AVDASI 1
AENG 10001

On-board Navigation and Sensing

Food for thought?

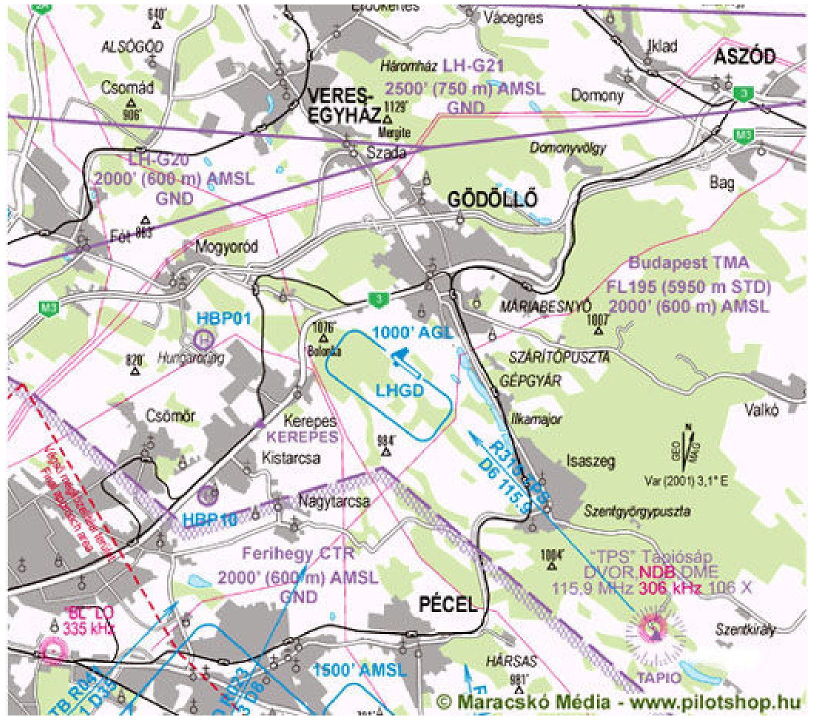
- How do we know how fast we are going?
- How do we know where we are heading?
- How do we know where we are?

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 (VSR) – The pilot uses a map (VSR Chart) and a compass to plan his flight and cross checks with features of the landscape below.



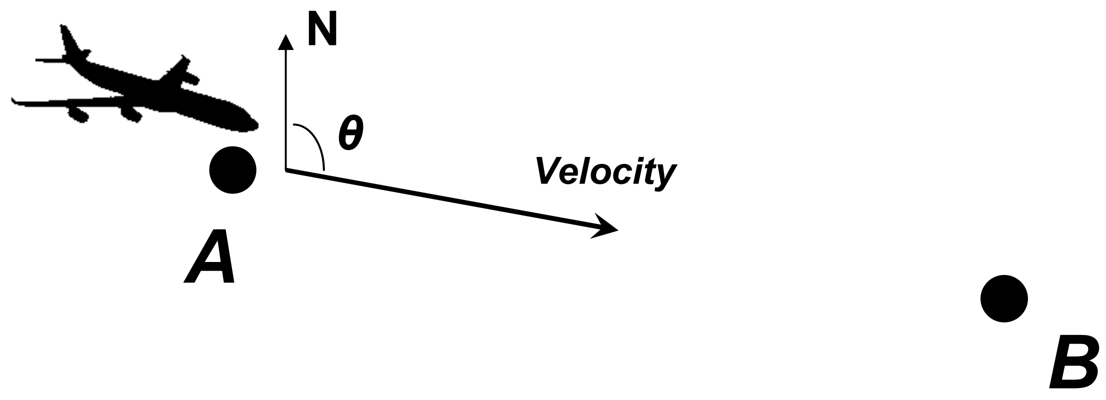
Instrument flying

- 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.



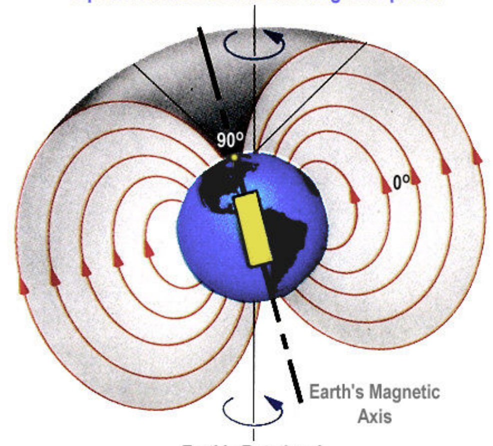
- The basis for this type of navigation system are the aircraft's instruments for measuring speed and direction of travel.

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 now be fluid damped

- Electronic versions are available.



Compass swinging

Compass swinging

Magnetic Compass limitations

- Slow response in aircraft environment.
- Less stable towards the poles. No use at the poles.
- Poles shift with time.

Most importantly….

- Direction plane is pointing (2D), not moving

Speed measurement

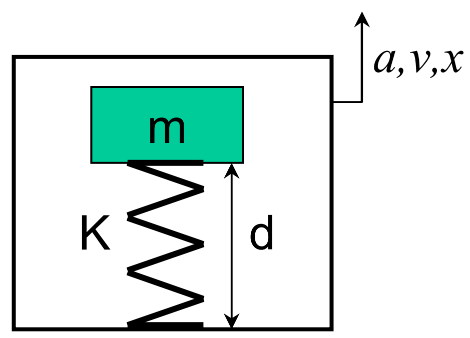
- Speed is determined from air velocity… More of this later.

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

Inertial instruments;

Gyroscopes and accelerometers

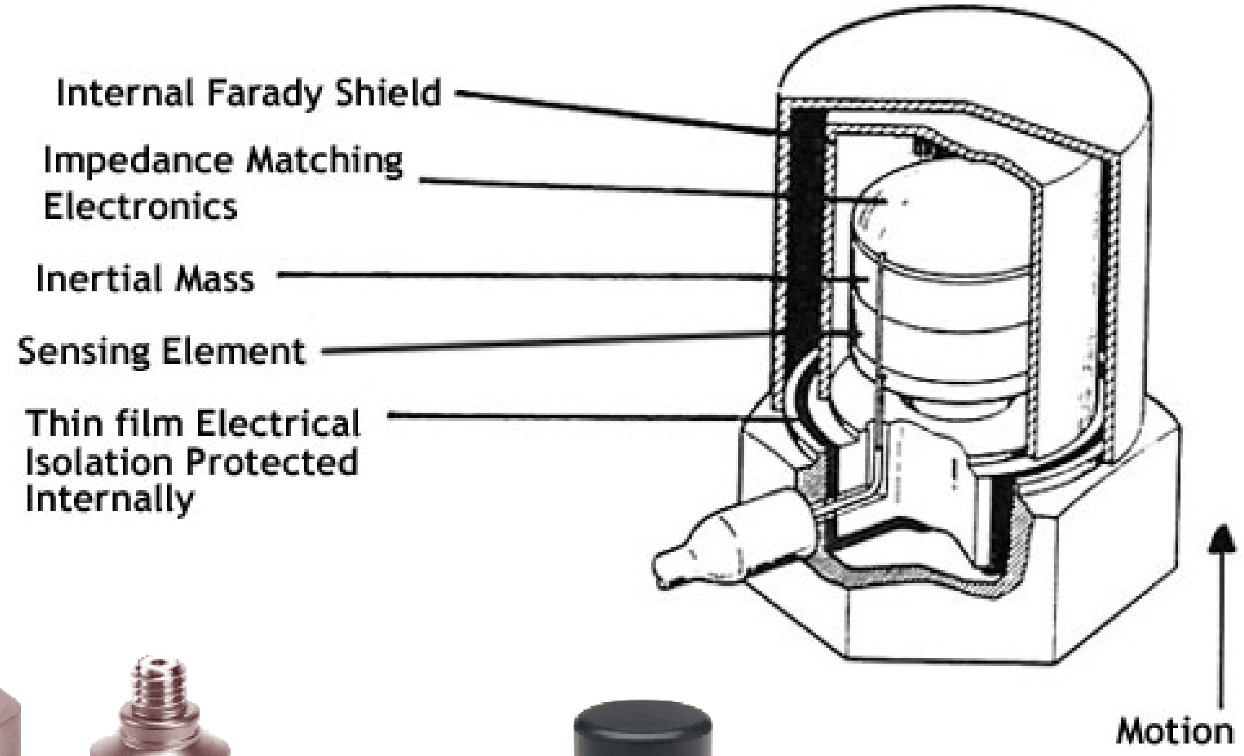
Inertial instruments – Linear motion

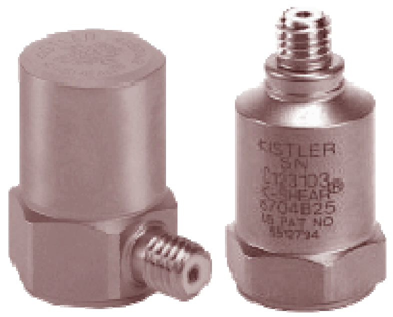


$$a = {kM}/{d}$$
$$v = \int a\,dt$$
$$x = \int v\,dt$$

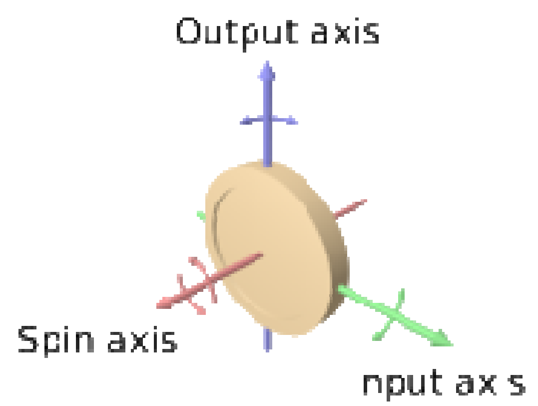
- Accelerometers – measuring force on inertial mass
  - Measures linear acceleration of aircraft
  - Multiple devices can give all 3-axis
  - Integrate to derive linear velocity
  - Gravity causes ambiguity

Components - Accelerometers





Inertial instruments - rotation

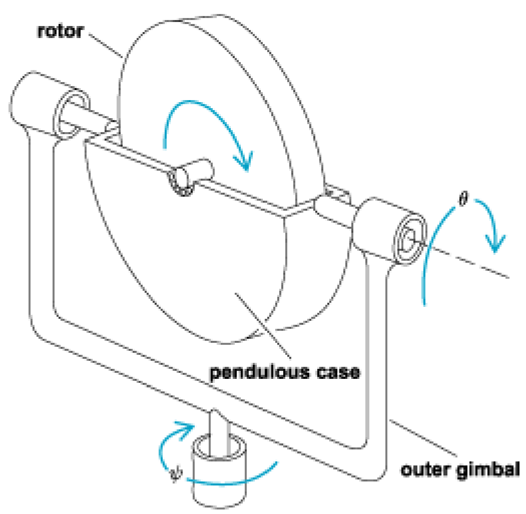


Gyroscopes – rotating mass in gimballed arrangement

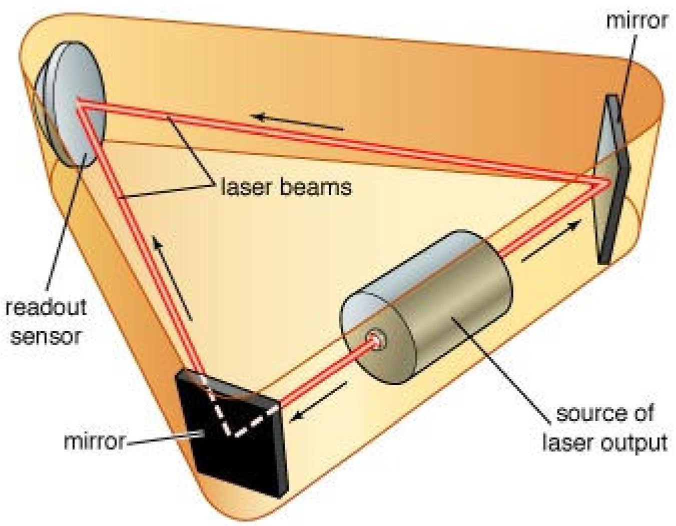
- Measures angular velocity of aircraft
- Integrate to derive angular position
- orientation relative to fixed co-ordinate system (fixed on ground)
- Removes gravity ambiguity when combined with accelerometers

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 horizontal to the earths surface, (using gravity). In this arrangement the rotation of the earth cause the gyro to point true north (axis of rotation)



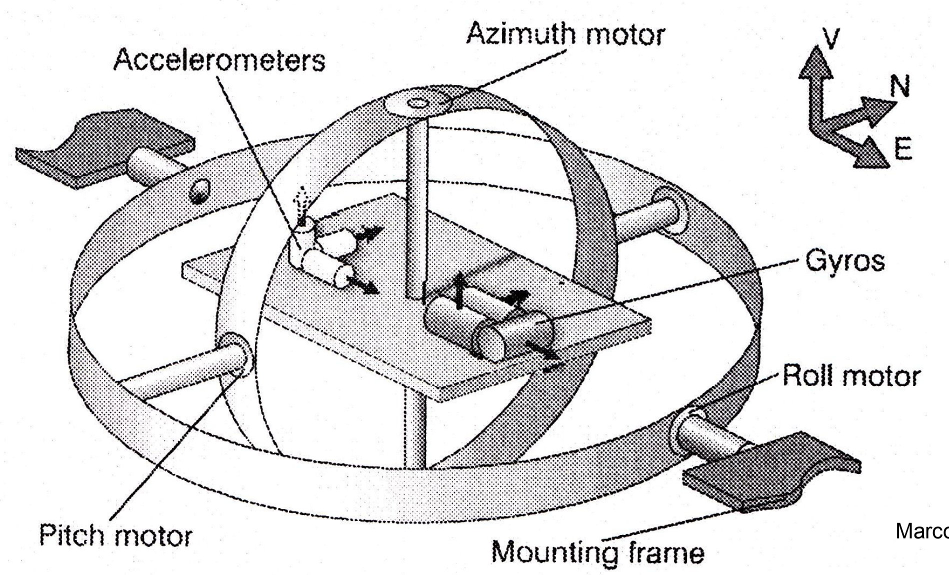
Components – laser ring Gyroscopes



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

Stabilised platform

- 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.

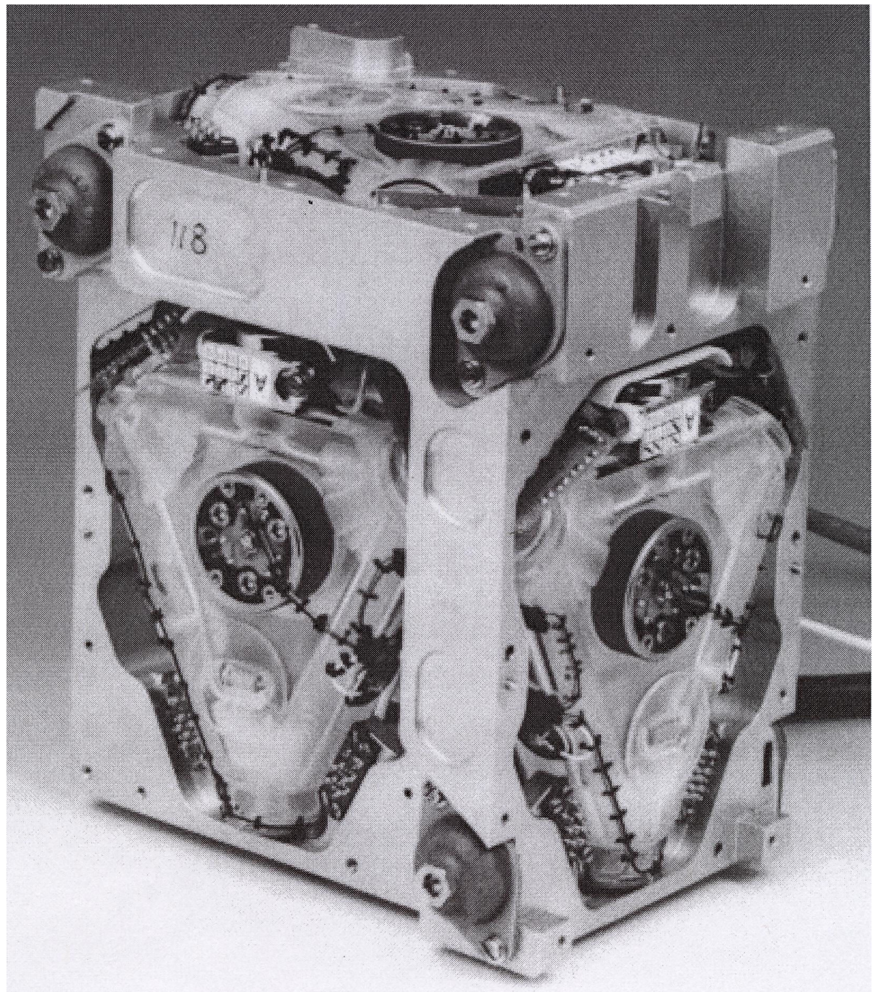


Marconi

System types – ‘strap-down’

- 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

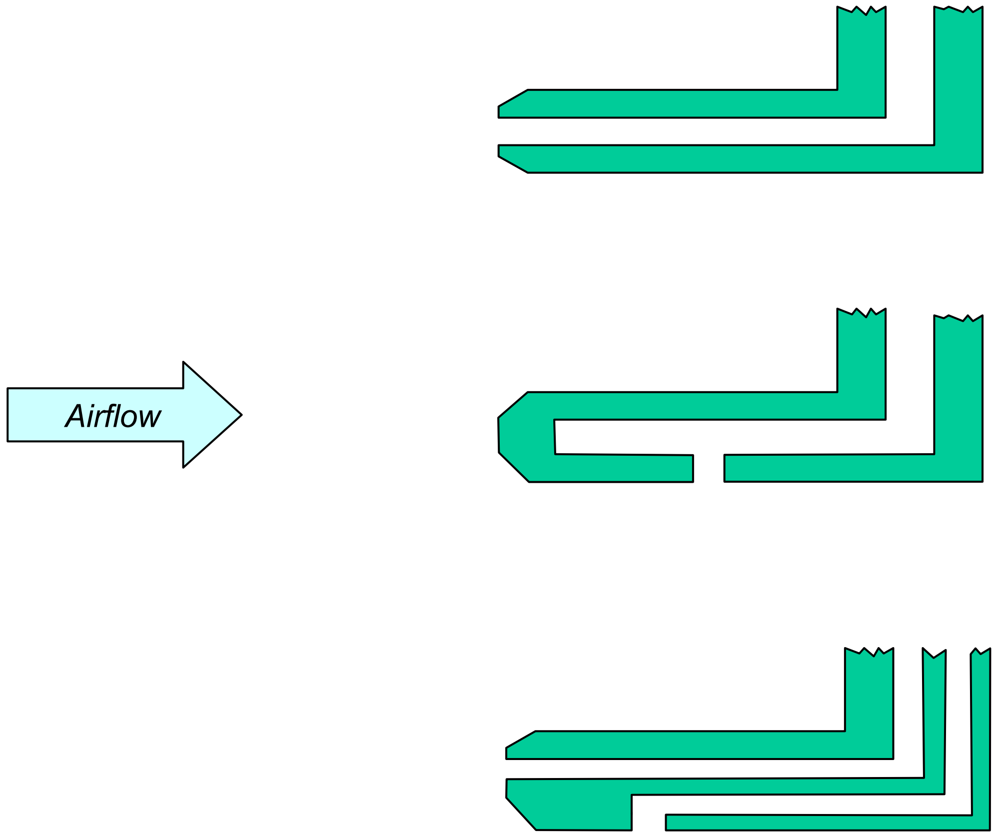
University of BRISTOL

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



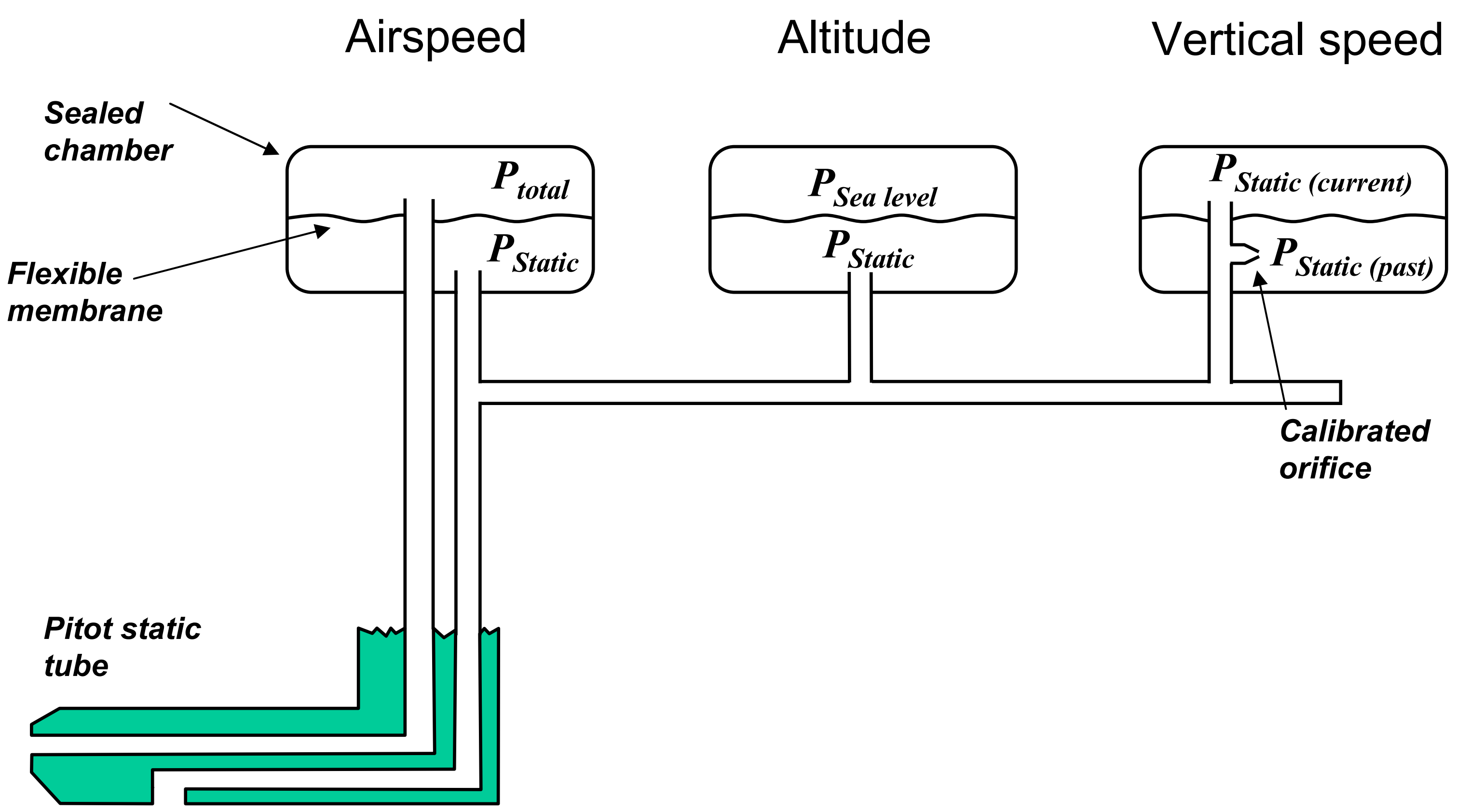
Pitot tube
Measures Total pressure (static + dynamic)

Static source
Measures static pressure

'Pitot static' *Total and static pressure*

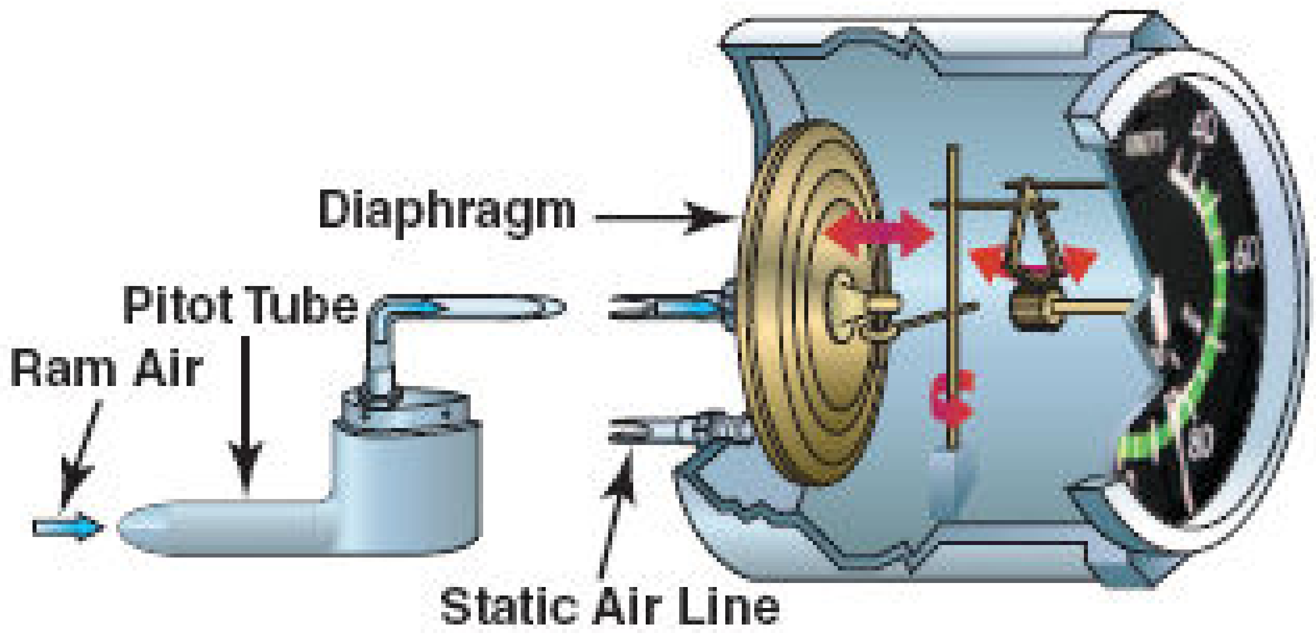
Pitot tubes

Mechanical Air Data Instruments

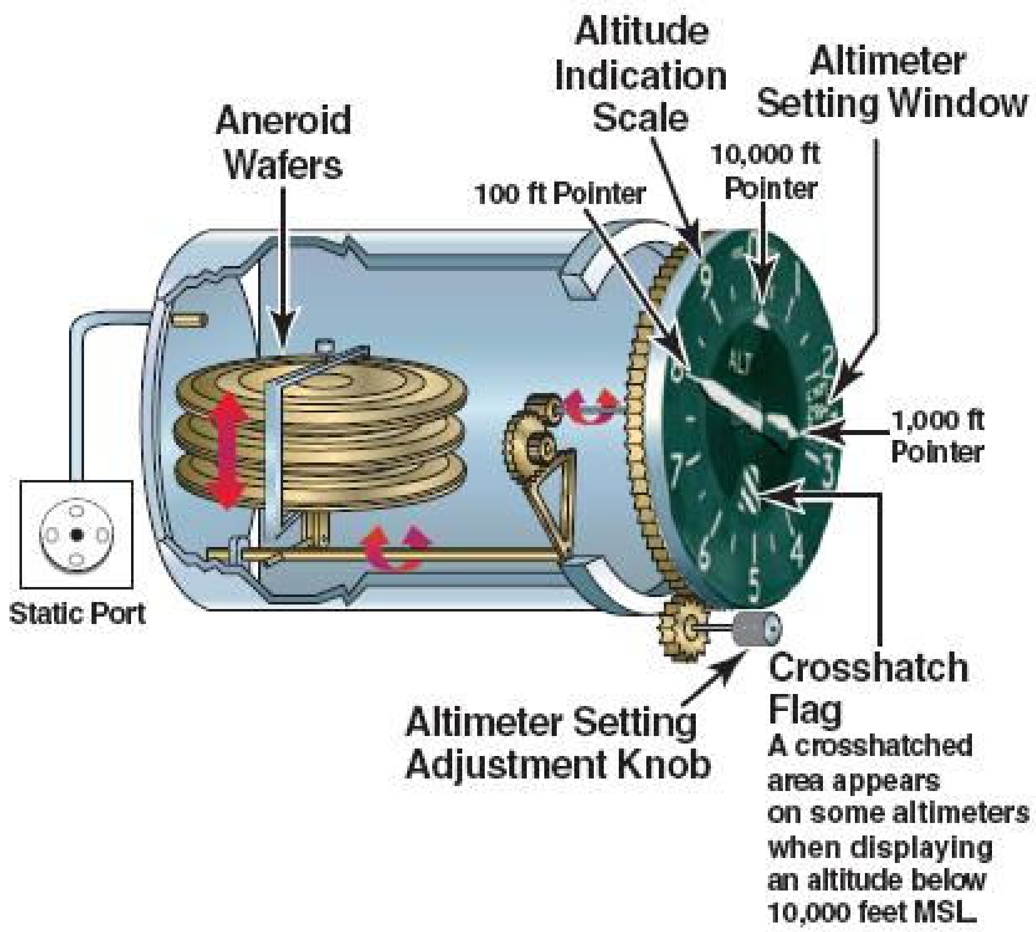


Air speed indicator

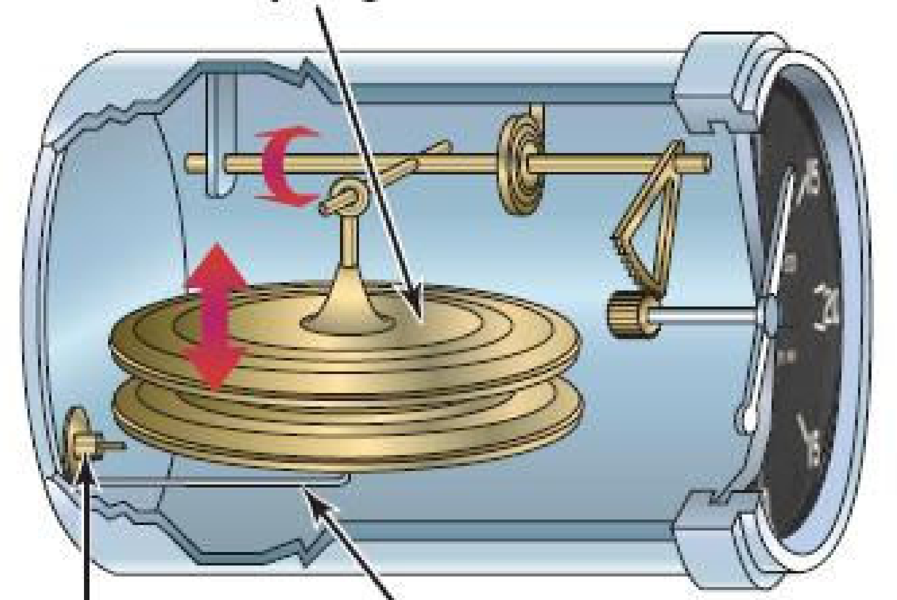
$$P_{total} - P_{static} = P_{dymanic} = \frac{1}{2}\rho V_{airspeed}$$



Altitude


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

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 through 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.