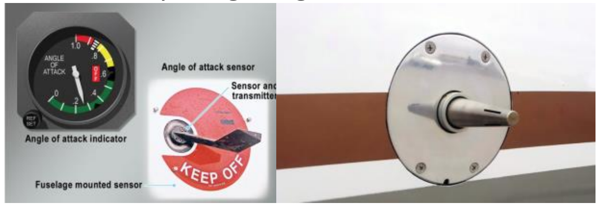
Manoeuvre:
Roll, pitch, yaw, and gusts. Can introduce transient and unpredictable static pressure errors that cannot be programmed out.
Large AC manoeuvre less important.
Any error induced by yaw can be minimised by siting connected static ports on both sides of the fuselage.

Angle of attack sensors (AOA):
Called Alpha.
‘Angle between chord line and the relative airflow’.
Main input to stall warning systems.



Alpha sensors: 2 basic forms: a vane that is free to line up with the relative airflow or a conical probe with slots above and below the zero alpha datum which measures relative pressure.

Vane type alpha Sensors: And pressure type
Small aerofoils free to rotate and line up with relative airflow. Positioned clear of any airflow influenced by wings engines etc.

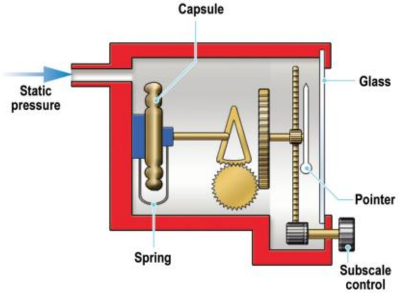


Pressure Altimeters:

The Standard Atmosphere:
ISA:
- **Sea level pressure = 1013.25hPa**
- **Sea Air Density = 1225g/m^3**
- **Sea Level temp = +15C**
- **Temp reduces at 2C/1000ft. Up to 36,000ft at -56.5C then stays constant to 65,600ft then rising 0.3C/1000ft.**

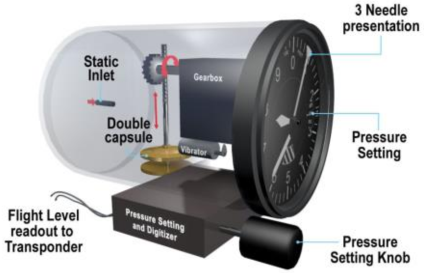
Altimeters:
Designed to indicate altitude based on changes in static pressure.
3 Mechanical types:
- **Simple altimeter**
- **Sensitive altimeter**
- **Servo-assisted altimeters.**
- **ADC**

Simple Altimeters:



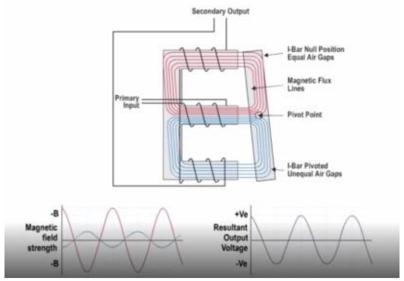
Static pressure fed into instrument casing. An Aneroid capsule is connected by a system of linkages to a rotating needle. As AC ascends static pressure decreases, the capsule **expands. Datum pressure can be adjusted in hPa or mb. Or inchMerc. Non-linear rise, only small AC, limited range.**

Sensitive Altimeters:
Same principle as simple altimeters:
Sensitivity is increased by having a stack of 2 or more capsules, thus increasing movement.
Some have vibrators to overcome static friction 'stiction'.
Allows 3 pointers.



Digitiser sends reading to transponder.

Servo-assisted altimeters:
Further increase sensitivity.
No need for mechanical linkages.



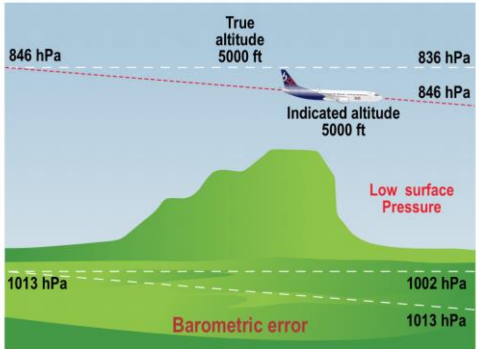
ADC driven systems:
'Aircraft Data Computer' to calculate altitude referenced on 1013 to a subscale set by the pilot.

Units and accuracy:
PANS-OPS sets accuracy requirement for altimeters.
Must show QFE or QNH accurately within plus or minus:
- 20m or 60ft for altimeters with a test range of 0-9000m (0-30,000ft)
- 25m or 80ft for altimeters with a test range of 0 to 15,000m (0-50,000ft)

1 meter = 3.28 ft.

Altimeter Errors:
Position Error:
Affects altimeter readings, minimised with good design but varies with TAS and angle of attack.
Instrument Error:
Caused by:
- Friction (Gearing 'stiction')
- Aneroid inertia. 'Hysteresis Error'

Barometric Error:
Any change of pressure from 1013 will give incorrect altitude readings.



Temperature Error:
Any change from ISA Temp of 15C will give incorrect altitude readings.

'High-Low-High'
– If you fly from high to low either temp or pressure your altimeter will read high.

'Low-High-Low'

- **Vice versa.**

2nd Mnemonic:
'High to low Careful go.'

- **High temp/Pressure to lower than you are closer to the ground than expected.**

Temperature Error Correction Tables:

Table III-1-4-1 a). Value to be added by the pilot to minimum promulgated heights/altitudes (m)

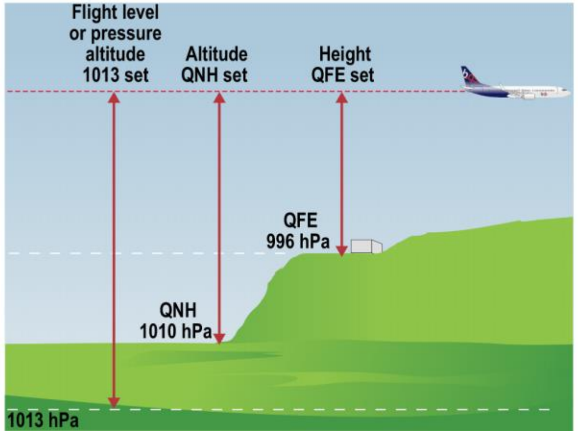
Aerodrome temperature (°C)	Height above the elevation of the altimeter setting source (metres)													
	60	90	120	150	180	210	240	270	300	450	600	900	1200	1500
0	5	5	10	10	10	15	15	15	20	25	35	50	70	85
–10	10	10	15	15	25	20	25	30	30	45	60	90	120	150
–20	10	15	20	25	25	30	35	40	45	65	85	130	170	215
–30	15	20	25	30	35	40	45	55	60	85	115	170	230	285
–40	15	25	30	40	45	50	60	65	75	110	145	220	290	365
–50	20	30	40	45	55	65	75	80	90	135	180	270	360	450

Table III-1-4-1 b). Value to be added by the pilot to minimum promulgated heights/altitudes (ft)

Aerodrome temperature (°C)	Height above the elevation of the altimeter setting source (feet)													
	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000	5000
0	20	20	30	30	40	40	50	50	60	90	120	170	230	280
–10	20	30	40	50	60	70	80	90	100	150	200	290	390	490
–20	30	50	60	70	90	100	120	130	140	210	280	420	570	710
–30	40	60	80	100	120	140	150	170	190	280	380	570	760	950
–40	50	80	100	120	150	170	190	220	240	360	480	720	970	1210
–50	60	90	120	150	180	210	240	270	300	450	590	890	1190	1500

Baro corrected by setting correct pressure.
When temp is warmer altimeters will underread.
Issue when low to the ground at low temps.

Altimeter Pressure Settings:



QFE – 2 types:

- **Airfield QFE (Highest point of airfield)**
- **Touchdown QFE (Touchdown of runway)**

QNH – Aircraft above mean sea level.

Actual Sea level pressure is QFF.
QNH – QFF at ISA.

The standard setting:
1013.25 hPa or 29.92 inchmerc.

Density Altitude:
'Density altitude is the pressure altitude corrected for temperature, in other words altitude in the inernation standard atmosphere which gives the same air density as the prevailing non-ISA combination of temp and pressure alt'.

To calculate density altitude on the CRP5 set pressure altitude against temperature in the AIRSPEED window and then, without moving the dial, read off the density altitude in the DENSITY ALTITUDE window.

For example, an aircraft at a pressure altitude of 10 000 ft and with an OAT of -25°C would have a density altitude of 7600 ft.

An alternative method of calculating density altitude is by the formula:

Density altitude = pressure altitude + (120 x ISA deviation).

For the previous example:

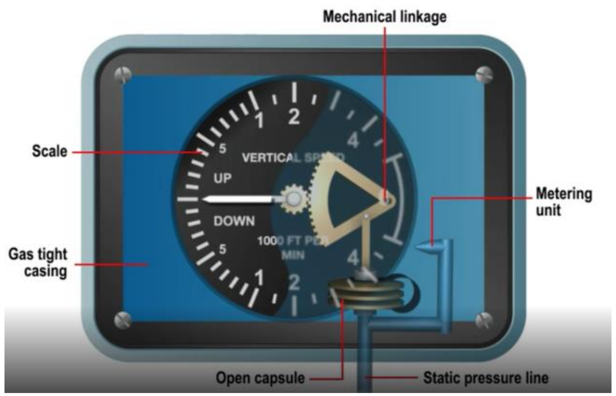
Density altitude = 10 000 + (120 x -20) = 7600 ft

Vertical Speed Indicators:

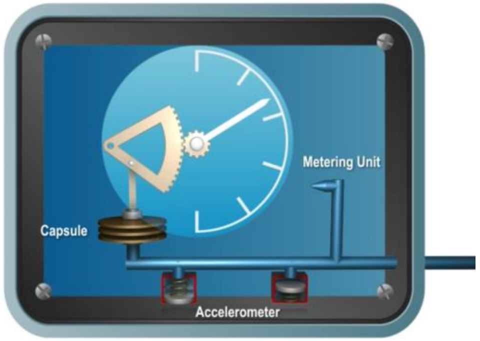
VSI:
Shows rates of climb/decent.
Positioned below the altimeter.
Ft/min or m/s
1000ft/min = 5m/s

Simple VSI:
A pressure operated VSI, records the rate of change of static pressure.
Consists of capsule fed with static pressure in a case with static pressure.
The static feed of the case passes through a very small gap, the metering unit, so that if the AC changes altitude the capsule reacts immediately whilst the pressure change in the case is slower.
Differential pressure is maintained if the AC continues a climb or descend once level pressure equalises the rate of climb or descent returns to zero.

A VSI measures rate of change of pressure and displays it as rate of change of height.



Instantaneous VSIs (IVSI)
Simple VSI do not show climb/descent immediately, there is a time lag.
IVSI, counters this by including in the static line two weights in a dashpot centred with springs, which cause an immediate differential pressure because of their inertia.



Once stabilised in climb/decent weights are centred by their springs.

When rolling into a steep turn the IVSI shows a climb, if turn is maintained it will stabilise. And indicate a decent on roll out.

IVSI better in turbulent air than VSI.
VSI lag can be = 6-8 sec. So useless in turb.

Other systems:
3 other systems:

- IRS inertial reference system
- ADC (barometric height is available in electronic form)
- Dynamic vane VSI (difference between static and metered static pressures induce a flow over moveable vanes like a small turbine instead of capsules.

Instrument displays:
Use a logarithmic scale with increased sensitivity at small values.

EFIS (electronic flight instrument system) show VSI right of AI.

Errors and blockages:

Instrument Errors: Compensated for with an adjusting screw to zero the reading.

Lag: IVSI compensates for lag. (Can be 6-8sec)

Static Errors: Error in the abs value of static pressure produces no error. But a change in static pressure when none is due will give a false indication.
Pressure driven system **susceptible to manoeuvre error. During take-off, go around and turbulence.**

Static blockage will cause VSI to read zero.
Static leak to cabin pressure will cause instrument to read cabin rate of climb and descent.
On start-up all VSI should read **zero.**

Air speed indication

IAS and TAS:
Air speed still measured with atmospheric pressure.
At height the air density reduced and therefore the same dynamic pressure effects a higher true air speed even though the AC handles just as before.
The same happens if the air was warmer than ISA, TAS would be higher than IAS
Dynamic pressure = ½ P V^2
If P reduces then V must increase to compensate.

At height we have two airspeeds, indicated airspeed based on dynamic pressure and higher true airspeed through the air.

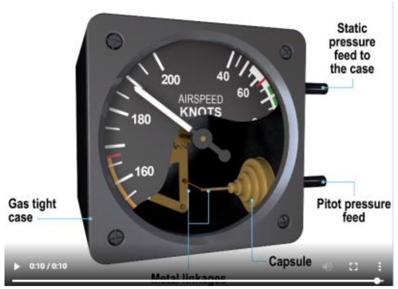
IAS is important for the handling of the AC.
TAS is important for navigation, because with the addition of wind it gives ground speed.

Mach = speed of sound.
Before Mach 1, Airframe buffeting (Mach buffet).
Fly set IAS at low speeds and set Mach number at high speeds.

<u>Units</u>
Kts, mph, km/h.
1Knot = 1 nautical mile per hour
1 nautical mile = 6080ft = 1852m
1 statute mile = 1760yards = 5280feet

Flat Plate Indicators:
Dynamic pressure would deflect the plate backwards against a spring force and scale would read speed accordingly. **Calibrated to**

The mechanical Airspeed indicator (ASI):
Feeds pitot and static pressure to an instrument in the cockpit.
Pressure sealed case supplied with static pressure. A capsule inside is supplied with pitot (dynamic) pressure. As aircraft speed up, pitot pressure increases.
IAS = TAS at calibrated sea level.
Issues with thermal conductivity omitted with bi-metallic strip.



ADC (Aircraft data comp) Driven instruments:
Modern Larger AC feed pitot and static line to an ADC.
Air data computers calculate CAS from sensed pressures using Saint-Venants formulae.

Errors:
Instrument Error: Older mechanical systems will suffer from mechanical errors, less moving parts = less mechanical error.
Position Error: Poorly designed systems due to location of sensors.

Calibrated Air Speed:
IAS (Dynamic pressure reading) corrected for **Instrument and position errors** specific to the AC is called 'Calibrated airspeed' **CAS.**
AC without ADCs may have an ASI correction table for different congifs and airspeeds, from: Knots indicated airspeed KIAS → Knots calibrated airspeed KCAS.

CAS used to be called RAS (Rectified Air Speed)
For large AC CAS = IAS. No instrument or positional error.

Cessna Model 172N PERFORMANCE

AIRSPEED CALIBRATION
NORMAL STATIC SOURCE

FLAPS UP											
KIAS	40	50	60	70	80	90	100	110	120	130	140
KCAS	49	55	62	70	80	89	99	108	118	128	138
FLAPS 10°											
KIAS	40	50	60	70	80	85	---	---	---	---	---
KCAS	49	55	62	71	80	85	---	---	---	---	---
FLAPS 40°											
KIAS	40	50	60	70	80	85	---	---	---	---	---
KCAS	47	54	62	71	81	86	---	---	---	---	---

IAS corrected for aircraft specific position and instrument errors is called CAS, Calibrated Air Speed

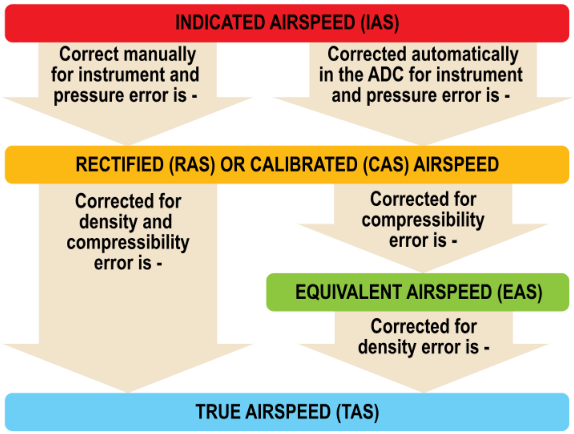
The EFIS shows CAS

Compressibility, CAS and EAS
Assumptions:
- Air incompressible fluid
- Density in Bernoulli's is the same as the free air density around the AC.

In reality only true at low speed at M0.3 to M0.4 air starts to compress. This causes dynamic pressure to be **greater** than it should, and the CAS will **overread. This is called compressibility error.**
Not an issue with ADC calculated speeds.
CAS corrected for compressibility = **Equivalent airspeed EAS.**
Correction always a reduction as comp makes it over read.

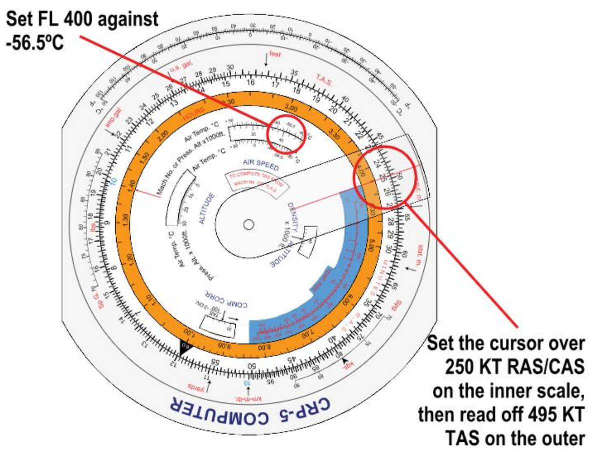
CAS corrected for compressibility is called EAS.
Compressibility becomes significant above

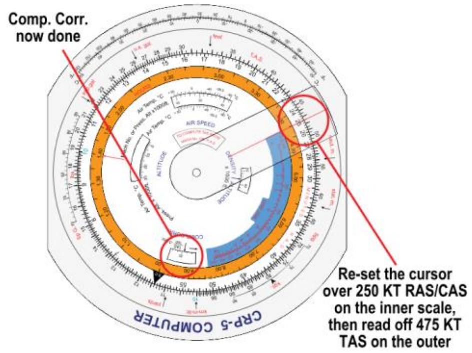
Density:
A correction for air density is required to calculate TAS from EAS.



EAS corrected for density is TAS

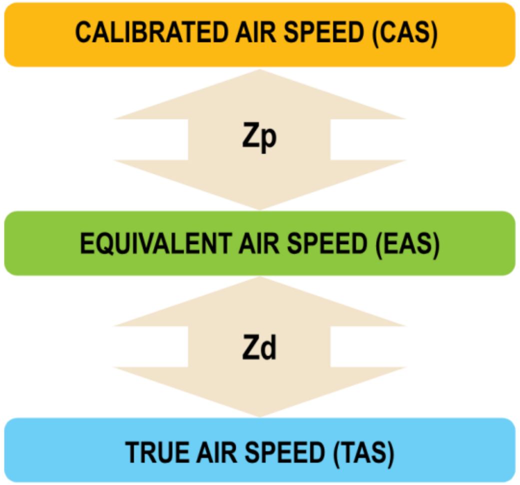
TAS calculation:
From CAS, if you know pressure and temp.
Pressure from pressure altitude of AC.





Compressibility corrections always bring TAS and CAS closer together

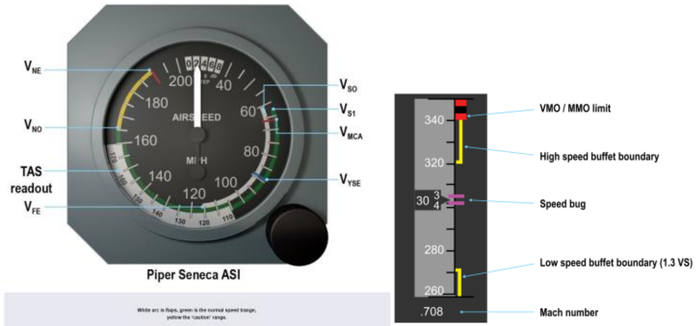
Alternative phraseology:



Converting from CAS to EAS requires Zp
Converting from EAS to TAS requires Zd

Pitot Static Blockages and Leaks.
Static Blockages:
'Pressure in the instrument remains the same'
As long as the external static pressure stays the same the instrument will read correctly, so if we maintain height the ASI reading will be correct.
A static blockage in the descent makes the ASI

Instrument Displays:



Pitot Static Blockages and Leaks.

If pitot blocked changes in airspeed will not be correct.
If altitude remains same, indicated airspeed will remain the same no matter of speed up or slow down.

Any leaks in pitot line will lower pitot pressure and cause instruments to under read.

SUC - static blocked, underreads in a climb
SOD - static blocked, overreads in a descent
PUD - pitot blocked, underreads in a descent
POC - pitot blocked, overreads in a climb

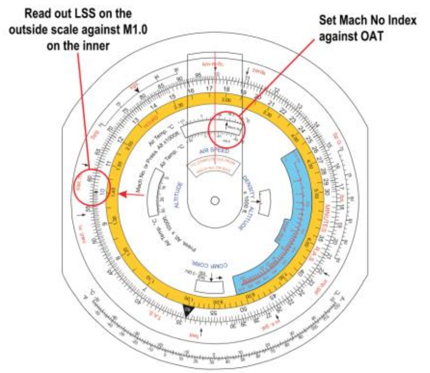
Machmeters and ADC

The machmeter:
'Gives speed relative to speed of sound'.

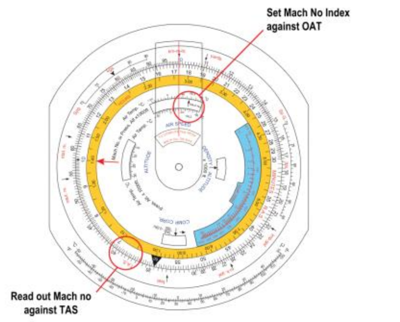
Local Speed of Sound:
Not constant, depends on air temperature or air.
Warmer the air = faster speed of sound.

Local Speed of Sound LSS = $38.94\sqrt{T}$
T = Static air Temp (K)

2nd Method using CRP5:



To find LSS

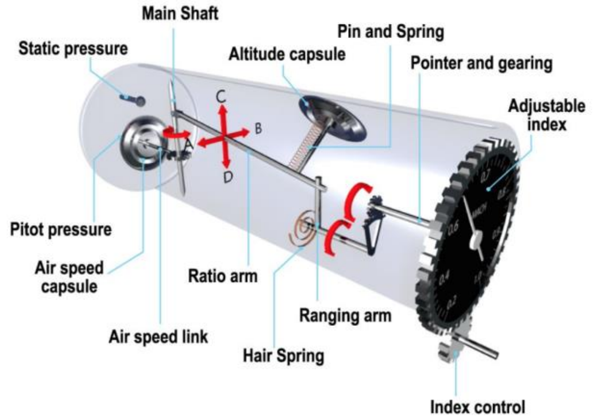


Set OAT against the Mach No Index in the air speed window as before and read off the Mach number on the inner scale against the TAS on the outer, see above.

To find Mach#

The Machmeter:
Mach number is a function of dynamic pressure / static pressure and is independent of air temp.

M = (pitot-static)/static



Construction:
Uses a capsule of pitot pressure to find dynamic pressure (ASI).
A capsule to find static pressure (altitude capsule).

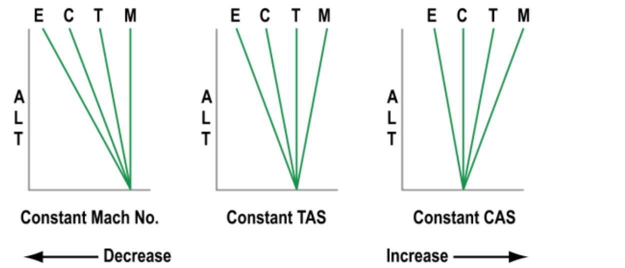
2nd Gen systems are either servo driven (From ADC or EFIS)

The machmeter is an ASI and an Altimeter interacting in the same case.

Machmeter suffers only from instrument and pressure errors. These errors are small so the indicated Mach number can be taken to be true.

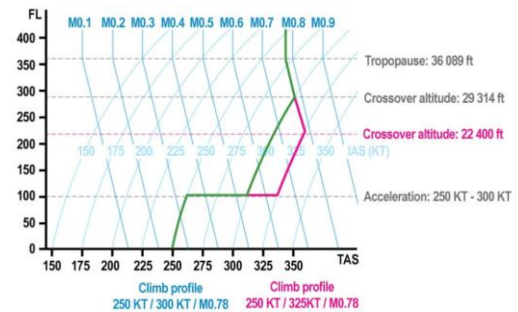
Blockages and leaks.
If Pitot blocked, same as ASI. Mach number stays same until static pressure changes in climb/descent. **SOD SUC PUD POC.**

EAS/CAS/TAS/Mach relationship:



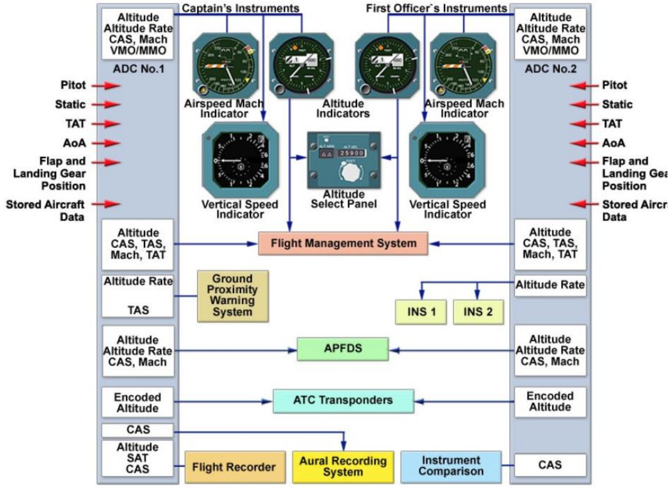
Draw parameter that is to be held constant as a straight vertical line. ECTM.

Crossover altitude:
Airliners climb on CAS (V_{MO} as their limit) until they reach '**Crossover altitude'** after which they climb using **Mach Number M_{MO}** as their limit.



Isothermal Layers:
If asked about a climb/descent through a layer where the **temp stays constant (ISOTHERMAL LAYER) draw the T and M lines Vertically together. Then use the ECTM as before.**
Inversions:
If asked about a climb/descent through an inversion layer, where temp increases with height, **Draw the ECTM diagram with T and M swapped round, inverted.**

ADC (Air Data Computers):
Advantage is that the data can also be fed to the Autopilot and flight director system (APFDS), Flight management system (FMS), ATC Transponder, Ground proximity warning systems (GPWS), area navigation aids and an instrument comparison system.



ADC inputs and outputs:
To provide outputs the ADC requires **inputs** from:

- **Static pressure**
- **Total pressure**
- **TAT (total air temp)**
- **Angle of attack**
- **Flap and landing gear position**

And **outputs**:

- **Pressure altitude/barometric alt. (using static pressure)**
- **CAS, correcting for known pressure/position errors so that IAS = CAS**
- **TAS, computed from pitot and static P**
- **SAT, by applying ram rise and recovery factors to the TAT.**
- **TAT, raw data**
- **Angle of attack**
- **Vertical speed (IRS accelerometer) (or** ΔP)

Some AC combines **ADC** with the **IRU** to make an **Air Data Inertial Reference Unit (ADIRU).**

If initial IR is lost so is all navigation capability of the system.
Modern systems have 2 ADCs/ADIRUs.
And multiple Pitot/Static/AOA sensors.

Magnetism

Molecular theory of magnetism:
For iron to be magnetic the molecules need to be aligned.

Magnetising and Demagnetising:
'Molecular magnets' can be induced to line up by:
- Stroking a nail repeatedly with a magnet
- Placing iron in a mag field
- If metal is hammered iron magnetises
- Inside a Strong DC current solenoid

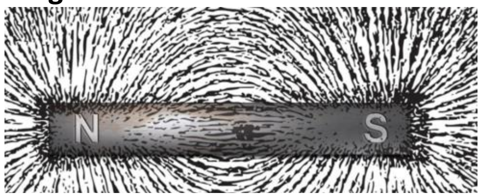
Can be demagnetised by:
- Iron loses magnetism at around 900C and stays demagnetised on cooling
- Hammered at right angle to a mag field.
- Placing it in an oscillating mag field in an AC current coil. (Degaussing)

Hard and soft iron:
Intensity of magnetism can vary.
When iron obtains its maximum magnetism, it is said to be **SATURATED.**

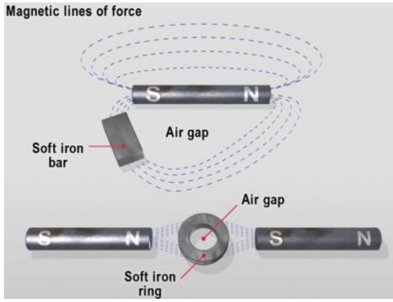
Iron that becomes saturated easily also loose magnetism easily 'SOFT IRON'.

Iron that holds is magnetism but is hard to magnetise is called: 'HARD IRON'.

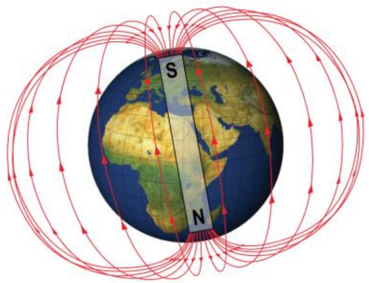
Magnetic Fields:



Magnetic Fields:
Poles labelled, north or red and south or blue.
North = North seeing when placed in earths mag field.



Earths Magnetism:
Earth has **IRON core = huge magnet.**
Magnetic north ≠ True (Geographic) north.

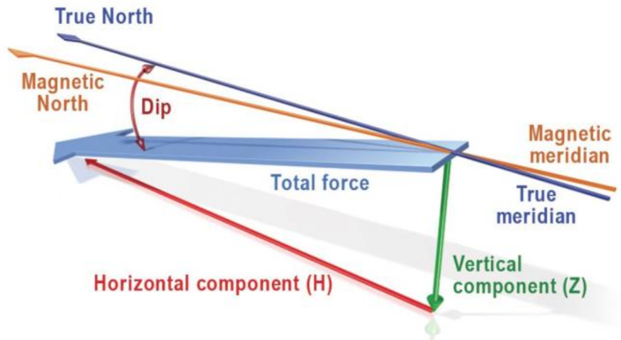


Variation:
The angle between true north and mag north is called variation.
Lines joining points of equal variation are called **Isogonals.**
Isogonals converge at both magnetic poles and at the true poles.
Lines joining points where variation is zero is called **Agonic lines.**

Dip:
We have seen the earth's magnetic field is not horizontal WRT the earth, except along the magnetic equator, called the **Aclinic** line.
Everywhere the angle between the Earth horizontal and the Earths mag field is called dip.

Max dip occurs at poles,
Zero dip occurs along the magnetic equator.
In north hemisphere at latitude of Europe and North America angle of dip is typically 55 to 60degrees.

Lines of equal dip = **Isoclinic lines or isoclines.**



Where dip occurs the resultant or total magnetic force can be divided into a horizontal component, called H and vertical Z.
The horizontal component may also be referred to as the directive force because this is the component that gives us an indication of magnetic north.

Aclinic = means 'No (in)cline'.
The field is horizontal on that line
Isoclinic = means 'The same (in)cline'

Deviation:
Before AC leaves a factory, it is Degaussed, to remove any magnetic build up in manufacturing. Never completely successful.
Always be some residual that'll cause the compass reading to be incorrect.

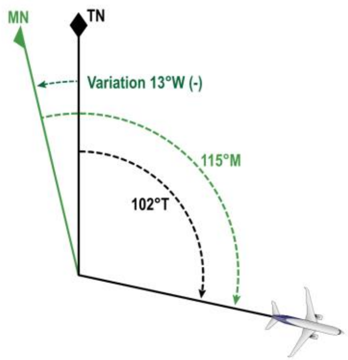
Not the only thing that affects the magnetism:
- **Cargo**
- **Electrical fields produced by aircraft equipment.**

This collective distortion is called 'Deviation'.

Magnetic direction:
Variation is the difference between the direction of the datums it is also the difference between all true directions and their corresponding magnetic directions at any point.

Magnetic heading +or- variation = True heading.

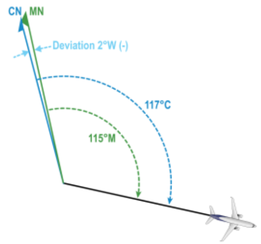
Variation can be described similarly,
+ = East
-= West
'Variation East magnetic Least'
'Variation West magnetic Best'



Compass Direction:
When a mag needle is influenced by the earths mag field it points to mag north.
If compass installed in AC, earths mag field will be distorted by the metal and equipment.
The needle now deviates and indicated 'compass north'.

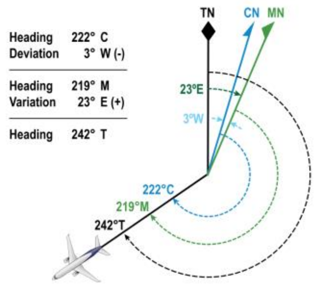
Difference between direction of magnetic north and compass north is called 'Deviation'.

'Deviation east compass least'
'Deviation west compass best'



Deviation varies with:
- **Magnetic latitude,** as the strength of the earth's mag field varies.
- **Aircraft heading,** as the orientation of the interfering mag field changes
- **Changes in AC electronic equipment.**

Calculations:
Cadbury's Dairy Milk is Very Tasty =
Compass Deviation Magnetic Variation True.



Example:
True heading = 005, Variation 32W, Deviation 4E. what is compass heading?
005 + 32 – 4 = 033.

Compass heading = 233, True heading = 246, Deviation = -3
233 – 3 + x = 246
x = 16

Compass swing:
Deviation is detected by a compass swing:
The AC is swung, North, South, East, and West. On each point compass is noted and compared to what should be to the deviation.

Purpose of compass:
- **Determine amount of deviation on a series of headings**
- **Correct for as much of the deviation as possible**
- **Record the residual deviation**

Reasons to Swing a compass:
- **Whenever a compass is installed or replaced**
- **Whenever the accuracy of the compass is in doubt**
- **After a maintenance period**
- **After significant AC modification**
- **When carrying magnetic freight**
- **After lightning strike**
- **Long term storage**

COMPASS DEVIATION CARD
SWUNG: 05 Jan 2011

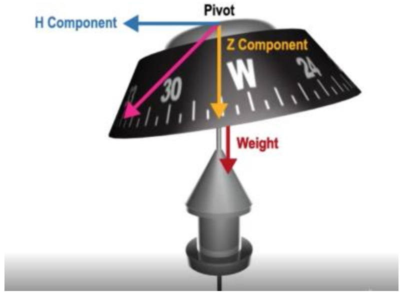
TO FLY	STEER	TO FLY	STEER
N	002	180	179
30	030	210	209
60	062	240	241
90	091	270	267
120	118	300	299
150	150	330	331

Main compass should be accurate to +- 5Degrees. Standby compass +- 10Degrees.

Direct reading compass

Direct reading compass:
Most basic form of a compass found in an AC.
Aka **'Direct reading'**

Principle of Operation:
Free suspended magnets attached to a compass card.



Direct reading Compass:
Vertically mounted (above windscreen)
Case filled with silicone fluid and a bellows system allows for fluid expansion with increased temp.
2 Pairs of magnets are fitted to the top of the case to correct for deviation as part of the compass swing process.
Lubber line = reading line.

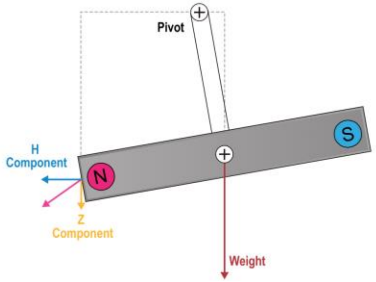
At very high latitudes close to mag poles, horizonal component (H) is too small to use, even with pendulous magnet. This is the compass unreliability area, sometimes called 'The six micro tesla zone.'

To reduce oscillation, magnet is suspended in a liquid filled case.
Several short magnets are used rather than one long one to keep moment of inertia down.
Fully damped system = **Aperiodic.**

Liquid must be = Transparent, non-corrosive, have a perfect viscosity to dampen.
Alcohol or paraffin normally used.

Acceleration Errors:
Design of the compass includes the pendulous suspension system, which counteracts some of the effects of dip, but not all.

In the balanced state the magnets are not quire horizontal, and centre of gravity (CG) is not directly underneath the pivot.



The fact that CG does not lie directly under the pivot means the compass is subject to acceleration errors.
Northern Hem:
If AC facing 270 (W) accelerates Inertia will tent to rotate anticlockwise, therefore = 285.
If AC 090 (E) accelerates = clockwise = 080
In northern hem, acceleration produces an apparent turn towards the NORTH.

Acceleration Errors Continued:
Summary:
- **E/W acceleration produces an apparent turn toward the nearer pole.**
- **E/W deceleration produces an apparent turn toward the far pole.**
- **N/S acceleration produce no error as the CG and pivot points are in line.**
- **On the Aclinic line there will be no error.**

Turning Errors:
In a balanced turn, combined effect of acceleration towards the centre and the effect of gravity continue to act through the AC.

Turning error is more to do with aircraft bank angle.

UNOS:
Under turn through North
Over turn through South

Undershoot or overshoot = Take latitude /2 +15.

Summary:
- **Turning errors are MAX when through north and south. Are ZERO when turning through east and west.**
- **Turning error are function of Dip, so MAX at poles, Zero at Aclinic line.**
- **Turning error Function of bank angle, Greater errors at greater bank angles.**

Steep Turns:
Only holds if the sum of bank angle and dip are less than 90Degrees.
Most obvious sign that the compass is unreliable is that the compass card will not rotate through a full 360 in a 360 turn, it will only vary about 50degrees.

Liquid Swirl:
Makes the compass lag and always works the same way. **Increases lag and decreases lead.**
UK CAA = amplitude of turning error for a rate 1 in mid-lat as 20degrees and liquid swirl as 5dgrees, hence final figure of 20-30degrees for turning error, including liquid swirl.

Attitude Errors:
Attitude limitation no relevant in balanced turns because compass card banks with AC. It could be relevant in unbalanced or pitching manoeuvres, in which the directed reading compass information should be disregarded.

Serviceability checks:
Compass should be checked before flight,
Clean, not distorted.
No bubbles visible clean and clear.
Comparison with runway heading (which is also magnetic).

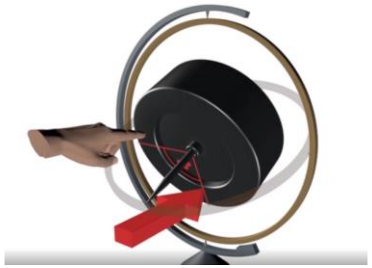
Gyroscope

Gyroscope:
Greek – Gyro = Turn, Skopein = See. (A turn see-

Rigidity:
Designers look for: High moment of inertia, high rotation speed, with mass concentrated at the rim.
If this is achieved the gyro will have high angular momentum and hold its position in space. This is called **Rigidity.** As gyro slows, angular momentum decreases, therefore losses rigidity.

Old gyros were air driven.
Newer gyros are motor driven (advantages include higher spin rate, more predictable, less

Precession:

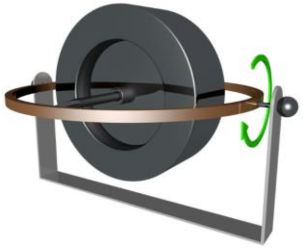


If an external force acts on a gyro, it acts at 90degrees in the direction of rotation.
The image shows a force being applied to the left of the gyro and it is precessed through 90 degrees in the direction of rotation.
More rigid = more force required to precess.
The 2 key properties of gyros are:
Rigidity and Precession

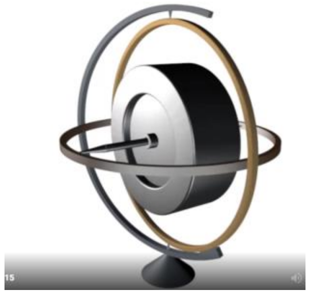
Gimbals:
Gyros are usually suspended in a system of frames, called gimbals, **which allow freedom of movement.**
Needs one gimbal per axis measured

Classification of Gyros:
Classed by: **Degree of freedom / Orientation of spin axis and or their use**

Classification of Degrees of Freedom:
Degrees of freedom = Number of axis the gyro displacement can be measured (# of gimbals).
Spin axis not counted as a degree of freedom as it cannot be measured.

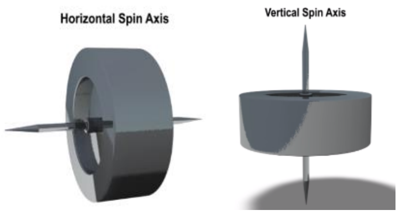


1 Degree.



2 Degree.

Classification by Spin Axis Orientation:
Gyros can be classified by reference to the orientation of their spin axis. Only meaningful if spin axis is vertical or horizontal and is maintained in its orientation in some way, within aviation this is often the case.



Classification by Use:
Unique to aviation, 5 cases:
- **Space gyros = 2 degrees of freedom** aka 'Free gyros'
- **Tied Gyros = 2 degrees of freedom,** but have an external influence controlling the orientation of the spin axis, maybe tying it to the AC horizontal and vertical
- **Earth Gyros =** Sub category of Tied gyros where the spin axis is tied by the earths gravity to remain in the earth vertical.
- **Rate Gyros = 1 Gimbal,** sense rate of rotation in one plane, e.g. yaw.
- **Rate-integrating gyros = 1 Gimbal,** sense

Gyroscopic Wander:
Rigidity = fix in space.
Force applied = Precess.

Wander = Gyro precess out of position due to external factors such as friction.
Drift and Topple = Wonder can be broken down into: **'Topple'** = Axis moves out of the vertical (relative to earth's surface).
'Drift' = Axis moves in horizontal plane.

Real wander = When gyro imperfections cause either toppling or drift. A perfect gyro will not experience this.

Apparent Wander:
The gyro may seem as if it has wandered due to e.g. the earth's rotation or by transporting the gyro across the earth.

Apparent TOPPLE Caused by Earth's Rotation:
A gyro on the equator will try maintaining its position in space as the earth rotates underneath it.
Because the earth spins at 15 degrees / hour, the gyro will appear to topple at the same rate. After 12hr it will appear to be erect again, but actually be upside down, after 24hr it will return.
Apparent Topple is MAXIMUM around the EQUATOR.
ZERO at the POLES

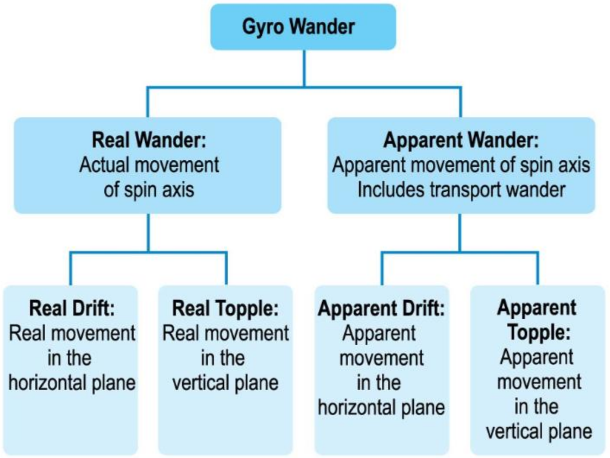
If a vertical gyro is placed at one of the poles it will produce no apparent topple as the rotation

Apparent DRIFT Caused by Earth's Rotation:
Vertically aligned gyro at north pole is unaffected by rotation. But if placed on its side, the gyro maintains is position in space by for the observer it appears to be drifting clockwise when viewed from above at a rate of 15degrees / hr.
Apparent DRIFT is MAXIMUM at POLES.
ZERO Drift at the EQUATOR

Between the poles and equator it will experience both apparent drift and apparent topple.

Alternative name for drift and topple =

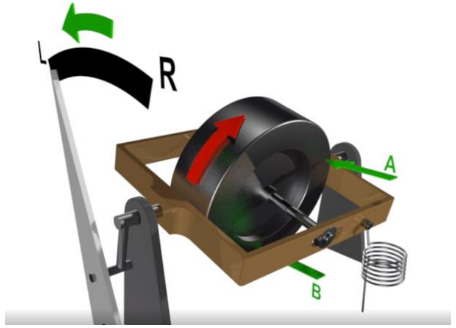
Transport Wander
Apparent drift and topple can occur also occur if a gyro is aligned to north on one part of the earth and then moved to another.
Transport wander is ZERO when moving North/South
Transport wander = Convergency.



Amount of error caused by transport wander is the amount caused by convergency.

Convergency = Transport Wander
= Change of longitude x Sine mean latitude

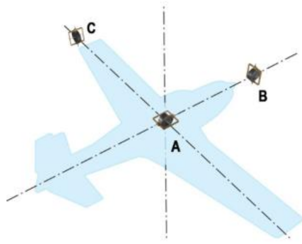
Rate Gyros:
Only 1 Gimbal, 1 DoF. I.E Yaw sensing.
In order to do this: Gyro is mounted in its gimbal with the gyro axis oriented horizontally across the aircraft.



The spring force produces a secondary precession equal to and in the same direction as the yaw.

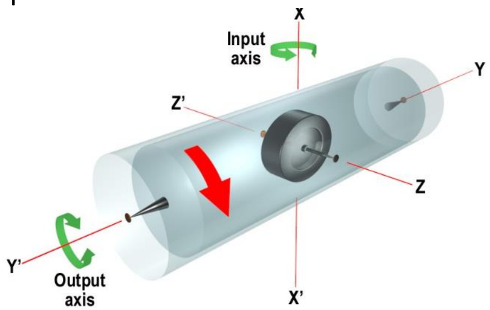
Rate gyro indicated rate of angular displacement

Rate Gyros:



A = Yaw rate
B = Roll rate
C = Pitch Rate.

Rate integrating gyros:
Detects the rate of displacement and the time it was applied for effective indication rotational displacement.

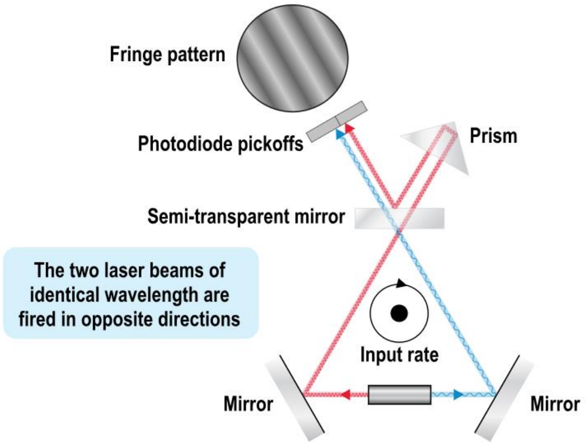


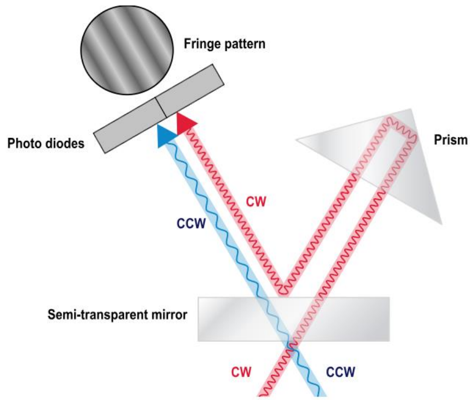
Used when extreme accuracy of output over a small angular movement is required.

Rate integrating gyro has 1 degree of freedom and is used to sense rotational movement about one axis only.

Ring Laser Gyros:
The Laser Gyro, or Ring Laser gyro (RLG) is new tech, used in Inertial Reference Systems (IRS).

Operation of RLG:
Uses gas discharge laser to generate monochromatic radiation in two directions. Mirrors are used to reflect each beam around an enclosed area, which produces a laser in a ring config either triangle or square.





Frequency Lock and Dither:
The RLG has one problem: Frequency lock. (Lock-in or laser lock).
At low input rates, when the frequency of the CW or CCW beams are very nearly the same, they shift frequency and lock together, taking a zero input. This is unacceptable.

The cure is called **Dither**. The whole triangular block with the laser system is mechanically rotated backwards and forwards around the input axis. The amplitude of rotation is very small, but the frequency changes it produces keep the RLG out of the lock in range. Since the rotation is one way then another way the sum over time is zero.

Real Wander:
Change in length of the ring, by thermal expansion or any bias in the discharge current on either side of the laser will produce a change in the readout which is equivalent to real wander in a mechanical gyro.
Compensated by active control of the discharge current through an error detection and feedback system and by active control of the path length by moving one of the mirrors.

Uses:
In a Strap down IRS 3 RLGs are mounted at 90degrees. The whole set is fixed to the airframe. The system measures rotation about all 3 axes, with very accurate readout of AC attitude.
Very small around 6cm across.
Have longer life cycle than normal rate sensing

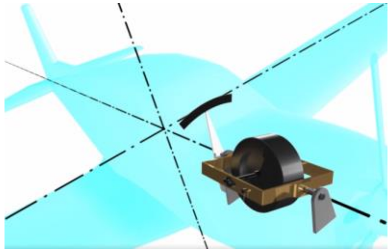
Turn Indicator:
2 instruments that indicate rate of turn:

- Turn Indicator
- Turn coordinator

Both use a 'balance ball' to indicate whether a turn is in balance or not.
Turn indicator = Indicates rate of change of heading.
Uses a **Rate Gyro,** which has a horizontal axis, 1DoF. Either electric or air driven.

The turn indicator has one degree of freedom and a horizontal axis parallel to the lateral axis of the AC, which is the pith axis.

Importance of Orientation:
Orientation of the gyro determines whether Yaw, Roll or Pitch is sensed.



AC bank angle for a given rate of turn is related to the AC TAS, so instrument has to be calibrated to a specific range of TAS.
Turn indicator calibrated for a Cessna will not work for a jet.

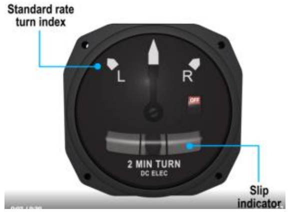
Turn indicators

Calculation of required angle of bank:
Rate 1 turn = 180° a min or 3° a sec.
Rate 2 turn = 360° a min or 6° a sec

Angle of bank required to achieve a given rate of turn increases with TAS.

Formula to calculate angle of bank in rate 1:
<u>Angle of bank</u> = (TAS/10) + 7

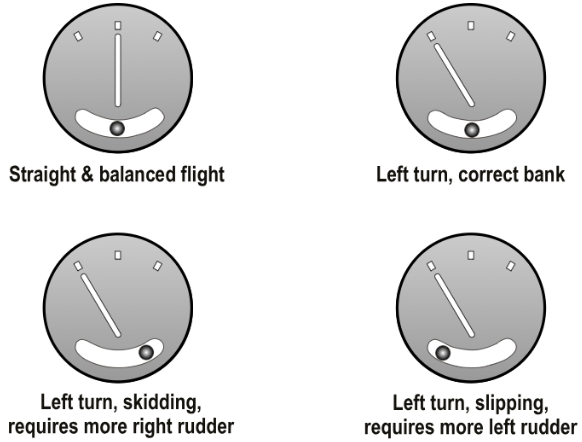
Turn indications:



L and R show rate 1 turns.

Slip and Skid:
Balance turn = coordinate amounts of bank with rudder.
Too much Bank = Slip
Too little bank = Skid
To ensure no slip or skid, 'slip' indicator needs to be centred.
In balanced turn, combined force of gravity and centrifugal force acts through the vertical therefore no slip or skid.

Slip and skid indications:



Turn coordinator:
Development of turn indicator.
Gimbal raised at the front by 30°
Makes it primarily sensitive to yaw but also slightly roll, allowing indication as soon as the AC turns.
Once AC established in the turn there is no more roll rate, so the instrument only shows yaw.

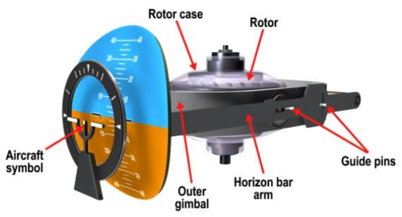
Downside:
Instrument indicates yaw, roll and a little pitch (if TAS is wrong). Therefore turn coordinator only indicates rate one turns accurately in a tight TAS range, within 5% of a specific speed.

Can be confused with artificial horizon.

Attitude Indicator:

Direct Reading Attitude Indicators:
Use an **Earth Gyro. 2 DoF.**
Spin axis maintained on the Earths vertical.
Air or electrically driven.

Air driven Attitude Indicators:



Air enters through the centre of the gimbal bearing, drives the rotor by impinging on buckets on its outside edge, and exhausts at the bottom of the rotor case. Gyro for most air driven artificial horizons **Rotate ANTI-clockwise when viewed from above.**

Bank Indications – Sky Pointers:
Bank indications usually shown with the indicator at the top of the instrument, called a **'Sky pointer'**.

Bank indicators = Earth Pointers:

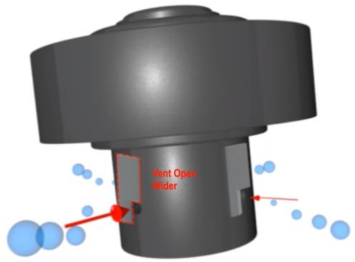
Air Driven Gyro Erection:
Air driven artificial horizons are made pendulous, centre of gravity below suspension point, so that they settle in their gimbals in a nearly erect position when not working. This reduces erection time on start-up.

Once the engine starts, and gyro rotates, gyro has its spin axis tied to the earths vertical by a system of pendulous vanes and air jets which make the gyro precess back to the vertical if displaced.

At the top of the rotor case are 4 air exhaust vents, each normally half covered by a flap which is hinged at the top called a 'pendulous vane'.

When gyro vertical = air escapes all 4 vents equally.
When displaced from the vertical, the pendulous vanes stay where they are under the influence of gravity, covering one vent and opening opposite.

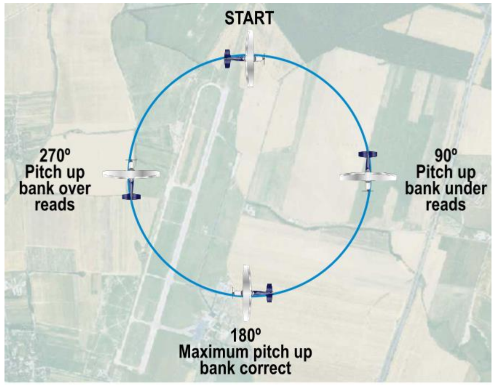
Unbalance in force allows for the restoration.



Turning Errors:
Gyros affected by any false indication of the vertical (may be caused by lateral acceleration in turns or AC linear acceleration and deceleration take off/landing).
In a turn the erection system will try to erect the gyro to the resultant acceleration, which in a balanced turn will be the AC vertical.

This false alignment will produce an initial roll error, which slowly changes to a pitch error as the AC turns direction through 90degrees.

REMEMBER THIS CHART:



Bank errors follow a different cycle under reading initally, then reading correctly after 180 degrees of turn then over reading before reducing to zero after a full orbit.

EFIS Displays:
Modern Airliners with inertial reference systems or ADAHRS take attitude signals from the IRS and send them to the EFIS. Instrument called Primary Flight Display (PFD)

Acceleration on Take-Off:

Pendulous vanes of the erection system can also be displaced by sustained fore-and aft acceleration when taking off, when a false nose up indication is given. The acceleration on take-off also affects the pendulous lower element of the gyro and this force is precessed through 90degrees to indicate a bank to the right.

These acceleration errors restrict use of air driven horizons to aeroplanes that **do no accelerate quickly** i.e. small Cessna.

The instruments typically are free
In pitch = +-60 degrees
In roll = +- 110degrees
Mechanical stops prevent movement outside these limits at which the gyro will topple.

Once gyro topples it re-erects at the rate of 2-4degrees per min.

Acceleration on take off = pitch up indication and bank to the right.

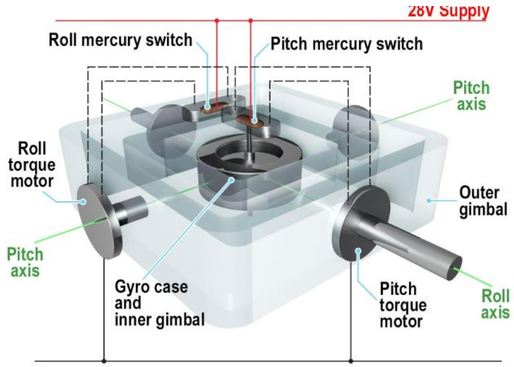
Electrically driven Artificial horizons:

Similar to air driven. **Most rotate CLOCKWISE when viewed from above.**
Tied to earth vertical
2 DoF.
Differences include:
More rigid (Faster 22,500rpm)
Faster erection (Not pendulous)

ELECTRICALLY DRIVEN artificial horizons DO NOT suffer from turning and acceleration

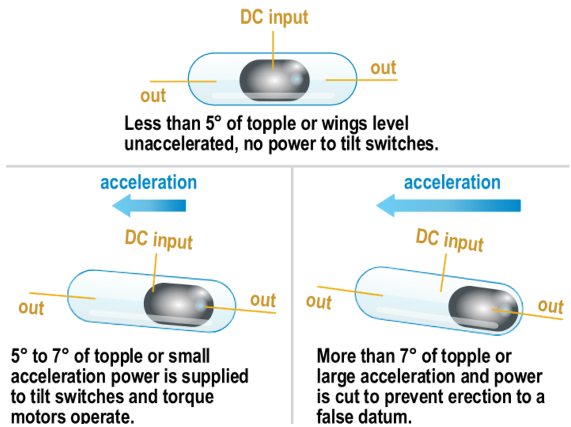
Principle of Operation:

Pendulous vane replaced by 2 mercury tilt switches mounted on the rotor case.



To prevent gyro erecting to a false datum in an extended turn there is a roll cut-out switch fitted on the roll axis, to disconnect the roll torque motor at bank angles >10degrees.

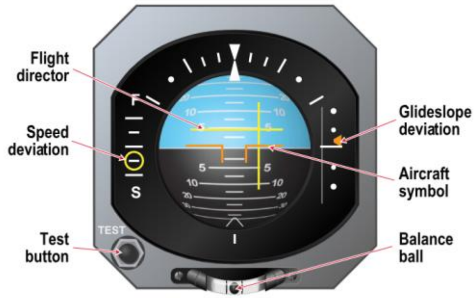
Electric attitude indicators usually have complete freedom but are restricted to +-85degrees in pitch.
A fast erection button is provided which supplies high voltage to torque motors, and by-passes the cut-outs, in order to erect gyro at 180degrees/min. (Only used on ground or straight flight).



Servo Driven Attitude indicators:

More modern AC uses remote indicators driven by servos.

Attitude information picked up from gyro gimbals and signals are amplified and sent to processor then to display called Attitude Director Indicator (ADI). (Signals can also be sent to auto pilot etc).



Independent and self-contained standby artificial horizon is always retained as a backup which uses electrical power from AC battery.

Vertical Gyros and AHRS:

Advantages of remote vertical gyro over more basic:

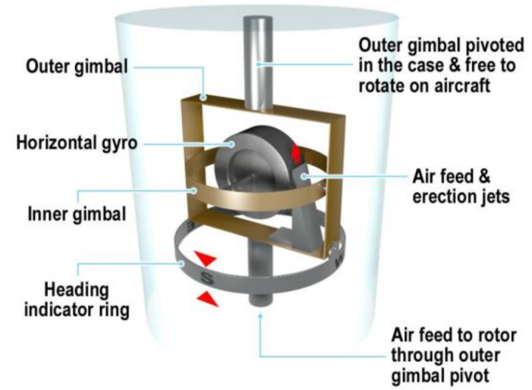
- Improved accuracy
- Better use of space, (vertical gyro not installed in the instrument panel)
- Better maintenance access, LRU (Line replaceable unit)
- When 3 gyros used, signals can be compared.

Such vertical gyros can be combined with a remote indicating compass system called: Attitude and Heading Reference System (AHRS).
AHRS use 1DoF combined with accelerometers in all 3 axis.

AHRS can be combined with ADC to make Air Data and attitude heading reference system (ADAHRS)

Directional Indicators

Directional Gyros:



Gyros can be used to indicate Direction (DI). Gyro spin axis **is TIED to the earths horizontal, but this is hard to achieve so we say: it is tied to AC horizontal.**

Gyro = Tied gyros with horizontal spin axis.
2 DoF = 2 Gimbals.
Air or Electric.

Used to supplement heading reading from magnetic compass. Rigidity of gyro gives better heading readings.
The DI **Cannot be used on its own** as it is susceptible to its own errors:

- **Apparent drift (caused by earth rotation) and transport wander)**

Two instruments (Compass and DI) used together.

DI Construction and Operation:

Gimbals give freedom in pitch +-55degrees.
As it turns, the aircraft effectively rotates around the outer gimbal, and indicated heading is read from the scale fixed to the outer gimbal.

DI Gyro Erection:

When rotor is out of alignment the stream of air strikes the buckets asymmetrically and produces a side force which processes to re-

DI Errors:

Gimbal Error:

Inner and outer gimbal 90degrees to each other when AC is straight and level.
When AC banks in a turn gimbals no longer in line, as AC turns the heading indication will sometimes lead and sometimes lag the true azimuth. **Effect is small at working angles of bank, as wings level gimbals line up and error disappears.**
Gimbal error IGNORED in the DI.

Drift Errors:

Di subject to **apparent wander. Because of Earth's rotation (opposite) and transport wander.**
Also subject to **Random Real Wander** (due to

Apparent Drift Caused by Earth's Rotation:

Apartment drift MAX at Poles (15degrees/hr)
Zero at equator.

Apparent drift between latitudes is:
ER Drift = 15 x Sin(latitude). Degrees per hour)
Latitude = AC Lat, if lat changes calculate mean lat.

In Northern Hem DI axis drifts clockwise and under reads. Opposite in southern.

ER (Drift due to earth's rotation), -ive in northern hem and +ive in the southern hem.

A DI Powered up and functioning stationary on the ground will misalign 15sin(lat) every hour.

Example:

Due to the rotation of the earth, the apparent drift of a horizontal free gyroscope at a latitude of 45°N is:

(a) 15° per hour to the left.
(b) 2° per hour to the right.
(c) 7° per hour to the left.
(d) 11° per hour to the right.

Solution:

This is northern hemisphere, so the axis would drift clockwise, or to the right. The amount of the drift would be

15 x sin latitude = 15 x sin 45°
= 10.6° per hour, answer (d)

Latitude Nut:

As this is a predictable error, a latitude nut was added.
Compensating the drift by 15sin(lat) in the **opposite** direction. This is set by maintenance and not by crew!
For classification purposes the action of the latitude nut produces real wander.
Latitude nut induces real wander to counter the apparent wander of Earth's rotation.

Transport wander:
As gyro moved from one point in earth to another, gyro maintains its orientation in **space.**
Further you travel **east/west** the **greater** the change.
Transport wander = the apparent loss of alignment caused by east/west travel and is the value of convergency between two points.

Transport wander(°) =
Change of longitude * sin(Mean Latitude)

Transport (northern hemisphere) to the:

DI Drift calculations:

Total drift =
Real Wander + Earths Rotation + Latitude Nut + Transport Wander.

+ = Anti-clockwise or left-hand rotation
- = Clockwise or right-hand rotation

	Northern Hemisphere	Southern Hemisphere
Earth's Rotation	-	+
Latitude Nut	+	-
Transport Wander East	-	+
Transport Wander West	+	-

Watch out for:

AC flying in one hemisphere with their latitude nuts set for the correct latitude value in the other hemisphere.

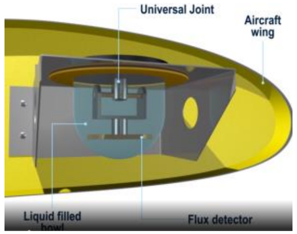
Remember = Mean latitude must be taken for ER and TW. **Do not use mean** latitude for a latitude nut correction!

Remember = Earth rotation and latitude nut corrections are **rates**, in degree / hr, whereas transport wander is a value in degrees!

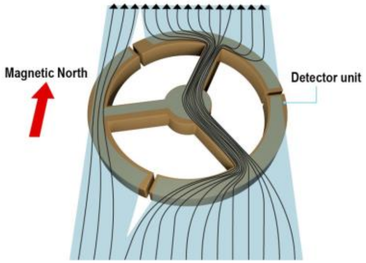
Remote Reading Compass

DI and compass have errors. But together work well.
Another option = Combine them into one.
Called ‘Gyro compasses’ or ‘Remote Reading Compasses’ or ‘Gyro Flux Gate Compasses’.

Flux detector:

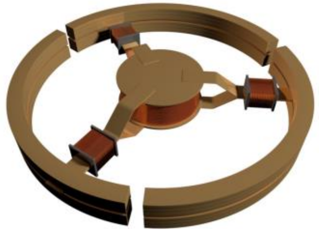


Remote indicating compasses detect the direction of the Earth’s mag field with a ‘flux detector’.
3Legs made of soft iron. Positioned on wing tip or tail (far from interfering instruments).
It is Pendulous, mounted on a **Hooke’s Joint** (universal joint).
Allows +- 25 Degrees pitch/roll.
As AC pitches, flux detector stays level
Possibility of small turning error in a turn.

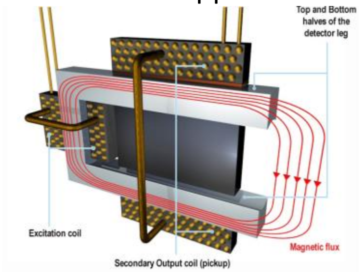


Not free to rotate.
Legs on flux each end in a ‘Horn’. Soft iron distorts earths mag field through the horn.

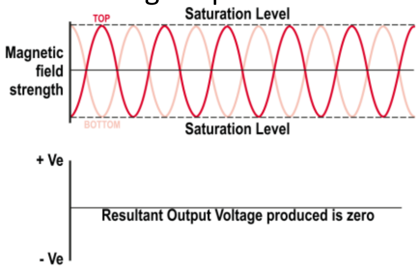
Measuring the component of H in each leg:
By using AC electricity to impose a fluctuation EM field on top of the steady earth’s mag field.
Legs of the detector are made of 2 sections, one on top of each other but connected by a core in the middle:



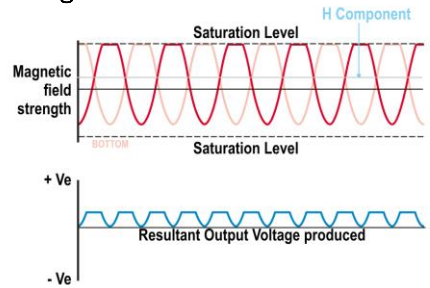
Primary coil around core supplied with AC (487.5hz), just enough to saturate the top and bottom legs as it reaches peak power. Because the 2 sections are connected through the core the mag field in the top and bottom sections is orientated in opposite directions:



The changing mag field induces a current in a secondary pick-up coil on each leg of the detector.
Without earth’s mag field the two opposing mag fields would produce equal and opposite currents in a secondary coil. Making output = 0

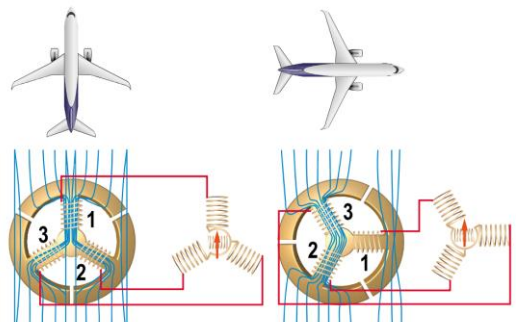


Measuring the component of H in each leg:
But because earth’s mag field actually does lie on top of the induced fields it has the effect of lifting the total so that a resultant is produced.



Meaning we can measure the H component.

Transmitting the signal:
Induced current sent = array of stator coils.
3 stator coils produce a mag field in the centre, varying amplitude, with a resultant direction that corresponds exactly in relation to the 3 legs, as does the direction of the original field.
A rotor coil placed in the stator field will have a current induced in it unless it remains 90degrees to the resultant field. Thus the rotor coil when turned to the null position is used to reproduce at the remote location the exact heading of the original field.
This is called a selsyn system, ‘self-synchronising’

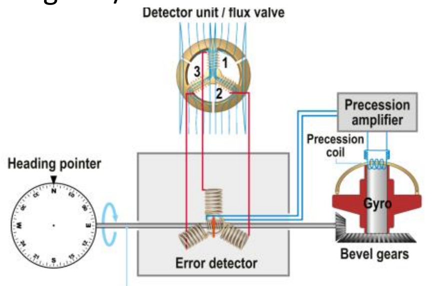


The Gyro Unit:

Gyro in remote indicating compass is a standard directional gyro like the DI.
2 DoF. Horizontal Axis.
The Selsyn rotor (the error detector) is mounted on the drive shaft, or the heading card aligned at 90 degrees to north on the card.

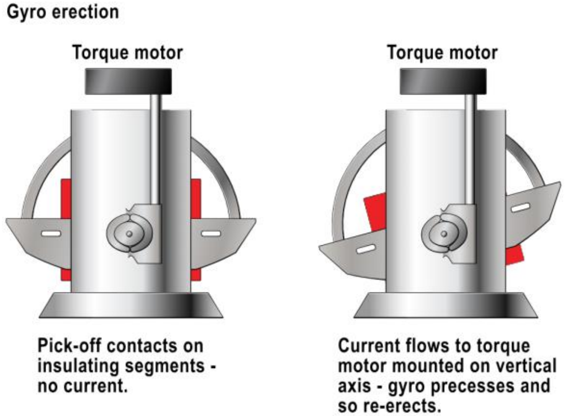
If this is not exactly magnetic north, (maybe due to gyro drift) an AC current is generated in the error detector, this is amplified and rectified to DC in the 'Precession amplifier' and then energises a 'Precession coil' wound around a curved 'Precession magnet' (permanent magnet) mounted on the inner gimbal. This creates a magnetic field.

The force created by the mag field of the precession coil acting on the precession magnet is precessed to rotate the gyro, the bevel gears, the drive shaft, the heading card, and the attached error detector to a point where the current to the precession amplifier dies away and the assembly is once more aligned with mag north.
This is called ' Synchronization' or a 'slaving loop' and realigns the gyro at a slow rate of 2degrees/min.



Gyro Erection:

To keep gyro spin axis aligned with AC horizontal, the inner gimbal which gives the gyro freedom in the vertical (topple), is fitted with a slip ring on its axis powered by DC. While gyro spin axis in line with AC horizontal, the pickoffs in contract with the slip ring sit on insulated segments and do not receive current.
If gyro spin axis goes out of alignment with AC horizontal pickoffs receive a current which is passed to a torque motor (Called a 'levelling erection torque motor'). This gyro axis is to be precessed back to alignment with the AC horizontal.



Digital Feeds of Other Systems:

Although the output of the combination of the Selsyn system and the Directional gyro is analogue it can be digitised and send to automatic flight control system (AFCS) and FMS and to an EFIS.

Indications:

The Radio magnetic indicator:
If info from VOR / NDB is added the remote indicating compass becomes a radio magnetic indicator or RMI.

- Lubber line = Magnetic heading
- Green arrow = VOR /

Initial Alignment:

At bottom right allows for manual fast alignment on start up.

DG/COMP switch:

Sometimes called: DG/MAG.
DG = disconnects the mag monitoring system and also the automatic synchronisation with mag north so the system can be used as a pure direction Gyro.

Horizontal Situation Indicator:

If info about deviation from a selected VOR, ILS or RNAV tracks is added, the remote indicating compass becomes a **Horizontal Situation Indicator, HIS**

System Errors:

Deviation:

Remote indicating gyro compass suffers from same errors caused by variations in AC magnetism as do Directional compasses but less.
They must also be swung periodically to establish compass deviation.
Deviation correction achieved by adjusting the EM fields near the flux valve with perm magnets.

Acceleration and turning:

Is susceptible to acceleration errors
Steady pitch up to 25degrees will produce no error as the flux detector remains horizontal in its Hooke's joint, but in balanced turns the flux will stay level WRT the AC leading to horizontal errors.

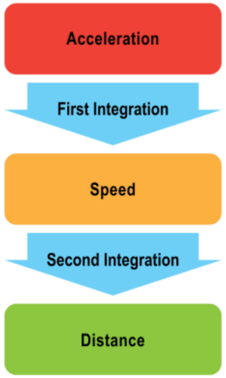
Inertial Navigation Principles:
Self-contained system that can provide continuous information on AC **Position, Track, Heading, GS, and height. Without any external assistance.**
Most AC will be fitted with at least 2 Inertial systems for redundancy.

Older inertial systems not fully integrated, fitted as optional extras known as **Inertial Navigation Systems (INS),** main function being **Navigation.**

Modern systems are fully integrated with other AC systems, they provide not only nav info but also attitude references. These are known as **Inertial Reference systems (IRS)** and individual units are called **Inertial Reference Units (IRU).**

Some IRS integrated into ADC = **ADIRU. (Air data and inertial reference unit)**

Basic Principles:
For INS, starts with **acceleration.**
From acceleration → Speed → Distance.
By integration.



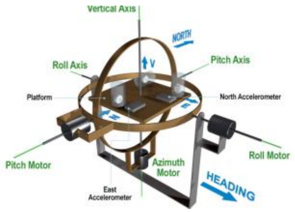
Inertial Navigation Principles

The acceleration axes:
North/South = X axis
East/West = Y axis
Vertical = Z Axis

Stable Platforms and Strapdown Systems:
We know where we start, we measure acceleration, we know where we will end.
How does the inertial system know which direction is north etc?
3 solutions:

- **Stable platform -** Keep the platform on which the accelerometers are mounted always level and aligned north.
- **Wander angle –** Keep the platform level, but not worry about north alignment.
- **Strapdown –** Not worry about either levelling or north alignment but just detect how far out of level and how far out of alignment the accelerometers are at

Stable Platform:



Keeps platform aligned to true north.
2 gimbals, driven by electrical motors.

Initial levelling and Alignment:
Done only once for each flight while AC stationary on ground. **Once aligned the inertial system is not (cannot) be re-aligned for the remainder of the flight.**

Levelling:
Achieved by motoring the platform until no acceleration due to gravity is sensed by either accelerometer.

Alignment:
If AC is stationary, only movement from planet.
Level platform rotated with the azimuth motor until the 'east' rate integrating gyro stops sensing rotation, meaning axis must be aligned north/south.
Once reached, the rotation sensed by the 'north' rate integrating gyro should be equal to the apparent drift caused by the earth's rotation, 15sin(lat).
This allows the INS to calculated, the latitude at which it is.
The alignment of the stable platform with true north is called gyro-compassing.
AC must not move during levelling and alignment.

Latitude and longitude:
After ALIGN is complete, Pilot inputs AC latitude and longitude through a keypad.
This data is used:

- So the INS has a correct start position
- To cross check calculated latitude

INS can calculate latitude, roughly but not longitude. Relies on pilot input for longitude.
Error check compares last known longitude. If >1Degree it'll show error.
Incorrect latitude may lead to loss of alignment and is more critical than incorrect longitude.
Alignment sequence is therefore in order:

- Automatic battery test
- Local Vertical Alignment
- Search for the True North
- The Definition of the Latitude
- The Insertion of Present Latitude and Longitude.

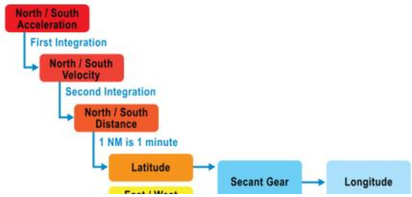
After Alignment, green nav light comes on, and NAV selected by pilot.

Navigation:
Rate integrating gyros now used to keep the platform level and aligned, the accelerometers outputs feed through integrators to become speed and distance.
Calculating Speed:
If initial speed and change in speed is known, new speed can be calculated.
Calculating Latitude:
The north accelerometer output is integrated once to find speed in the north/south sense and then a second time to get north/south distance travelled.

Calculating Longitude:
Similarly, east accelerometer output integrated twice.
Need math, as 1 mile of east/west distance is not a minute of longitude.
Departure = Change of longitude x Cos(Latitude)

Or change of longitude = departure x 1/cos(lat)
1/cos = secant.
Change of longitude = departure x secant(lat).

To find longitude, the latitude output from the North/south integrators is fed with the departure from the east/west integrators into a secant gear to find first the change of longitude and the, knowing the start position, actual longitude.



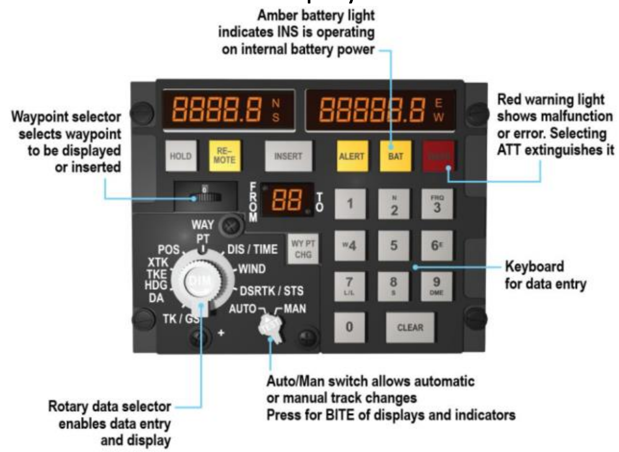
Calculating Heading, Track and Drift:
Knowing new position and old, INS able to calc the track using spherical trig.
TAS not calculated by the INS. Is normally fed by the ADC.
Variation is input provided by a database of variation values around the world.
With these 2 inputs INS can calculate wind and mag headings and tracks.
Attitude outputs:
INS can feed into APFDS (Auto pilot and flight director system), the main attitude.

Controls and indicators:
Cockpit equipment consists of a mode selector unit (MSU) and a control display unit (CDU) for each INS unit.

Mode selector units (MSU):
Switches equipment on:

- **OFF –** Power off
- **STBY –** Power is on, display test performed, battery test is performed AC can be moved
- **ALIGN –** System aligns automatically. Present position must be inserted before sequence will complete. AC must not be moved
- **NAV –** Normal navigation mode. NAV must be selected before moving the AC.
- **ATT –** Disables the nav function of the INS and provides pitch roll and heading outputs to the attitude indicators and APFDS.

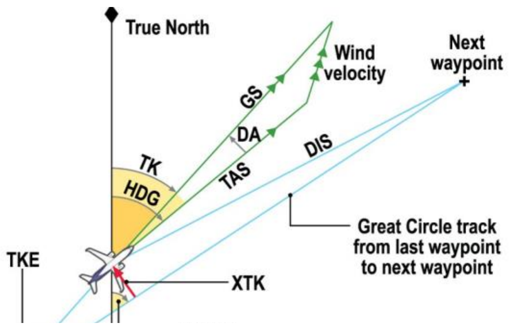
Control Display Unit CDU:
Main control on the CDU is a rotary data selector switch that controls the info displayed.



ISN terminology:

Rotary data switch functions are as follows:

- **TK/GS:** True Track and instantaneous groundspeed
- **HDG DA:** True Heading and drift angle
- **XTK/TKE:** Distance left or right of track 1/10 of a mile and on the right hand display the angle between desired track and track.
- **POS:** AC position as a lat and long to 1/10 of a min.
- **WAY PT:** Lat and long of the waypoint selected on the rotary waypoint selector.
- **DIS/TIME:** Distance/Time to next waypoint
- **Wind:** Computed wind direction (T) and Speed.
- **DSTRK/STS:** Desired track and system status. If the WARN light is illuminated STS shows a malfunction code followed by an action code.



INS Normal Operation:

INS will navigate between a sequence of waypoints flying the shortest, great circle, tracks.

Way points are entered as lat and long by the pilot of the CDU.

To do this rotary switch selected to WAYPOINT, each waypoint is selected in turn with the waypoint selector.

Current waypoints are displayed in the FROM/TO window.

Passing a Waypoint:

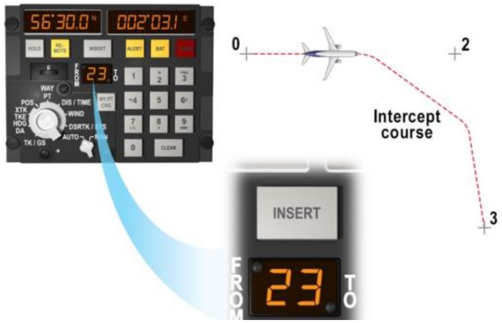
INS can be redirected to waypoint 3 in one of 3 ways:

- If nothing is done and the AUTO/MAN switch is set to AUTO, the AC will fly towards waypoint 2
- Just before waypoint the alert light will illuminate, the INS will turn AC smoothly onto the new track and the FROM/TO window will change read to from 2 to 3. (23)
- If Auto/Manual switch selected AC will overfly the waypoints.

An intercept course:

2nd method will direct the AC to fly an intercept heading to join the new track.

Select WY PT CHG, key in (From) 2 (to) 3 and then INSERT.



Go Direct:

3rd option, Select WT PT CHG, (from)0 (to) 3, then INSERT. This redefines waypoint zero as the AC position when INSERT is pressed and steers the AC direct to 3.

The XTK TKE Selection:

XTK TKE selection on the rotary switch is used when the AC is steered away from the track it should be on, IE when steering around thunderstorms.

XTK on the left hand part of the display show displacement left or right of track, TKE on the right hand part display shows the angle from the actual track to the desired track.

An AC 20.3NM right of track, between waypoints 2 and 3 and closing to the desired track with 30degrees cut:

Stable Platform Configuration:
It is normal to have 2 or even 3 INS fitted and compared for redundancy.
Advantages:
Advantages of a stable platform INS is that, although the concepts are complex, the maths of converting east/west and north/south acceleration are simple and suited to an age before computers.
Disadvantages:
A disadvantage of the north aligned stable platform system is that it cannot easily maintain north alignment as it crosses the poles.

Summary:
A stable platform INS required:
- **3 Rate integrating gyros**
- **2 accelerometers**

A stable platform INS measures acceleration in a trihedron which is free from the AC trihedron (AC pitch roll and

The wander angle INS:
- **A wander angle INS is stable platform with no North alignment**
- **It is mathematically more complex, but better for polar navigation.**

Inertial Systems Errors:
Classed as: bound/unbound, or other errors. Bounded errors are either fixed or oscillate about a mean they do not get bigger with time or distance flown. Unbounded errors get bigger with time.

Earth Rotation:
Although the platform was level and aligned with north on initial alignment the effect of apparent wander due to the earth's rotation will cause it to both drift and topple over time.
INS compensates by adjusting at 15sinlat.

Transport Wander:
Transport wander = Drift and topple.
INS computers calculate the corrections.

Coriolis Effect:
Compensated by INS.

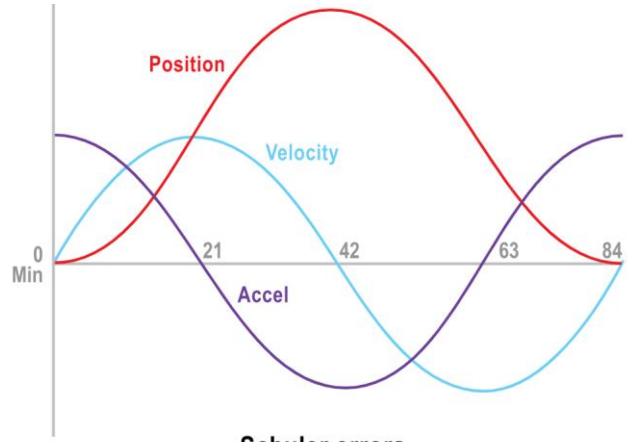
Centripetal Acceleration:
Compensated by INS.

Real Wander
The largest source of unbounded error is the imperfection of the gyroscopes leading to real wander.

Schuler Tuning:
The period of oscillation of a pendulum depends only on length.

A platform that displays these 93.3 min cycles is said to be Schuler tuned.

Schuler Errors:
All Bounded errors.



Schuler errors

Accuracy

EASA's view is that the **average** value for the position error in an INS is 1.5 NM per hour, although many stable platform systems achieve much better than this in practice.

Inertial Reference System

IRS Inertial Reference System:
Strapdown IRS.
IRU used to feed into FMS.
Whole system called IRS.
IRS = Strapdown inertial system.
Within an IRS = 2 or 3 IRU's.

Each IRU on alignment senses the vertical, the direction of true north from earth's rotation and from that calculate latitude. With pilot initial input, it will sense position in space.

Unlike the strapdown INS the IRS has a concept of **inertial altitude.**

RLG's replace mechanical rate integrating gyros to sense angular rotation.
RLG's = Lighter, + Accurate, + Reliable
3 Required.
3 MEMS accelerometers also needed.

Accelerometers and RLG's are known as the 'Computing trihedron'.

Initialisation:
AC Stationary on ground as before.
3 accelerometers will sense elements of gravitational acceleration and computer will determine which way is down.
No gyro stabilised platform.
Once vertical established, attitude changes only come from earth rotation, allows the IRU to determine axis of the earth's rotation and calc true north.

Initialisation:
Alignment varies with latitude.
5 mins = equator
10 min = 70 degrees
17mins = 70-78 degrees
Summary

- **Accelerometers sense the gravity vector**
- **Earth rotation sensed by RLGs is used to compute**
- **North and**
- **The approximate latitude**
- **Pilots/FMS inputs accurate Lat and Long**
- **Takes 5/10 mins at temperate latitudes.**

Controls and indicators:
IRU controlled from start up, alignment and monitoring by a single Inertial Reference mode panel (IRMP)
No STBY mode is provided as there are no mechanical gyros to spin up.

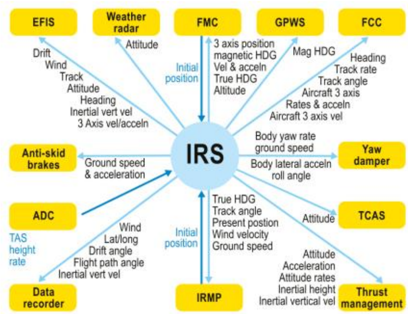
LED Display can be set to show outputs from left or right IRU.
Include: Track/Groundspeed, Present Position, Wind Velocity, True heading, and Status.
To start: Move selector to ALIGN or NAV. Do not move AC. ON DC light comes on to test standby Battery, then ALIGN will illuminate, Lat and Long entered by pilot. IRU compares the entered pos with pos of last known, if too far ALIGN will Flash. Once pos is accepted, ALIGN light will go out. AC moved.

Fast Re-alignment:
During turn around, realignment is best.
Fast re-alignment is also available.
AC at Gate → Turn IRUs from NAV to ALIGN on the IRMP → ALIGN Lights illuminate → New gate position can be entered if required → IRU will align in <u>30 sec</u> → ALIGN lights go out → NAV reselected.

ATT function:
If IRS or INS fails, no lat/long data but may provide attitude. **Selecting ATT disables navigation function.**
Once ATT selected NAV CANNOT BE RESELECTED.

IRS Errors:

- **Strapdown IRU require:**
- **3 Ring Laser Gyros (RLG)**
- **3 Accelerometers**
- **IRU measures acceleration in a trihedron which is FIXED regarding the AC trihedron.**
- **IRU has faster alignment and is more accurate in time than stable platform system**
- **BOTH stable platform and strapdown inertial systems suffer from <u>Schuler</u> errors.**

- 

Flight Management System

FMS:
Holds two data bases: **Performance and Navigation.**
Consists of:
Flight Management Computer (**FMC)**, holds the large databases
Control Display Unit (CDU)

Sometimes referred to as FMGC (Flight management and guidance computer)
FMS + CDU = MCDU. (Multifunction control display unit.
FMS Navigation database updated every **28Days**
Usually uploaded to FMS 7-10days before they are active.

__Navigation__ Database Contains:
- **Reference data for Airports**
- **VOR/DME station data**
- **Waypoint data (5 letter ICAO code)**
- **STAR Data**
- **SID Data**
- **Runway Data, Length, Position, Orientation**
- **NDB Stations (2-3 Letter)**

FMS __Performance__ Database Contains:
Updated when required:
- **V1, Vr and V2 speeds**
- **AC drag data**
- **Engine thrust characteristics**
- **Max and operating altitude**
- **Speeds for long range cruise (LRC), endurance and holding.**
- **Max Zero Fuel Mass, (ZFM), Take-Off Mass (TOM) and Landing Mass (LM)**
- **Fuel Flow**
- **AC flight envelope.**

Predicted fuel flow can be modified by a 'Performance Factor' per AC, where **drag** and **engine** differs from fleet (due to age). +- 9.9%.

FMS Cannot calculate fuel for any other configurations than standard. (clean)

__LNAV and VNAV__
Routes can be recalled from data base and flown automatically.
In the **Horizontal sense** it known as **LNAV (Lateral NAVigation)**
In the **Vertical sense** it known as **VNAV (Vertical NAVigation)**

Can be modified by crew.
When route is altered, its stored in RAM the ROM(read only memory) is not altered.

__FMS Lateral Navigation:__
FMC uses inputs from IRS, GPS, Radio Nav aids, to compute its position. Known as a multi-sensor system.

FMC will tune its own DME and VOR frequencies in sequence and ILS localiser info.
FMC sends demands to AFCS and show on the EFIS and ND.

__FMS Vertical Navigation:__
Follows stored min/max heights for a route. 3-Dimensional navigation plus Time = 4-dimensional aircraft trajectory.

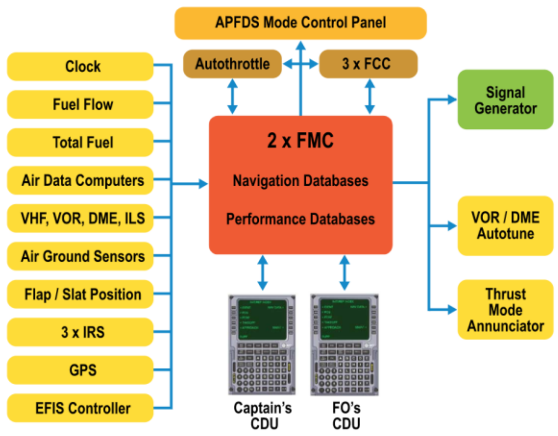
__Cost Management with the FMS:__
Calcs cost and profit of a flight.
2 Major costs:
- **Fuel Cost**
- **Flight time cost (excluding fuel)**

Longer time airborne, higher maintenance, salary, leasing chargers.
Flying faster = Save money on flight time BUT increase cost in fuel.

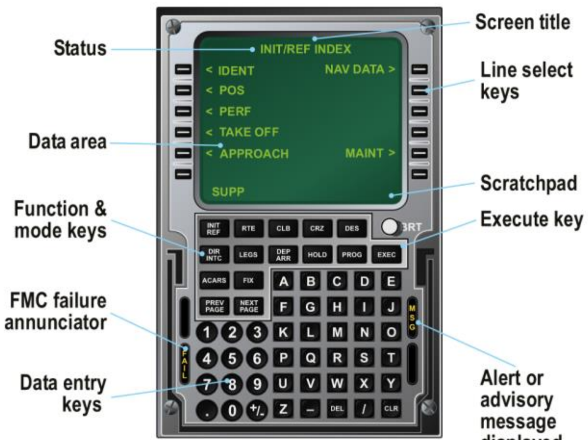
Cost Index (CI) = AC operating cost / Fuel Cost

Cost index = 0 = minimum fuel.
High-cost index = high airspeed and high fuel consumption.

__FMS Input:__



Control Display Unit CDU:



The B737 FMS CDU

CRT screen and a keyboard for entry.

Determining the AC Position:

The uses an algorithm called: Kalman Filter to computer position from all available inputs taking account of likely errors of each system.

GPS very accurate but signal loss.
IRS Less accurate but more stable.
Kalman computes in-between theses.
Most accurate radio updates come from double DME.

FMS SETUP:

Step 1: Identification
Check data relates to your AC and check validity of database.

Step 2: Position initialisation
3 pages, Asks for start-up details.
Input Airport, Gate number to update IRS.
Next page

POS REF
Page lists the entered start positions for the FMS and for the left and right IRS together with computed Ground speed.
Next Page
POS SHIFT
Shows true bearings and distances of the IRSs and the radio fixes from the FMC position.

Routing:
To begins set up, press **RTE**
Back through POS pages and select ROUTE.
Stored company routes.
FMS automatically inserts origin and destination airfields, but it is left to the pilot to enter runway and flight number.
RTE LEGS:
Shows 1/6 pages of the active route, ACT RTE LEGS, giving waypoints, ranges and bearings, speeds, and heights.
Ranges and bearings, speeds and heights.

Performance initialisation:
Once route is loaded, perf can be input.
Temps, Winds, are inputted so power settings and speed can be calculated and VNAV and cost profiles assessed correctly.
INSUFFICIENT FUEL means the predicted fuel at destination is less than the entered value for 'reserves'

Altitudes and Winds:
ACARS is VHF datalink, it can be used to load route, performance, and meteorological data.

Take-Off Reference:
Used to verify take off settings
Flex Take-offs use a higher than ambient temperature input to achieve a reduced thrust setting.

Summary:
The following FMS inputs are required:

- Gross weight or zero fuel weight
- Fuel Reserves
- Cost index
- Cruise altitude
- Transition altitude
- ISA deviation or Temp
- Flex Temp
- High level winds

Using Flight Management Systems

Using the FMS:

In flight:
Once AC is airborne, FMS display shows next waypoint, course and heading to be flown, with speed and height. Mandatory restrictions on speed or height are shown in large characters.

With LNAV selected the AC will fly programmed route.
The FMS FLIGHT PLAN or LEG page shows track and distance to waypoints and required altitudes and speeds.

Flight Progress:
Alternative/more informative display: **FLIGHT PROFRESS page.**
Shows track
Distance to go
ETA and fuel remaining.

Nav Display Output:
Nav fed from the FMC to the EHSI or ND with active route selected in magenta.
FMS LNAV and VNAV commands will also show on the PFDs

Navigation:
FMS uses IRS, GPS, VOR, DME, and ILS.
FMS Uses Receiver Autonomous Integrity Monitoring (RAIM) to exclude a GPS giving contradictory information.
The FMS does not update the IRS position without GPS, the most accurate radio updates come from double DME.

Most accurate. DME/DME > DME/VOR > VOR/VOR

ANP RNP:
Actual Navigation Performance ANP. 95% confidence the actual position lies within a circle of the radius of the given ANP value, centred on the FMS position.
Lower ANP = Higher confidence.

RNP Required Navigation Performance.
The desired limit of navigation accuracy and is specified by the kind of airspace.
ANP always be less than RNP.

Map Shift:
Flight crew advised to monitor FMC position when approaching destination without radio navigation and GPS.

Calculated ETAs:
Waypoint and destination ETAs are calculated using the actual wind to the next waypoint and then cruise wind entered on the PERF INIT page for all other waypoints. Forecast winds can be entered to increase accuracy.

Waypoints:
Normally turn starts shortly before the waypoint to stay on route, unless waypoint annotated 'Overfly'

Changing the Routing:
Pilots can change route in flight.
Simply command the FMS **direct** to waypoint.

Lateral Offset:
On some systems the FMS can be instructed to fly parallel to an FMS route, offset by some miles left or right.

Cruise Speed Options:
Default cruise speed = **ECON CRUISE**
'Best range speed as modified by the cost index'

Long Range Cruise (LRC) is a speed 4% faster than the still air unmodified best range speed but gives 99% of the range. Made when pilot has no cost index (maybe for diversions).

Required Time of Arrival (RTA) allows pilot to input time at a waypoint from which the FMC will calc speeds.

Fuel Calculations:
Can be relied upon.
In 'Abnormal AC configurations' the calculations may prove very wrong.

Effect of Configuration on fuel flow:
Flaps, Spoilers, Landing Gear, Anti-Ice, or another bleed air sys. Have profound effects if outside their predicted profile.

Approach and Landing:
In the decent APPROACH REF page can be called from the main index.
Gives: target threshold speed, VREF for calculated landing gross weight for diff flap settings.

FMS approved to provide guidance for RNAV approaches, VOR/DME and DME approaches and localiser only approach.

Where Vertical guidance is provided it will base its altitudes on a barometric altitude from the ADC or ADIRU as fitted.

FMS Outputs:
Apart from displaying information and guidance on the CDU the FMS can, as selected, feed the LNAV and VNAV information to the pilot's instruments, flight directors and auto throttle and AP. Outputs include:

- CDUs
- APFDS
- FCC
- Auto Throttle
- PFD, FD
- ND
- Autotune system for navaids

Operating:
Crew can give full navigation and performance to the FMS, called 'Managed guidance'.

Single FMC Dual MCDU Operation:
Some AC have single FMC with dual CDU's or MCDUs. Care should be taken to not enter data simultaneously.

Dual FMC Dual MCDU operation:
Most sophisticated AC have Dual FMS fir with 2 FMCs, 2 MCDUs and 2 AFCS.

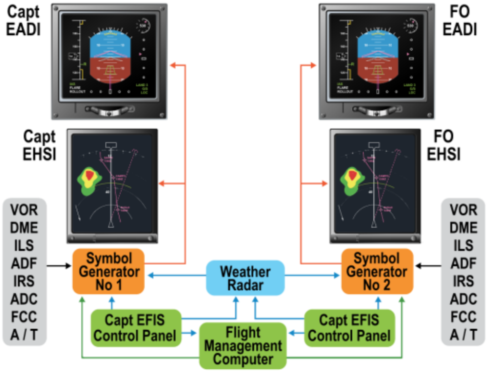
Dual FMC used:
Master/Slave Operation:
One mode is used as the input unit. And shared with the 2^{nd} unit, Computers talk to each other, as well as sharing data they compare. Each FMC retains control of its associated AFCS, Auto-throttle and selection of radio nav aids.

Independent Use:
The FMS units operate totally independently.
Allows pilots to operate with one displaying performance while other displaying nav data.

Back up
One 1 FMC has failed.

EFIS Electronic Flight Instrument System

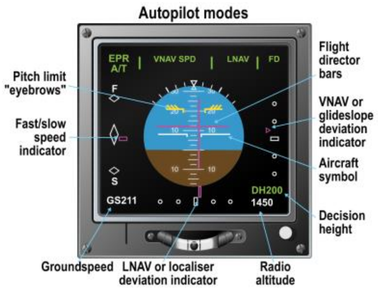
Components:
Complete EFIS consists of Left and Right systems.



EADI = Electronic Attitude Director Indicator Aka PFD.
EHSI = Electronic Horizontal Situation indicator Aka ND.

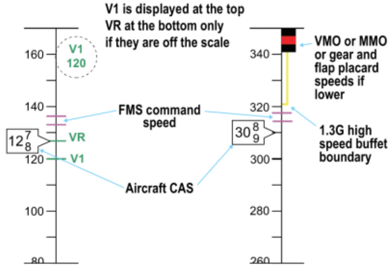
Symbol Generator (SG) creates the graphic outputs for display on the PFD/ND.

Primary Flight Displays:
An EADI or PFD is a sky pointing ADI.



Combines all basic T instruments into one.

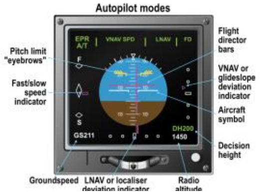
Speed Tape:
Shows **CAS Calibrated airspeed** from the ADC between 45-420Kts.



Decision Height DH and Radio Height RH:
DH can be supplemented with a digital Radio Altitude RA.
Radio altimeter is only active below **2500ft**.
On B737 radio altitude can be displayed either at the top right of the PFD or at the bottom right.

Airbus decision height display:
Radio altitude shown in digital in the bottom centre of the attitude display.
Green until 100ft of the DH, when it changes to amber.
It flashes for 3 seconds at DH. Same time amber DH flag appears above the RA.

Pitch Lift Symbols:
The pitch lift 'Eyebrows' show the attitude to select in the event of a wind shear go-around or in response to a GPWS warning. At this Attitude the AC will be climbing just on the light buffet/stick shaker.

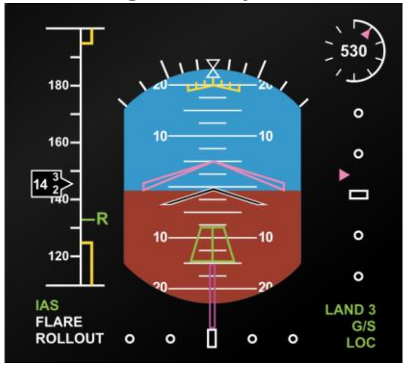


Flight mode annunciator:
Autopilot active modes shown on top of PFD in the FMA (Flight mode annunciator).
Boeing and Airbus:
Armed = white
Captured = Green.

Boeing:

Left = Auto-throttle / speed control
Middle = Lateral Modes LNAV
Right = Vertical Modes VNAV

The Rising Runway:



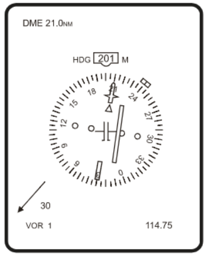
For rising runway symbol to be displayed all must be met:

- Valid ILS localiser frequency
- Data supplied by the radio altimeter must be valid
- Radio altitude less than 2500ft.

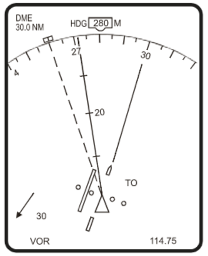
Boeing Navigation Displays:
Navigation Displays (ND/EHSI) provide mode-selectable colour depiction of nav and supplemental information.

In all nav displays heading is supplied by IRS display is referenced to **Magnetic north between 60-65degrees South and 73 Degrees North.**
Outside the ND **is referenced to TRUE north. Also selectable by crew.**

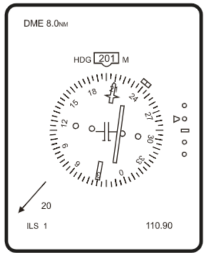
Full and Expanded Modes:
Certain modes, VOR, ILS, and NAV can be displayed in 'full' format, meaning the whole compass is visible, or as 'expanded' modes. Which only show the forward 90degrees.
Expanded = Arc
Full = Rose.



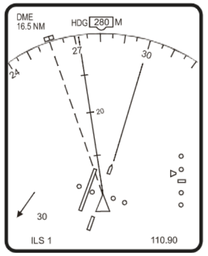
Full VOR



Expanded VOR



Full ILS



Expanded ILS

Full VOR/ILS modes:

FULL VOR.

- **DME distance shown top left**
- **Present heading indicated in 'heading box' with true and magnetic**
- **Magenta heading = heading select.**
- **FMC calculated wind shown bottom left**

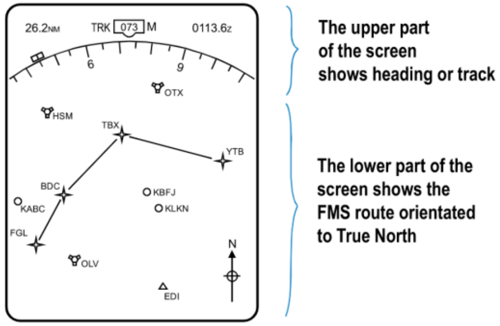
Course deviation indicator (CDI) also shown.
VOR = 1 dot = 5 degrees.
ILS = 1 dot = 1.25dgrees.

Weather radar not shown on Boeings full rose displays.

MAP mode:

Shows the computed FMS Track.
FMS track shown by **magenta** line connecting **Star shaped waypoints**, active waypoint is **Magenta, others are white.**
Map can be overlaid with weather.
Off route Airfields = Cyan

PLAN mode:
Does NOT show a aircraft symbol.



Plan

Only display with a north arrow.
Used to look ahead down track by scrolling through the route's pages on the FMS.

Weather Radar Colouring:

BLACK	0 – 1 mm/hour
GREEN	1 – 4 mm/hour
YELLOW	4 – 12 mm/hour
RED	12 – 50 mm/hour
MAGENTA	> 50 mm/hour

MAGENTA is alternatively used to indicate turbulence using a selectable Doppler based radar, by selecting WX+T, or TURB on the radar control panel.

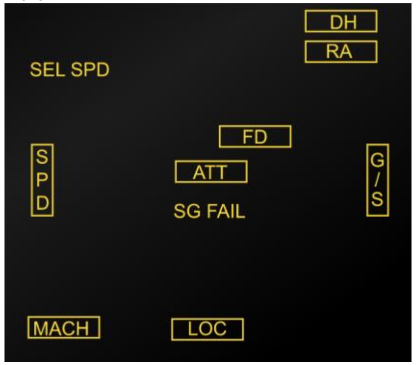
Other symbols and colours
Colour coding on the EFIS can be generalised:

GREEN	Active or selected data, engaged autopilot modes
WHITE	Current data, values, armed autopilot modes
MAGENTA	Command information, weather radar turbulence,selected heading, flight director bars
YELLOW	Cautions, abnormal sources
CYAN	Non active and background, sky
RED	Warnings, flight envelope & system limits
BLACK	Off
BROWN/TAN	Earth

This indicates a waypoint. When coloured magenta it is the one that the aircraft is currently flying to and is deemed active. A white waypoint is considered inactive and shows a navigation point making up a selected active route.
This is the symbol for an airport and is coloured cyan.
This is a navigational aid and is coloured cyan unless it is one of the two currently in use by the FMS.
This is a manually selected navaid showing the selected course and reciprocal coloured green.
This is an off-route waypoint, coloured cyan.

Remote Light Sensor:
Respond to ambient light sensors auto adjust brightness of the EFIS displays.

EGFIS Failure Warnings:
Amber in colour and appear at the point on the screen where failed information would have appeared.



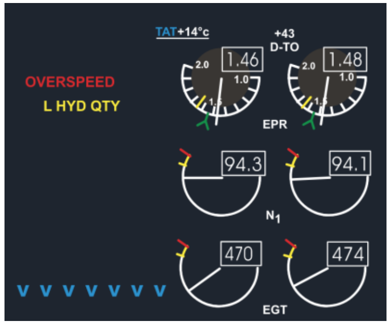
Failure = Amber.

Airbus Navigation displays:
Boeing system have 5 modes:

- ROSE LS (landing system, ILS, GLS, MLS)
- ROSE VOR
- ROSE NAV
- ARC
- PLAN

Engine and System Screens:
Boeing EICAS:

Engine Indicating and Crew Alerting System (EICAS).



Primary engine operating parameters.
Engine Pressure Ratio – EPR
N1 RPM
Exhaust Gas Temperature – EGT

Warnings = RED
Cautions = AMBER
Advisory = White

Typical Indications:
Fuel:

- **Fuel quantity in each tank**
- **Total Fuel quantity**
- **Fuel temperature**

N1:

- **Present N1**
- **Commanded N1**
- **N1 Operating limits**

EGT:

- **Present (Instantaneous) EGT**
- **Maximum continuous EGT limit**
- **Maximum Take-Off (or go around) EGT limit.**

Datalink Communications

Different Systems:
Datalinks allow for transmission or exchange of messages between suitably equipped found systems and AC.

Analogue radio system passes messages through text-based operator to AC system known as **ACARS (AirCraft Addressing and Reporting System).**

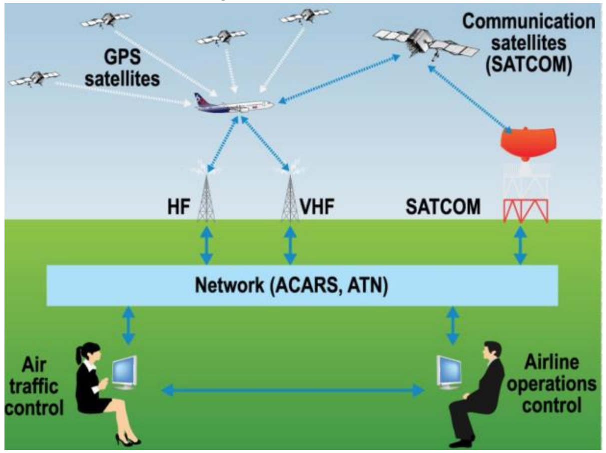
Datalink messages in common use:

- OOOI (times **O**ut of the gate, **O**ff the ground, **O**n the ground, **I**nto the gate)
- Load sheet data
- Passenger information (connecting flight details)
- Weather reports (METARS, TAFs)
- D-ATIS (ATIS Provided by datalink)
- Maintenance reports
- Free Text Messages.

Controller Pilot Data Link Communication (CPDLC) type of ACARS, Text based messaging. Can replace voice communications, for example for departure clearances.

Latest datalink systems remove human interface and allow direct communication between the AC avionics systems and ground agency.
This is **Automatic Dependent Surveillance (ADS).**
2 Forms:
ADS-B (B = Broadcast)
ADC-C (C = Contract) AC interrogated by ground station.

CPDLC Ground systems:

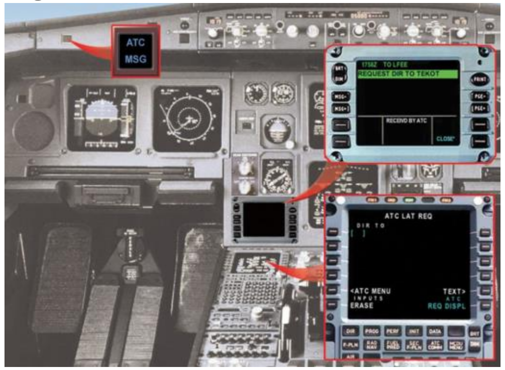


Ground routing of messages is usually operated through ACARS digital service providers (DSP) such as SITA and ARNIC.
Most recent developments use **Aeronautical Telecommunications Network (ATN)**

CPDLC Aircraft Equipment:
AC equipment known as the **Air Traffic Service Unit (ATSU).**
Typical ATSU has:

- Communications management unit which receives msgs from the appropriate radio equipment and allocates messages for transmission
- FMS multi-function control display unit (MCDU) input and display msgs.
- On Airbus, additional **Data communication Display Unit (DCDU).**
- Visual and aural warning of incoming msgs.
- A printer.

An AC ATSU is said to 'enable access to all available communications media, to manage the HMI (Human Machine Interface), and select the appropriate ATC centre for datalink through the flight.



The CMU
Core of the ATSU is the CMU. Connected to the CMU is:

- FMS MCDU (and DCDU on airbus)
- HF Communication Unit
- VHF Communication Unit
- Satcom

Audio control panel is not a part of the ATSU
Msgs originated on the MCDU and displayed on DCDU.

CPDLC in use:
To establish comms with the active data authority the flight crew must log on with that agency.
Initiate CPDLC procedure = sending CONTRACT MESSAGE containing 4letter ICAO site designator of the ATC unit. Latter responds with acknowledgment msg.

CPDLC Messages:
Once logged on following ATC msgs are typical:

- Level assignment
- Crossing constraints
- Lateral deviations
- Route changes and clearances
- Speed assignment
- Radio frequency assignments
- Voice contact request

The pilot can:

- Respond to messages
- Request clearance and information
- Report information using a free text capability
- Declare or rescind an emergency
- Initiate a voice request.

Take-off and landing clearance will NOT be made over CPDLC

CPDLC Messages:
A msg may come from ATC,
3 options – Standby, Reject, Accept.
Certain uplink msgs will such as amended routes will give flight crew option to directly load into FMS.

CPDLC frequencies:
Can use: VHF, HF or SATCOM. With the Aeronautical Telecommunications Network (ATN)

Method	Good	Bad
VHF	Cheap High quality transmission	Line of sight Medium speed of data tranmission
HF	Available in polar regions	Propagation affected by ionospheric conditions
SATCOM	Not affected by ionospheric conditions	Expensive, not available in polar regions Fastest data route

Automatic Dependent Surveillance (ADS) - B Broadcast.
Uses a **Mode S** transponder.
Broadcasts unsolicited information such as:

- GPS derived position
- Airspeed
- Altitude
- Heading

To any station that can receive data.
In Europe ADS-B uses **SSR frequency 1090MHz**
Transceiver **frequency 978MHz.**

ADS-C
'Contract' aka ADS-A (Addressed).
Relies on a 2way contract being established between ground station and the AC.
Contract initiated and controlled by the ground station.
ADS-C operates through **ACARS, not transponders.**
Controlled by the FMS.
3 types of contracts

- **Periodic**
- **On event**
- **On Demand**

Periodic = Sets a reporting rate at which the requested info is downloaded.
On event = Sends a downlink report whenever specified events occur:

- **The Vertical Rate Change Event**, Rate of climb or descent outside parameters defined in request.
- **The Lateral Deviation Event,** Distance off track exceeding specified in the contract request.
- **The Altitude Range Change Event,** Level variations greater than specified.
- **The Waypoint Change Event,** New next waypoint in the FMS

On Demand = one-off contract for a basic ADS-C report, such as to obtain instantaneous altitude in a descent.

ADS-C Report Contents:
ADS-C contains:

- Latitude
- Longitude
- Time Stamp
- Figure of merit (FOM) (navigational accuracy 0-7) 7 = Best.

EG:

BA432
periodic
06:44:09
basic_group
latitude: 44.392 N
longitude: 16.272E
Alt: 33000
FOM:6

On-request groups can be added to basic group to provide:

- Meteorological information
- Predicted position at a particular time
- FMS intended route
- FMS projected optimum level.

Emergency Mode:
Flight crew can set this by:
Sending Mayday Msg
Which puts both CPDLC and ADS-C into emergency mode.
Or by switching the ADS-C to emergency mode which increases periodic reporting rate.

Future Air Navigation System (FANS)

ICAO committee proposed CNS/ATM concept (Communication, Navigation, Surveillance, and air traffic management)

Purpose of FANS = to allow more AC to safely and efficiently utilise a given volume of airspace.

Performance Based Navigation (PBN)

FANS A:

Works in same way as ACARS.
Used mainly in oceanic areas.
ATC control provided by CPDLC
AC position, height and speed data may be downlinked to ATC using ADS-C if available using the acronym CNS/ATM:

- Control is provided by ATC and AOC datalink
- Navigation is GPS based
- Surveillance by ATC Datalink
- Uses standard Air Traffic Management (ATM) procedures.

FANS uses electronic handshake through ARINC 622 Network called ATS facility notification (AFN)

FANS B:

Airbus development for use in high density airspace with radar surveillance in en-route phases.

It is intended to use the ATN air/ground communications network using CPDLC and ADS-C and will automate elements of ATC and ATM.
FANS B only on A320 Family.

- Control is provided by ATC over the ATN
- Navigation is to RNP standards using GPS
- Both elementary and enhanced surveillance are used
- Uses standard ATM anticipating eventual ATM automation.

Automatic Flight

AFCS = Automatic flight control system
APFDS = Autopilot Flight Director System

AFCS classification:
Classified by number axis controlled:
Single Axis: Roll only
Two Axis: Roll and pitch, can capture and hold heading/altitude. Pilot controls power and trim.
Three Axis: Roll, Pitch, Yaw.

A Three Axis System:
Following operating modes:
- Heading, altitude and vertical speed capture and hold
- IAS or Mach hold
- Coupling to VOR track and to ILS localiser and glidepath
- Coupling to FMS horizonal and vertical profiles
- Autoland (some AC)

Autopilot comprised of:
- Sensors
- Comparators
- Computers
- Amplifiers
- Servo-actuators

Regulatory Requirements:
It is not a requirement to have AP.
CS 25.1329 lays down ways AP must be fit and operate.
Some operations need AP.
Only mandatory requirement for fit is the 2-axis AP with altitude and heading hold for single pilot IFR.

Autopilot control and stability:
The AFCS has 2 functions:
- Control of AC movement about its CG, (stability)
- Guidance of AC CG along a flight path

Open and Closed loop:
Open = no feed back
Closed = feedback loop

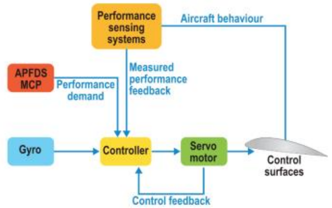
Closed Loop Operation – Pitch Stability:
Pitch axis's change sensed by RLG. (In IRU)
Signal produced → Signal processor computes suitable corrective signal → Sends to elevator servo → Servo motor feedback position.

Feedback is an essential requirement of a closed loop control system.
Id closed loop system overcompensates, AC may enter self-induced oscillations.

Inner and Outer Loops:
Although AFCS control loops are closed, they are further divided into inner and outer loops.
Inner loop systems = provide stability **(Stabilise)**
Outer loop system = flight path guidance **(Control)**

Outer loop flight path modes are operated by low-speed rotary actuators fitted parallel to flight control system. Operation of a parallel actuator moves both flying control surface and flight deck

Outer Loop Operation – Controlling Rate of Climb:
Input determined by the pilots on the AFCS Mode Control Panel (AFCS MCP)
→ Computed by signal processor (Flight Control Computer) (FCC)
→ Sent to flight controls
→ AC climbs, Performance system senses climb and feeds back to FCC.
→ Performance achieved against performance measured. (Error)
→ Error Reduced to zero.



Inner loop (stability) e.g.:
- Yaw damper
- Holding pitch / roll attitude

Outer loop (Flight path control) e.g.:
- Altitude hold
- VOR and ILS track
- Speed control.

Gain Variation:
Gain needs to be adjusted in proportion to for example speed as surfaces don't need to move that much at high speeds.
-Gain Variation gives more gain generally at low speeds, less at high speeds.
-Too much gain produces instability, too little gain gives not enough control

Gain Adaptation:

Adjusts the AC behaviour so it matches that of a computer model for the relevant speed, height, and configuration.

Direct Control Law:
Basic mechanical connection between input and output is called direct control law.
A nose up pitch demand applied and held will initiate a nose up pitch rate.

Pitch Rate Demand/Attitude Hold Law:
Nose up pitch applied and held will initiate a nose up pitch rate as before, but the computer will continuously increase elevator deflection to maintain the pitch rate constant.
Zero pitch rate = constant attitude hold.

G Demand/Flight Path Hold Law:
Relies on the idea that level flight is a constant 1G flight path, increased G will make the AC up, reduced G make AC go down.
Good for maintaining a defined flight path – level flight or glideslope angle.
There is Lag = sharp and rapid corrections.

C* Law:
Fully developed (A320)
Flight path hold law with an element of pitch rate demand introduced at low speed to improve response on the approach.

Flight Envelope Protection:
Control laws protect AC from exceeding flight envelope limits (Overstress / overspeed):
Protection available for:

- Overspeed – Limit is VMO or MMO
- Stall protection/alpha protection

Fly-By-Wire AC have additional protection:

- Pitch attitude
- Bank angle
- Excessive G
- Excessive Roll and pitch rate
- Flap and undercarriage limit speeds etc

Failures of other systems not directly related to AP may make the AP unavailable or unreliable.

Trim Systems:
Basic Trim systems adjust the position of control surfaces to hold a given attitude.
Large AC have trim in all 3 axes.

Auto Trim:
Auto flight systems adjust trim settings to relieve the autopilot servo motors and to keep AC in trim.
Auto trim functions in pitch and prevents snatching when the AP is disengaged.

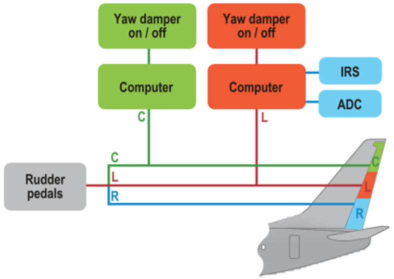
Mach Trim:
At M0.75-M1.0, shockwave formation on the upper wing surface causes wing centre of pressure to shift rearwards. This leads to a large tail up/nose down pitching force known as Mach tuck.
Mach trim operates at higher Mach numbers to prevent the pitch down known as 'Mach tuck'

Yaw damping:
Too much directional stability is bad in turns.

Too much lateral stability leads to continuous roll and yaw in straight flight (Dutch Roll).

Lateral and directional stability of an AC not constant in flight, at high TAS directional stability decreases as aerodynamic dampening on the fin decreases.
At low speed, in swept wing AC, lateral stability increases sharply.
Necessary to artificially modify stability by active control of the rudder (Yaw dampening).
Yaw damper counters Dutch roll.

Parallel and Series Yaw Damper Systems:
In AC with 3 axis AP, rudder is used to balance AC in turns. (Roll/Yaw Coupling)
Yaw damper channel will be integrated with this system. Called 'Parallel System'



Alternatively, the yaw damper may have a separate channel. Known as a 'Series system'.
Separate from the AP system.

AFCS Protection Systems:
Interlocks – Prevent AP engagement if: Electrical supply is faulty, roll control knob not centred, Synchronisation fault, Fault in attitude ref unit.
Torque Limiters – Limits torque applied.
Synchronisation – Removes Jerk when AP off.

Automatic Flight Path Guidance

Automatic Flight Path Guidance:
AP and Flight director systems are controlled on a single Mode Control Panel (MCP).

APFDS has following outer loop functions which can be fed into the Flight Director System,
Can be followed manually or on full AP command (CMD):

- Altitude Hold
- Airspeed Hold
- Mach hold
- Vertical Speed Hold
- Heading Hold
- ILS Tracking
- INS Tracking
- VOR Tracking
- LNAV / VNAV

Selected Modes:
Shown on the PFD Flight Mode Annunciator (FMA) specifically:

- AFCS lateral and vertical modes
- Auto-Throttle Modes
- FD selection
- Autopilot engagement and Autoland capacity
- Failure and alert msg

Engaging the Autopilot:
If flight director selected, then selecting one of the CMD will engage AP.
The FMA on top of the PFD will display CMD.

Autopilot Disengage:
A single AP can be disengaged by pressing A/P Engage switch again. Or by pressing the disengage bar/control column disengage.

If AP randomly disconnects continuous warning will sound.

Lights and tone can be extinguished by pressing control column button again.

LNAV and VNAV
Selecting LNAV and VNAV will hand the AP to the FMS.
In VNAV AP sets required thrust.
In level flight VNAV holds cruise altitude and sets throttle as commanded by the FMS.

Vertical Speed and Flight Path Angle:
With V/S button pressed the AP will adjust the pith to hold the vertical speed selected in VERT SPEED Window.
Only 1 pitch mode can be engaged at a time:

- **ALT Hold**
- **VNAV**
- **V/S**

Altitude Control:
Normal way to climb/descend → Select it in the ALITUTDE WINDOW, select V/S.
Once altitude is reached ALT HOLD is engaged and announced on the PFD.
ALT HOLD switch light on the MCP does not light up.

ALT NTV and ALT HOLD:
Altitude intervention (ALT NTV) is used during VNAV climb/descents to delete FMC altitudes and allow a continued climb/descent to the altitude selected on the MCP.
If ALT HOLD is selected during the climb/descent the altitude selection is held.

Heading Control:
Pressing HDG SEL on the MCP will command the AP to turn to and hold a heading.
Displays on the FMA.
Max and min bank angles can be set in HDG SEL and VOR modes but **not in LNAV.**

VOR Tacking:
Controlled by the VOR/LOC selection.
Once overflown the VOR signal becomes unreliable, and the AP is cut off. This is done by an Over Station Sensor (OSS) which cuts the VOR signal for a present time.
AP will maintain a heading while the OSS is active.

Control Wheel Steering:
Rarely used alternative to outer loop control is to select Control Wheel Streeting (CWS).
CWS allows AC to be flown manually but, if pilot removes hands from the column, AC holds the last pitch and roll attitude selected.

CWS can be engaged by engaging the AP without any modes selected.

Some AC have a system called **Touch Control Steering (TCS).** It is subtly different from CWS. TCS the autopilot remains engaged, but autopilot servos/actuators are disconnected from the control surfaces. Manual control of the AC continues for as long as the TCS button is depressed.
The AP servos/actuators reconnect when the TCS button is released and the AP returns. Rather than adopting a new attitude as it would with CWS.

Speed Control:
Result of Trust and pitch attitude combined, Under some circumstances, such as VNAV Climb, the auto throttle will command the limiting thrust and the autopilot will control speed with pitch. Under other circumstances, e.g., in cruise the AP will hold height and Auto throttle control speed.
Speed can be set manually in the IAS/MACH window

Auto throttle:
Controls the thrust of an AC engines.
2 commands can be given:
Selected speed (SPEED)
Deliver a selected amount of trust Engine pressure ratio (EPR).

An Auto throttle may be disengaged:
- By pressing the disengage buttons on the throttles
- On most systems, by selecting reverse thrust
- Automatically, 2 seconds after touchdown
- Selecting A/T arm switch to off
- If there is a throttle asymmetry of more than 10degrees in the late stages of a multichannel Autoland.

Boeing A/T Stall Protection:
If Autothrottle system is set to ARM at high angles of alpha autothrottle will auto engage to give stall protection.

Autothrottle Take-Off:
Normal take-offs will be with reduced thrust selected on the FMS, called 'FLEX' take-off.

In this case AC is lined up and N1 engaged by pressing TOGA on the throttle.
Throttle will be driven forward to selected N1 and held.
At 84Kts g/s sensed by IRS, FMA changes to THR HOLD

Autothrottle Mode Annunciation:
Speed modes shown top left side of the FMA.
Possible modes include:
N1, GA, REATARD, FMC SPD, MCP SPD, THR HOLD, ARM.

Autothrottle will not automatically adjust speed when turbulence is encountered.

Autoland

Autoland:
Most challenging manoeuvre for an AP to undertake.
Needs great precision and reliability.
Less taxing is an ILS, flown to a DH and then disconnected. (Semi-automatic approach).

ILS Categories:
CAT I - Guidance to 200ft
CAT II – Guidance to 100ft
CAT III – Guidance down to touchdown and beyond.

Cat depends on equipment certification, calibration etc.

Before making automatic approach, AC must be certified for that approach and the crew must be trained to make the approach.

Fail Operational and Fail Passive:
In low ceiling and vis, must be complete confidence in the system.
Usually, 3 functioning and engaged AP all working together, failure of one will result in being voted out. **'Fail operation' system. (Fail active in USA)**

If only 2 AP, and one fails, no way to know which is right, therefore both disengage and leave AC in trimmed state. Called **'Fail Passive System'.**

Definitions:
Fail operational: An automatic landing system is fail-operational if, in the event of failure, the approach, flare and landing can be completed by the remaining part of the automatic system.
Fail passive: An automatic landing system is fail-passive if, in the event of a failure, there is no significant out-of-trim condition or deviation of flight path or attitude- but the landing is not completed automatically.

Two Channel Fail operation systems:
Possible for a two AP system to be certified as fail operational in one of two ways:
- If there is an external monitoring and comparison system which can identify and disconnect the failed AP
- If a primary fail passive system is supplemented by a 2nd independent guidance system such as a HUD, 'Hybrid system'

The Alert Height:
Component failures have different implications at different heights.
Alert height is around 200ft RA.
Failure before alert height gives more time to react, either go around or reversion.
If below A go around is still possible, less critical failure will allow continuation of landing.
Triggers that warn below alert height:
- **All AP disengages**
- **Loss of ILS signal or components**
- **Excessive ILS deviations**
- **Radio-altimeter failure**

Other AP considerations:
To keep AC on centre line on roll out after landing, nosewheel steering actuator must work through the rudder channel, called '**Rudder fine Nosewheel Steering'.**

Autoland limitations:
Headwinds, Tailwinds, Cross wind limits.
Flap Settings, All engines operative.

The Final Stages

At 400 ft to 330 ft RA the aircraft trims nose up but holds the approach attitude with nose down elevator.

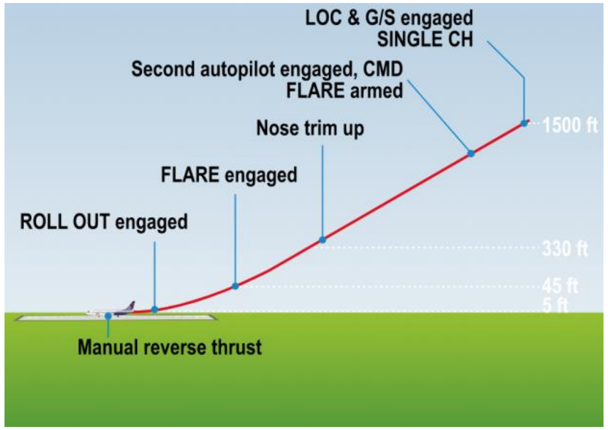
At 300 ft RA the sensitivity to glideslope deviations is reduced to prevent pitch oscillations.

At 200 ft RA the aircraft longitudinal axis is lined up with the runway centre line, holding drift with rudder and aileron.

At 50 ft to 45 ft RA FLARE mode takes over pitch control from the glideslope signal and descends the aircraft towards the runway at 2 ft per second.

At around 25ft RA the MCP speed control drops out, the RETARD mode is announced on the left of the FMA and the throttles close.

At 5 ft RA GA is inhibited. The touchdown and ROLLOUT mode engages to decrease the pitch attitude.



Go-Around:
GA arms itself at 1500ft and is engaged by pressing TO/GA on throttle.

When TOGA is pressed AP will pitch up to +15degrees and autothrottle will select full thrust.

Once 2000fpm reached, thrust will adjust to hold 2000fpm at the airspeed existing at GA engage.

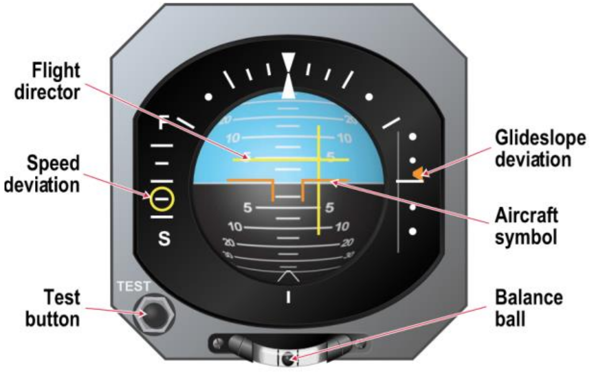
Pilots retract flaps and gear to reduce drag.

Some AC pressing TOGA once gives reduced EPR
Twice for full thrust.

Back Course:
Some AP have back course (B CRS or BC) options. If fitted, this is sued at airfields which have two instrument runways but only one ILS and where there is a published back course procedure (Usually only in USA).

Flight Directors

Flight Directors:
'Guides pilot in manual flight'
Displays on the ADI, PFD, EFIS.



Architecture:
Systems of autopilot and FD are similar.
Need info from sensors:
- ADC (Height and speed)
- IRS (Heading and alt)
- Nav receivers (Track and glidepath)

FD usually = Yellow on analogue
FD usually = Magenta on EFIS.

Interpreting the Display

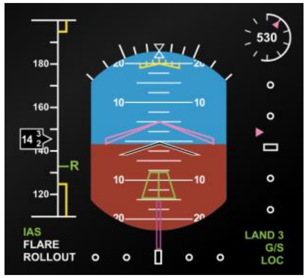
Interpreting the display:
Magenta lines that are NOT part of the FD include:
- On left, fast and slow come from autothrottle system
- ILS localiser
- G/S

FD shows pitch and roll commands in centre of PFD.

Pilots treat the first small movement of the FD roll bar as a cue to start a steady roll out which matches the commands from the FD.
With AP engaged it follows the demands smoothly and without delay.

Ignoring a roll demand:
If first roll command is ignored FD bar moves further to direct pilot back to the localiser.

Flying wedge Display



Magenta wedge

B737-800 FD system operation:
Each FD system can operate from its respective FCC, with comparison between the FCC to error checking, or be controlled by a master FCC.

Master/Slave Operation:
The NORM.
Which side is the master depends on:
- If neither AP is engaged in CMD the master FCC is the one whose FD is switched on first. Both FDs will display the same information.
- If one or both AP are engaged in CMD the FCC for the first AP engaged in CMD is the master FCC, regardless of which FD is switched on first. Both FDs show the same information.

Master FD displays green light 'MA' just above the FD ON/OFF.

Independent operation:
Occurs automatically but only rarely.
For this to occur, there must be no AP in CMD and either APP is selected with LOC and G/S engaged or TO/GA below 500ft RA.

In independent operation both FD MA lights are illuminated.

FD modes on the FMA:
FD replaces CMD on the PFD to just no AP.

Alerting Systems

Alerting system:
Includes:
- Warnings
- Cautions
- Advisories

Airbus = Flight warning system (FWS).
Boeing = Master Caution.

Levels of Alert:
Warning:
Require **Immediate recognition**, and **corrective** or **compensatory** action by the crew. Timely attention getting cues through at least two different senses by a combination of aural, visual, and tactical indications are required. **Visual alert must be red.**

Cautions:
Require **Immediate** crew **awareness,** and subsequent crew action **will be needed**. Timely attention-getting cues through at least 2 different senses, combination of aural, visual, and tactical indications is required. **Visual alert must be yellow.**

Advisories:
Require crew awareness, and subsequent action **may be required.** No aural warning is required. They may be any colour **except red**, **yellow/amber, or green.**
Most use **yellow/white.**

Alerting Mechanisms:
Sight, Sound, Feel.
Visual, Aural, Tactile.

Visual Alerts:
Lights, Electronic displays and msgs on EFIS/EICAS and flags or markers. Level of alert matches the CS25 being:
- Red for warnings, flight envelope or system limits
- Yellow for cautions or abnormalities
- White for advisories.

Flashing red = top of the alert scale.
Steady white = bottom.

Aural Alerts:
Bells, Klaxons, Sirens, Spoken Messages.
Loud bells/intermittent klaxons more attention getting
Calmy spoken words = least.
Type specific

Tactile Warnings:
Stick-shaker mechanism in the stall warning system.

Master warnings and cautions:
Pressing the Master Warning light cuts the associated bell but leaves light on until fire is out.
Pressing Master Caution light resets the system.

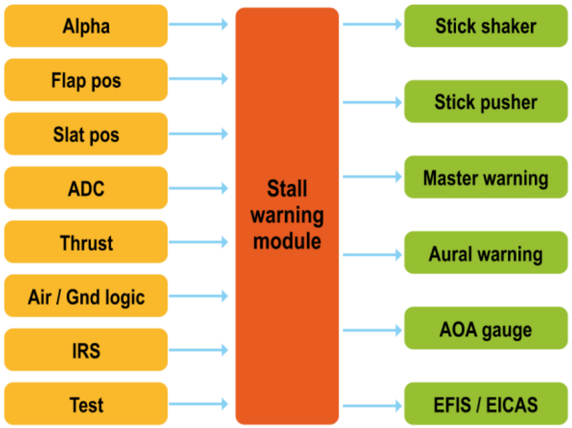
Automatic suppression of warnings and cautions:
Some are inhibited during start-up to avoid transient false warnings; others are inhibited at critical stages of flight:
On take-off master caution is inhibited from passing 80kts up to 400ft and engine fire warning bells are usually inhibited from V1 to 400ft.

EICAS:
Airbus = ECAM
Boeing = EICAS

Stall warning and protection:
CS23 and CS25 require AC give clear warning of approaching stall.
Warning begins at V_{SW} **, exceeding the speed at which the stall is identified by not less than 5 kts or 5% CS, once initiated the stall wanting must continue until AOA is reduced to approx. where the stall began.**

Stick pusher = Stall protection.

Inputs and Outputs:
Stall = f(AoA) = f(alpha)



Stall warnings:
Primary stall warning = **Stick shaker.**
This shakes and knocks the control wheel and is accompanied by an audio knocking noise.
Some systems have '**STALL, STALL'.**
Master warning will illuminate.
Red STALL warning appears on EICAS.
Takes precedence over GPWS and WINDSHEAR

Stall Protection:
T-Tail AC susceptible to Deep stall (Super stall) these AC fitted with **stick-pusher**.
Crew can overcome stick-pusher if false warning.

Fly-by-Wire Stall protection:
Flight protection system will execute series of corrective actions, the key points in this system as the stall is approached are:

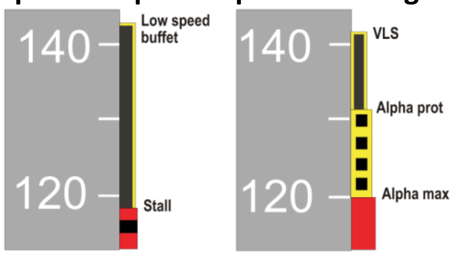
- **Alpha V_{LS}** – 1.23 times the level flight stalling speed, the normal maximum alpha on the approach
- **Alpha port** – the control law changes to hold alpha constant even if the AC begins to descend, only If pilot pulls stick back will alpha increase.
- **Alpha floor** – TO/GA thrust automatically applied
- **Alpha max –** Max alpha without stalling, max performance alpha, just short of C_L max.

With TO/GA thrust and the stick hard back the AC will climb at alpha max. (Terrain avoidance manoeuvre).

Autothrottle Stall protection:
Speed will not fall below 1.3 V_S

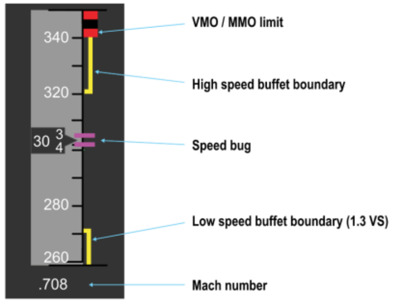
On B737 if Autothrottle is armed but with no speed selected, autothrottle will not function until AoA close to stall is sensed, called 'Alpha floor'.
At which autothrottle will auto engage and maintain alpha floor.

Speed Strip Low Speed Markings:



Overspeed Warning:
Alerts crew if the AC exceeds max operating limits, VMO or MMO.
Only the altitude is needed to calculate the limit, not the CAS.

Speed Strip High Speed Markings:



At low altitude AC will reach VMO first, at high altitude MMO.
When either is reached:

- Sound aural alarm
- Illuminate the master warning light
- Display an OVERSPEED on the EICAS in red.

Warning cannot be cancelled.

Take-off Warning System:
Systems that may trigger a take-off warning system include:

- Flaps
- Leading edge devices
- Wing spoilers
- Speed breaks
- Parking Brakes
- Trims

Alternative name = **CONFIG warning.**

Altitude Alerting System:
Required for all jets over 5700kg or with more than 9 seats to have altitude alerting system:
Must be capable of:

- Alerting crew on approaching the selected altitude
- Alerting crew by at least an aural signal when deviating above or below the selected altitude.

Takes data from the **Barometric altitude** from the **ADCs** and reference height from the AP control panel.

Frequency Bands:
Varies between **4200 MHz and 4400 MHz** known as frequency modulated radio altimeters.
Super High Frequency (SHF) band of radio spectrum.

Hight compensation:
Zeroed to compensate for both aerial height and length of wiring inside the AC so the altimeter reads zero when wheels touchdown.

Accuracy:
RA accurate to +-2ft in the first 500ft or +-1.5% whichever is greater.

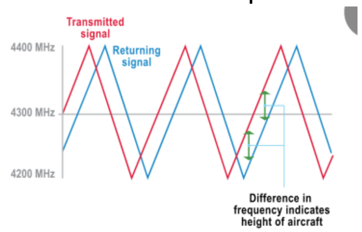
Low Level Radio Altimeters:
Active 2500ft down.
Primary function of radio altimeter is to provide accurate decision height (DH) info for precision approaches.

Radio altitude also used as an input to the ground proximity warning (GPWS) and TCAS

RA primary height input to: **GPWS/TAWS/HTAWS.**
If RA failed, you will not have these protections.

Radio Altimeter System Operation:
Radio beam directed to the ground in a 30degree cone is reflected to AC.

Radio altimeters use a continuous wave radar rather than a pulse radar.



GPWS and TAWS

GPWS = Ground proximity warning system
TAWS = Terrain Awareness Warning System

TAWS Requirements:
EU-OPS any AC with >9 seats or >5700kg must have TAWS.

GPWS must provide audible signals:
Mode 1 – Sink Rate
Mode 2 – Ground Proximity
Mode 3 – Altitude loss after take-off or Go-around
Mode 4 – incorrect landing config
Mode 5 – Below G/S deviation.

ALERTS – Corrective response
WARNINGS – immediate climb manoeuvre.

TAWS Requirement:
Must provide visual and aural display of terrain forward of AC, this is called FLTA (Forward looking terrain avoidance)

Cockpit Equipment:
Varies between manufacturers.

2 PULL UP waning lights illuminate when modes 1-4 are active. With voice warning.

Amber BELOW G/S, illuminates when mode 5 active. With voice 'GLIDESLOPE' warning.

B737 control panels have 2 guarded switches.
FLAP INHIBIT – inhibits or cancels warnings caused by flap selector not being set to 30-40degrees (landing position)

GEAR INHIBIT – inhibits warnings caused by gear selector not being down (only used in gear up landing).

INOP – illuminates if system fails or Circuit breaker pulled.

SYS TST – Pressed on ground or in flight >1000ft RA conducts BITE (Built in test equipment) test.

MODE 1:
Gives warning of excessive barometric rate of decent.
Active below 2500ft RA.
When Barometric rate of descent >3xRA it gives alert '**SINK RATE, SINK RATE'.**
If higher rate of descent closer to ground alert becomes '**WHOOP, WHOOP, PULL UP'**

Mode 2:
Triggered by reducing RA and warnings of rising ground beneath the AC.
Initial alert is '**TERRIAN, TERRIAN'**
If worsens is **'WHOOP, WHOOP, PULL UP'**
Until RA has stopped reducing and an increase of 300ft of barometric altitude is registered.

Mode 1 and Mode 2, together capable of dealing with most **Controlled flight into terrain (CFIT)** incidents.
Neither Mode 1 nor Mode 2 will stop you flying into a vertical cliff face.

Mode 3:
Warns of barometric height loss after take-off or go-around.
For mode to be active flap selectors must be moved away from 'land' position and gear up.
Alert '**DON'T SINK, DON'T SINK'.**

Mode 4:
Warns of proximity to the ground without the appropriate gear and flaps selections.
At speed AC is unlikely to making an approach, the aim of the alert is to inform pilot of ground proximity.
Alert '**TOO LOW TERRIAN'**
If ac is low without correct gear of flaps:
Alert '**TOO LOW, GEAR' or 'TOO LOW, FLAPS'**
TOO LOW, TERRIAN = warning = immediate action.

Mode 5:
On GS more than 1.3 dots below GS triggers:
'GLIDESLOP, GLIDESLOPE' gets louder as worsens.

GPWS Mode 6:
Includes height and bank angle call outs.

Basic mode 6: '**MINIMUMS, MINIMUMS'** As assigned by pilot.
'50,40,30,20,10 RETARD, 5'
'BANK ANGLE, BANK ANGLE'

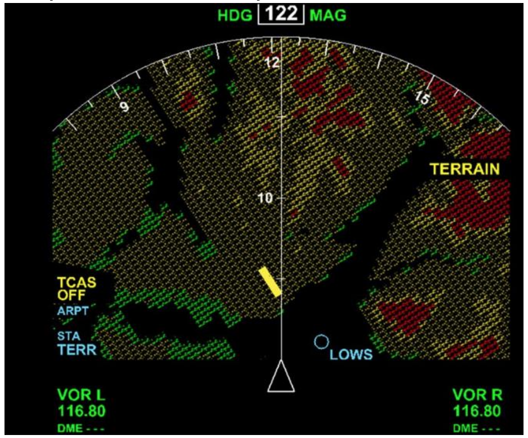
GPWS Mode 7:
Not required by EU-OPS
Provides **Wind shear alerts and warnings**.
Uses: ADC, Temp, Rate of climb, AoA, RA, IRS.
Alert: '**CAUTION WINDSHEAR'**
If AC enters microburst
Red light illuminate followed by:
'WINDSHEAR, WINDSHEAR'

EGPWS
3D GPS Satellite fix.
EGPWS needs precise position fix.
Aural Warnings:
CAUTION, TERRIAN
TERRIAN, TERRIAN, PULL UP
There is no Whoop, whoop

Red PULL UP lights illuminate.

EGPWS
Said to provide:
- **A terrain Clearance Floor (TCF)**
- **Terrain Look Ahead Alerting**
- **A Terrain Alerting and Display (TAD)**

No expiry date, but the obstacle database is only valid for 28 days.



Initial Actions:
TOO LOW GEAR requires either gear down or go around.

WIND SHEAR warning requires full wind shear go-around.

Classification of Warnings and Alerts:
Genuine – Correctly generated by GPWS.

Nuisance – Pilot flying an accepted safe procedure. Criteria for alert have been infringed by situation is not unsafe. EG 'TERRAIN, TERRAIN' on approach.

False – generated by GPWS not accordance with technical spec, i.e., its broken

Summary of inputs:
basic GPWS (Modes 1-5) receives inputs from:
- **CAS**
- **RA**
- **Pressure Altitude**
- **Vertical Speed**
- **G/S deviation**
- **Flaps Position**
- **Gear Position**

IRS for optional Mode 6 Bank callouts.

The EPWS element needs:
- Accurate positioning (perhaps a 4D FMS)
- An obstacle/terrain database.

ACAS/TCAS:
TCAS II version 7 is compliant with the ACAS II standard.

TCAS = Traffic Collision Avoidance System
ACAS = Airborne Collision Avoidance System

EU-OPS require new AC >19 passengers or MTOM >5700kg to carry and use ACAS II

Principle of Operation:
TCAS uses **MODE S** transponder to interrogate the SSR transponders of nearby AC and plot their positions and velocities.

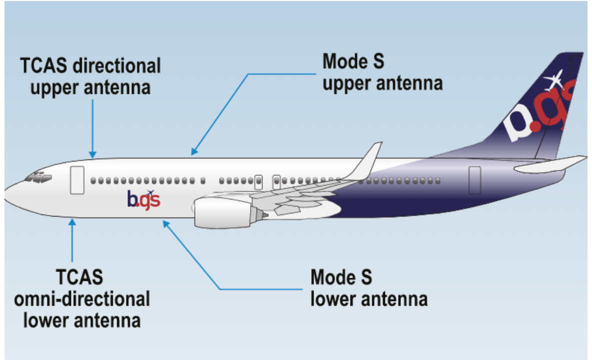
Receives and transmits Squitters.
Includes an ICAO 24-bit address, uniquely identifying the AC system status and pressure altitude information.
Extended squitters used in ADS-B, carry 49 individual parameters in a data package.

Bearings = Direction finding receiving aerials
Distance = Time delay between transmitted and received.

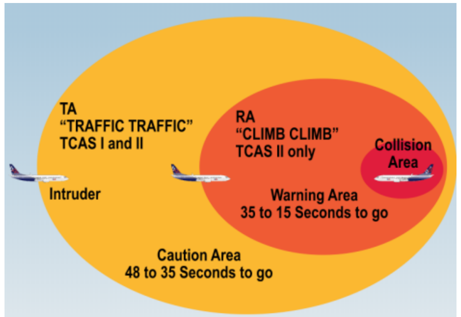
TCAS can cope with Mode A, C or S.
When both AC have TCAS II and Mode S, the advice on how to avoid collision will be coordinated by the mode S data link between AC.

TCAS can only see transponding AC.

ACAS/TCAS



The Tau Area:



TCAS Envelopes vary between AC.

Traffic Advisory (TA):
AC assessed as being likely to enter the collision area in between **48-35 sec** results in audio caution of: **TRAFFIC, TRAFFIC**
AKA Traffic advisory (TA).

Resolution Advisory (RA):
If time to enter collision area reduces <u>35-15</u> sec TCAS II will generate a resolution advisory (RA).
Audio Command of: **'CLIMB, CLIMB', 'DESCEND, DESCEND'** if already climbing:
'INCREASE CLIMB' or 'INCREASE DECENT'
When conflict clear: **'CLEAR OF CONFLIT'**

Audio Commands and advisories for TCAS II Version 7:

TCAS Advisory	Version 7 Aural Announcement
Traffic Advisory	TRAFFIC; TRAFFIC
Climb RA	CLIMB; CLIMB
Descend RA	DESCEND; DESCEND
Altitude Crossing Climb RA	CLIMB, CROSSING CLIMB; CLIMB, CROSSING CLIMB
Altitude Crossing Descend RA	DESCEND, CROSSING CLIMB; DESCEND, CROSSING CLIMB
Reduce Climb RA	ADJUST VERTICAL SPEED; ADJUST
Reduce Descend RA	ADJUST VERTICAL SPEED; ADJUST
RA Reversal to a Climb RA	CLIMB, CLIMB NOW; CLIMB, CLIMB NOW
RA Reversal to a Descend RA	DESCEND, DESCEND NOW; DESCEND, DESCEND NOW

TCAS Advisory	Version 7 Aural Announcement
Increase Climb RA	INCREASE CLIMB; INCREASE CLIMB
Increase Descent RA	INCREASE DESCENT; INCREASE DESCENT
Maintain Rate RA	MAINTAIN VERTICAL SPEED; MAINTAIN
Altitude Crossing, Maintain Rate RA (Climb & Descend)	MAINTAIN VERTICAL SPEED, CROSSING; MAINTAIN
Weakening of Initial RA	ADJUST VERTICAL SPEED; ADJUST
Preventative RA (No change in vertical speed required)	MONITOR VERTICAL SPEED
RA Removed	CLEAR OF CONFLICT

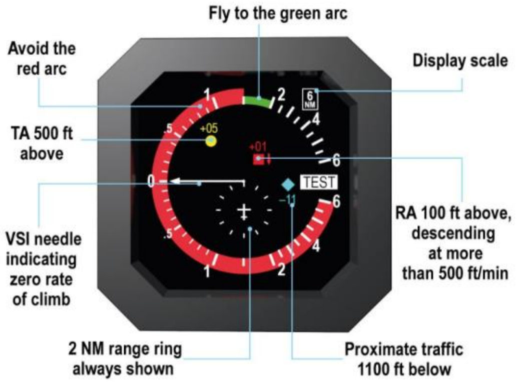
Range and limitations:
Range of system outside terminal areas = 30NM and +- 2700ft.
All aural commands are inhibited by Stall, GPWS, Terrain and wind shear warnings.

Range and limitations:
As the radio altitude progressively decreases resolution advisories are progressively inhibited:

- RAs that recommend an increase in rate of descent are inhibited below 1450ft RA
- RAs that recommend a descent are inhibited below 1100ft RA
- All RA's are inhibited below 1000ft.
- All Aural commands are inhibited below 500ft.

Cockpit displays and terminology:
TCAS can be displayed on a dedicated display on a VSI/TCAS Display or in an EFIS Display.

Combined VSI/TCAS unit can be referred to as an electronic VSI (EVSI)



TCAS may also be displayed on the PFD and ND.

+ = Above you
- = Below you

Trend arrows show AC is in climb/descent 500-600ft/min

Symbol for Traffic causing an RA:
Most threatening traffic = RED BOX

Symbol for traffic causing a TA:
TA **Soldi Yellow or Amber Circle**

Proximate Traffic:
Transponding traffic not generating a TA or RA and inside 6NM and +-1200ft are called 'Proximate Traffic'.
Solid Diamond (Lozenge) Cyan or White.
If own ship is white, proximate = cyan.

Other Traffic:
Transponding traffic not generating a TA or RA and outside 6NM and +-1200ft is called 'Other Traffic'.
Hollow Diamond (Lozenge) Cyan or White.

Required Reactions:
TA only for information. Crew should liaise with ATC for separation.

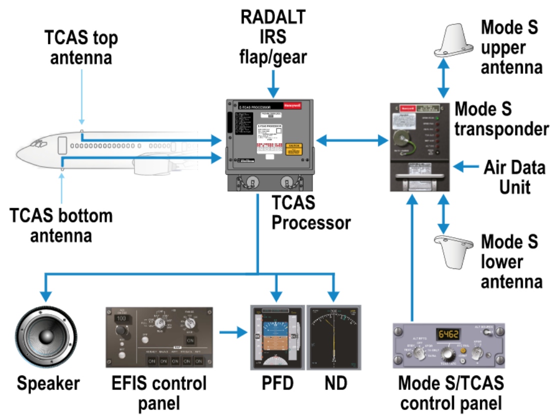
RA requires crew to respond and follow instructions promptly. **Where the required action conflicts with ATC clearance the pilot must follow the TCAS RA for the purpose of avoiding immediate danger** but must in from ATC of his deviation asap. And return once 'CLEAR OF CONFLICT' heard.

TCAS Aims to resolve between 300-500ft. Pilot reaction time expected by the TCAS logic **is 5 seconds** with the pilot achieving the pull up/push over in 3 seconds.

Pitch change requirements depend on speed.
Typical g value = 0.25g aiming for 1500ft/mins.

For enhanced RA, INCREASE CLIMB
G value = 0.35g aiming for 2500ft/min.

TCAS System components:



Mode S Transponder/ TCAS Control Panel

Mode S/TCAS transponder controls are almost the same as those for traditional mode A/C.
Mode A Code set with larger knob.

Control Panel:

TEST: TCAS System functional test
STBY: Power applied to TCAS Processor and Mode S transponder. The TCAS does not issue any interrogations and the transponder will only reply to discrete interrogations.
ALT RPTG: Altitude reporting Off.
XPDR: The Mode S transponder is fully operational and will reply to all ground and TCAS interrogations. TCAS Remains in standby.
TA ONLY: Mode S Transponder fully operations.
TCAS will issue appropriate interrogations.
TCAS Will only issue TAs.
TA/RA: Mode S Transponder fully operational
TCAS will issue appropriate interrogations and perform all tracking functions
TCAS will issue TAs and RAs.

TA ONLY maybe a company procedure, ie when approaching parallel runways.

Flight Data Recording:
Cockpit Voice Recorders (CVRs)
Digital Flight Data Recorders (DFDRs)
The CVR and DFDR can be both single units
Or combined to make a:
Cockpit Voice and Data Recorder (CVDR)

- **Fire resistance**
- **Corrosion Resistance**
- **Waterproof**
- **Large impact force**

Cockpit Voice Recorder (CVR):
Must Record:
- **Voice communications transmitted from or received at the flight deck.**
- **Aural environment of the flight deck including audio data from each boom or mask mic.**
- **Voice Comms from AC interphone system.**
- **Voice/audio signals identifying nav or approach aids in use.**
- **Voice or audio signals introduced into a headset or speaker.**
- **PA system.**

CVR = 2hr recording retained
AC <5700kg = 30mins

Components include:
- Solid state memory mounted in shock proof case.
- An area microphone
- A control unit.

Flight Data Recording

Digital Flight Data Recorder (DFDR).
Records parameters such as:
- **Time**
- **Attitude (Pitch/Roll)**
- **Airspeed**
- **Pressure altitude**
- **Heading**
- **Normal acceleration**
- **Propulsive thrust or power on each engine and cockpit thrust lever position**
- **Flaps/slat config**
- **Ground spoiler selection**

AC >27,000kg must record:
- **Position of primary flight controls**
- **Pitch trim**
- **Radio altitude**
- **Primary nav information**
- **Cockpit warnings**
- **Landing gear position**
- **Any unique design parameters**

DFDR Components:
Include:
- Recording system, solid state memory in shock case.
- A data interface and acquisition unit
- Up to 2 control units (Test and event making button).

Records information for MINIMUM 25 hours
<5700kg MTOM = 10 hours
Starts recording on engine start.

An EVENT button allows pilots to put a marker on the recording.

ACMS
Aircraft Condition Monitoring System (ACMS):
Monitors AC and engine data for maintenance.
Inputs from:
- Air conditioning system
- AFCS
- Flight controls
- Fuel systems
- Landing gear
- Nav system
- MCDU
- Pneumatic systems
- APU
- Engines.

On B737 data sent to **Digital Flight Data Acquisition and Management Unit (DFDAMU).**
Less robust than the FDR but samples more parameters. 'First point of storage'

Data from the DFDAMU or its equivalent is sent on the DFDR.
Unit can also:
- **Transmit data in flight to operator via ACARS, without crew notification.**
- **Transmit data via a cellular telephone link on landing, without notification.**
- **Store data in flash memory on SD or PMCIA cards which can be removed and read on the ground.**

Last element is sometimes referred to as the **Quick Access Recorder (QAR).**
The data captured used primary for maintenance.

AIDS
Airbus use similar system to ACMS called Aircraft Integrated Data System (AIDS). It has an additional print option as an output.
Airbus, equivalent of DFDAMU is Flight Data Interface and Management Unit (FDIMU).

Powerplant and system Monitoring

Colouring:
Normal: GREEN
Cautionary: YELLOW
Upper and lower limits: RED.

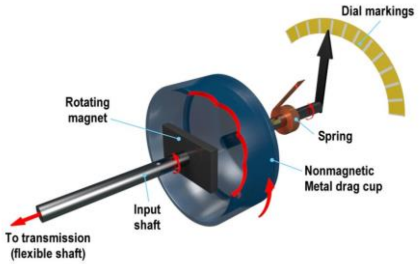
RPM Measurement:
Required to measure RPM of:

- Piston engine crankshaft (Power)
- Gas turbine compressors and turbines (Engine performance)
- Variable pitch propellers, correct operation, and sync.
- Helicopter rotors (Correct operation)
- AC Wheels (Anti-skid).

Rotational speed measured by 'Tachometer'. (Speed measurer).
3 Types:

- **Mechanical, Electrical, Electronic.**

Mechanical Tachometer:



Only for light piston single engine.
Sleeve turns magnet
Max length = 2m.

Green = Operational range
Yellow = Caution, Vibration
Red line = RPM Limit.

The Electrical Tachometer:
Modern AC – measured by small generator – **Tach generator.**
Tach generator can output DC, single phase AC, or 3 phase AC.
Independent of AC electrical supply.
Allows engine far from cockpit.

DC Electrical Tachometer:
DC generator attached to and driven by the engine.
DC voltage increases as RPM increases.
Voltage drives needles in flight deck.
2 Disadvantages:

- **DC Gen requires Commutator and carbon brushes = Wear and electrical sparking = radio interference.**
- **Line resistance = voltage drops.**

Single Phase AC Electrical Tachometer:
To stop wear and spark replace to DC gen with single phase brushless AC Gen which is **rectified to DC.**
Still subject to indication errors from voltage loss in transmission.

3 Phase AC Electrical Tachometer:
AC frequency varies with RPM.
3 Phase drives motor called 'Squirrel cage' at the instrument.
Consists of = 3 Phase generator, Synchronous motor, and magnetic tachometer.
Advantage = Frequency measured, so no loss in transmission
Disadvantage = more wiring.

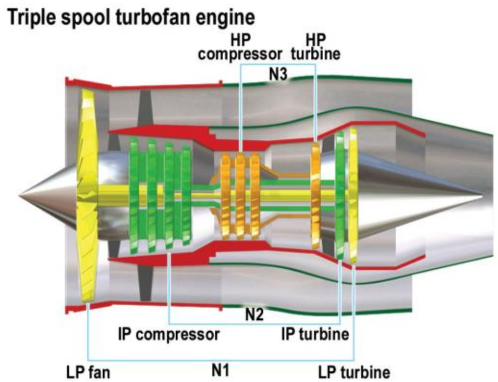
The Electronic Tachometer:
All prev tachometers require a drive from the engine gearbox.
Electronic tachometer uses a probe, which is a small electromagnet, detects teeth on shaft by changes to its magnetic field.
'Inductive probe'
Sometimes called 'Inductive probe tachometer'.
Whole assembly = phonic wheel.

Processing the signal:

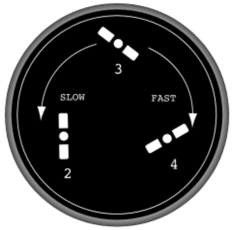
Electronic tachometer requires a power supply.
Raw AC signal processed into digital. # Of pulse = RPM.
Unaffected by signal loss.

Turbine Displays
Turbine engine RPM display as a percentage of MAX.
Some have Max RPM pointers.

N1, N2 and N3



The Synchroscope:
'Used to balance the RPM of multi-engine turboprop, piston and sometimes, jet, to reduce noise levels.'
Synchroscope works from RPM gauges.



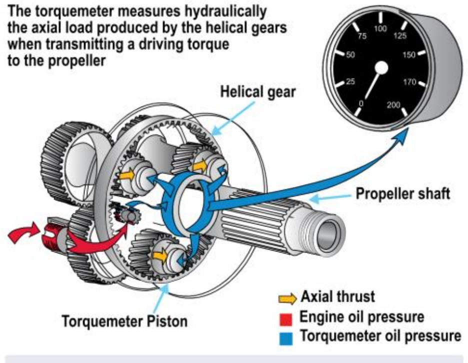
Vibration Sensors:
Jet engines usually low vibration, higher vibration usually means problem.

High freq vibration usually indicated serious damage.
Vibration sensors can be piezoelectric (Send electrical signals when distorted).
Or magnets mounted loosely in coils.

Vibrations picked up at the sensors are amplified before being transmitted to the indicator.
The indicator indicates the vibration amplitude at a particular frequency.

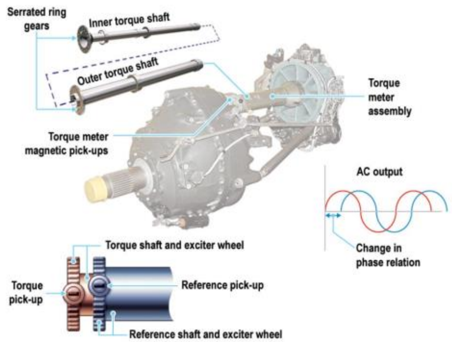
Torque measurement:
Turning force produced by the prop or rotor.
Torque x RPM = Power.
Torque measured either: hydraulically at the output or electronically at the shaft which connects the engine to the gearbox.

Hydraulic Torque meter:



Torque can be computed by measuring oil pressure at the fixed crown of a reducer gear on an epicyclic main engine gearbox.

Electronic Torquemeter:



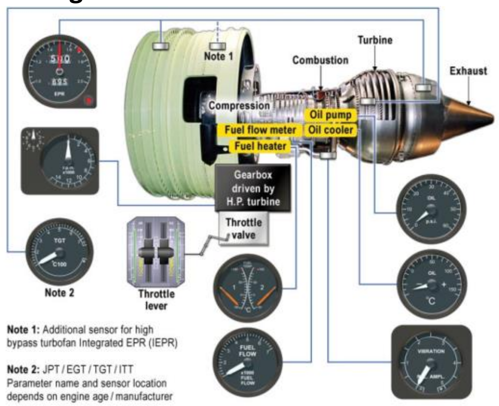
Torque can be computed by measuring the change in phase between the torque shaft and the reference shaft.

Gas turbine Thrust Indication:
Thrust produced by jet engine measured by acceleration of a mass of air.
Engine pressure ratio

$$EPR = \frac{Turbine\ outlet\ pressure}{Compressor\ Inlet\ Preassure.}$$

EPR gauges: EPR should always be checked against N1. Icing = over reading.

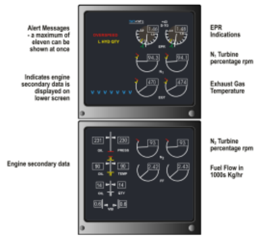
Analogue instrumentation:



Digital Instrumentation:
Boeing = EICAS (Engine indicating and Crew Alerting System)
Airbus = ECAM (Electronic centralised aircraft monitoring)

EICAS
EICAS can be fed by either of 2 computers either manually or auto switched. One computer on standby.
EICAS = 3 modes:

- **Operational** (Primary engine parameters shown on top screen and bottom screen either blank or secondary parameters.
  Secondary shows: Oil pressure, Oil Temp, Oil Quantity, Vibration.
- **Status** (On ground to show control surface positions and system status)
- **Maintenance** (Only on ground, assist maintenance engineers)



B757 Standby Engine indicator:

If EICAS fails a standby indicator shows:

- EPR
- N1
- EGT
- N2

On LED display

B737-800:

Uses 2 screens and displays both engine and system information. Limits on a placard in white next to the displays.

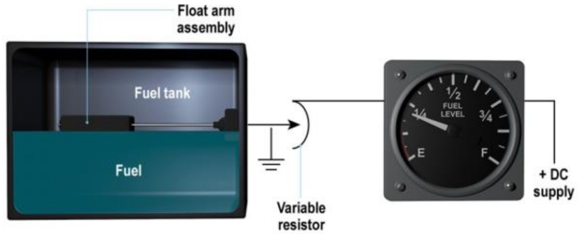
Fuel Flow and Contents

Indications Provided
1 KG = 2.2LB
For ATPL pilots, the following indications:

- **Fuel quantity –** Indicated either as volume or weight.
- **Fuel Flow –** Indicated pressure, weight per hour, volume per hour or as percentage of power (Tells fuel efficiency)
- **Fuel Temperature –** More important for turbine engine AC.
- **A Filter Light –** Light shows when starts to clog.

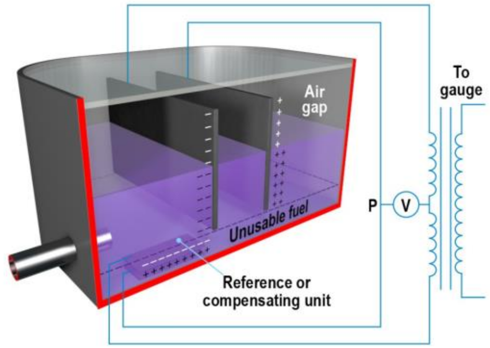
Fuel Contents Gauging:
Mechanical Float Volume Indicators:
Older tech, only accurate when AC is level, not accelerating and constant temp.
Cheap but reliable.

Resistive Float Volume Indicators:



Float Type fuel gauges indicate volume, which varies with temperature and typically use DC Power.
Suffers similar issues to normal float.

Capacitive Mass Measurement:



Eliminates previous issues, by measuring mass of fuel. Mass sensed by capacitance.

$$Capacitance = E * \frac{A}{D}$$

$$Q = CV$$

Q = Charge in Coulombs,
C = Capacitance in Farads,
V = Voltage in volts.
Require AC circuit.

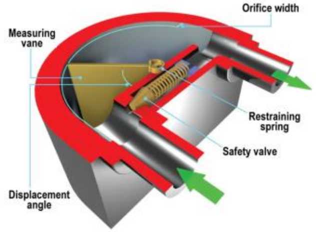
Fuel gauges only indicate the usable fuel and electrically operated gauges will always go to zero when the power is removed or if the system fails.

Manual Fuel Contents Checking:
Drip Stick:
To take reading the tube is drained, then lowered until fuel starts to drip steadily from the tap, showing the fuel quantity on a scale.
Magnetic Stick:
Uses magnetics.
Refuelling:
Check fuel uplifted and gauge are equal.
Sometimes may require conversion of mass and volume.

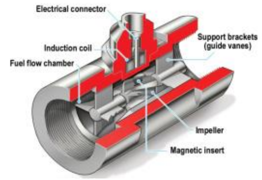
Fuel Flow Gauging:
Can be used to monitor performance of a jet engine.
Either Volume flow or Mass flow.
Usually measured just before point of use in the engine.

Venturi Volume Flow Indicators:
Primitive flow indicators rely on a venturi tube.
Fuel feed narrowed at a point, velocity increases, pressure at right angles to flow decreases.
Reduced pressure in venturi compared to normal pressure in the pipe is an indication of flow rate.

Variable Orifice Volume Flow Indicators:
Hinged measuring vane placed in a shaped chamber slightly offset from the centre. Fuel flow exerts a pressure on the vane countered by a spring force.
Vane position converted to electrical signal.
Mass flow can be shown with added temp sensor.



Turbine Volume Flow Indicators:
Modern AC measure fuel flow with a turbine inserted into fuel lines.
As turbine rotates, it passes an induction coil in the casing.
Like a tachometer, makes AC pulses which can be squared to digital.
Do not cope well with large flow rate and temp changes on modern AC.



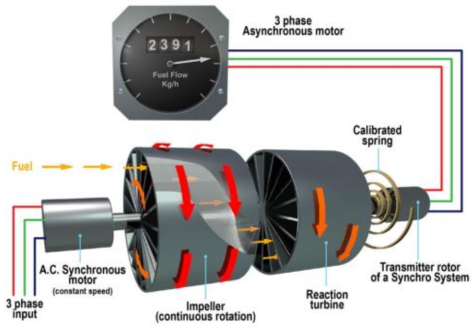
Mechanical Mass Flow Indicator

True mass flow indicators rely on deflecting the fuel so that it swirls in the pipes and then sensing its angular momentum. As Angular momentum is a product of rotational speed and mass. True mass can be calculated.

Two Systems exist: Stator torque and Rotor Torque.

Stator Torque:

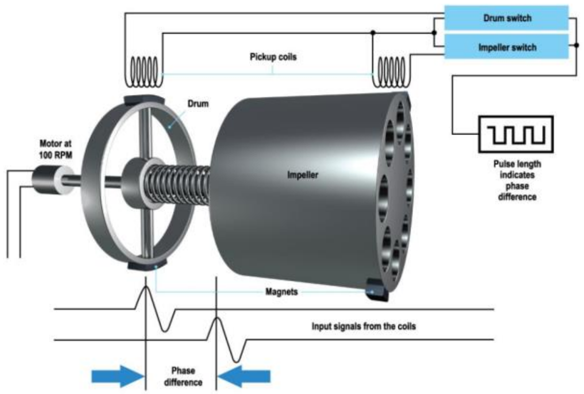
Uses an impeller rotating at contact speed to put a swirl in to the fuel. Stator downstream of the impeller takes the swirl out of the fuel. Greater the angular momentum, greater the twisting force on the stator as it does this.



Rotor Torque:

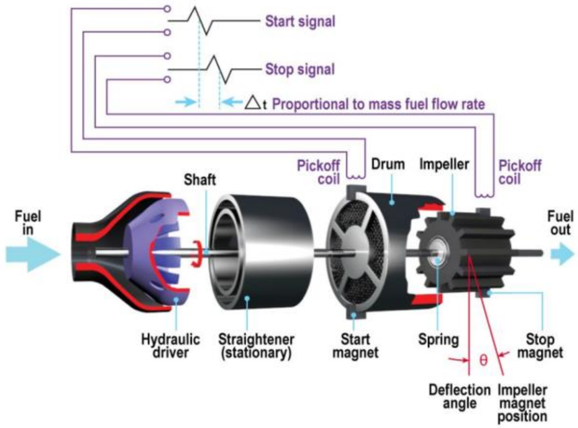
Impeller is turned by a motor at fixed RPM. Rotor is connected to the motor by a twisting spring the greater the resistance the mort ether rotor lags behind the motor and the more the spring is twisted.

Both rotor and motor have magnetic inserts which create pulses in inductive pick-ups. Time intervals indicate amount of twist on the spring and hence mass flow.



Electronic Mass Flow Indicators:

Fuel enters body of the flow meter and turns a hydraulic driver, which drives the shaft, the drum, and the impeller. Fuel then enters static straightener to remove swirl. Then drum into impeller. Deflection of impeller relative to drum is then measured by pulses generated by magnets on both the drum and impeller as they pass pickoff coils. System uses time between start and stop pulses caused by angular displacement, which is directly proportional to the mass flow.



Digital Circuits and Computers

Digital Computer:
Data in → Input Peripherals → Computer → Output Peripherals → Data out.

The von Neumann Model:
6 Features and capabilities:
- Input and output facilities
- A Processing unit
- Memory
- Programs and data sharing the same memory
- Program steps carried out in a sequential manner
- Processor and memory joined as a pair

Central Processing Units:
CPU = Brains
CPU job is to execute programs stored in memory.
CPU = FETCH-DECODE-EXECUTE cycle.
3 main parts:
- **A control unit** (responsible for fetching the instructions from memory and determining their type)
- **An Arithmetic and Logic Unit (ALU).** Does maths and logic
- **A small, highspeed, memory used to store temp results and control information.** Made up of registers, often 32bit.

Memory:
Stores programs and data while computer is operating.
If the information does disappear when power is off it is called 'volatile memory'.

Random Access Memory (RAM) – aka read/write memory.

Static RAM (SRAM) – Holds info without being refreshed for as long as power is supplied.
Dynamic RAM (DRAM) – Needs refreshing every few seconds. Slower than DRAM, but denser.

ROM, PROM, EPROM:
ROM – Read only memory. – Data stored in chip that cannot be removed.
PROM – Programmable Read Only Memory. – Can be programmed once into a blank chip.
EPROM – Erasable Programmable Read Only Memory. – Allows chips to be re-used.

Software:
CPU – bank of switches on or off.

64 bit = Architecture of computer.
64-Bit Binary:

Decimal	Binary
0000	0000
0001	0001
0002	0010
0003	0011
0004	0100

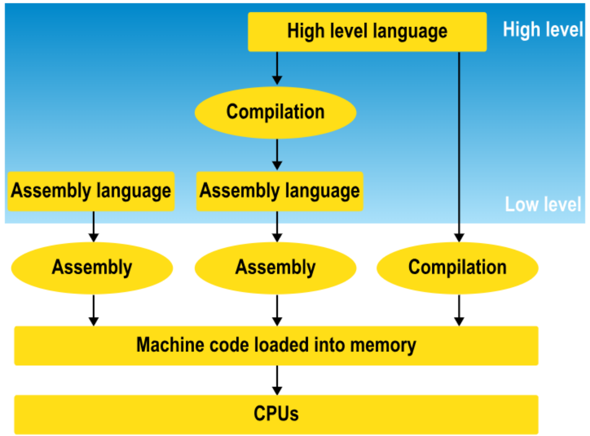
Hexadecimal:
More compact number system.
Binary = Base 2
Hexadecimal = Base 16

Decimal	Binary	Hexadecimal
0000	0000	0
0001	0001	1
0002	0010	2
0003	0011	3
0004	0100	4
0005	0101	5
0006	0110	6
0007	0111	7
0008	1000	8
0009	1001	9
0010	1010	A
0011	1011	B
0012	1100	C
0013	1101	D
0014	1110	E
0015	1111	F
9999	10011100001111	270F
65535	1111111111111111	FFFF

Machine Code:
Low-Level vs High Level Languages:
Assembly = more robust, used for auto break and some flight control systems.
- Is used to programme mission critical software
- More user-friendly than machine code
- Low-level

Abstraction = degree to which a language uses easily understood phrases.

High-level Language:



High-Level:

- Most commonly used to write computer programmes.
- High abstraction, very user friendly.
- Files must be compiled, either into assembly or directly into machine code.

Scripting Languages:

Scripts are set of instructions which are interrogated by other software.
Languages such as:

- **JavaScript**
- **ASP**
- **Perl**
- **Python**

Scripting languages:

- **Are not compiled into machine code to produce a file which can run on a computer.**
- **Used to produce scripts which are a series of instruction used by other software**
- **Primarily used on websites**
- **Maybe used in applications such as database on server.**
- **Maybe low or high level.**

Connections:
Computers connected via buses = 'omnibus' meaning all together.

Can be
Serial: Data sent in packages one after the other.
Parallel: Multiple data paths exist allowing flow in both directions.

Software Certification:
Different parts of the AC can use different operating systems.

Flight safety regarding AC software is certified under:
European Organization for Civil Aviation Equipment **(EUROCAE)**

Software is never certified as a standalone entity.
Hardware also considered.
Five levels of failure defined:

Failure Condition	Software Level
Catastrophic	A
Hazardous	B
Major	C
Minor	D
No Effect	E

New Technology

Electronic Flight Bag (EFB):
Portable electronic device for use by flight crew.
EFB can calculate things otherwise done by hand.

'Portable' and 'Installed' devices.

Type A applications: No adverse effect on the AC in the failure or misuse case. Document storage and retrieval would have no direct effect on flight safety.

Type B applications: Applications are more safety critical:

- Independent performance calculations
- Aeronautical Charts (without AC position display)
- Electronic checklists
- Internal and other AC operation communications.
- Weather information
- AC Video cam surveillance

Type C applications: Relates to active control of AC therefore not EFB.

EFBs may carry charts etc, so a backup is needed in case of failure, maybe a second EFB or smartphone etc in non-commercial flying.

Electronic Check List (ECL):
Manufactures now showing not only what's going wrong, but what needs to be done about it.
2 Types in modern flight deck:

Sensed ECL – takes inputs from systems or switches positions to decide which parts of the ECL should be displayed, or to test if actions declared complete by the pilot have been carried out correctly.

Standalone (unsensed) ECL – Displays like normal paper checklists.

ECL should be used with training and judgment.

Head-Up Display (HUD):
Display critical information to pilot, through window field of view.
Advantages of HUD include night and low vis close to the ground.

HUD can be decluttered with buttons on the hand controls.

HUD Displays:

- Attitude (Pitch, Roll and Balance)
- Speed (Speed trend)
- Heading
- Flight Path Vector (FPV)
- FMA
- Crew Alerting System (CAS)
- TAWS
- Windshear command annunciations

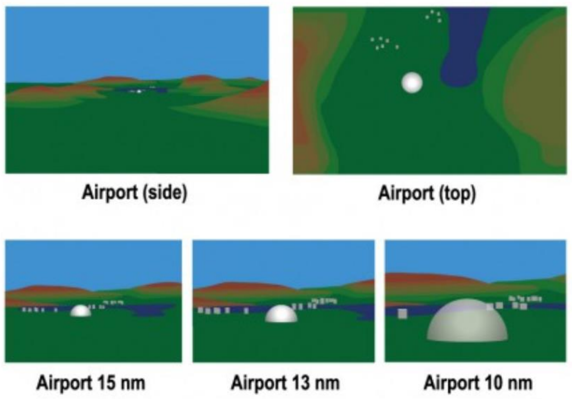
Head-Up Display (HUD):
Also expect to see:

- Localiser, G/S
- AoA indication
- Notional Runway Depiction
- Flare Cues
- Tail strike warnings
- Unusual attitude alerting
- Stall margin indications
- ACAS/TCAS alerts and advisories
- Runway distance remaining
- Ground deceleration display (auto break indications)

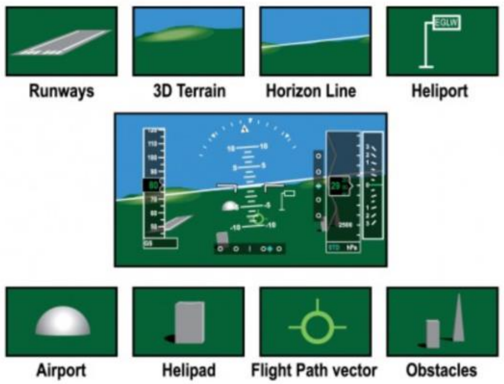
Makes situational awareness better.

Synthetic Vision System (SVS):
Images produced from same database in EGPWS/TAWS/HTWAS

Synthetic Vision System (SVS)



Shows terrain colour like TAWS.
If the AC is not where it thinks it is, it will show where the AC expects, which may be wrong.
Therefore cannot be used to reduce landing minima.
Very useful in adverse weather conditions



Enhanced Vision System (EVS)

Real time view of outside world, with sensors.
Uses infra-red.
Like SVS image can be displayed on PFD or HUD.
Unlike SVS it uses real images.

Thermal cross over : when two objects like tarmac and grass are at the same temp, with little temp differential the image produced is more like green fog.

Very useful in poor visibility on approach to land, Lights are picked up as different heat signatures to their background, so stand out well.
EVS equipped AC are likely to have better landing minima than non-EVS AC.
EVS dramatically reduces CFIT.