Chapter 7

Air Data and Air Data Systems

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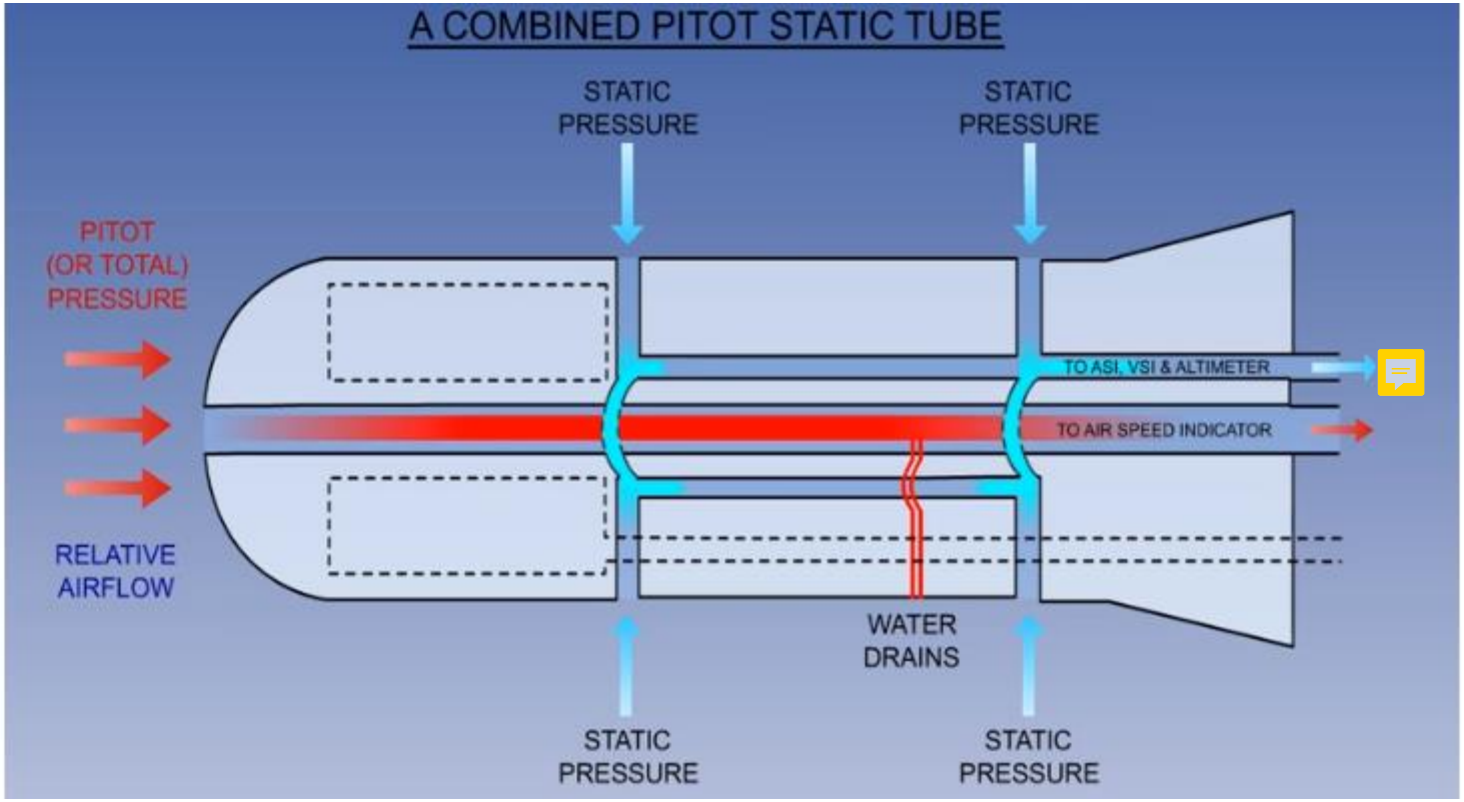
1. Introduction

- Air data systems provide accurate information on quantities such as pressure altitude, vertical speed, calibrated airspeed, true airspeed, Mach number, static air temperature and air density ratio.
- This information is essential for the pilot to fly the aircraft safely and is also required by a number of key avionic sub-systems which enable the pilot to carry out the mission.
- The air data quantities pressure altitude, vertical speed, calibrated airspeed, true airspeed, Mach number, etc., are derived from three basic measurements by sensors connected to probes which measure:
  - Total (or Pitot) pressure
  - Static pressure
  - Total (or indicated) air temperature

Pitot Static System



Pitot Static System

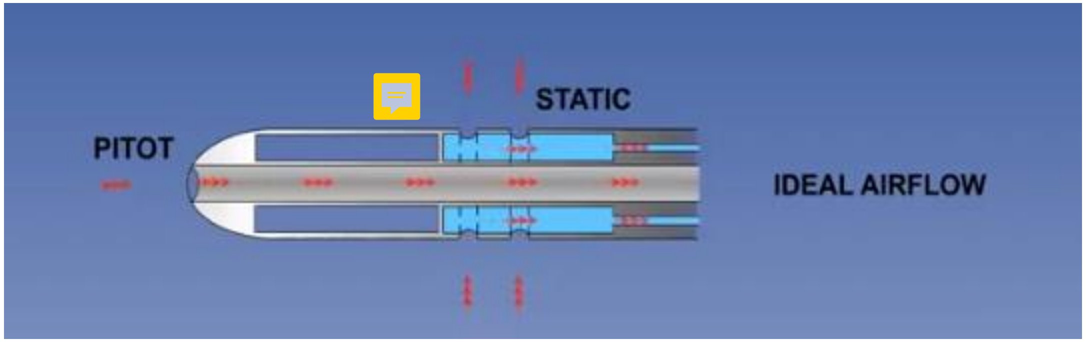
- Static Pressure is the ambient air pressure experienced by an aircraft because it is in earths atmosphere.
- Dynamic Pressure is the force the air exerts when brought to rest against a moving body.
- Pitot pressure is the combined pressure of Static and Dynamic Pressure exerted on the head of pitot pressure.
- Static Pressure instruments are the altimeter and VSI
- Dynamic Pressure instruments are ASI and Machmeter
- Pressure Heads have heating elements.

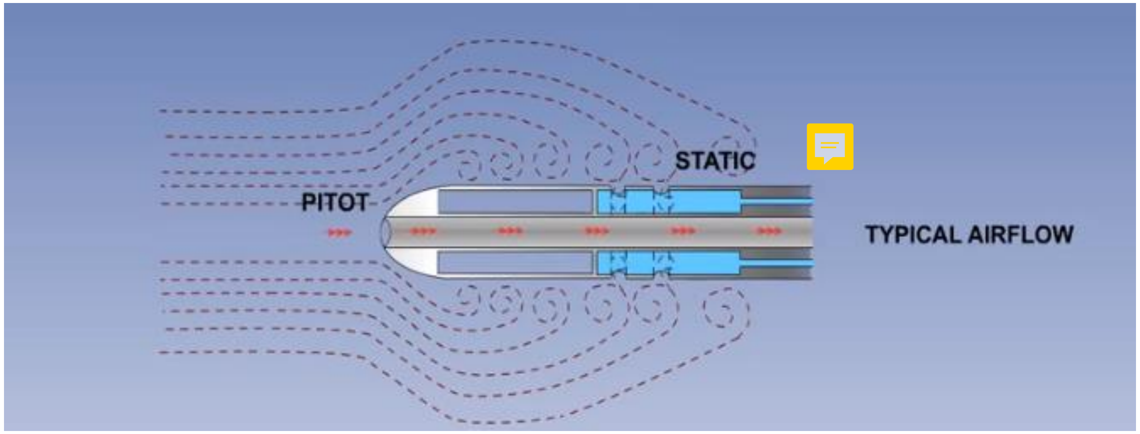
Pitot Static System-Errors and Corrective Measures

- This segment will look at the errors which pitot static air pressure sensing systems are subject to and the corrective measures taken to balance out or reduce these errors.

Pitot Static System-Errors and Corrective Measures

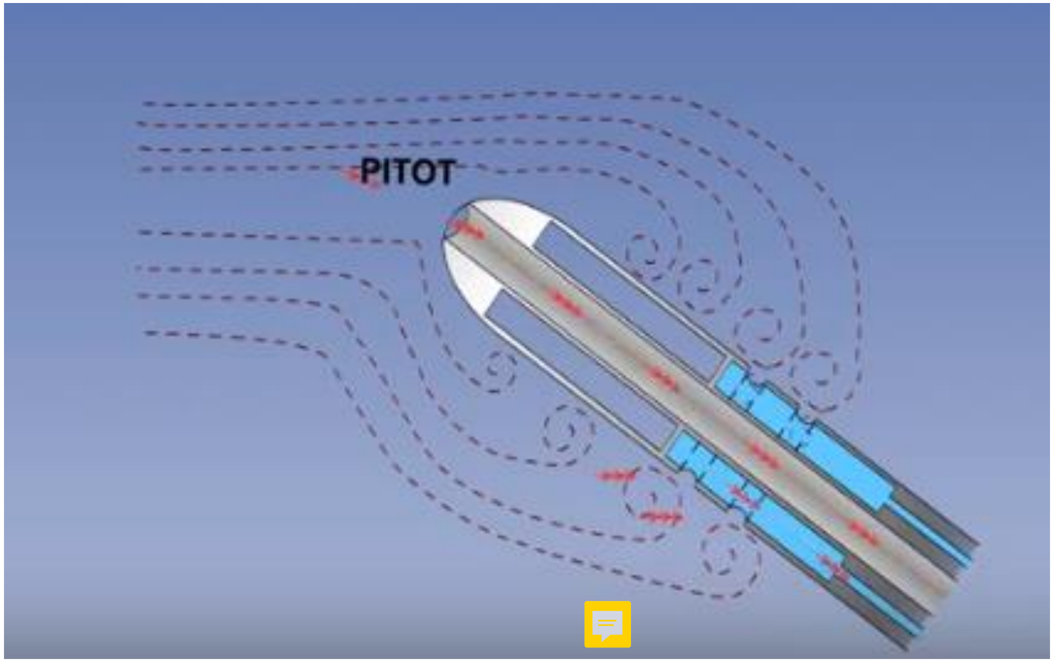
Position Error: Ideal airflow is shown below





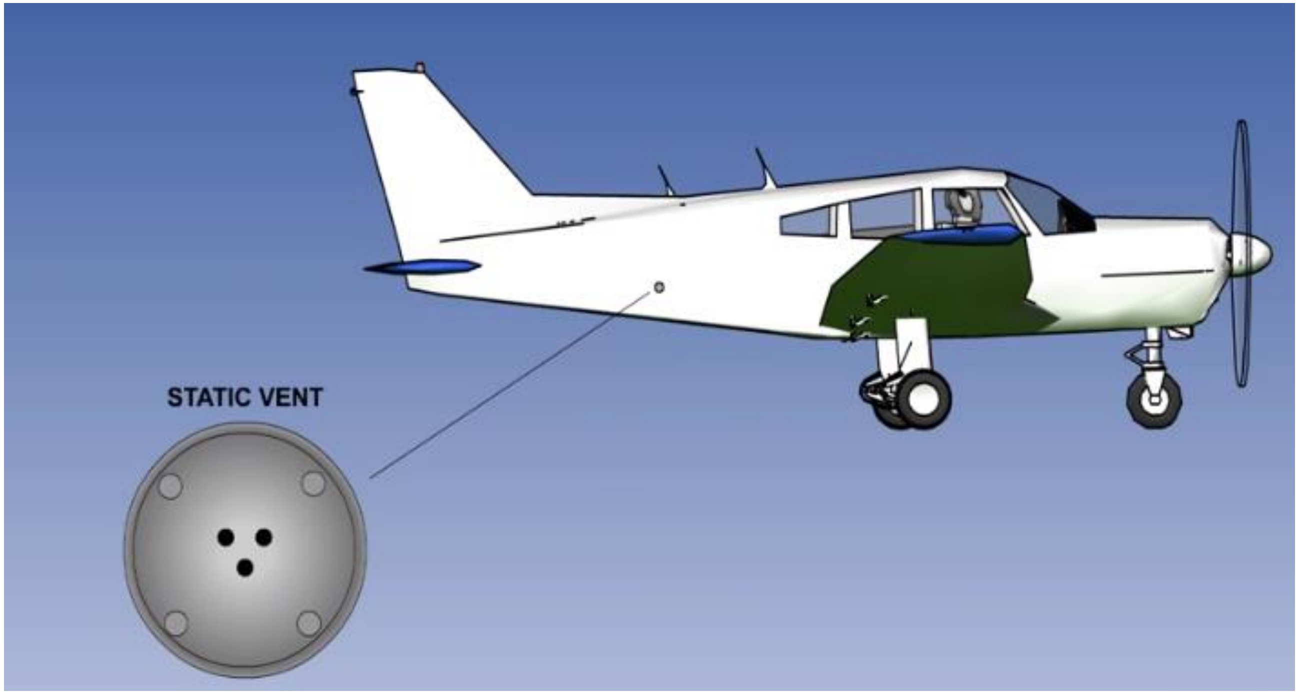
Pitot Static System-Errors and Corrective Measures

At high AOA, the static vent also senses dynamic pressure, error might be great at high AOA



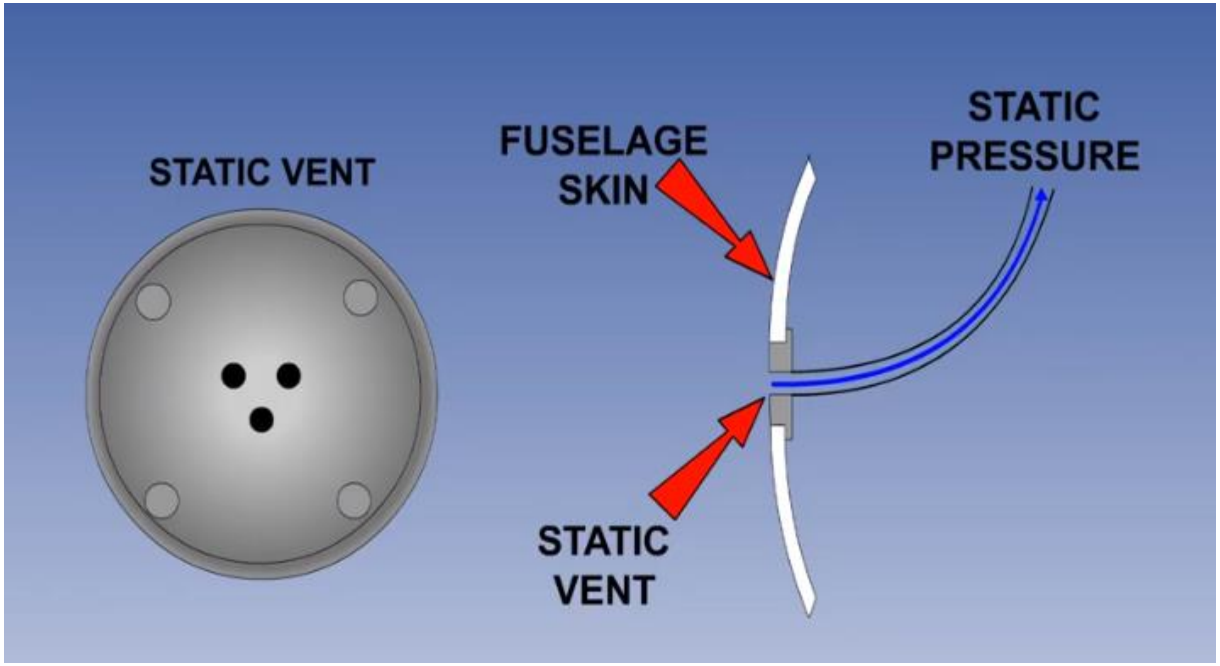
Pitot Static System-Errors and Corrective Measures

Position Error effect can be substantially reduced/eliminated by replacing static pressure head by **Static Vent.** Usually mounted on side of the fuselage where nearly true static pressure is sensed.

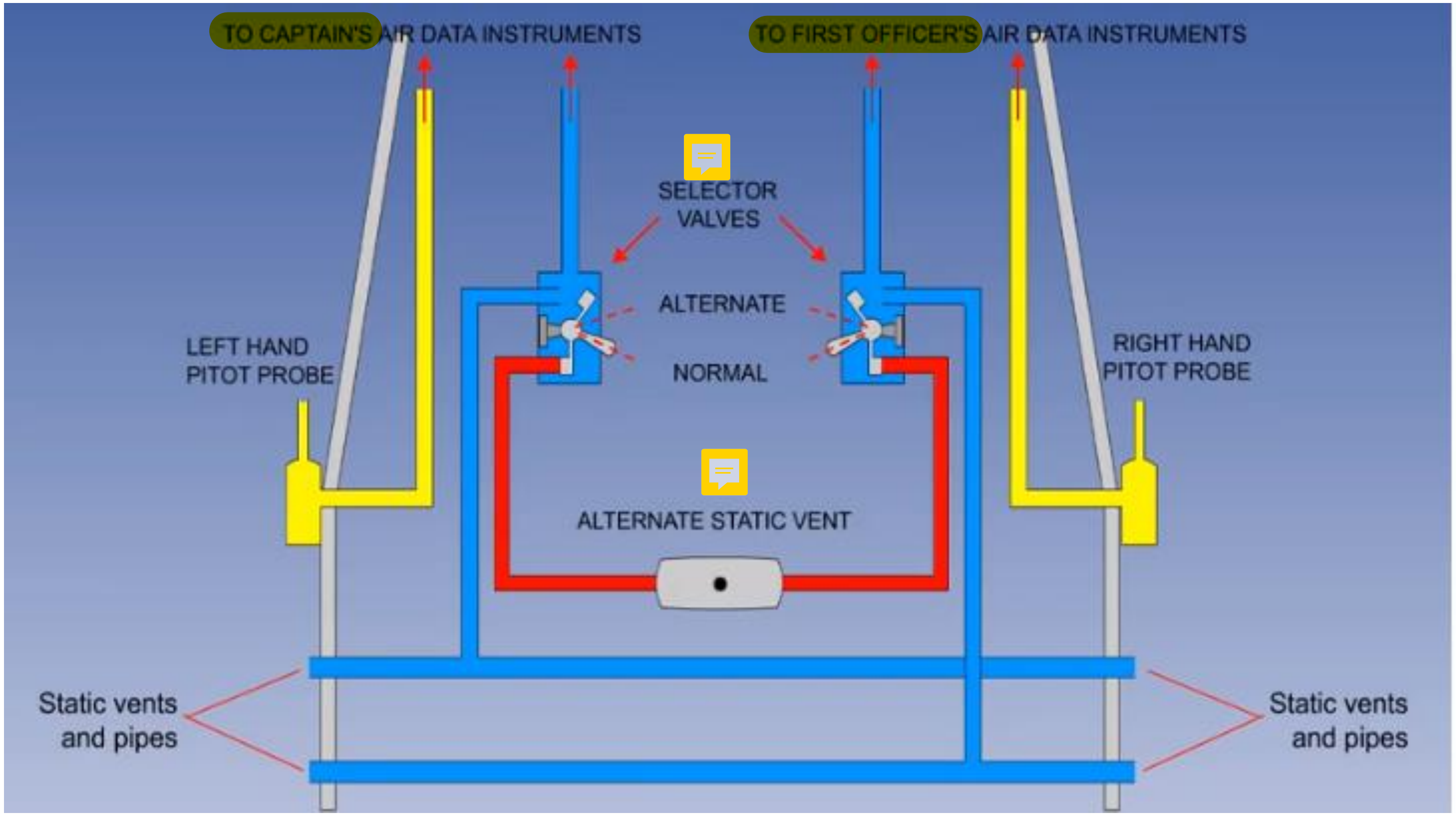


Pitot Static System-Errors and Corrective Measures

Vent is simply a metal plate, with holes in the center of the plate, the vent is fitted flush with the fuselage and is connected to the pressure lines which feed the pressure instruments. The pressure line is angled upwards from the vent (no heating required). About 90% of the error can be eliminated by the use of a separate static vent.

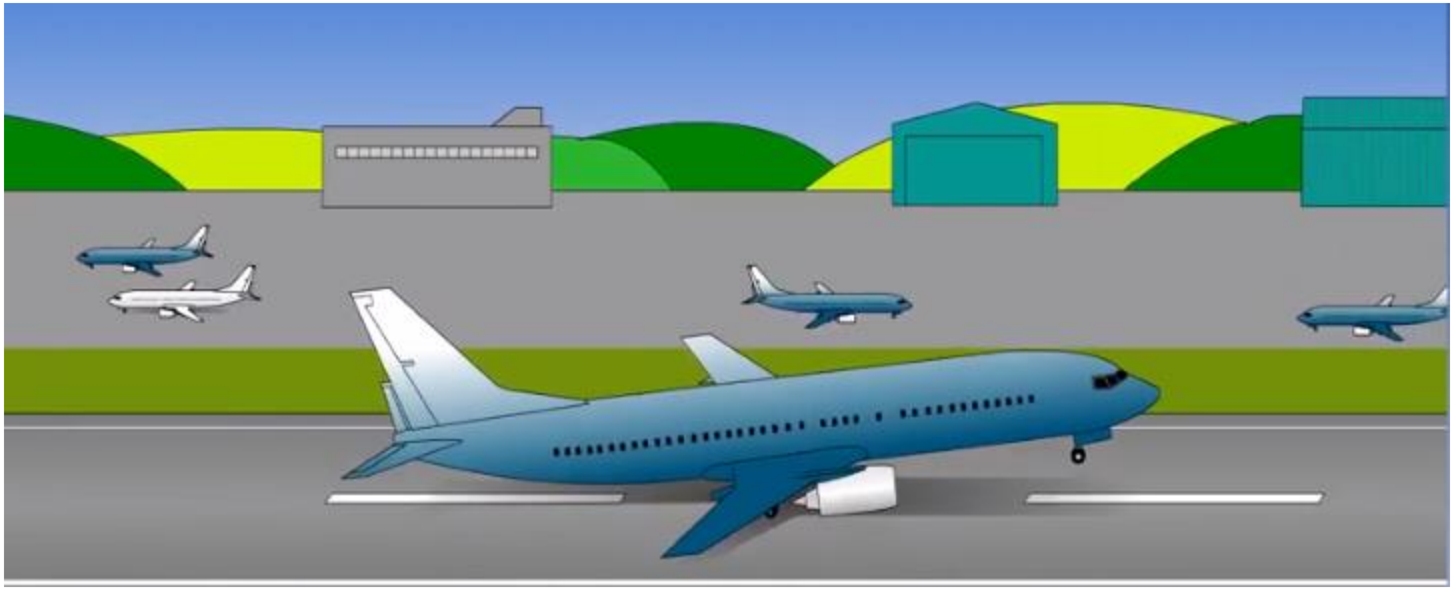


Pitot Static System-Errors and Corrective Measures



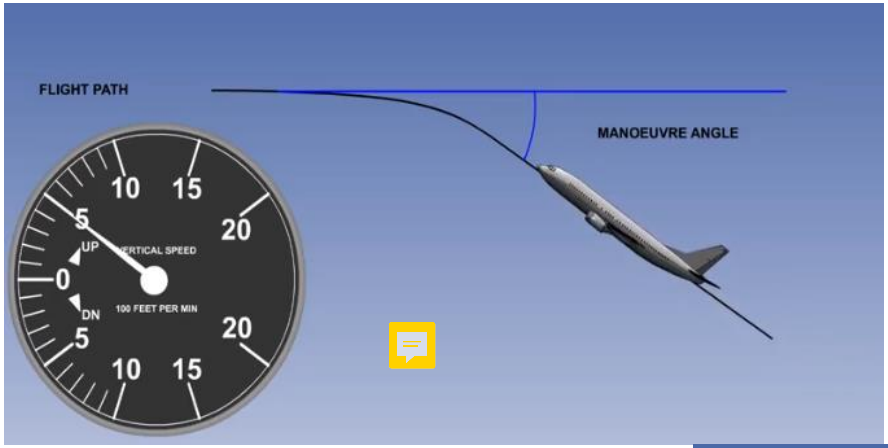
Pitot Static System-Errors and Corrective Measures

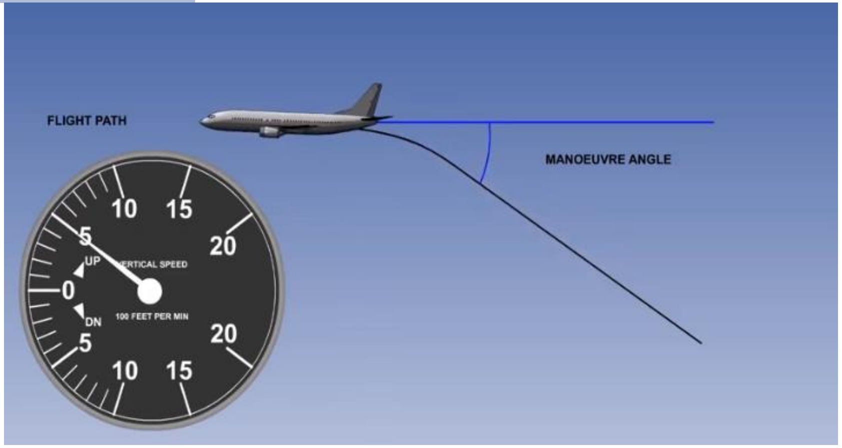
Maneuver Induced Error: Temporary fluctuation of air pressure at the static vents caused in particular by change in the aircrafts AOA. It is most significant in pitch changes especially during Start of Climb, Levelling off and Descend.



Pitot Static System-Errors and Corrective Measures

Maneuver Induced Error normally causes a lag in pressure instrument readings. The error is best illustrated in VSI. Not accurate reading for Instantaneous Rate of Change



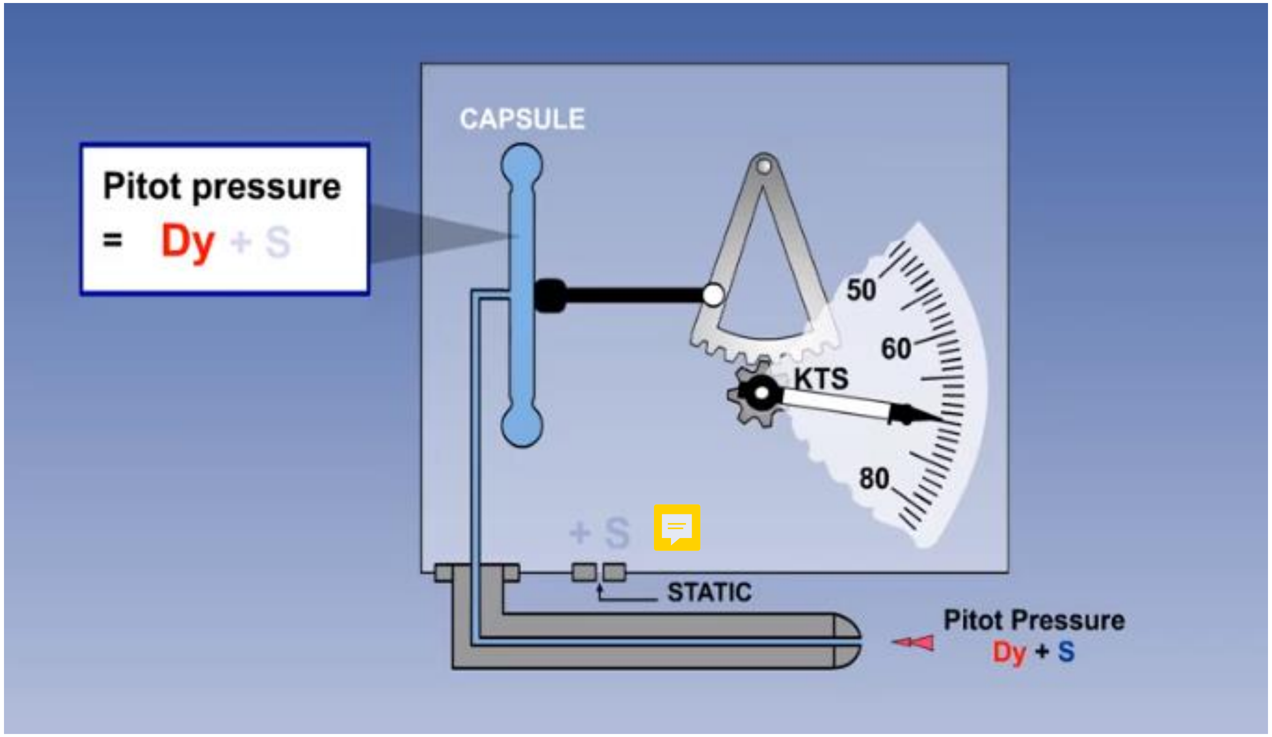


Air Speed Indicator (ASI)- Principle of Operation

ASI is pressure sensing instrument.

Air Speed Indicator (ASI)- Principle of Operation

The speed (airspeed) shown in the indicator is Indicate Air Speed (IAS). The ASI can be thought of as an air tight box in which static pressure is fed as shown here. Usually, IAS is calibrated in ISA condition and does not account for density changes so the True Air Speed (TAS) is not indicated in ASI.



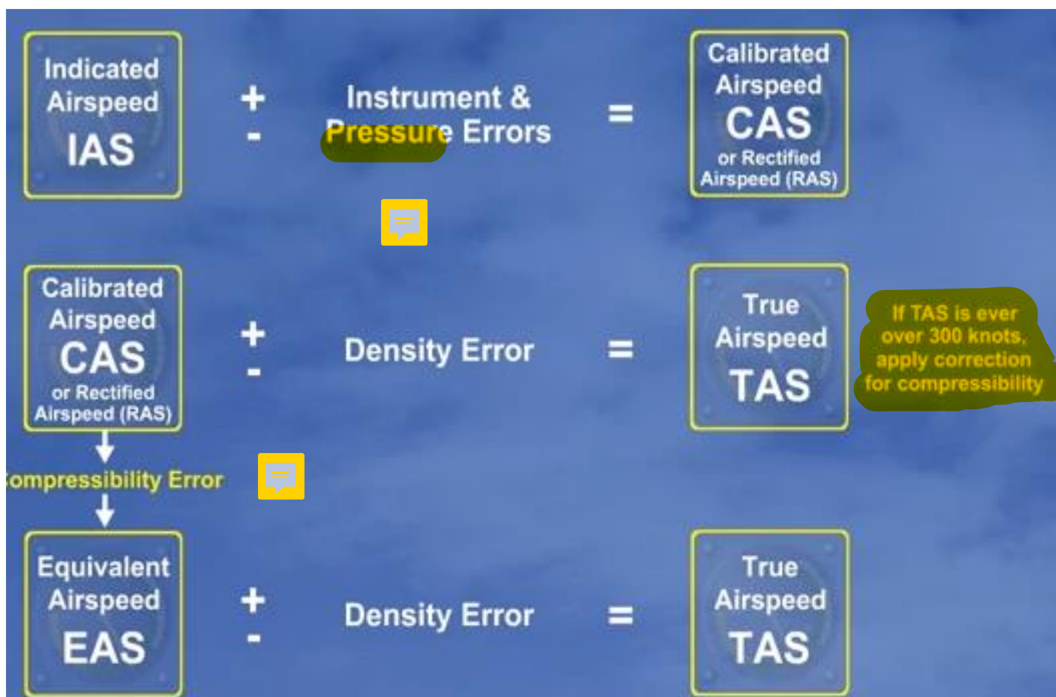
Air Speed Indicator (ASI)- Error

Instrument Error: Manufacture Error

Position Error: Also known as Pressure Error (Suction of turbulent airflow in the vicinity of Pitot Static Heads).

Density Error: It can cause the ASI to under read the TAS (True Air Speed)

If both errors (listed above) are rectified then its Calibrated Air Speed (CAS)



Air Speed Indicator (ASI)- Marking

White- V_{so}-V_{fe}- Flap Operating Speed to Maximum Flap Operating Speed

Green- V_{s1}-V_{no}- Starting of Normal Speed- Maximum Normal Speed

Yellow- V_{NO}-V_{NE}- Cautionary Speed to Never Exceed Speed

Blue- V_{YSE}- Best ROC (Rate of Climb) Single Engine, in case of twin engine.

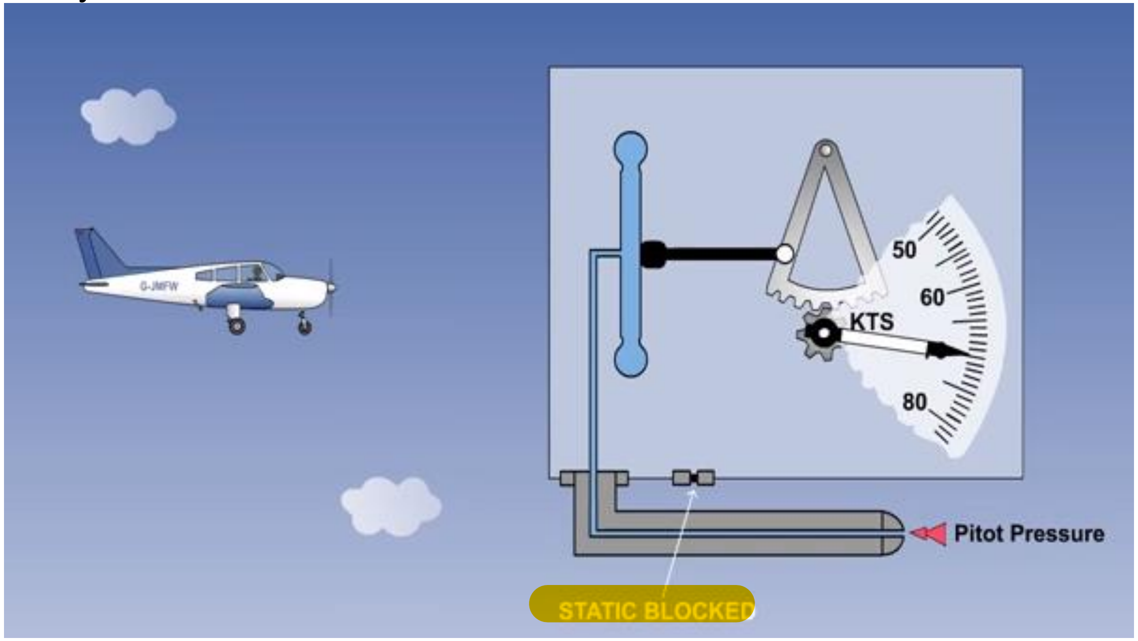
Air Speed Indicator (ASI)- Leaks and Blockages

Blockages and Leakage are major concerns in Pitot Static system, ice formation on pitot tube is common, insects and sand deposit are major contributors in blockages of pitot tube, presence of heating element inside the pitot system somewhat tends to resolve the issue, however, considering the flight safety the effect of blockage and leakage should be known.

Air Speed Indicator (ASI)- Leaks and Blockages

Static line Blocked: It means that static pressure inside the ASI instrument is trapped and is constant. As long as there is no change in Altitude the ASI will give correct reading. NO CHANGE IN ALTITUDE, NO CHANGE IN IAS.

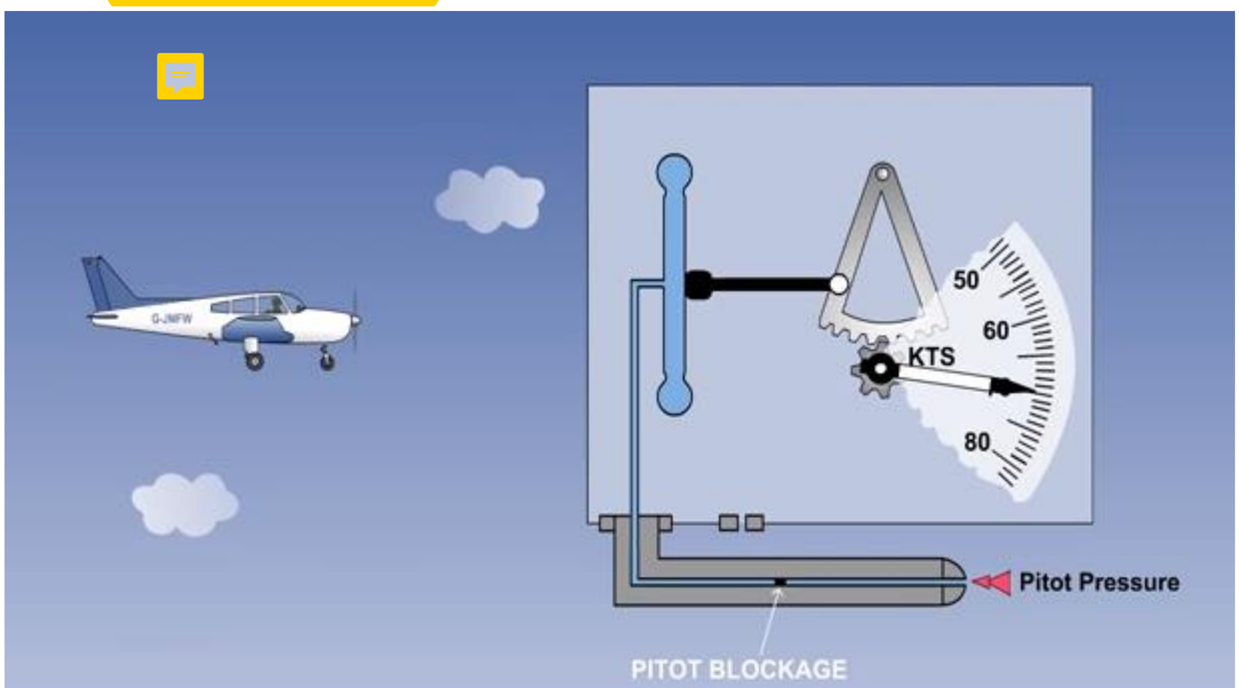
However, in descent, since the static pressure inside the instrument is trapped inside the instrument at low pressure, this will allow the metal capsule, which is being fed by pitot pressure to expand by an excessive amount, there for in descent the ASI will over read. Conversely, the ASI will under read if static is blocked.



Air Speed Indicator (ASI)- Leaks and Blockages

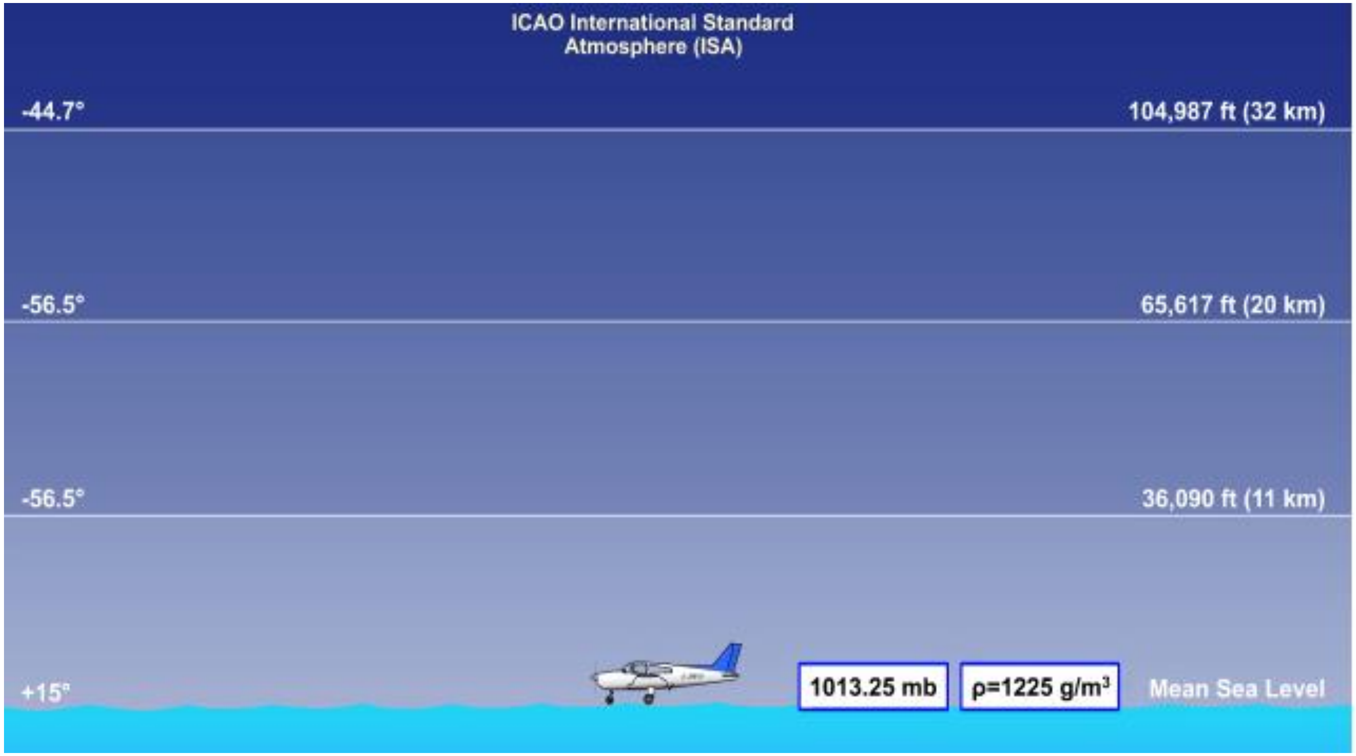
Pitot line Blocked: It means that pressure in the metal capsule is constant. If altitude is constant no any changes in the ASI reading.

However, in descent, the static pressure in the instrument will increase, the pressure in the metal capsule is constant, this means that as altitude is lost, the capsule will compress by an excessive amount and the ASI will under read. Conversely, it will over read in climb. Leaks in Pitot Line makes ASI to under read.



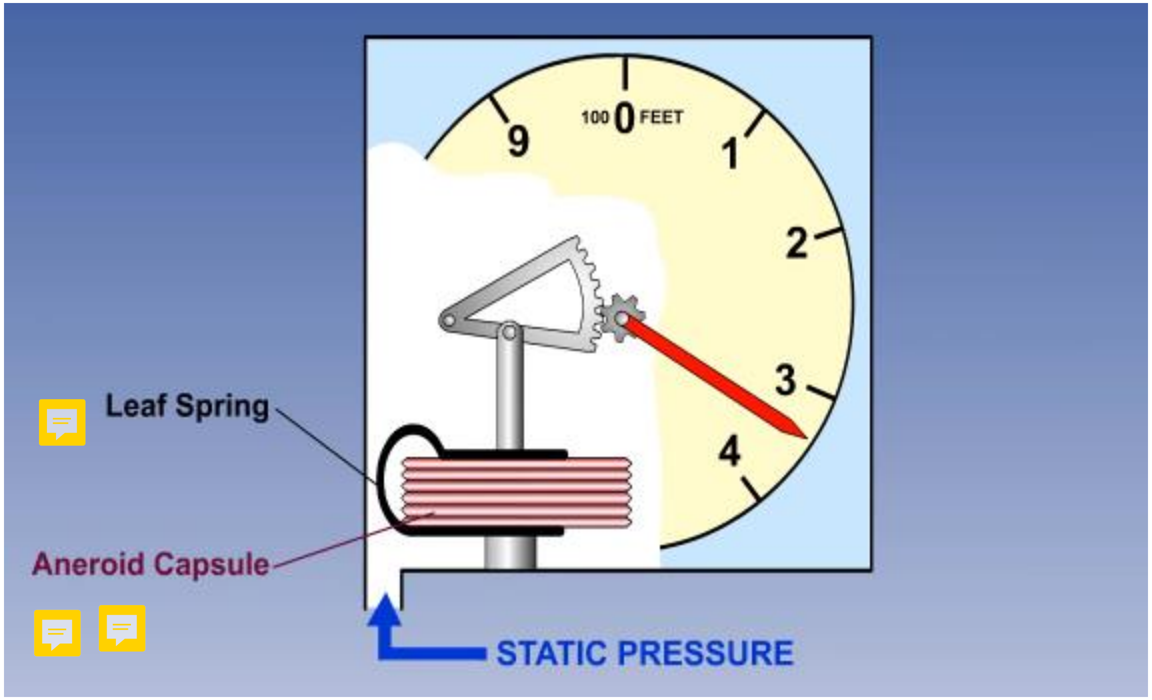
Pressure Altimeter-Operations

It can be thought of pressure gage, which senses change is static pressure and by means of calibration, expresses the change of static pressure as change in altitude.



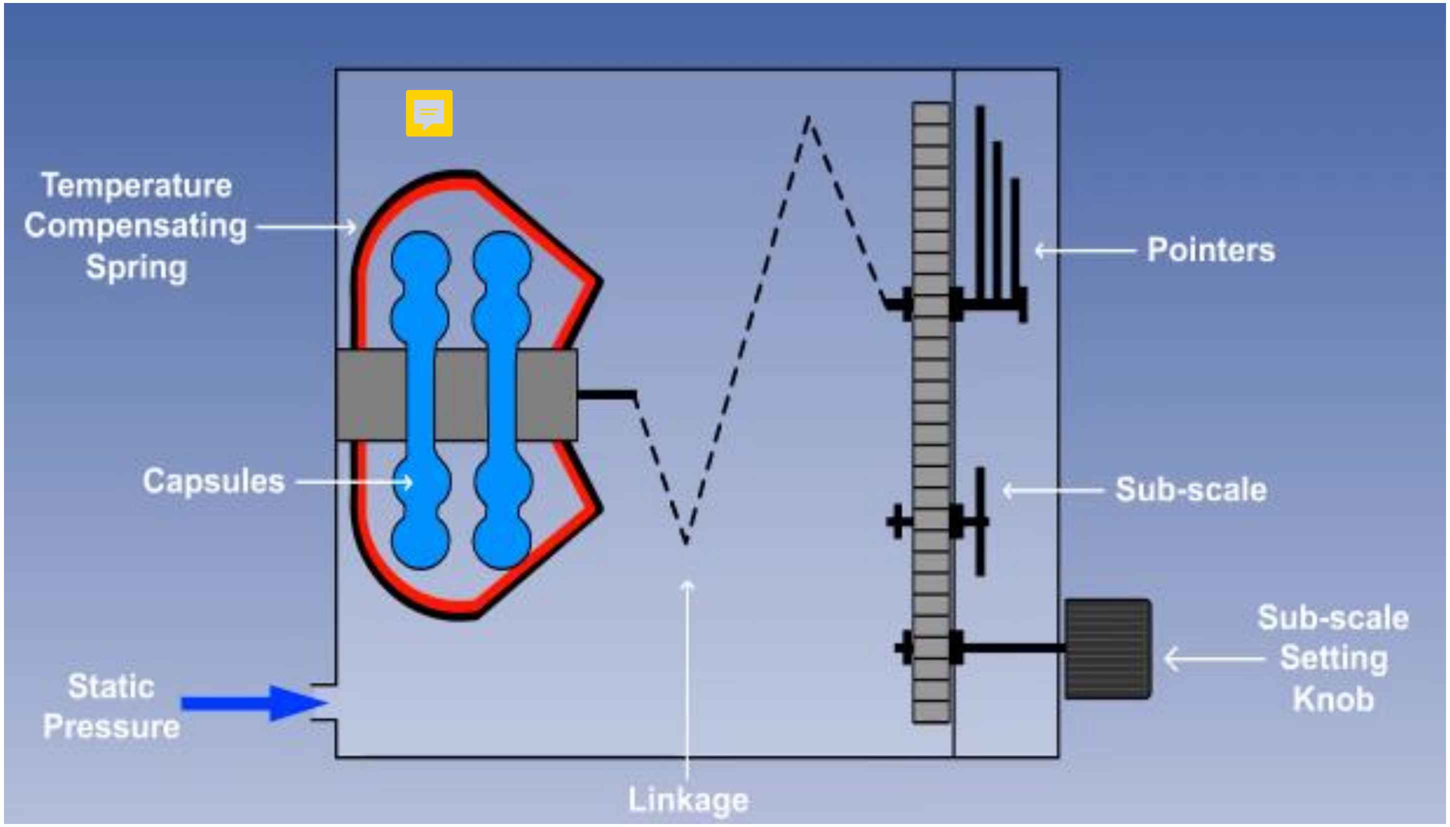
Pressure Altimeter-Operations

Static Line is Fed inside the pressure altimeter, Aneroid Capsule expands and contracts and leaf spring controls the expansion and contraction. As altitude increases, the static pressure decreases inside the box, which allow the capsule to expand in controlled manner indicating increase in height. Conversely, it will show decrease in height.



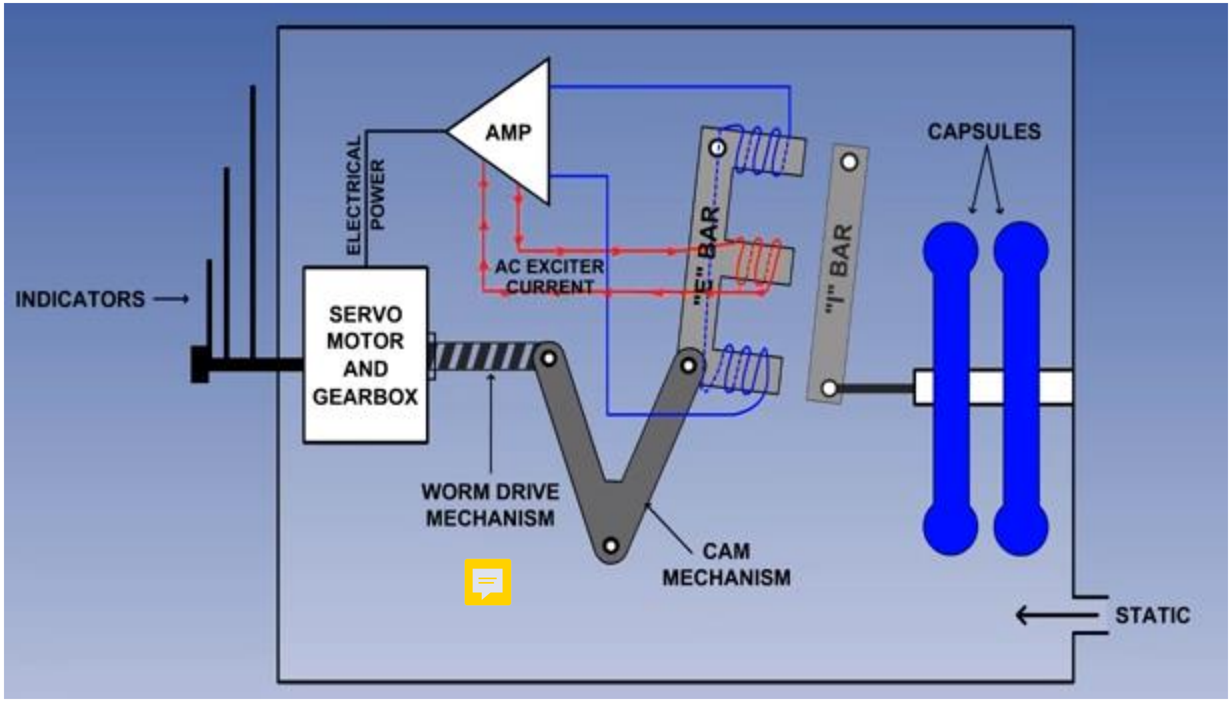
Sensitive Altimeter-Operations

Faster response rate in change of altitude.



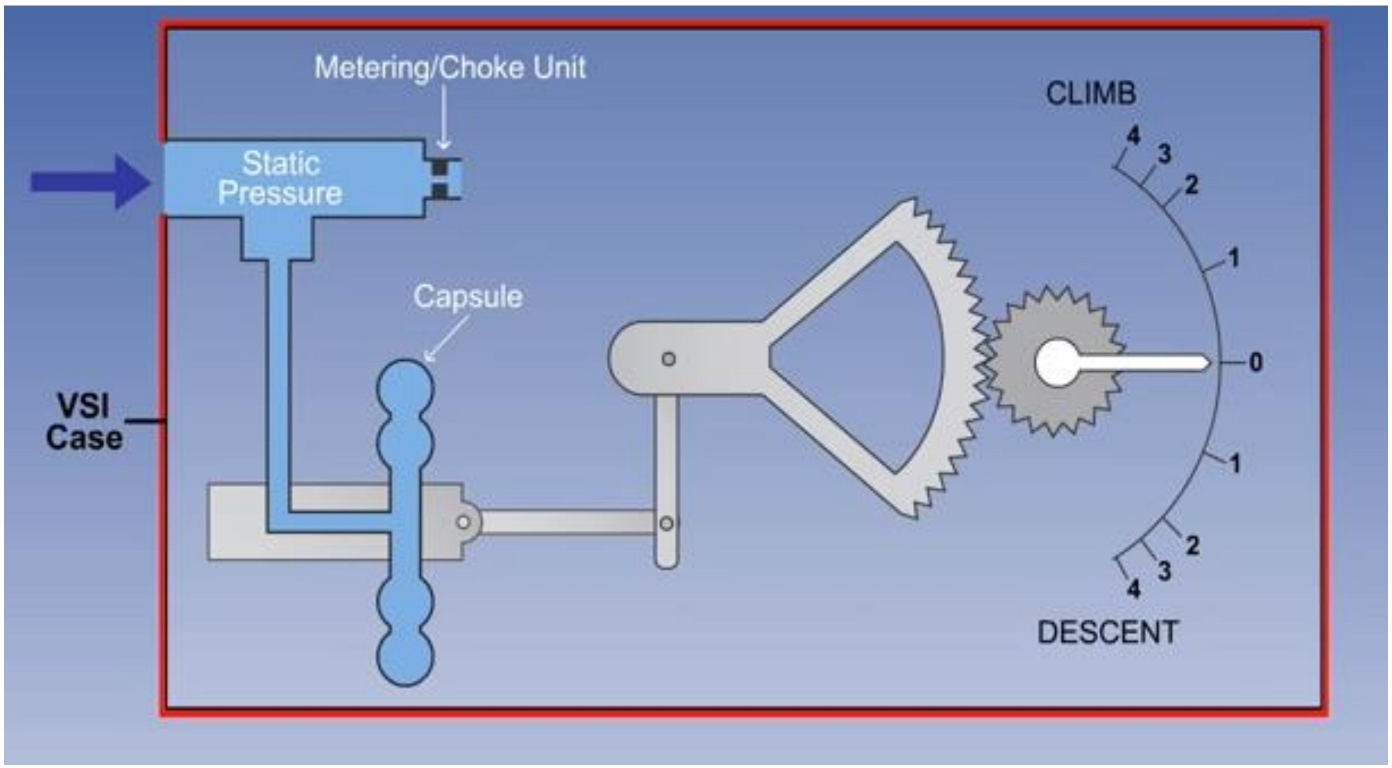
Servo Assisted Altimeter-Operations

- Improved Accuracy specially at high altitudes
- Frictions and Manufacturing Imperfections in conventional mechanical linkages are reduced.
- Digital Readouts and altitude warnings are easily incorporated.

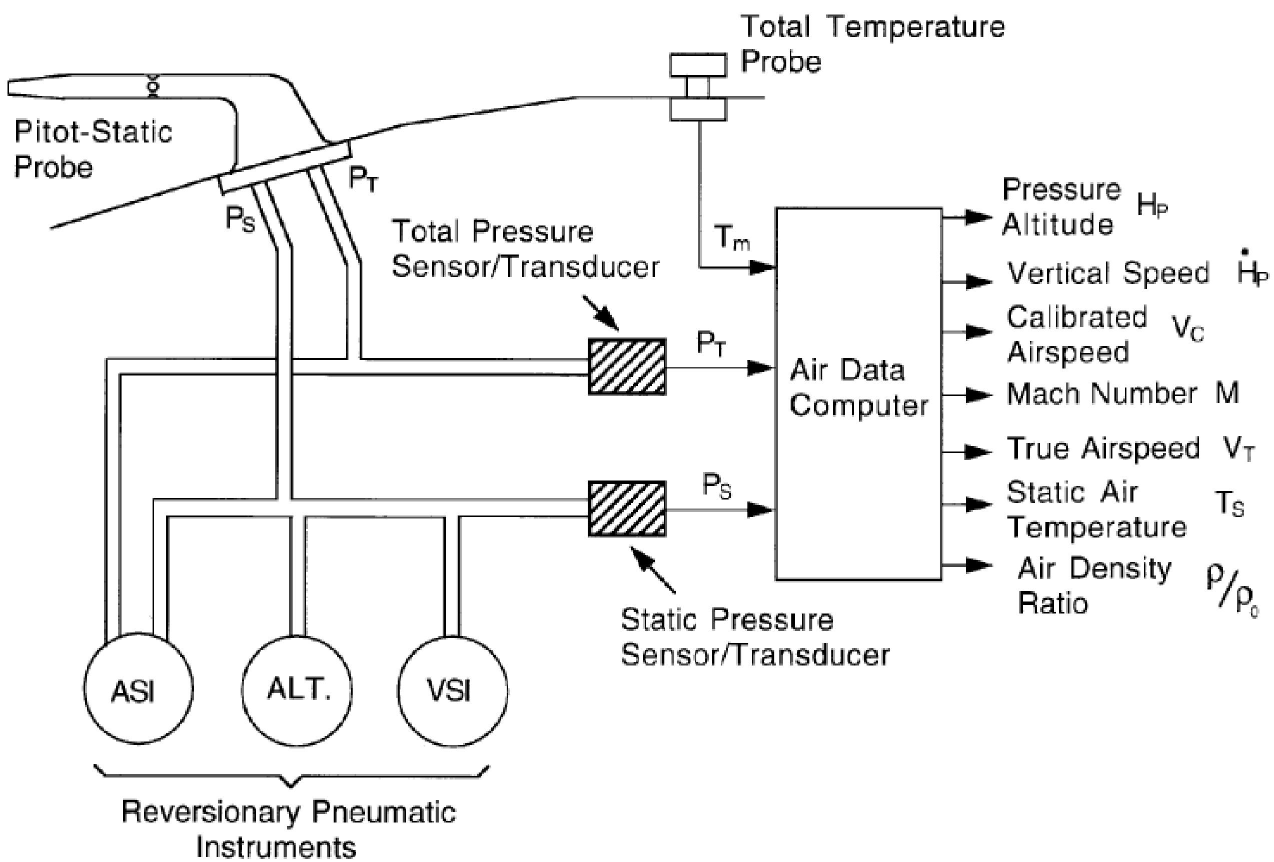


Vertical Speed Indicator (VSI)

ROC (Rate of Climb)



2. Air Data Management and Its Use



Basic Air Data Management

2. Air Data Management and Its Use

Air Data Measurement

- The **total pressure** is measured by means of an absolute pressure sensor (or transducer) connected to a Pitot tube facing the moving airstream.
- The **static pressure** of the free airstream is measured by an absolute pressure transducer connected to a suitable orifice located where the surface pressure is nearly the same as the pressure of the surrounding atmosphere.
- High performance military aircraft generally have a combined Pitot/static probe which extends out in front of the aircraft so as to be as far away as practicable from aerodynamic interference effects and shock waves generated by the aircraft structure.

2. Air Data Management and Its Use

Air Data Measurement

- Some civil transport aircraft have Pitot probes with separate static pressure orifices located in the fuselage generally somewhere between the nose and the wing.
- The exact location of the static pressure orifices (and the Pitot tubes) is determined by experience and experimentation.
- From the measurements of static pressure, PS , and total pressure it is possible to derive the following quantities:
  - **Pressure altitude**- derived from the static pressure measurement by assuming a 'standard atmosphere'.
  - **Vertical speed**- ~~basically derived by differentiating the static pressure.~~
  - **Calibrated airspeed** - derived directly from the dynamics pressure.

2. Air Data Management and Its Use

Air Data Measurement

- **Mach number, M-** the ratio of the true airspeed to the local speed of sound and is ~~derived directly from the ratio of the total pressure to the static pressure.~~ (True airspeed is defined as the speed of the aircraft relative to the air.)
- The third measurement, namely that of the measured (or indicated) air temperature is made by means of a temperature sensor installed in a probe in the airstream.
- The temperature assuming the air is brought totally to rest (i.e., recovery ratio = 1) is known as the total air temperature.

2. Air Data Management and Its Use

Air Data Quantities and Their Importance

- The pilot is presented with displays of the above air data quantities, all of which are very important at various phases of the flight or mission.
- However, the two basic quantities which are fundamental for the piloting of any aircraft from a light aircraft to a supersonic fighter are the **pressure altitude**, and the **calibrated airspeed**.
- *Pressure altitude* is the height of the aircraft above sea level derived from the measurement of the static pressure assuming a standard atmosphere.
- *Calibrated airspeed* is the speed which, under standard sea level conditions, would give the same impact pressure as that measured on the aircraft.

2. Air Data Management and Its Use

Air Data Quantities and Their Importance

- The critical speeds which affect the aircraft's behavior, controllability or safety are specified in terms of calibrated airspeed as this is independent of the air density variation with altitude or temperature.
- Such critical speeds include the **rotation speed for take off**, the **stalling speed** and the 'not to exceed' **speed in a dive** when the aerodynamic forces and moments exerted during the pull out would approach the structural limits of the airframe or the controllability limits would be reached.
- The Air Traffic Control (ATC) authorities also require very accurate measurement of the pressure altitude for air traffic control to ensure safe vertical separation in busy airways. Pressure altitude is therefore automatically reported to the ATC Ground Control by the ATC transponder.
- True airspeed information is displayed to the pilot for navigation purposes.

2. Air Data Management and Its Use

Air Data Quantities and Their Importance

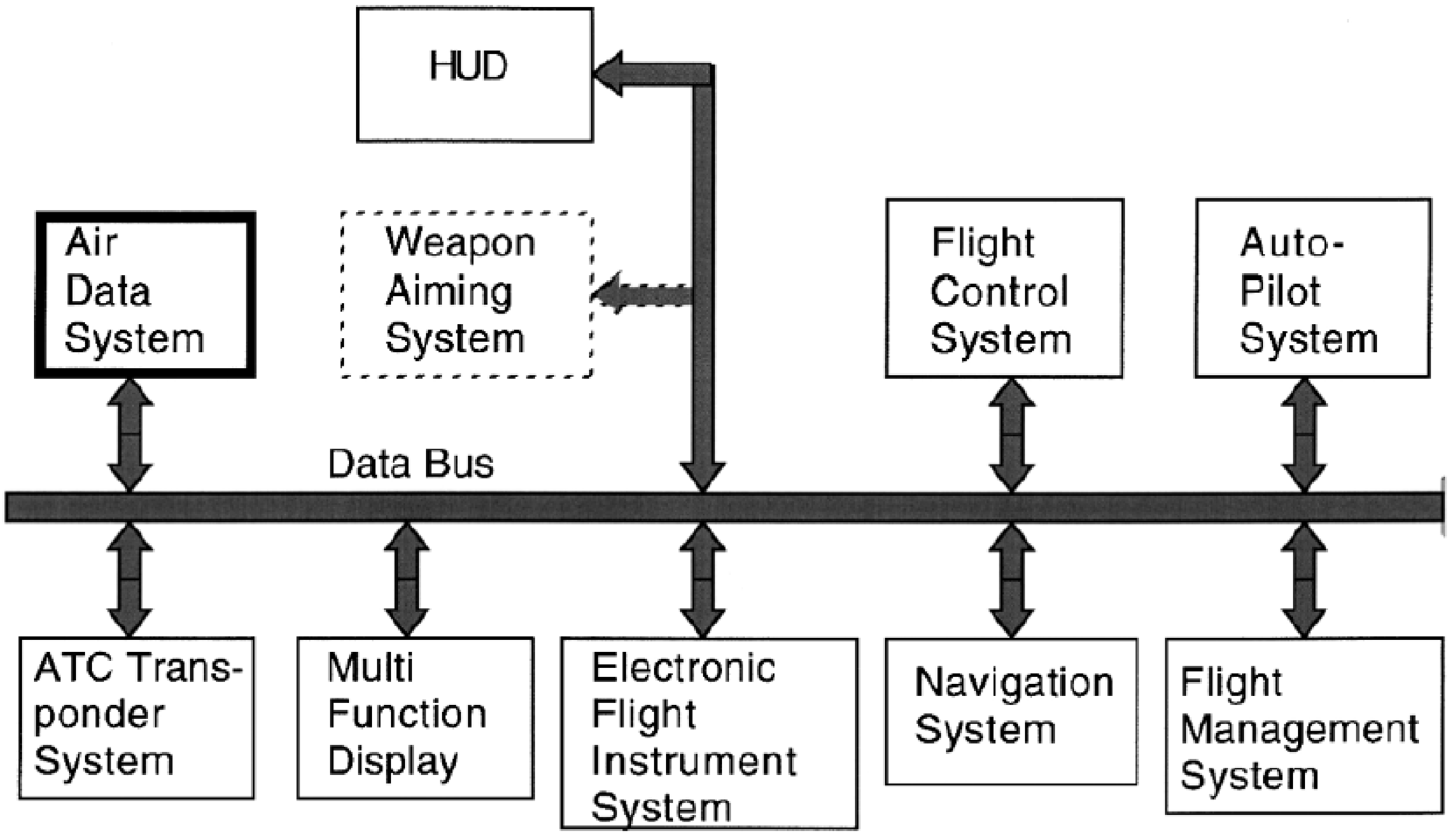
- The performance and controllability of the aircraft is dependent on the aircraft's Mach number in high speed regimen. Accurate information on the aircraft's Mach number is thus an essential display for the pilot.
- Rate of descent is particularly important during a ground controlled approach (GCA) where the pilot will set up a given rate of descent (and speed) in the approach to the airfield.
- The vertical speed indicator (VSI) display is also used during a turn to detect any tendency to lose height, the pilot applying appropriate corrective movements to the control column or 'stick' to hold a constant height turn.
- Airflow sensors to measure the angle of attack are thus frequently installed so that the pilot can monitor the situation and ensure the critical value is not reached.

2. Air Data Management and Its Use

Air Data Quantities and Their Importance

- Pressure altitude is supplied to the air traffic control (ATC) transponder for automatic reporting to the air traffic ground control system.
- The ATC authorities specify the flight levels which aircraft must maintain in 'controlled airspace' in terms of pressure altitude and these are set so that there is a minimum of 1,000 ft vertical separation between aircraft flying in the vicinity of each other.
- Calibrated airspeed and pressure altitude information is also required by the flight control system (FCS).
- A number of autopilot control modes require air data information, e.g., 'height acquire/hold', 'Mach number acquire/hold' and 'airspeed acquire/hold' (auto-throttle system).
- ~~Pressure altitude is required for navigation in the vertical plane. It can be combined (or mixed) with the inertially derived information from the INS to provide vertical velocity and altitude information which is superior to either source on its own.~~

2. Air Data Management and Its Use



Flow of Air Data to Key Avionic Sub-Systems (redundancy omitted)

2. Air Data Management and Its Use

Air Data Quantities and Their Importance

- The flight management system (FMS) requires information on all the air data quantities: pressure altitude, vertical speed, Mach number, static air temperature, true airspeed and calibrated airspeed.
- Height and calibrated airspeed information is required by the engine control systems.

2. Air Data Sensors and Computing

- The key air data sensors, as already mentioned, comprise two pressure sensors and a temperature sensor.
- The temperature sensor generally comprises a simple resistance bridge with one arm of the bridge consisting of a resistive element exposed to the airstream, the resistance of this element being a function of temperature. The siting of the probe and establishing the recovery factor, r, are the key factors of the sensor.
- The pressure sensors, however, have very high accuracy requirements and thus influence on the overall system accuracy, long term stability, reliability and overall cost.

2. Air Data Sensors and Computing

- Pressure sensors require an extremely high accuracy (which will be explained shortly) and involve a long expensive development to establish and qualify a producible, competitive device.
- Like most sensors, they not only sense the quantity being measured but they can also be affected by:
  - Temperature changes
  - Vibration
  - Shock
  - Acceleration
  - Humidity, etc.
- The art of sensor design is to minimize and if possible eliminate these effects on the sensor.

2. Air Data Sensors and Computing

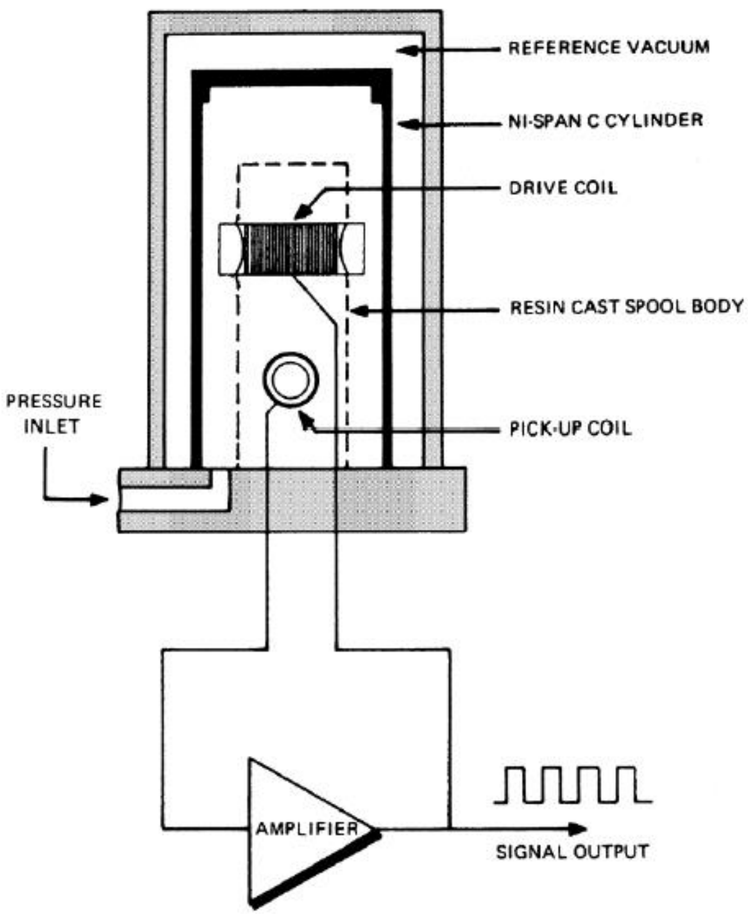
Pressure Sensor Technology

- Two basic types of pressure sensor have now become well established in modern digital air data systems:
- **Vibrating pressure sensors**
  - The basic concept of this family of sensors is to sense the input pressure by the change it produces in the natural resonant frequency of a vibrating mechanical system.
  - The output of the sensor is thus a frequency which is directly related to the pressure being measured. This confers a significant advantage as it enables a very simple and very accurate interface to be achieved with a micro-processor for the subsequent air data computation.

MEMS Manufacturing Technology:
https://www.youtube.com/watch?v=EALXTht-stg

2. Air Data Sensors and Computing

Pressure Sensor Technology



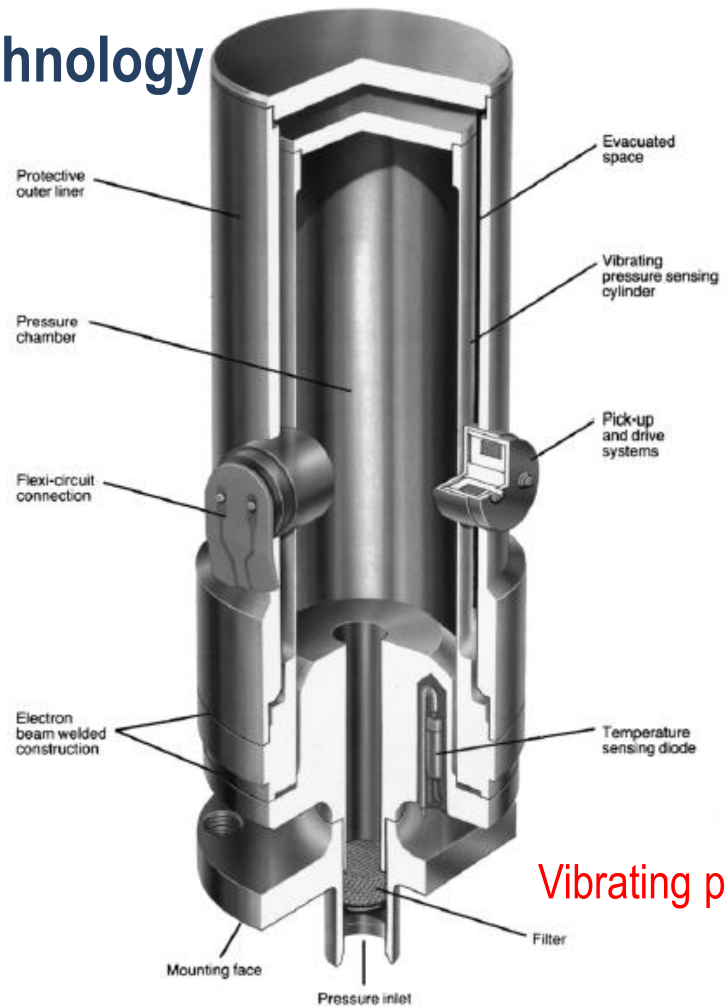
- The pressure sensing element consists of a thin walled cylinder with the input pressure acting on the inside of the cylinder and with the outside at zero vacuum reference pressure.

- The cylinder is maintained in a hoop mode of vibration by making it part of a feedback oscillator by sensing the cylinder wall displacement, processing and amplifying the signal and feeding it back to a suitable force producing device.

Vibrating pressure sensor schematic.

2. Air Data Sensors and Computing

Pressure Sensor Technology

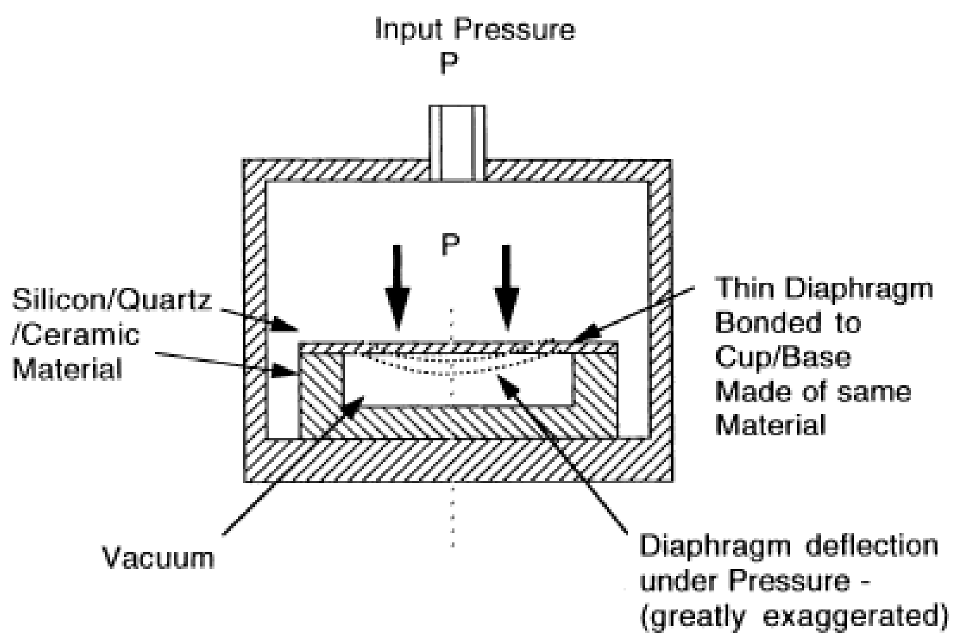


Vibrating pressure sensor.

2. Air Data Sensors and Computing

Pressure Sensor Technology

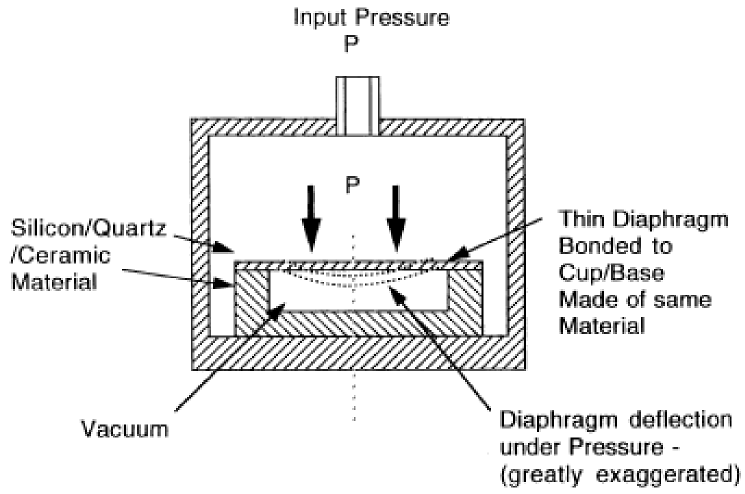
- Solid state capsule pressure sensors
  - This type of pressure sensor consists essentially of a capsule with a relatively thin diaphragm which deflects under the input pressure. They are fabricated from materials such as silicon, quartz, fused silica, or special ceramics.



2. Air Data Sensors and Computing

Pressure Sensor Technology

- The deflection of the diaphragm is linear with input pressure but is also very small and a number of techniques are used to measure this deflection.
- Semi-conductor technology is used in the fabrication of these sensors and this together with the absence of moving parts has led to the description 'solid state'.
- The technology also enables very small sensors to be fabricated with excellent repeatability
- because of the semi-conductor processes used.



2. Air Data Sensors and Computing

Pressure Sensor Technology

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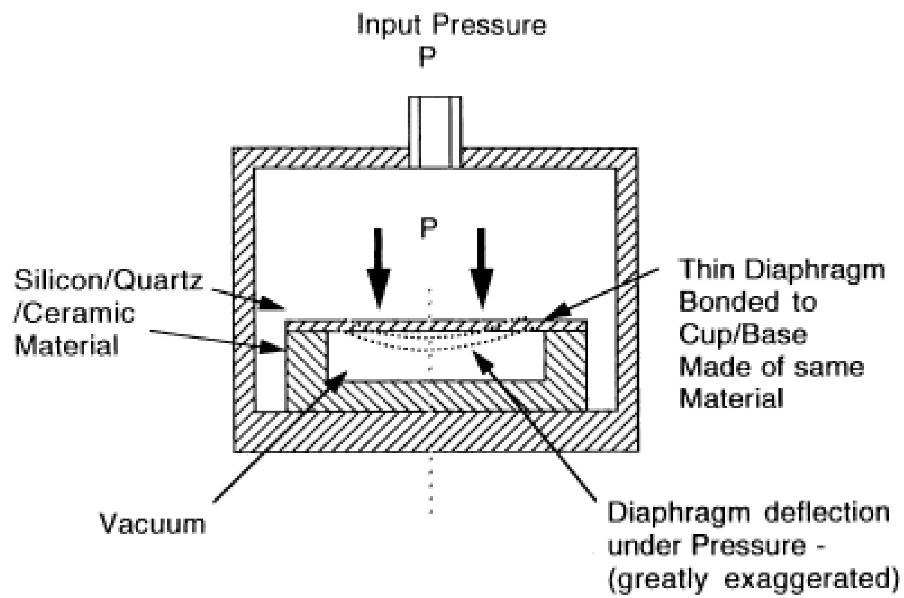
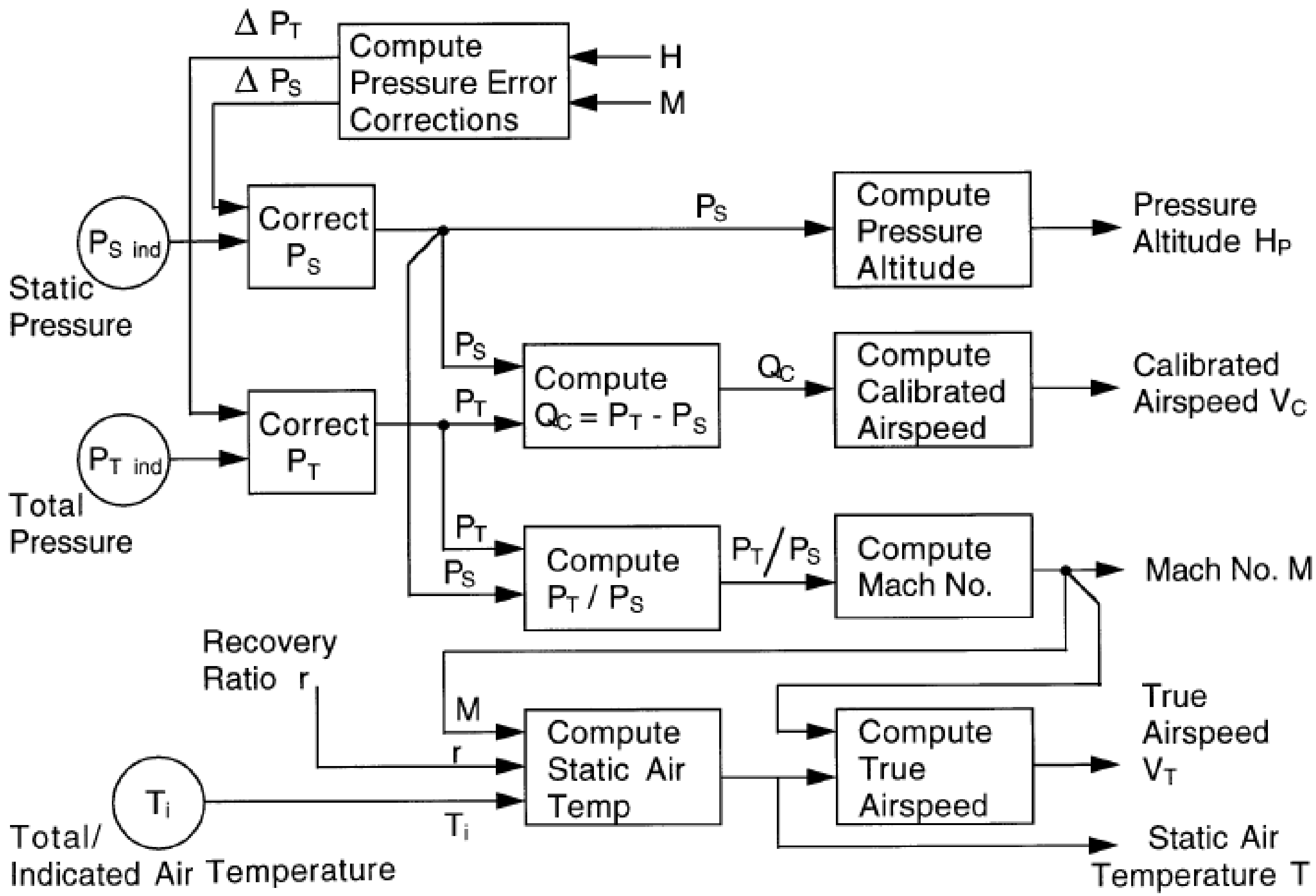


2. Air Data Sensors and Computing

Angle of Incidence Sensor

- A typical incidence sensor comprises a small pivoted vane suitably located on the aircraft fuselage near the nose of the aircraft. The vane is supported in low friction bearings so that it can align itself with the incident airflow under the action of the aerodynamic forces acting on it, like a weather vane.
- It is also possible to locate the Pitot probe on the vane together with the static pressure orifices to form an integrated unit which together with the appropriate sensors measures angle of incidence, total pressure and static pressure.
- This type of integrated Pitot probe/incidence vane is being adopted on several new high performance aircraft as it minimizes incidence contamination effects on the pressure measurements at high angles of incidence as well as providing a compact integrated solution.

2. Air Data Sensors and Computing



Air Data Computational Flow Diagram.