On-board Navigation and Sensing

Food for thought?

- How do we know how fast we are going?
- How do we know where we are heading?
- How do we know where we are?

On-board navigation and sensing: Content

- Visual Flying Rules
- On board instruments;
- Compass
- INS
- Air data

Visual flying rules – maps and compasses

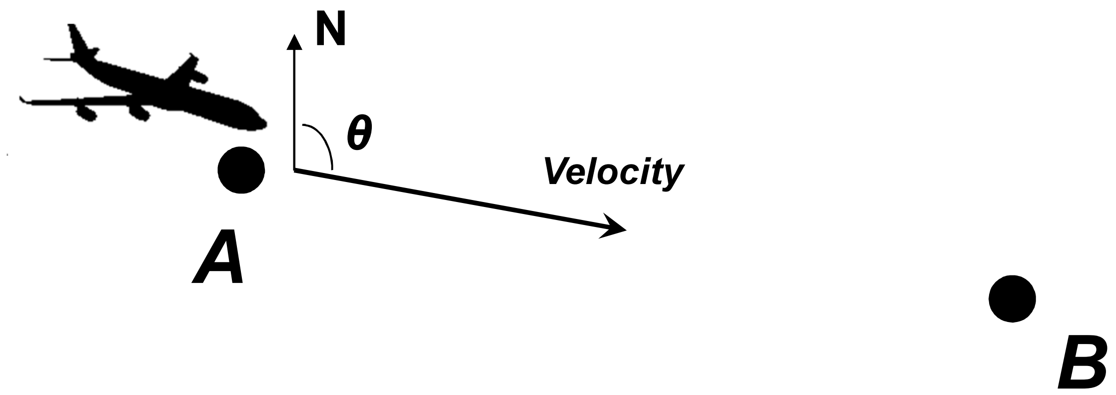
- Light aircraft are flown under visual flight rules (VFR) – The pilot uses a map (VFR Chart) and a compass to plan his flight and cross checks with features of the landscape below.

Instrument flying

- VFR has obvious limitations:
  - Only effective at low speeds and altitudes
  - Requires maps covering all of planned route
  - Doesn't work at night, or over featureless terrain
  - No autopilot option
- Not surprisingly, instrument based navigation systems have been developed. We will consider two types of navigation aids, ones that are wholly on-board the aircraft and ones that involve external infrastructure.

On-board systems

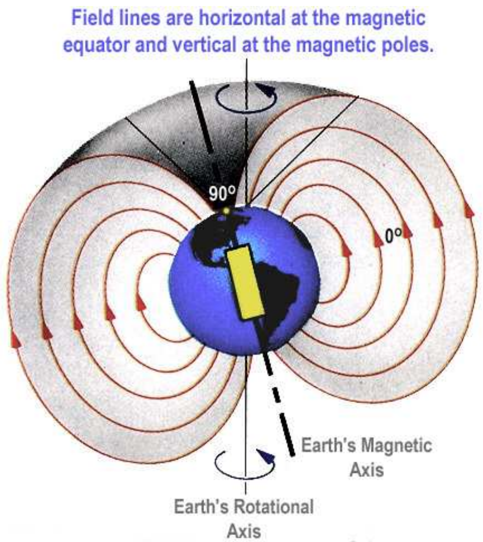
- In theory it is possible to work out location by knowing the starting point, the direction of travel and speed travelled.



- The basis for this type of navigation system are the aircraft's instruments for measuring speed and direction of travel.

Heading - Compass

- A basic tool for determining heading is the familiar magnetic compass
- Uses a magnetic element to align with the magnetic field of the earth.
  - The earths magnetic field is very weak.
  - A compass will be affected by local metallic structures, electrical currents etc.
  - Most will be fluid damped
- Electronic versions are available.



Compass swinging

Compass swinging

Magnetic Compass limitations

- Weak effect mean slow response in aircraft environment.
- Less stable towards the poles. No use at the poles.
- Poles shift with time.

Most importantly….

- Tells us direction plane is pointing (2D), not moving

Speed measurement

- Speed is determined from air velocity… More of this later.

- Limitations;
  - What about head winds?
  - What about cross winds?
  - Air speed is not ground speed

  - Plus not all airspeeds are the same!

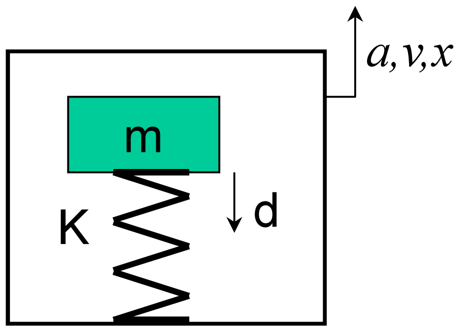
Inertial instruments;

Gyroscopes and accelerometers

University of BRISTOL

DEPARTMENT OF aerospace engineering

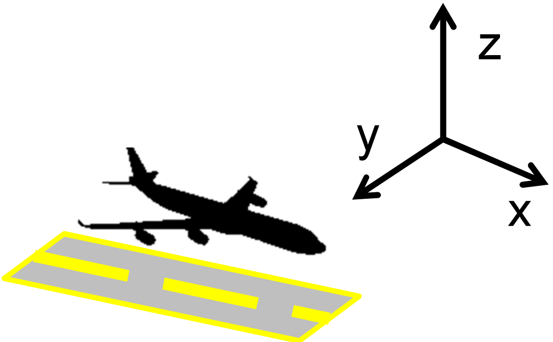
Inertial instruments – Linear motion

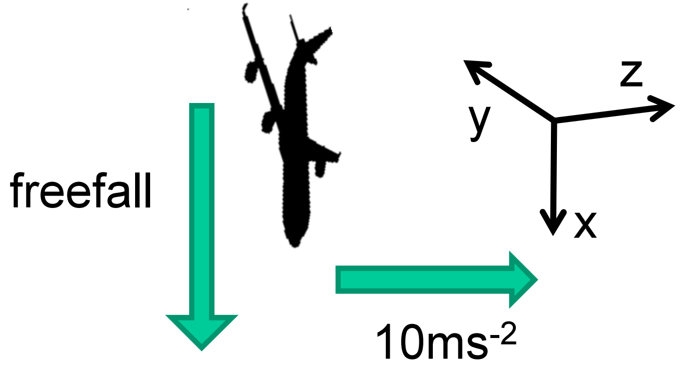


$$a = {kd}/{m}$$
$$v = \int a\,dt$$
$$x = \int v\,dt$$

- Accelerometers – measuring force on inertial mass
  - Measures linear acceleration of aircraft
  - Multiple devices can give all 3-axis
  - Integrate to derive linear velocity
  - Gravity causes ambiguity

Gravity Ambiguity



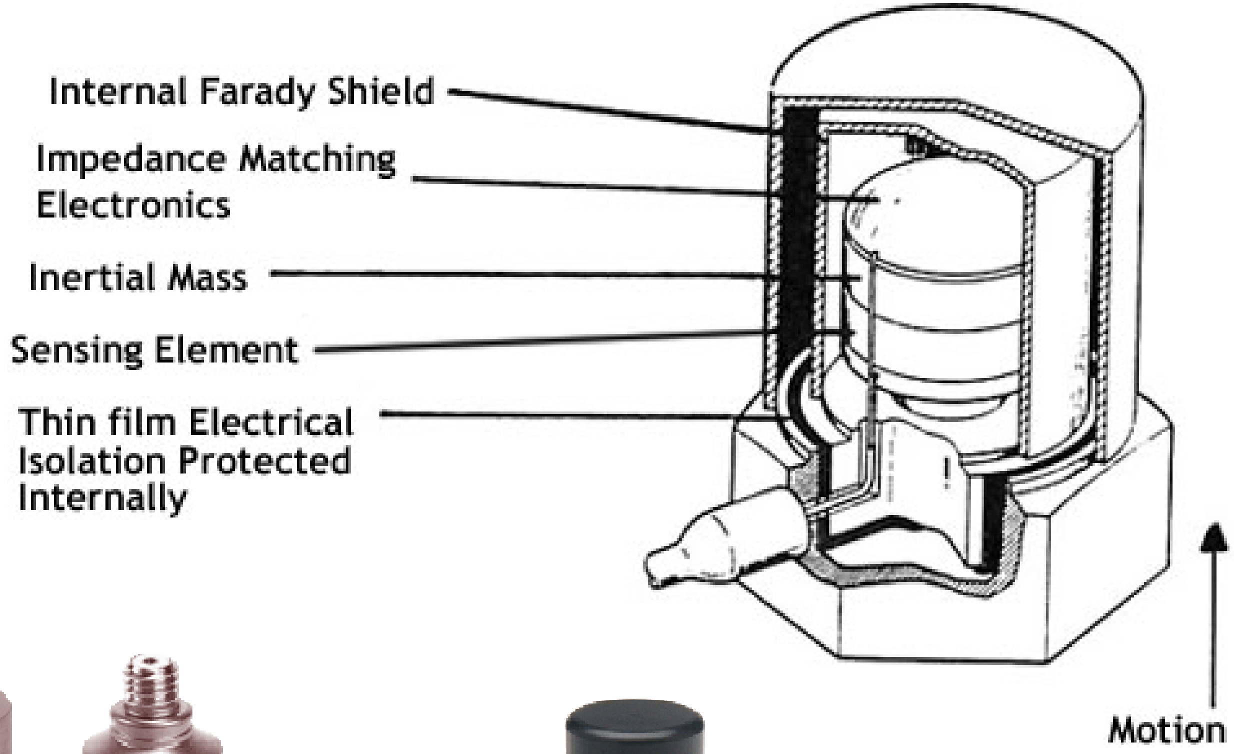


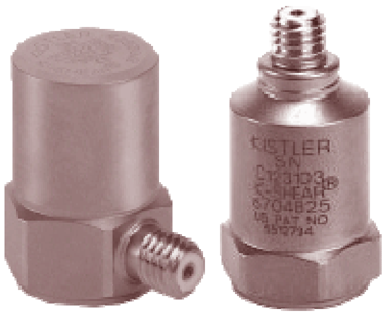
What will our accelerometers measure?

- $Y = 0ms^{-2}$
- $X = 0ms^{-2}$
- $Z = 10ms^{-2}$

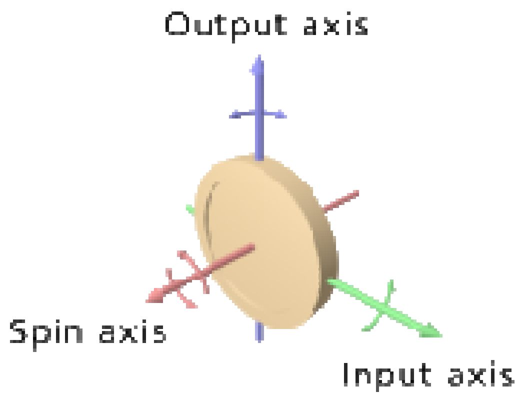
- $Y = 0ms^{-2}$
- $X = 0ms^{-2}$
- $Z = 10ms^{-2}$

Accelerometers





Inertial instruments - rotation

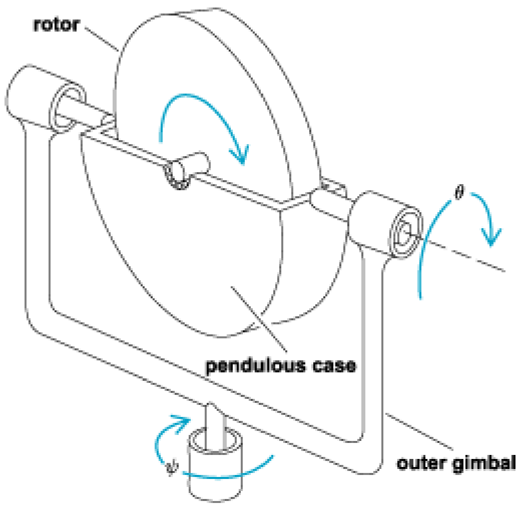


Gyroscopes – rotating mass in gimballed arrangement

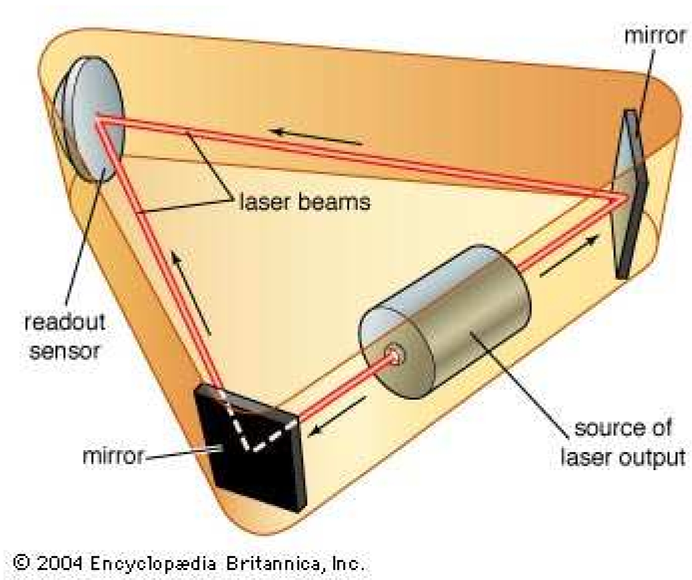
- Measures angular velocity of aircraft (roll, pitch and yaw)
- Integrate to derive angular position
- orientation relative to fixed co-ordinate system (fixed on ground)
- Removes gravity ambiguity when combined with accelerometers

Gyro compasses

- ‘Gyro compasses’ are often used as the heading indicator in over magnetic compasses, especially in ships.
- They align a rotating mass with the axis of rotation tangential to the earths surface, (using gravity and a pendulous housing). In this arrangement the rotation of the earth cause the gyro to point true north (axis of rotation)



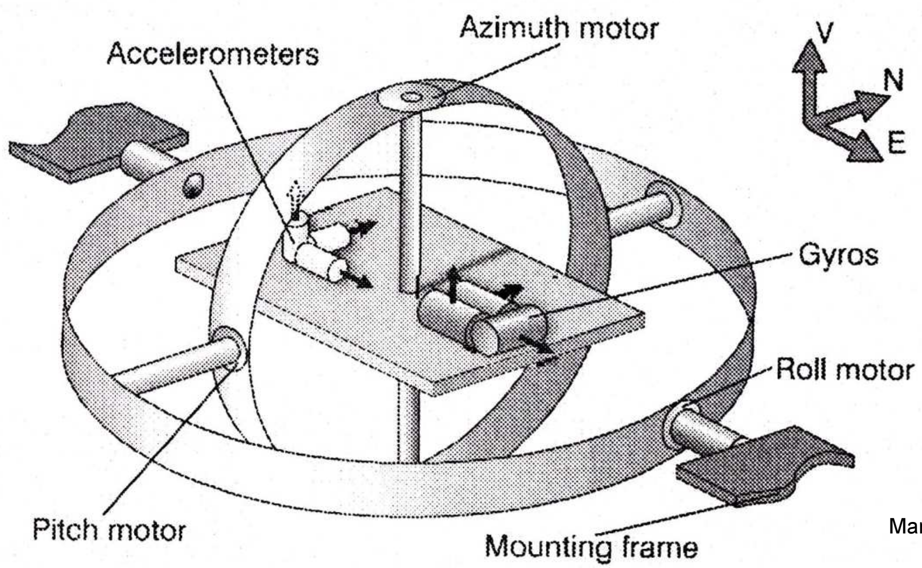
Laser ring Gyroscopes



Some modern gyroscopes use a laser ring structure – if the gyro is rotating, light takes longer to complete an optical circuit.

Stabilised platform IN systems

- Early (1950-70) Aircraft INS featured accelerometers mounted on a gimballed gyro-stabilised platform. The gyros were to measure angular velocity and drive the platform via motors on each gimball – a ‘null seeking’ arrangement. this turned out to be the best way to utilise mechanical gyros and eases their specification.

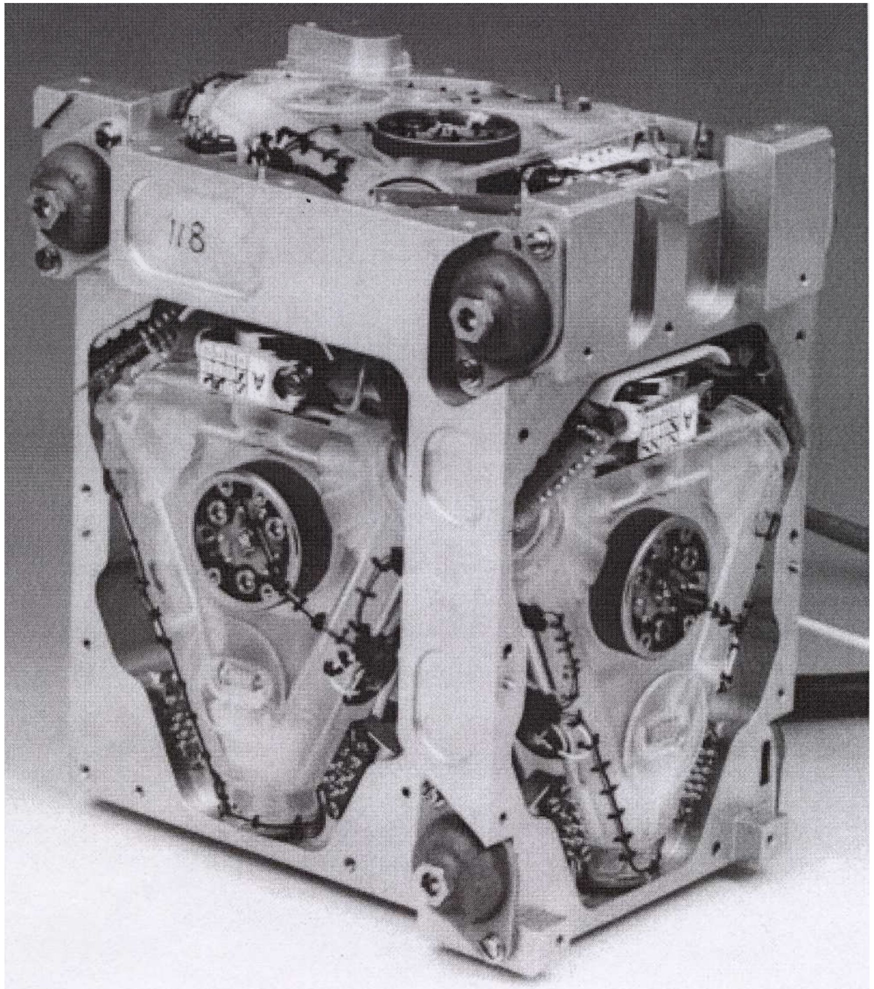


Marconi

‘Strap-down’ IN systems

- Modern systems overcome the limitations of the complex mechanical systems by fixing the gyros and accelerometers in a reference frame static in relation to the aircraft and use mathematics to implement virtual ‘gimballs’. Hence these are called strapdown systems.
- Strapdown systems require much higher performance components – since the gyros now needs to have a wide range as well as high accuracy. Modern laser ring gyros have enabled these systems.
- Surprisingly strapdown systems are not much more reliable than gimballed systems, but are much easier to construct.

System types – ‘strapdown’



Summary - Inertial Navigation Systems

- An inertial navigation system (INS) combines sensory data from accelerometers and gyroscopes (calibrated on the ground) to determine position.
- The sums to determine position are calculated using a navigation computer.
- Modern systems replace mechanical moving parts with solid-state equivalents e.g. optical gyroscopes.
- The main drawback of INS is drift – cumulative errors in position a few 100's meters per flight hour
- Also cost can be prohibitive – military systems costing ~£300k

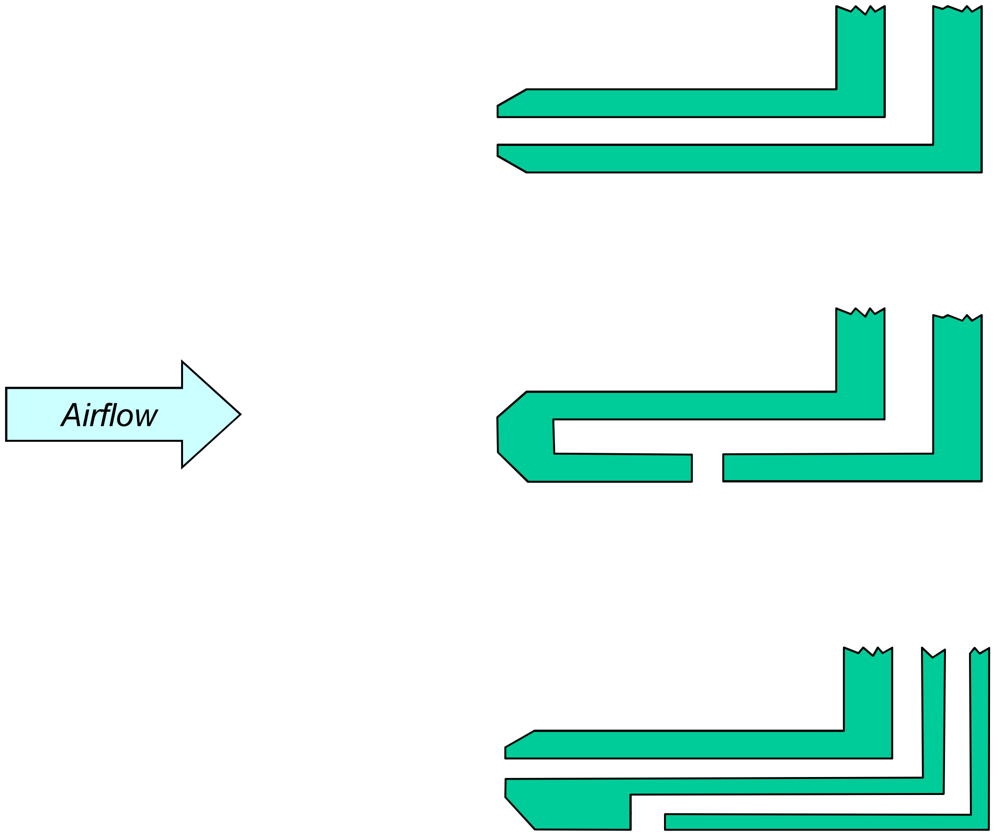
Air Data

Air Data

- By measuring air pressure is various ways we can determine several important flight parameters.

- Airspeed
  - Found from dynamic pressure, P_d
- Altitude
  - Found from static pressure, P_s
- Vertical Speed
  - From rate of change of static pressure, $\delta P_s / \delta t$

Pitot tubes



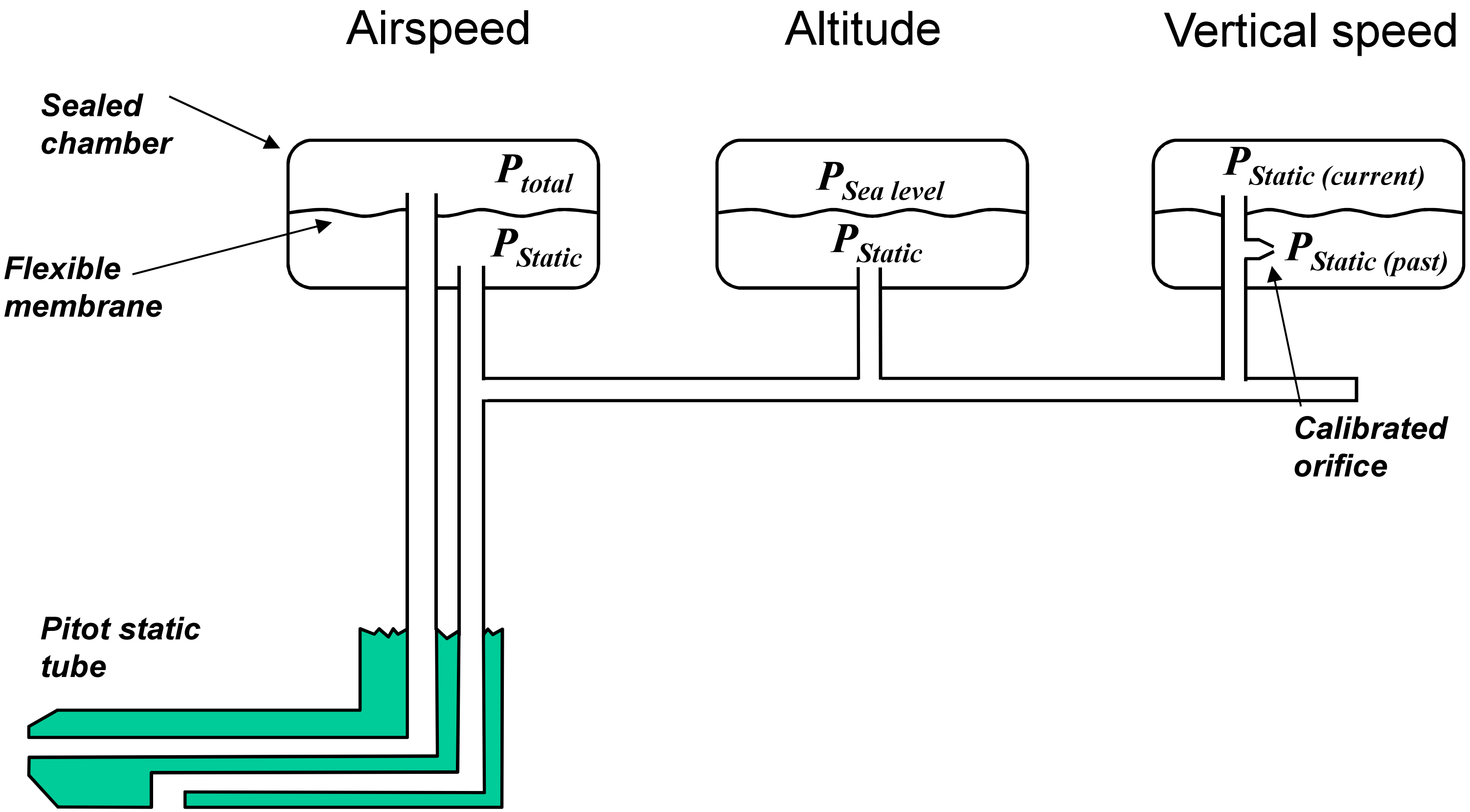
Pitot tube
Measures Total pressure (static + dynamic)

Static source
Measures static pressure

'Pitot static' *Total and static pressure*

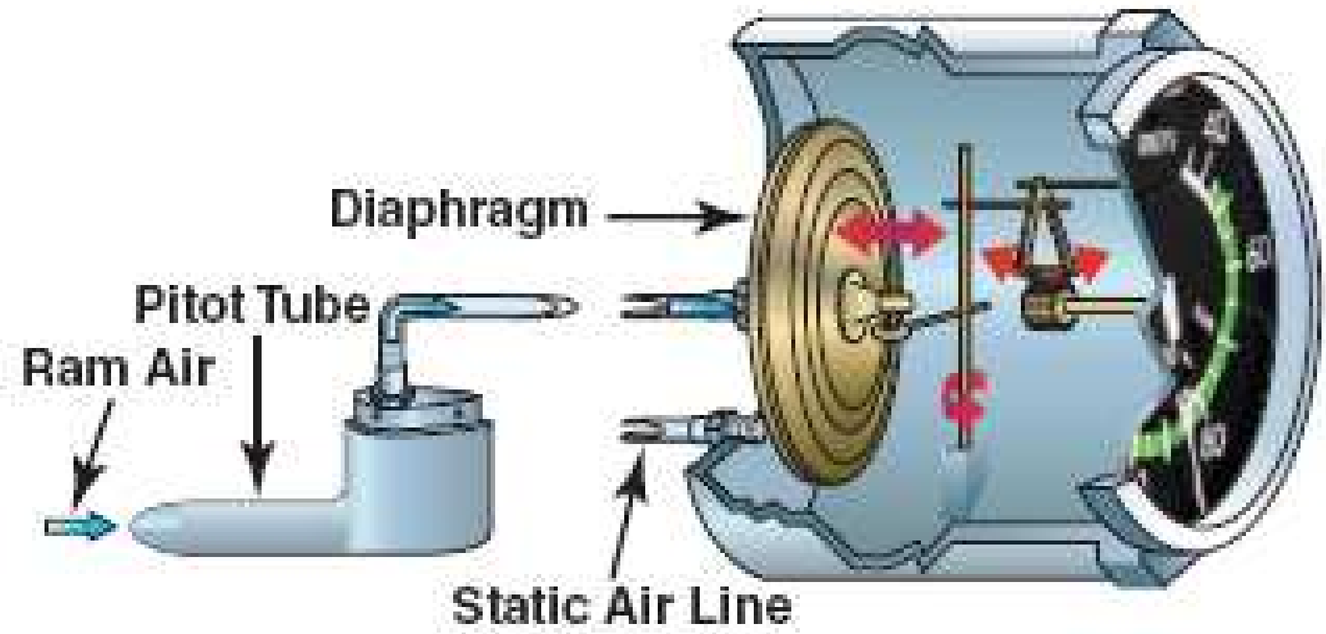
Pitot tubes

Mechanical Air Data Instruments

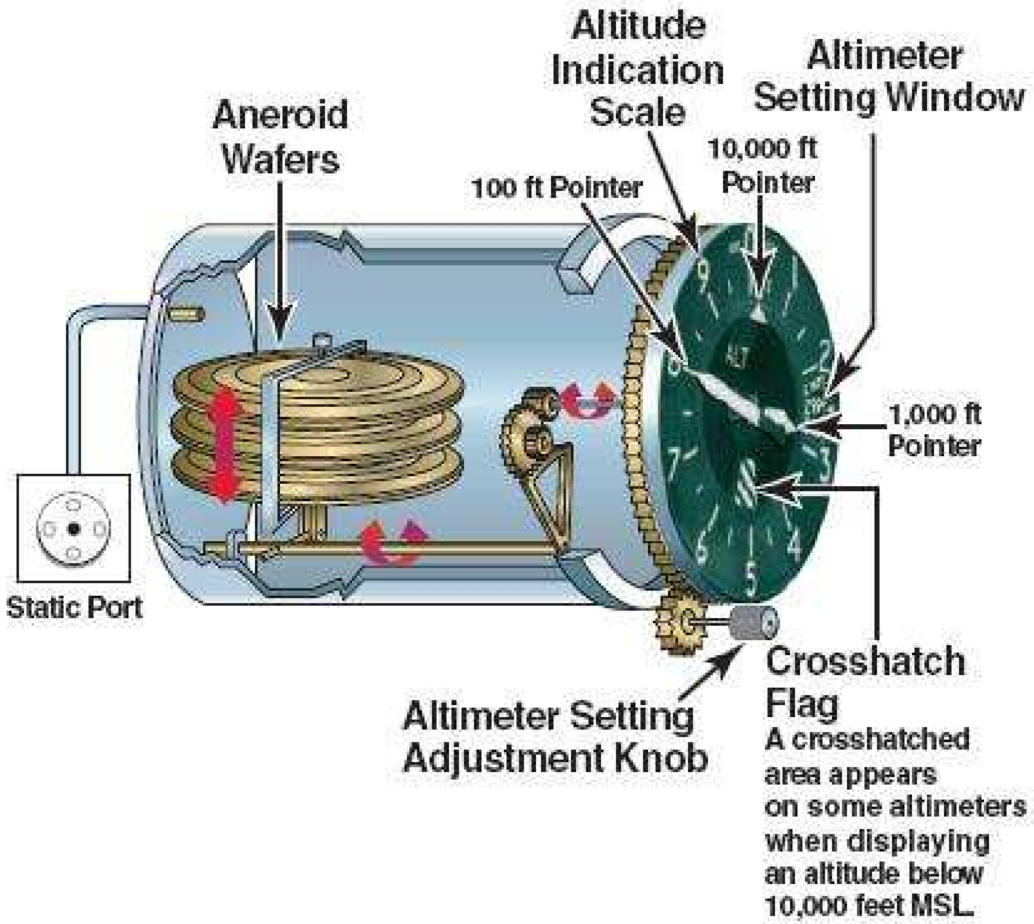


Air speed indicator

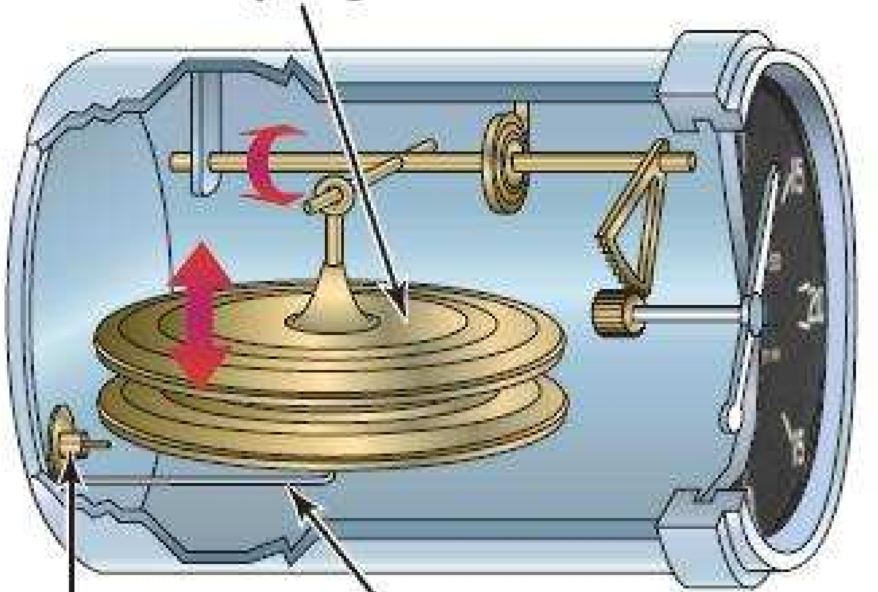
$$P_{total} - P_{static} = P_{dymanic} = \frac{1}{2}\rho V_{airspeed}$$



Altitude


Altitude Indication Scale
Altimeter Setting Window
Aneroid Wafers
10,000 ft Pointer
100 ft Pointer
1,000 ft Pointer
Static Port
Crosshatch Flag
A crosshatched area appears on some altimeters when displaying an altitude below 10,000 feet MSL.
Altimeter Setting Adjustment Knob

Vertical Speed



Air Speed

- The pitot tube air speed indicator output is referred to as ‘indicated air speed’ (IAS).
- This measurement is affected by changes in temperature and pressure, so IAS will not always correlate to the actual speed of the aircraft relative to the surrounding air mass.
- To derive true air speed, TAS, compensation for altitude and temperature are required

Air data Computer

- Modern air data systems have moved away from the ‘puff and blow’ mechanical instruments and towards electronics to perform calculations.
- Electronic pressure sensors measure dynamic and static pressures as well as temperature.
- It is much easier to perform calculations with electronics than with mechanical mechanism – e.g. mach number (which requires division) can be calculated.

Air Speed is critical….

- Air France flight 447:
  - Problem indicated with air speed indicators

- Birgenair flight 301
  - Problem indicated with air speed indicators caused pilot to stall aircraft as he thought they were flying too fast.

Summary

- Inertial Navigation System INS
  - A primary means of navigating aircraft.
  - Good short term accuracy but suffers drift.
  - Equipment fitted to the aircraft is expensive
- Air data
  - Essential for safe operation of the aircraft, especially true air speed.