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Department of Electronics and Instrumentation Engineering

22EIT603D Aircraft Instrumentation

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Unit-I

An aircraft is a vehicle designed to travel through the air by generating lift or thrust, typically using wings, rotors, or jet propulsion. Aircraft are used for transporting people and goods, military operations, scientific research, and recreation.

Key characteristics of an aircraft:

- Operates within Earth's atmosphere
- Capable of controlled flight
- Uses aerodynamic forces (lift, thrust, drag, and weight)

Common types of aircraft:

- **Airplanes** (fixed-wing)
- **Helicopters** (rotary-wing)
- **Gliders**
- **Drones (UAVs)**
- **Airships and balloons**

Aircraft Instrumentation:

A coordinated group of instruments that provide the flight crew with information about the aircraft and its subsystems.

Crew: A group of 6 to 8 people working in an aircraft

These instruments provide:

– Flight situation of the aircraft

– Direction

– Attitude

– Altitude

– Airspeed

Figure 10-7. *An engine instrumentation located in the middle of the instrument panel is shared by the pilot and co-pilot.*

5 Main Components of an Aircraft

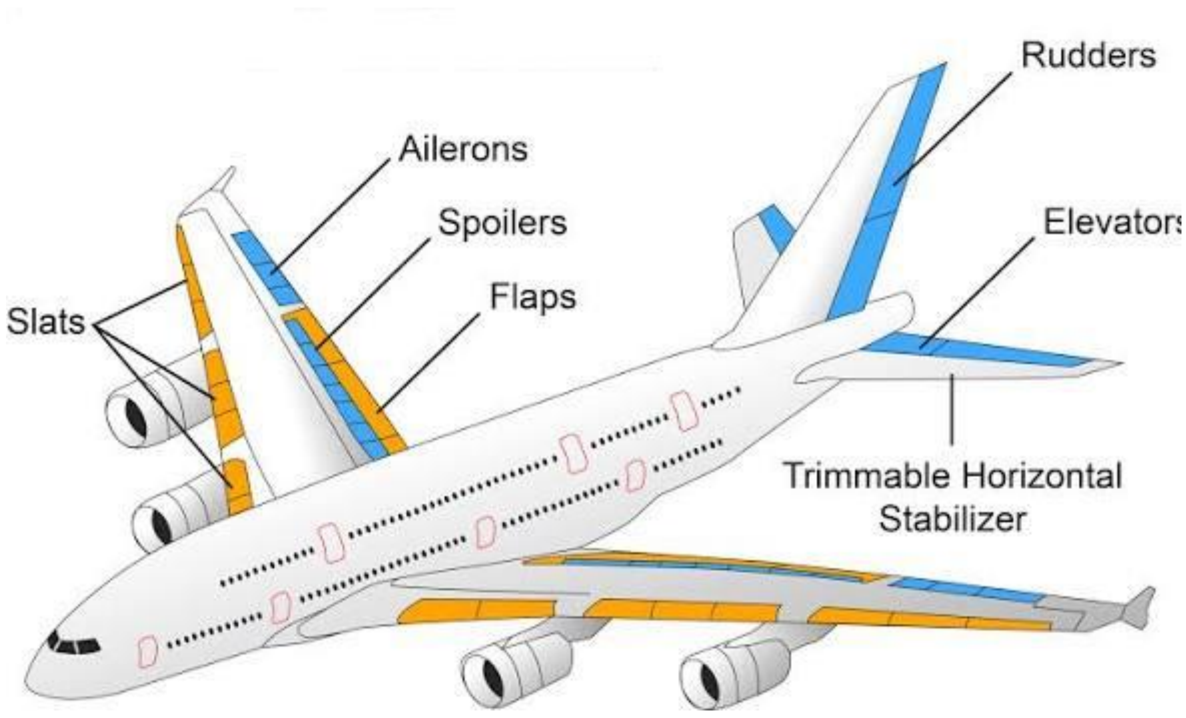
Fuselage
The main hollow tube that holds passengers and cargo, also known as the body of the airplane.

Wings
Also known as foils, the wings generate the lifting force needed for flight. The wings are in the middle and back of the airplane.

Empennage
The tail end of the aircraft is the empennage, which helps with stability using assistance from the rudder and elevator.

Power Plant
The engine and propeller make up the power plant.

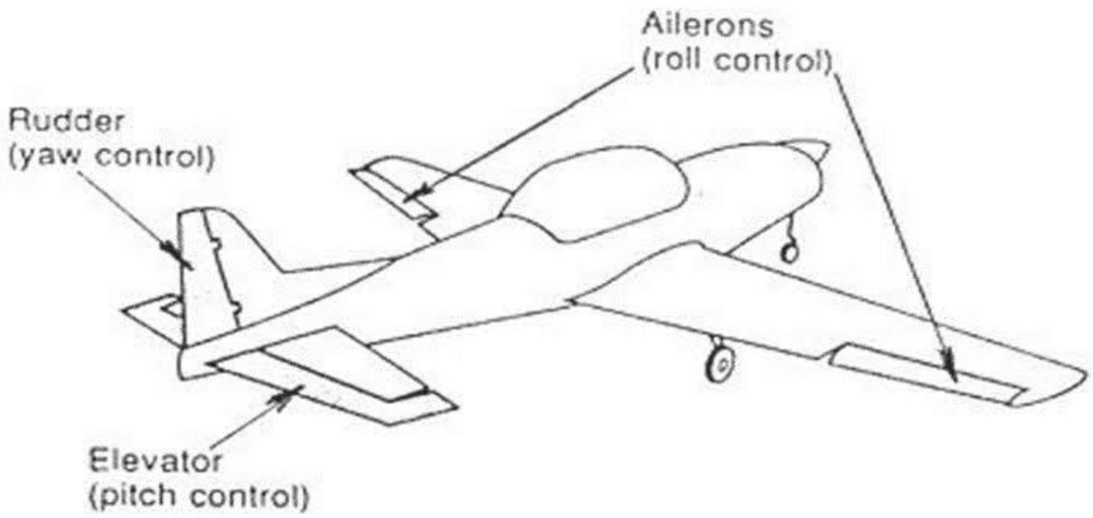
Flight Control surfaces:



- **Primary control surfaces:**

The three primary aircraft control surfaces are the **ailerons, elevators, and rudder,** which control the aircraft's roll (around the longitudinal axis), pitch (around the lateral axis), and yaw (around the vertical axis), respectively, enabling the pilot to move the aircraft safely.

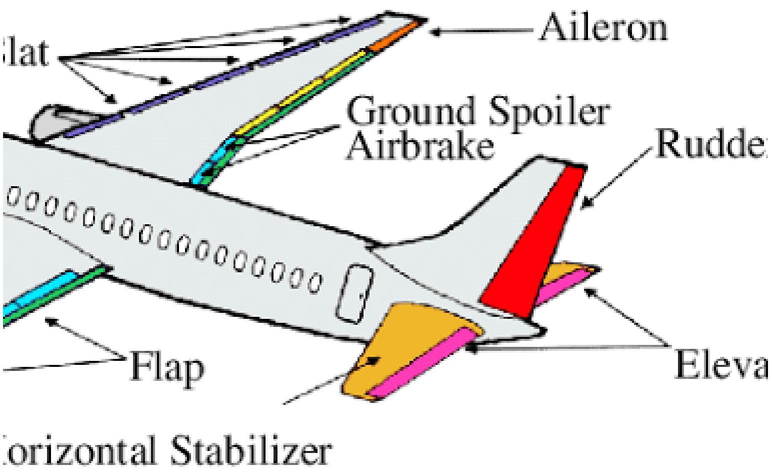
- The **ailerons** control the rolling motion of the aircraft through the longitudinal axis.
- The **elevator,** which controls the pitch of the aircraft through the lateral axis.
- The **rudder controls** the yaw of the aircraft through the vertical axis of the aircraft.

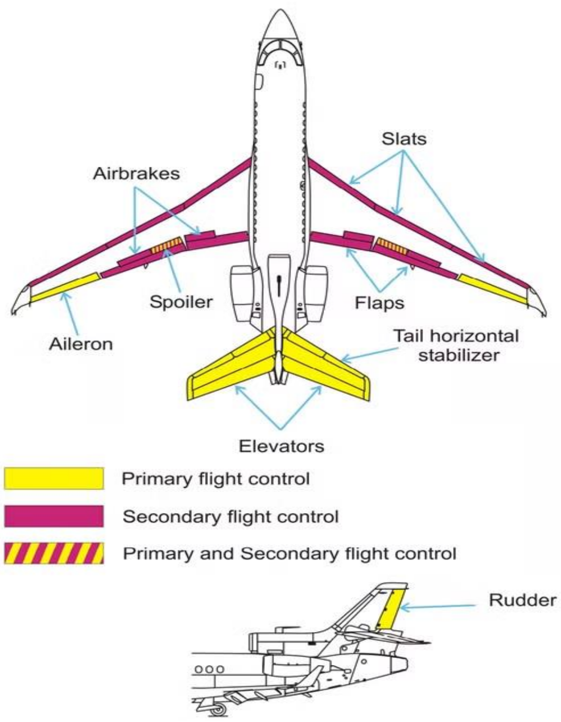


- **Secondary control surfaces:**

  Secondary control surfaces on aircraft, like flaps, slats, spoilers, and trim tabs, aren't essential for basic flight but improve performance, efficiency, and safety by modifying lift and drag for takeoff, landing, and descent.

- The flaps and slats help to slow down the aircraft for landing and help to reduce the ground roll on take-off.
- The trim control surfaces reduce the effort the pilot has to apply to fly the aircraft.
- Spoilers and speed brakes assist the pilot in roll and speed and lift reduction.





Forces of flight:

Aircraft basics involve the four forces of flight (Lift, Weight, Thrust, Drag) and key components like the fuselage, wings (airfoils), tail (empennage), engines, and landing gear, all working together through aerodynamics, where wings generate lift as air flows over them, overcoming gravity and allowing propulsion (thrust) to move the plane forward against air resistance (drag).

The Four Forces of Flight

- **Lift:** Upward force generated by wings, creating lower pressure above the wing and higher pressure below.
- **Weight:** Downward force due to gravity.
- **Thrust:** Forward force from engines (propellers or jets).
- **Drag:** Backward force opposing thrust, caused by air resistance.

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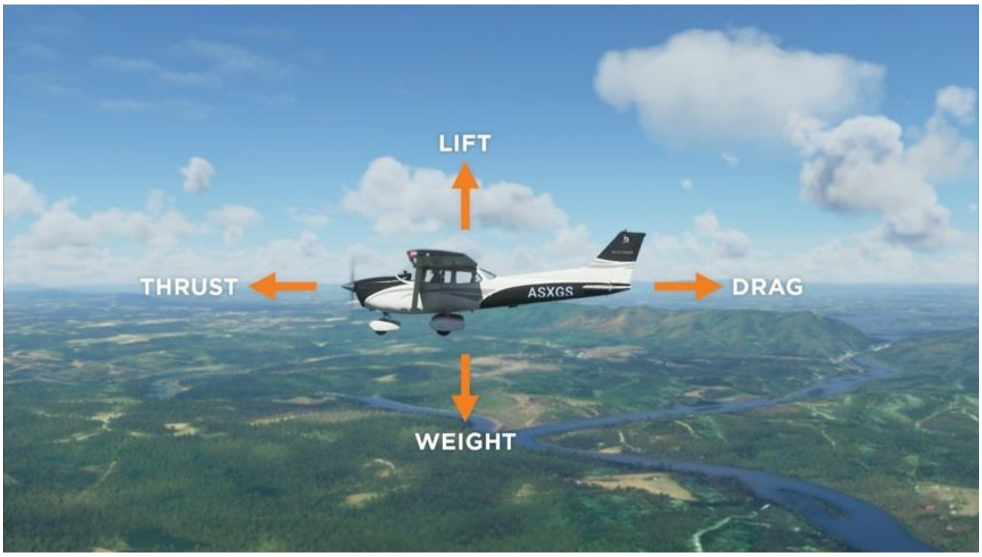
https://youtu.be/ojHFu3R_JM0

Working of an aircraft

1. **Lift**: While in flight, the airplane is supported by lift. Lift is the force acting opposite of gravity and is generated whenever air flows smoothly over a wing. As air flows over and under the wing, an area of low pressure is created above the wing, acting to pull the airplane up. When lift exceeds gravity, the aircraft will leave the ground and climb.
2. **Weight**: Weight is caused by gravity and acts to pull the airplane toward the ground.
3. **Thrust**: The airplane's propeller acts like a wing turned on its side. In this case, the lift is known as thrust, and the low pressure in front of the propeller pulls the airplane forward, much as the engine and propeller of a ship provide thrust in the water.
4. **Drag**: Drag is the force that opposes thrust. It's the same force you feel if you extend your arm out of the window of a fast-moving car. As you might imagine, drag increases as speed increases.



Flight Controls and Movement

Pilots control the aircraft's "attitude" (orientation) across three axes using primary control surfaces:

- Pitch (Lateral Axis): Controlled by elevators on the tail. Moving the nose up or down allows the plane to climb or descend.

  “Pitching” is the nose-up or nose-down movement of the aircraft. The pilot controls aircraft pitch by moving the elevator.

- Roll (Longitudinal Axis): Controlled by ailerons on the outer rear edges of the wings. They allow the plane to bank left or right for turns.

  “Rolling” is the left or right banking motion of an aircraft. The pilot moves the ailerons to roll the aircraft left or right for turns, just as a cyclist would lean left or right in a smooth turn.

- Yaw (Vertical Axis): Controlled by the rudder on the vertical stabilizer. It moves the nose left or right, often used in coordination with ailerons for smooth turns.

  “Yawing” refers to moving the nose of the airplane left or right. The pilot banks into a turn with the ailerons and moves the nose in the proper direction with the rudder. It is possible to turn an aircraft using rudder or aileron alone, but the turn is smoother and what pilots call “coordinated”—if both controls are used.

- High-Lift Devices: Flaps and slats are extended during takeoff and landing to increase lift at lower speeds, allowing the aircraft to fly safely while moving slowly.

https://www.aopa.org/training-and-safety/online-learning/safety-spotlights/pinch-hitter/the-basics-of-flight

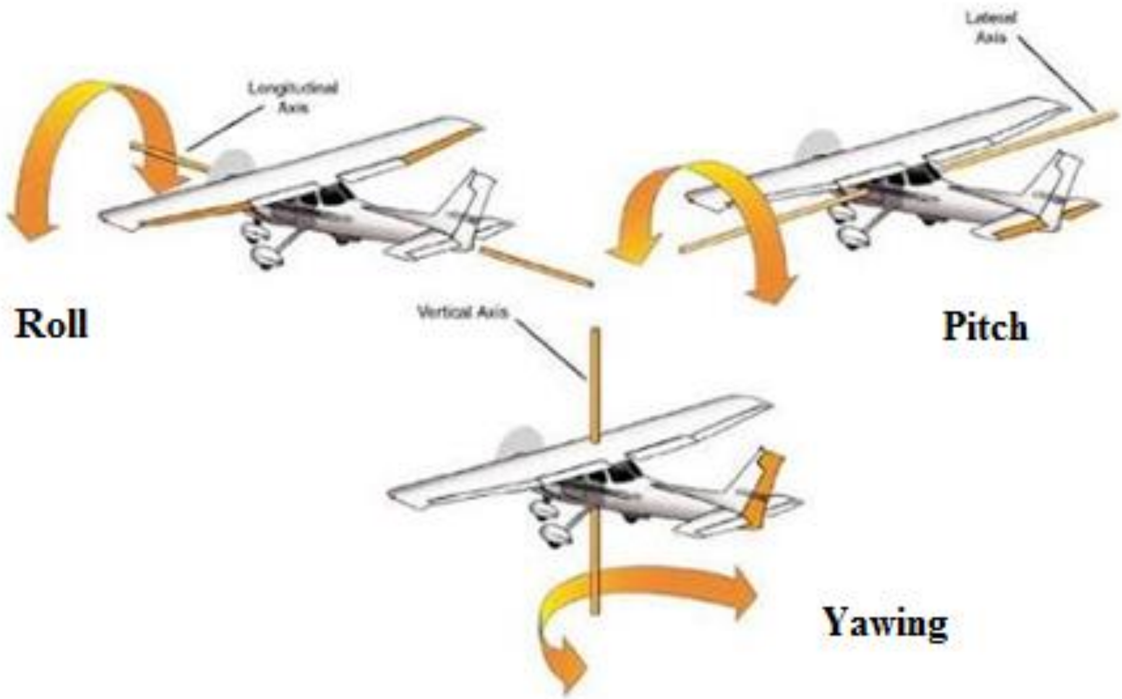


FIG 03-27

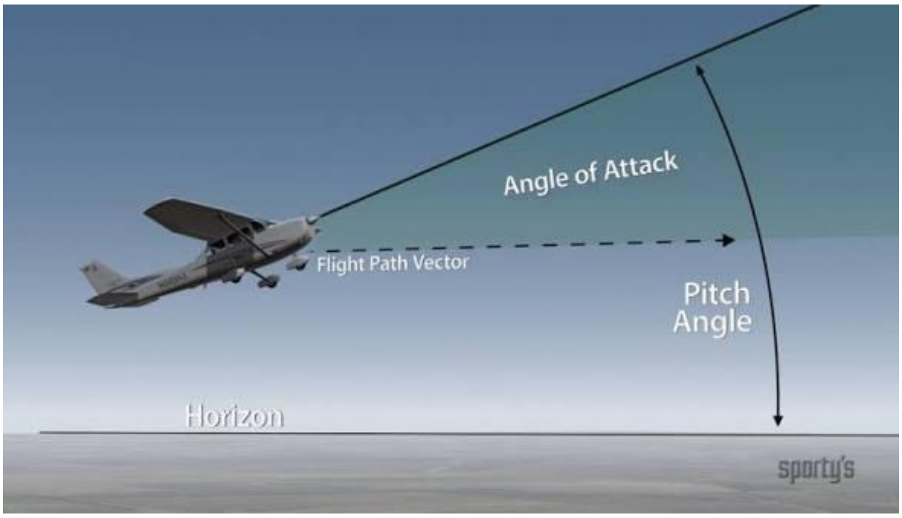
Guided Flight Discovery Private Pilot Manual

Angle of Attack (AoA) in an Aircraft

The Angle of Attack (AoA) **is the** angle between the wing's chord line (an imaginary straight line from the leading edge to the trailing edge of the wing) and the relative airflow (the oncoming air).

Key Points

- AoA determines how much lift a wing produces.
- Increasing AoA → more lift, up to a certain limit.
- If AoA exceeds the critical angle of attack, the wing stalls(loss of lift) and lift decreases sharply.
- AoA is independent of aircraft speed—a stall can occur at any speed if the critical AoA is exceeded.



The angle of attack (AOA) is the angle between an airfoil's chord line (an imaginary straight line from the leading edge to the trailing edge) and the relative wind.

Engine Control

Throttle: The throttle controls the amount of air entering the engine. Treat the throttle like a gas pedal in a car: push it in to go faster and pull it out to go slower.

Mixture: The mixture controls the fuel to air ratio mixture in the engine. Pilots "**lean the mixture**" (reducing the amount of fuel relative to air) to keep the engine running efficiently at high altitudes.

History of aircraft

- **Early Ideas of Flight**

Humans observed birds and imagined flying, leading to early concepts and designs.

- **Balloon and Glider Era**

Balloons and gliders showed that flight was possible using air support and lift.

- **First Powered Flight (1903)**

  The **Wright brothers** achieved the first controlled, powered aircraft flight.

- **War and Commercial Development**

  World Wars improved aircraft speed and strength; later aircraft were used for passenger transport.

- **Modern Aviation**

  Aircraft use jet engines, advanced materials, automation, and unmanned systems.

Fig: Wilbur Wright executes a banking turn to the right in the first fully controllable glider, at the Kill Devil Hills, North Carolina, October 24, 1902.

FLIGHT DECK CONTROLS

https://www.aopa.org/training-and-safety/online-learning/safety-spotlights/pinch-hitter/flight-deck-controls

Aircraft instruments and their layout

1. **Airspeed Indicator:** The airspeed indicator is like the speedometer in the car. (Reads: 122 knots)
2. **Attitude Indicator:** The attitude indicator, sometimes called an **artificial horizon**, shows the airplane's pitch and bank in relation to the horizon. **(Shows level flight)**
3. **Altimeter:** The altimeter shows the aircraft's height above mean sea level (msl). (Reads: 3,000 feet msl)

4. **Heading Indicator:** The heading indicator shows the direction the aircraft is flying. (Reads: 150 degrees)
5. **Vertical Speed Indicator:** The vertical speed indicator (VSI) shows the rate in feet per minute that the aircraft is going up or down. For most airplanes, a comfortable rate of climb or descent is between 500 and 1,000 feet per minute. (Reads: 0 fpm descent)
6. **Tachometer**: The tachometer indicates how much power the engine is producing. (Reads: 2600 rpm)
7. **Fuel Gauges:** Most general aviation aircraft have one fuel tank in each wing, but airplane may have more. This gauge shows how much fuel is in each tank. (Reads: 11 gallons (left tank) 12 gallons (right tank))

Aviation English

MSL—Mean sea level. This is the aircraft height above sea level and is measured by the altimeter.
AGL—Above ground level. This is the distance between the aircraft and the ground. This distance is generally determined from the MSL altitude minus the estimate ground height.

Knots—Most airspeed indicators measure airspeed in knots. When you are flying 100 knots it means you will travel 100 nautical miles in one hour. 100 nautical miles = 115 statute (normal) miles. So, if your airplane is flying at 100 knots, its speed is 115 mph. Some older aircraft have airspeed indicators that read in mph.

<u>Instrument location in cockpit</u>

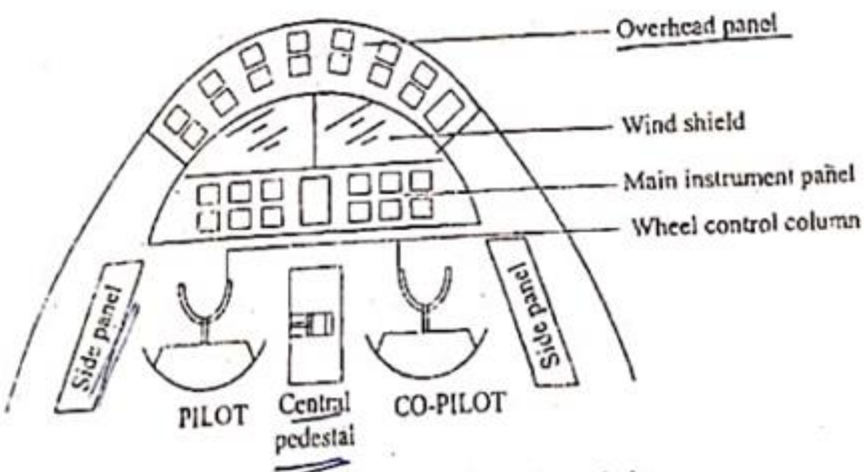


Fig. 2.1 Instrument location in a cockpit.

Figure 2.1, illustrates the general instrument location in an aircraft cockpit. The text refers to various locations for instruments, including the main instrument panel directly in front of the pilot and co-pilot, the overhead panel, side panels, and the central pedestal.

Cockpit Layout

Overhead panel: Located above the windshield, housing various system controls like electrical, hydraulic, and lighting systems.

Windshield: The primary visual reference for a pilot during visual flight rules (VFR) flight.

Main instrument panel: Positioned in front of the pilots, this area typically houses the primary flight instruments, often arranged in a standardized "Basic Six" or "Basic T" configuration.

Wheel control column: The primary control for aircraft pitch and roll.

Side panel: Locations on the side of the cockpit for additional controls or less frequently used instruments.

Central pedestal: Located between the pilot and co-pilot, it often contains engine controls (throttle, mixture), communication and navigation radios, and trim controls.

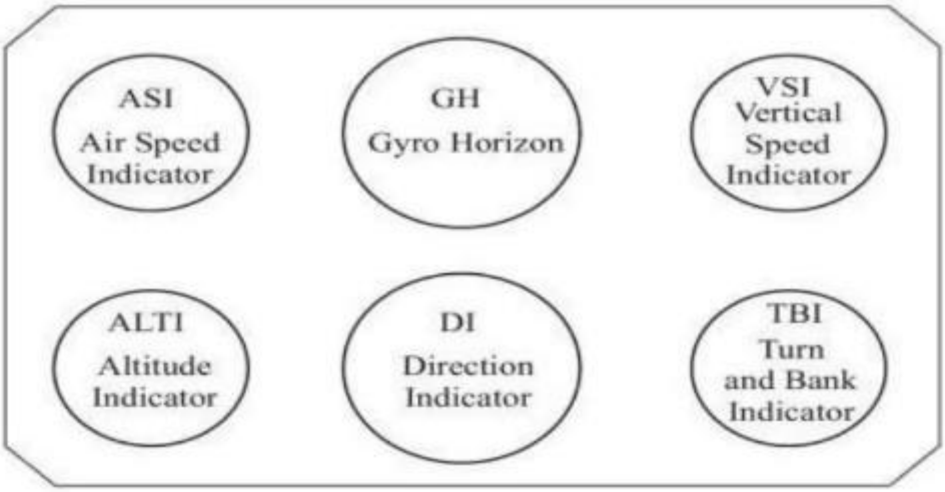
Aircraft instruments provide critical flight data, grouped into the **"Basic Six"** (Attitude, Airspeed, Altimeter, Heading, Vertical Speed, Turn Coordinator) arranged in a standard **"T-layout"** on the panel for easy scanning, supplemented by engine, navigation, and system gauges, with modern cockpits using integrated "glass cockpits" that display this info electronically.

The "Basic Six" (Instrument Flying Panel)

These six instruments form the **core of flight information**, typically arranged in a "T" shape on the instrument panel:

- **Airspeed Indicator (ASI):** Displays speed in knots relative to the air.
- **Attitude Indicator (Gyro Horizon):** Shows the aircraft's orientation (pitch and roll) relative to the horizon.

- **Vertical Speed Indicator (VSI):** Shows the rate of climb or descent in feet per minute
- **Altimeter:** Shows altitude above sea level.
- **Heading Indicator (Directional Gyro):** Shows the aircraft's direction (heading).
- **Turn Coordinator/Turn & Bank Indicator:** Shows the rate of turn and the quality of the turn (coordination).



Basic six grouping of aircraft instruments in earlier aircraft

Basic T arrangement:

After reviewing modern instruments, requirements of newer generation of aircraft, and pilot feedbacks, designers arrived at this “basic T” grouping of most important flight instruments required for safely flying the aircraft, without much effort and eye scan by the pilots. Most important indicators are: Air Speed Indicator (ASI), Attitude Director Indicator (ADI) and Altitude Indicator – ALTI, which form the horizontal bar of T. Horizontal Situation Indicator (HSI) is at the centre, and makes up the vertical bar of T, as shown in Fig.

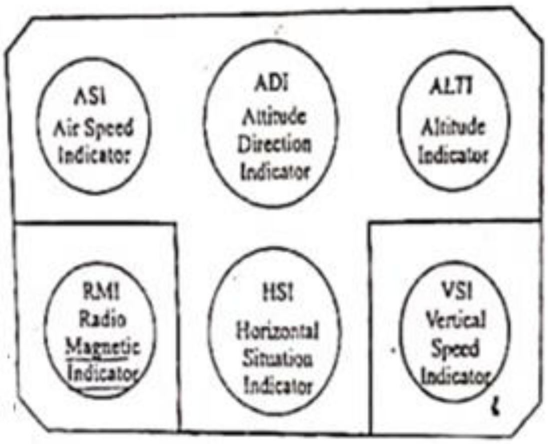


Fig. 2.3 Basic T arrangement of aircraft instruments.

Magnetic Indicator (RMI) is located on the left side of HSI, and gives: (i) magnetic heading derived from flux gates which **detect the direction of the aircraft** with reference to earth's magnetic field, and

(ii) **Bearings to two radio stations located on the ground**, hence the joint name Radio and Magnetic Indicator or Radio Magnetic Indicator. In some designs, RMI position is filled up by a TBI—the Turn and Bank Indicator or by another instrument of recent origin called as Turn Coordinator (TC).

<u>Classification of aircraft instruments:</u>

The most common forms of data display are:

a) Quantitative display:

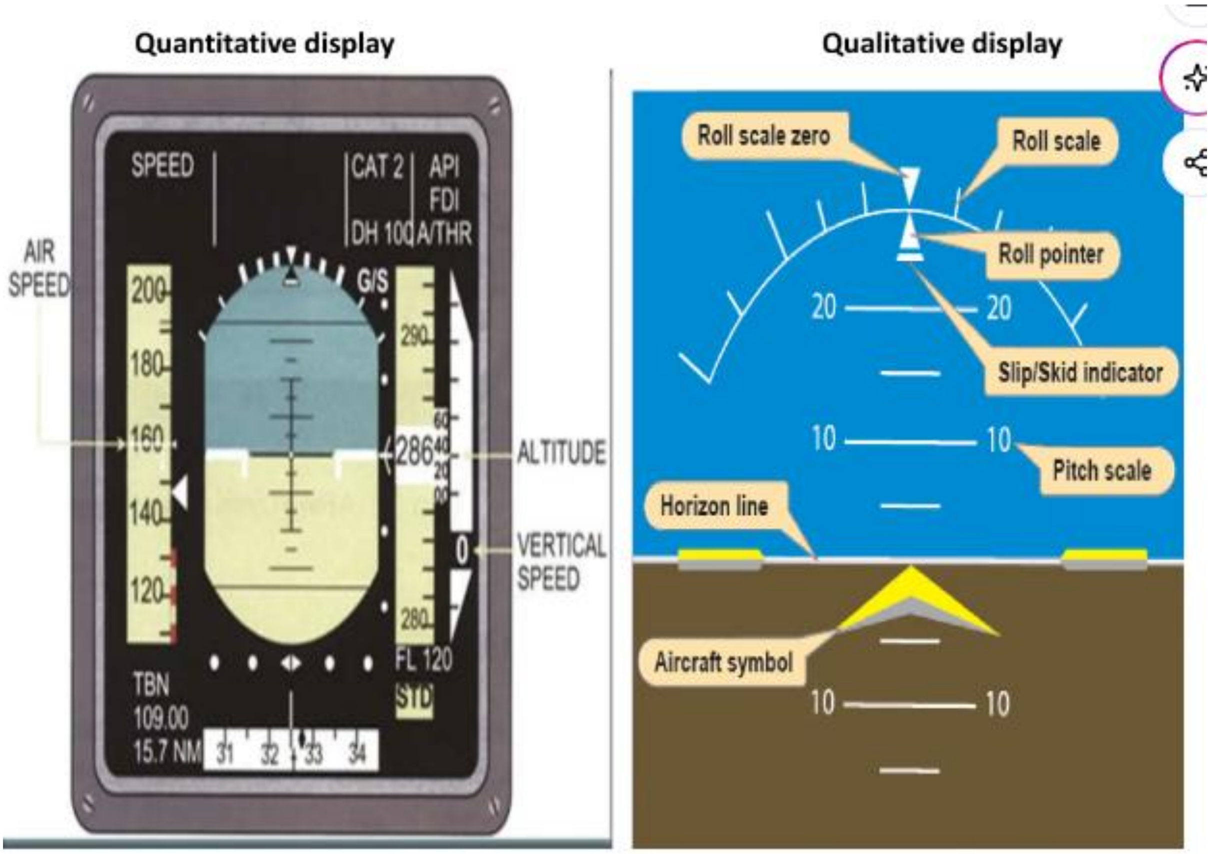
Variable quantity which is measured is presented in terms of a **numerical value** by moving the pointer or index over a graduated scale.

Example – airspeed

b) Qualitative display:

Data (changes in parameters measured) is presented in **symbolic or pictorial format**.

Example – flight situation



The factors that govern the choice of scale length for a particular range are:

- Size of the instrument
- Accuracy with which it needs to be read
- Conditions under which it is to be observed

Quantitative displays:

There are three principal methods by which data may be displayed:

i) **Circular Scale** – clock type of scale

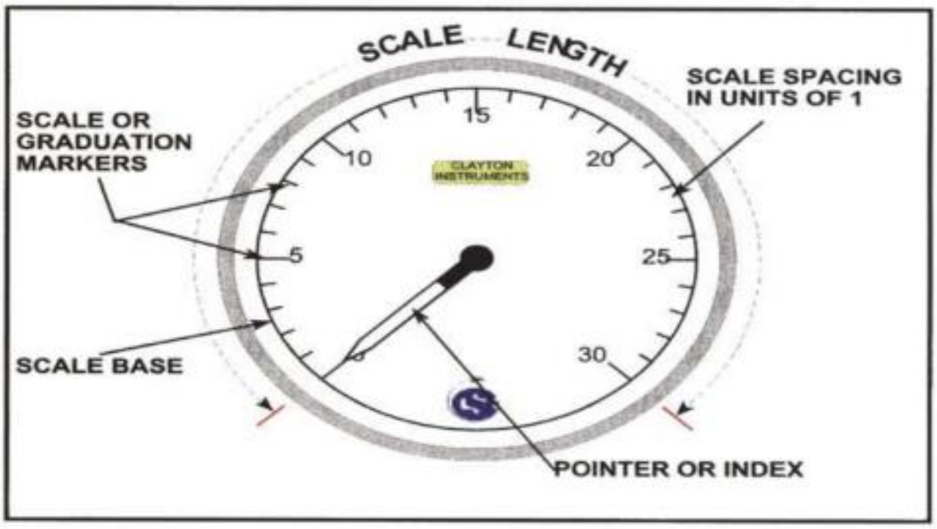
ii) **Straight Scale**

iii) **Digital, or Counter**

i) Circular scale:

Classical method of displaying data in quantitative form.

A simple indicator showing the change of value of the parameter to be measured over a range of 0 to 30.

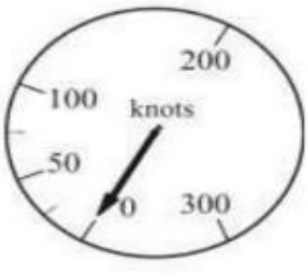


• In circular displays, again there are two types:

- **Linear displays**
- **Non-linear displays**

Square-law: Airspeed

Logarithmic: Rate of altitude change



Square law

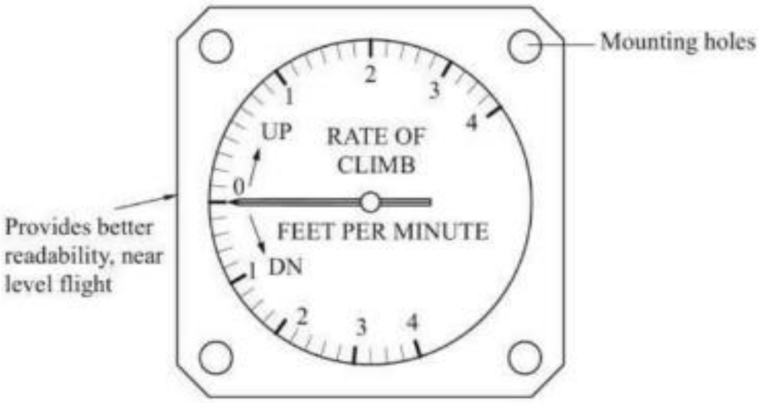


Fig. 2.8 Vertical speed indicator—logarithmic scale.

High Range long-scale displays

b) Concentric Scales
c) **Fixed and Rotating Scales**
d) **Common Scale and Triple Pointers**

Concentric Scales

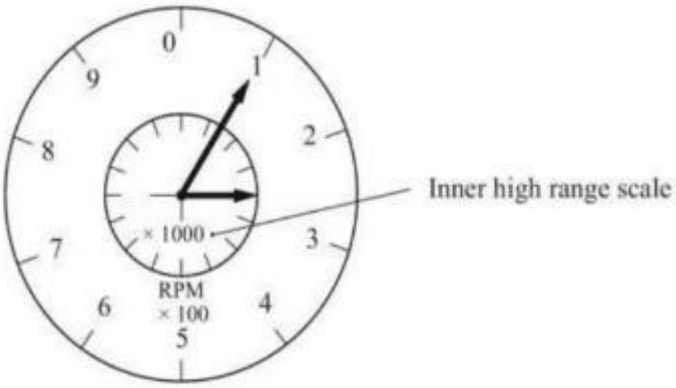
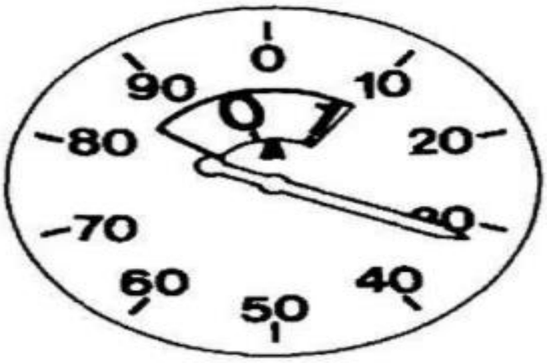


Fig. 2.6 Concentric scale, in RPMI.

Example: engine speed Indicator

b) Fixed and Rotating Scales

- Used in pneumatic airspeed indicator
- single pointer rotates against a circular scale a drives a second scale plate instead of a pointer.
- This rotating plate records hundreds of knots as the pointer rotates through complete revolutions.



(b)

c) Common scale and triple pointers

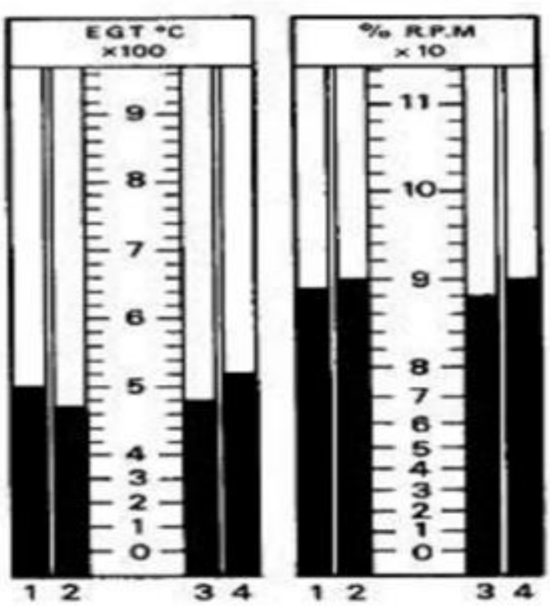
- Used in altimeter
- Large pointer indicates hundreds
- Intermediate pointer indicates thousands
- Small pointer indicates tens of thousands of feet

ii) Straight scale:

• The advantages of using straight scale; saving panel space and improved observational accuracy

• EGT – Exhaust Gas Temperature

Engine No.	E.G.T. °C	% R.P.M.
1	500	89
2	470	90
3	480	88
4	520	90



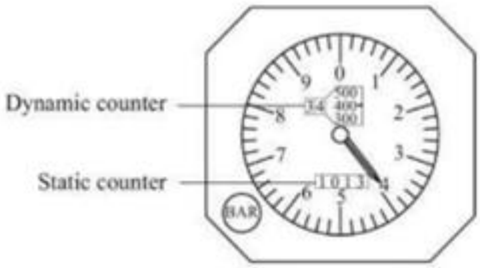
• Each display unit contains a servo-driven white tape in place of a pointer, which moves in a vertical plane and registers against a scale in similar manner to the mercury column of a thermometer.

• There is one display unit for each parameter, the scales being common to each engine in the particular type of aircraft.

iii) Digital display:

• A digital, or counter, type of display is one that is generally to be found operating in conjunction with the circular type of display.

• The presentation of altitude data by means of a scale and counter is another method of solving the long-scale problem.

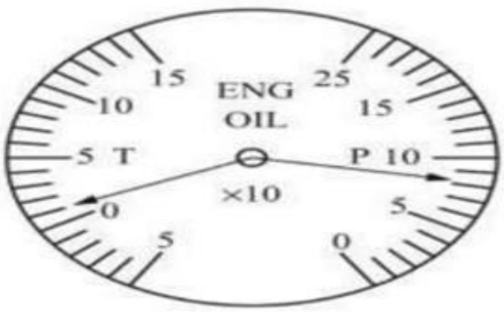


(d) Digital counter display
(Altitude)

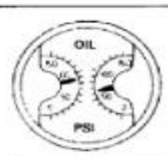
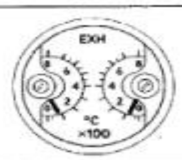
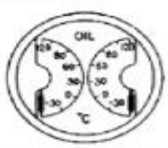
(c) Digital display
(Total air temperature)

Dual-indicator display

• These displays are designed for conserving panel space, particularly where the measurement of various quantities related to engines is concerned.



(e) Dual indicator
(to conserve space)

MEASUREMENT	PRESENTATION
A. TWO DIFFERENT QUANTITIES OF ONE SYSTEM	
B. SAME QUANTITY OF TWO DIFFERENT SYSTEMS	
C. SAME QUANTITIES OF TWO IDENTICAL SYSTEMS	  

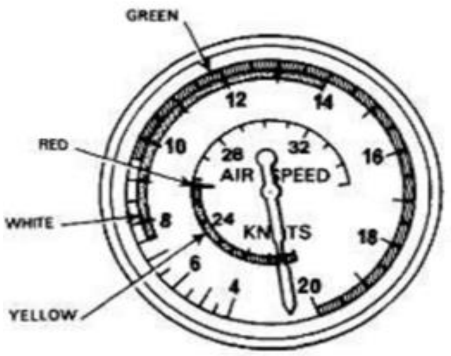
Operational range Markings (Coloured Displays)

• These markings take the form of coloured arcs, radial lines and sectors applied to the scales of instruments.

• Their purpose is to highlight specific limits of operation of the systems with which the instruments are associated.

The definitions of these marks are as follows:

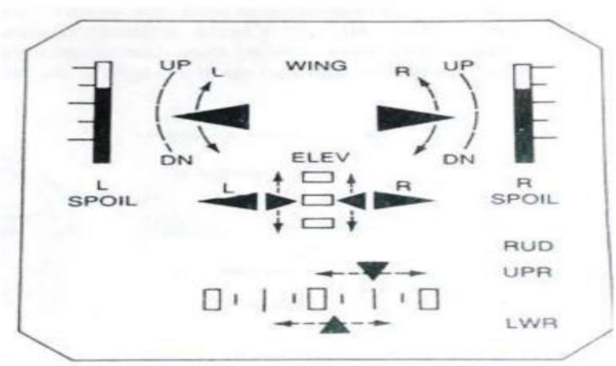
RED radial line: Maximum and minimum limits
YELLOW arc: Take-off and precautionary ranges
GREEN arc: Normal operating range
RED arc: Range in which operation is prohibited

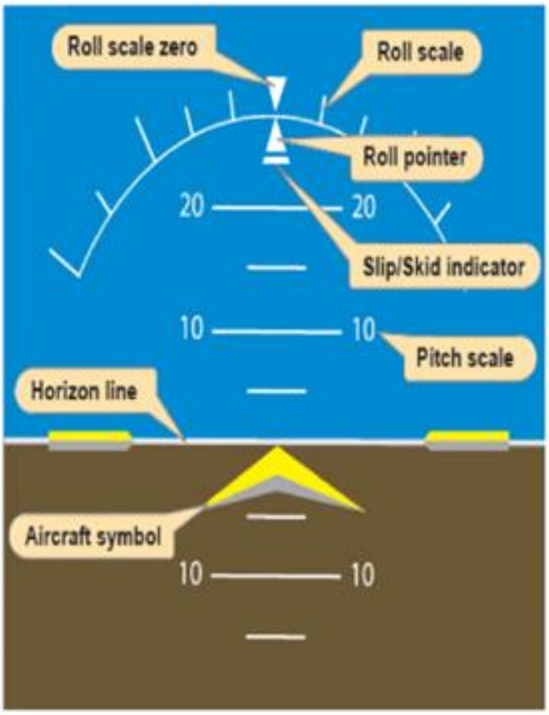


Qualitative displays:

• These are special type of displays in which information is presented in a symbolic pictorial form to show the condition of a system.

• It shows whether the value of an output is increasing or decreasing, or it shows the movement of flight control surfaces.





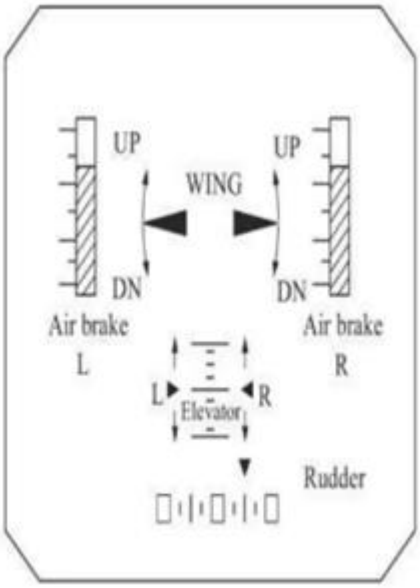


Fig. 2.10 Some qualitative displays in position indicators.

Basics of Director displays:

These displays are associated with the monitoring of flight attitude and navigational data, and present it to the flight crew such that they will be able to control movements and correct any departure from a desired flight path. The different director displays are:

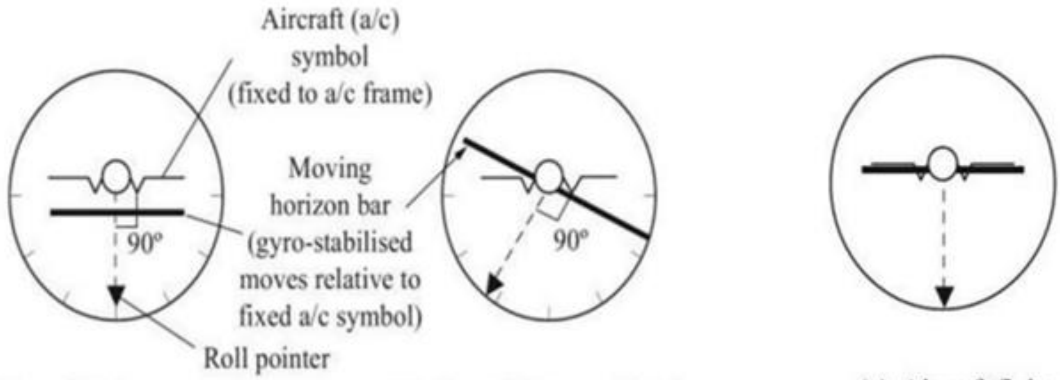
- **Gyro Horizon (GH)**
- **Attitude Director Indicator (ADI) – New**
- **Electronic Attitude Director Indicator (EADI) – Latest**

Gyro Horizon: also called the **Artificial Horizon** or **Attitude Indicator** — is a gyroscopic flight instrument that shows the aircraft's attitude with respect to the Earth's horizon.

Note: Attitude of an aircraft refers to the orientation or position of the aircraft in space with respect to the Earth's horizon.

Horizon is a horizontal reference line used to judge the pitch and roll of an aircraft.

The **Gyro Horizon** indicates the pitch (nose up or down) and roll (bank angle left or right) of an aircraft by using a rigidly mounted gyro that maintains a fixed position in space.



(a) Aircraft flying, nose up, and wings level. Pilot must make the nose down to fly straight and level

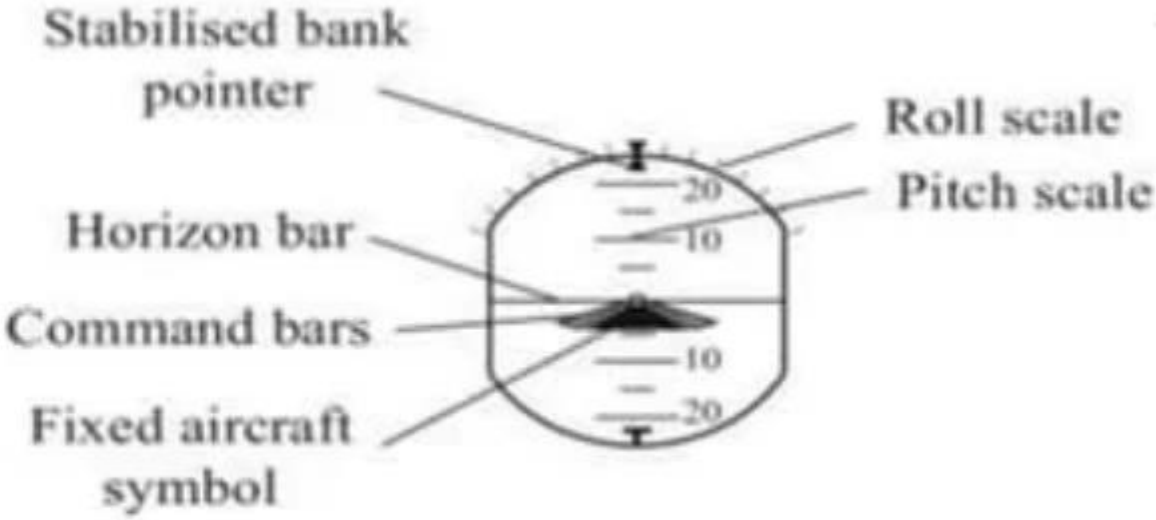
(b) Aircraft flying, with left wing below horizon (left banked). Pilot should roll right to fly straight and level

(c) Aircraft flying, straight and level

Fig. 2.14 Attitude Indicator (gyro horizon) with different aircraft attitudes (a) Pitch up (b) Left roll and (c) Straight and level flight.

Attitude Director Indicator (ADI):

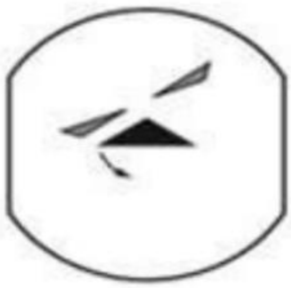
- ADI is a primary flight display which displays all information critical to flight.
- Earlier GH/Flight detector/Artificial horizon was used in an aircraft to indicate to the pilot about orientation of the aircraft relative to earth.
- It indicates pitch (nose up/down) and roll (wings not level) of the aircraft.
- The commands has to be satisfied by pilot.



(a) A/C flying straight and level

(b) A/C flying nose up

(c) Nose up command.
A/C must fly with nose up to satisfy the command



(d) Fly left command.
Fly the a/c to left to satisfy command bar

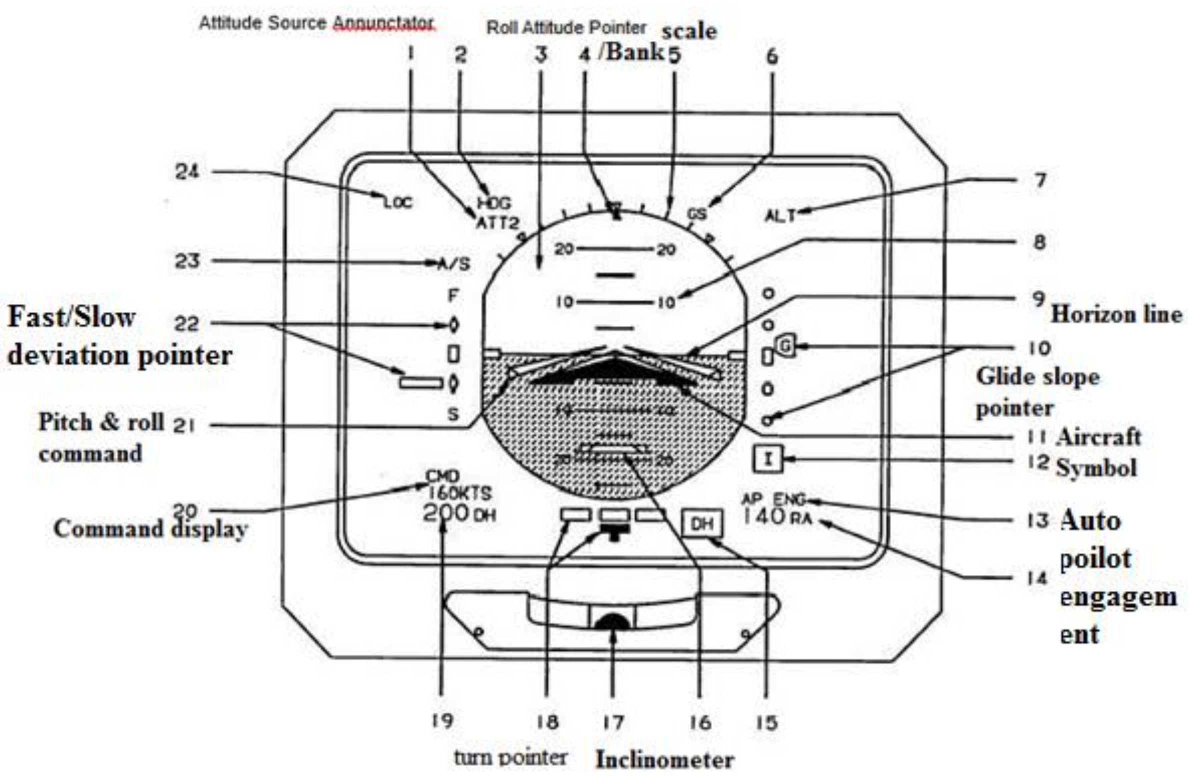
(e) Fly right command.
Fly the aircraft to right to satisfy command bar

(f) Commands have been satisfied

Electronic Attitude Director (EADI)

An EADI is a digital flight instrument in modern "glass cockpit" aircraft, displaying the aircraft's pitch and roll (attitude) against a simulated horizon, but also integrates crucial data like flight director command bars, ILS deviation, and autopilot status, providing pilots with a comprehensive view of the aircraft's orientation and guidance cues, especially vital for low-visibility flight and complex approaches. It's essentially an advanced, multifunction artificial horizon that replaces older mechanical gyros with solid-state sensors for greater reliability and functionality.

Note: Flight Director (FD) Command Bars are visual guidance bars displayed on the Attitude Indicator / Primary Flight Display (PFD) that show the pilot how to fly the aircraft to follow a selected flight path.



1. Attitude Source Annunctator
2. Lateral Mode Capture Annunctiator
3. Attitude Sphere
4. Roll Attitude Pointer
5. RoLL Attitude Scale
6. Vertical Mode Annunciator
7. Vertical Mode Capture Annunctator
8. Pitch Attitude Scale
9. Horizon Line
10. GLideslope Pointer, Annunctator, and Scale -
11. Aircraft Symbol
12. Marker Beacon Annunciator
13. Autopilot Engagement Annunciator
14. Radio Altitude Display
15. Decision Height Annunciator
16. Resting Runway Radio Altitude Display
17. Inclinometer
18. Expanded Localizer or Rate-of-Turn Pointer and Scale
19. Decision Height Display
20. Air Data Command Display
21. Pitch and RoLL Command Cue
22. Fast/Slow Deviation Pointer and Scale
23. Fast/Slow Source Annunctator
24. Lateral Mode Arm Annunciator

Key functions:

- **Attitude Representation:** Displays the aircraft's pitch (nose up/down) and **roll** (bank angle) relative to a two-color artificial horizon representing sky and ground.
- **Flight Guidance:** Integrates Flight Director (FD) command bars, which provide visual cues for the pilot to follow a specific trajectory or flight plan.
- **Navigation Integration:** Often displays Instrument Landing System (ILS) localizer and glideslope deviation markers to assist in precision approaches.

- **Situational Data:** Consolidates additional information such as radio altitude, decision height, slip/skid indicators (inclinometers), and flight mode annunciations (e.g., autopilot or autothrottle status)

  Note: Autothrottle status displays whether the autothrottle is actively controlling engine thrust to maintain a required airspeed, thrust, or flight mode.

Horizontal Situation Indicator (HSI)

• The HSI is primarily a Navigation display (ND). It is an aircraft instrument located in main instrument panel just below ADI (Attitude Director Indicator) replacing conventional Gyro Horizon.

• HSI provides a basic horizontal view of the aircraft's navigation around the earth.

- HSI provides a basic horizontal plan view(map view) of aircraft motion which is important to navigate to the desired airport.

Electronic Horizontal Situation Indicator (EHSI):

An EHSI in an aircraft is a digital display, part of the glass cockpit (EFIS), that shows the aircraft's position, direction, and navigation data in a plan-view (map-like) format, combining traditional heading info with dynamic navigation aids like VOR/ILS, route waypoints, weather radar, and Traffic Collision Avoidance System (TCAS) symbols, providing pilots a comprehensive view of flight progress on the primary flight display.

Note: VOR (VHF Omnidirectional Range) is a ground-based radio navigation system that provides information to an aircraft

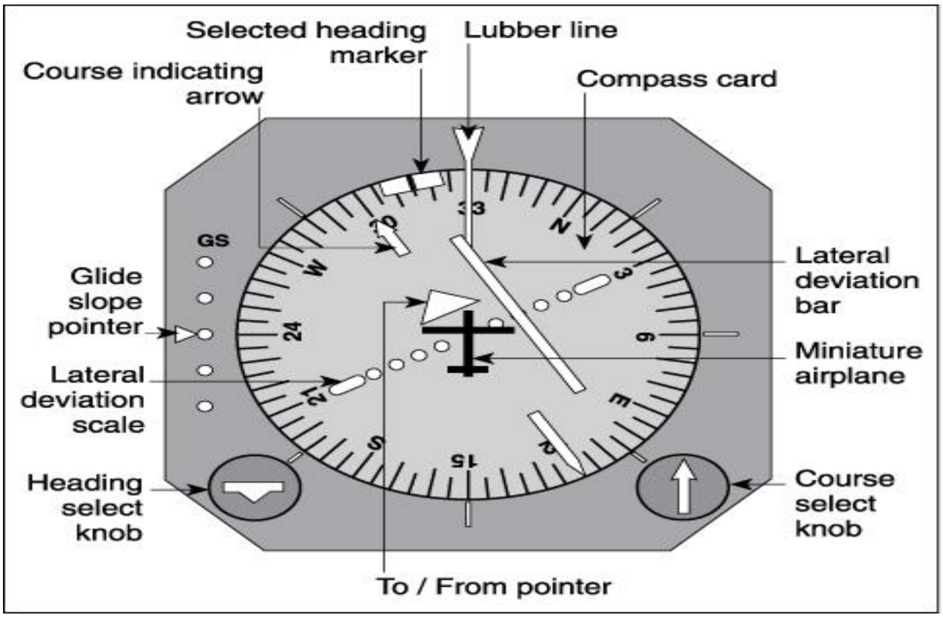


Fig:EHSI

Key Functions & Information Displayed are:

- **Glideslope** for guiding the aircraft into the **aircraft runway** in a vertical direction
- ┼ aircraft symbol
- **Course deviation indicator(CDI)/lateral deviation** indicator is shown relative to airplane symbol in azimuth(plan) direction
- **Heading & Track:** Displays aircraft heading and selected track (course).
- **Navigation Aids:** Shows VOR/ADF bearings, ILS deviation, and Flight Management Computer (FMC) data.
- **Plan View:** Presents a customizable map showing routes, waypoints, and the aircraft's position.
- **Weather & Traffic:** Can overlay weather radar, ground mapping, and TCAS (Traffic Collision Avoidance System) symbols.
- **Performance Data:** Includes ground speed, wind direction/speed, DME (Distance Measuring Equipment) readouts, and time/distance to go.
- **Heading select memory bug** to aid the pilot to navigate to destination.

Combining DG and NAV indicator into a single instrument reduces the pilot workload by providing the following information:

- **Heading-**which direction the aircraft is going
- **Course reference-** which direction the aircraft has to go

- **Course deviation-** indicates how far the aircraft is left or right of the desired course**.**
- **Glideslope information**- while landing

Flight deck of modern aircraft (glass cockpit)

Modern aircraft cockpit is called as **'glass cockpit'** which has electronic instrument displays similar PC glass monitor displays (hence the name glass cockpit).

- They utilize few computer controlled displays that can be configured and adjusted to display flight information as required by pilots.
- There are a large number of computers, sensors and actuators working behind these computer glass monitors.

• Such avionic (Electronics) systems increase flight safety, improve efficiency of the aircraft and greatly assist flight crew by reducing their workload.

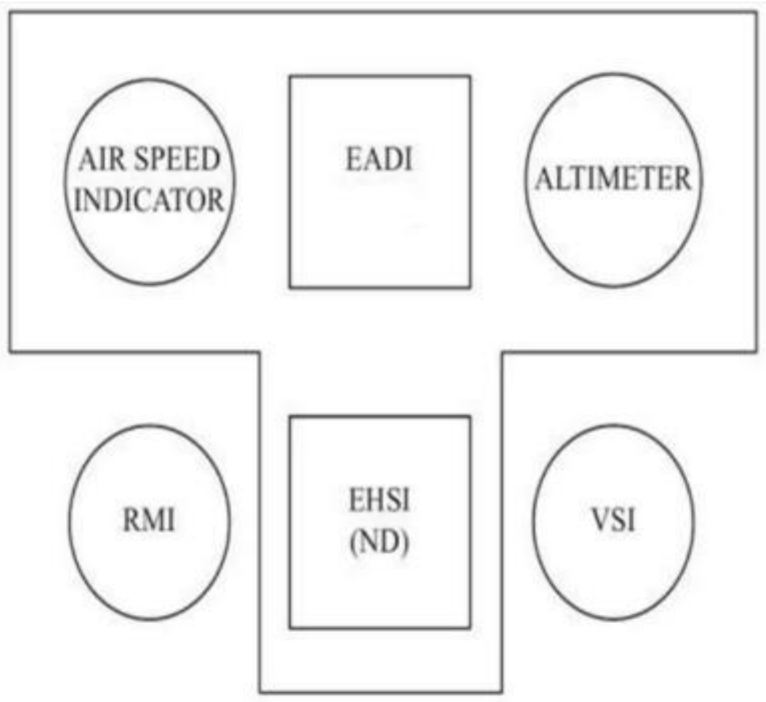


Fig. 2.12 Modern "glass cockpit" configuration with EADI and EHSI.

https://www.slideshare.net/slideshow/aircraft-instrumentspptx/263066098

- A modern aircraft's flight deck, or glass cockpit, replaces traditional analog gauges with large, integrated electronic displays (like LCD screens) showing digital flight data, engine info, navigation (GPS maps), and systems status, enhancing pilot situational awareness, reducing workload through automation (Flight Management System (FMS), autopilot), and allowing customizable information presentation for greater safety and efficiency.

- Key components include the Primary Flight Display (PFD) for core flight instruments, Multi-Function Displays (MFD) for other data, and integrated systems for communication (COMM), navigation (NAV), surveillance (SURV), and weather, all managed via buttons, knobs, or touchscreens.

Key Features of Glass Cockpits

- **Electronic Flight Displays (EFDs):** Large, flat-panel screens that digitally present critical flight information, reducing clutter.
- **Primary Flight Display (PFD):** Shows essential flight data like attitude, airspeed, altitude, and heading, often with a digital tape layout.
- **Multi-Function Display (MFD):** Displays engine data, system status, GPS moving maps, and can show weather, terrain, and traffic overlays.
- **Integrated Systems:** Communication, navigation (FMS), and surveillance systems are integrated, allowing pilots to manage flight plans and radio frequencies digitally.
- **Automation:** Features like Flight Management Systems (FMS), autopilot (AP), and auto-throttle (AT) simplify complex tasks and reduce pilot workload.
- **Enhanced Situational Awareness:** Digital tools like Synthetic Vision Systems (SVS) provide 3D views, while ADS-B gives real-time traffic data, improving safety.

AIR DATA INSTUMENTS

Air data instruments are crucial aviation tools, primarily using a pitot-static system, that measure atmospheric pressure to provide vital flight information like airspeed, altitude, and vertical speed (rate of climb/descent). These instruments, including the Airspeed Indicator (ASI), Altimeter, and Vertical Speed Indicator (VSI), work by sensing differences between total air pressure and static air pressure, often processed by an Air Data Computer (ADC) for enhanced accuracy and digital displays in modern aircraft.

Basic Pneumatic airdata system

A combined pitot-static probe integrates a pitot tube (measures stagnation pressure with an opening facing the flow) and static ports (small holes parallel to flow) into a single, dual-chambered device, allowing it to measure both total and static air pressure simultaneously for calculating airspeed, altitude, and Mach number in aviation, especially for UAVs, using Bernoulli's principle. It works as an inner tube captures total pressure (static + dynamic), while an outer tube senses static pressure, with the pressure difference yielding dynamic pressure to determine velocity, all in one streamlined package.

Working principle:

- Inner tube (Pitot): The open end points directly into the airflow, measuring total pressure (P), which is the sum of static pressure (Ps) and dynamic pressure (P_D).

• Outer tube (Static): Has small holes perpendicular to the airflow, sensing only the static pressure (Ps).

• Pressure Calculation: The difference, $P_D = P_T - P_s$, gives the dynamic pressure, from which airspeed can be derived using fluid density and Bernoulli's equation.

Key Features & Uses

- **Compact Design:** Combines two functions into one lightweight tube, ideal for drones (UAVs) and smaller aircraft.

- **Air Data:** Provides essential data for airspeed indicators, altimeters, and Mach meters.
- **Material:** Often made from lightweight materials like carbon fiber and aluminum for reduced weight.
- **Applications:** Widely used in general aviation, research, and unmanned aerial vehicles.

Air data computer

Air Data Computers (ADCs) are crucial avionics components that compute flight parameters—such as altitude, airspeed, and Mach number—by processing raw pressure and temperature data. They evolved from complex, direct-reading mechanical instruments that used pneumatic lines to centralized, electronic units that enhance accuracy, reduce maintenance, and eliminate errors associated with traditional pneumatic systems.

Pneumatic Systems in Air Data

- **Traditional Pneumatic Systems:** Historically, aircraft used a network of plumbing to carry pitot (total) and static air pressure directly to analog instruments, which were prone to leaks, lag, and friction errors.

- **ADC Pneumatic Inputs:** Modern ADCs still receive raw pneumatic inputs from pitot tubes and static ports. These pressures are fed directly into the unit, where they are converted into electronic signals.

- **Air Data Modules:** These units often convert pneumatic information directly into numerical data for transmission over digital data buses.

Air Data Computers (ADC)

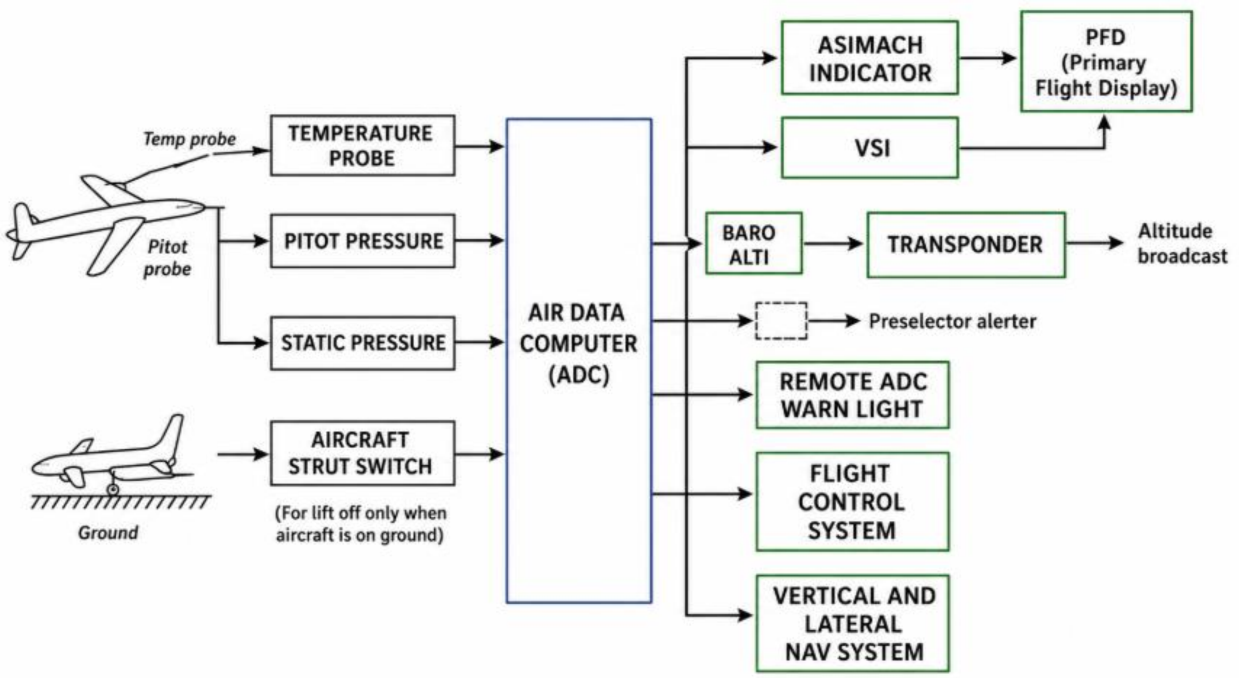


Fig: Block diagram of Airdata computers

- **Function:** ADCs receive inputs—pitot pressure, static pressure, total air temperature (TAT), and often angle of attack (AOA)—to compute pressure altitude, vertical speed, calibrated airspeed, and true airspeed.
- **Evolution:** Early systems were electromechanical, using gears, cams, and shafts. Modern ADCs are fully digital, utilizing solid-state transducers and microprocessors for high accuracy.
- **Significance:** ADCs allow for the correction of sensor errors, such as position errors, which improves safety and performance.

International standard atmosphere (ISA)

The **International Standard Atmosphere (ISA)** is a static atmospheric model that defines how properties like pressure, temperature, and density change with altitude. It serves as a universal, theoretical reference for aviation and aerospace engineering, enabling consistent aircraft performance calculations, instrument calibration, and flight testing, despite variations in real-world weather.

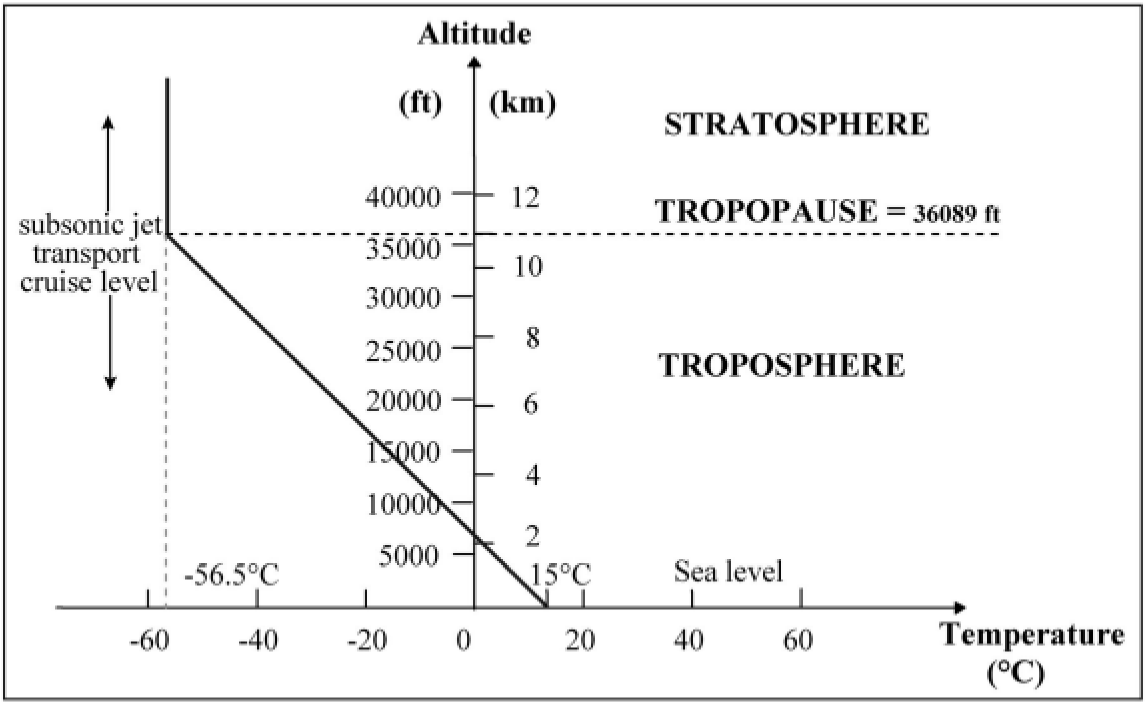


Figure 1 International Standard Atmosphere temperature variation [2].

ISA is useful for aircraft operations, design, and safety:

1. Standardizing Flight Instruments

The primary use of ISA is for calibrating critical flight instruments to ensure they provide consistent and reliable data regardless of actual weather conditions:

- **Altimeter Calibration:** Aircraft altimeters measure altitude by sensing changes in atmospheric pressure. These instruments are built and calibrated assuming ISA sea-level pressure (1013.25 hPa) and the ISA lapse rates. This standardization allows all aircraft and air traffic control centers globally to use a common, unified measure of "pressure altitude," which is crucial for maintaining safe vertical separation between planes.
- **Airspeed Indicator Calibration:** Airspeed measurements depend heavily on air density. Since the ISA provides a standard, predictable model for how density changes with altitude, airspeed indicators can be designed to display consistent readings, which is essential for managing safe flight envelopes (e.g., stall speeds and maximum operating speeds).

2. Aircraft Design and Performance Calculations

Engineers and manufacturers use ISA conditions as a benchmark during the design phase and for publishing performance data:

- **Baseline Performance Data:** Every aircraft's performance metrics—such as takeoff distance, climb rate, maximum speed, fuel consumption, and range—are initially calculated and certified under ISA conditions. This allows operators to have a guaranteed baseline for how the aircraft should perform.
- **Engine Performance:** Jet engines operate by burning fuel and compressing air. Engine performance is highly dependent on the density and temperature of the incoming air. ISA provides a standard temperature and pressure input for engineering simulations and real-world testing.

3. Flight Planning and Operations

Pilots and dispatchers rely on ISA data when planning flights to make critical decisions:

- **Weight and Balance Calculations:** Since air density affects lift and engine thrust, deviations from ISA conditions must be accounted for. The ISA provides the baseline from which pilots calculate the adjustments needed for hot, high-altitude airports (which have lower air density and thus reduced performance).
- **Consistency in Communication:** The ISA provides a universal language for air traffic control (ATC), pilots, and meteorological services. Everyone involved operates using the same standard reference model, which enhances safety and coordination across international airspace.

Creating a Common Reference Plane

By standardizing all altimeters to the ISA pressure setting:

1. **Everyone is relative to the same baseline:** All aircraft display their altitude relative to this theoretical ISA sea level.
2. **Vertical separation is guaranteed:** Air traffic controllers can confidently assign different *flight levels* (FL) to different aircraft (e.g., FL350, FL360). Because all aircraft are using the exact same pressure reference provided by the ISA standard, ATC knows for certain that there is a minimum safe vertical distance (usually 1,000 feet) between them, preventing collisions.

In essence, the ISA turns the complex, variable atmosphere into a predictable, standardized measuring stick, which is critical for global aviation safety and collision avoidance systems.

Pitot-Static System

A pitot-static system is a system of pressure-sensitive instruments that is used to determine an aircraft's airspeed, vertical speed, altitude, and Mach number**.**

It uses the principle of air pressure gradient, i.e., it measures pressures/pressure differences and uses these values to determine the speed and altitude.

Basics of Pitot-Static System

Static Pressure

Static pressure, as the name suggests, is the absolute pressure (pressure referenced to a vacuum) of the air surrounding the aircraft.

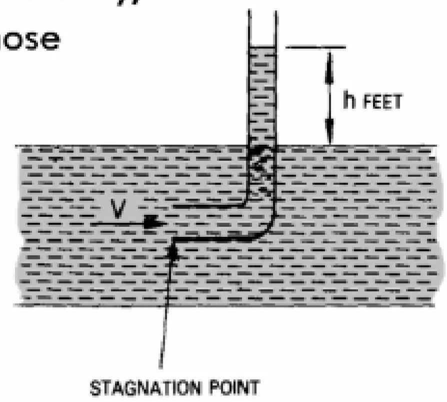
This is easily obtained while the aircraft is stationary on the ground, but it is affected as the aircraft moves through the air, giving rise to errors. Modern aircraft sample static pressure through pairs of Static Vents**.**

Pitot Pressure:

The pitot pressure is a measure of ram air pressure (the total air pressure created by aircraft motion)

To understand this, let us consider a probe placed in a flowing fluid. When the fluid flows at a certain velocity, v over the probe, it will be brought to rest at the nose known as the stagnation point.

The stagnation pressure of the fluid, also known as the total pressure or the pitot pressure.



At the stagnation point, kinetic energy of the fluid is converted into pressure energy.

Kinetic energy=pressure energy

$\frac{1}{2}mv^2 = PV$ (P=dynamic pressure=difference between pitot and static pressure)

» $\frac{1}{2}\rho v^2 = P$

» $v \alpha \sqrt{P}$

So, by measuring dynamic pressure we can determine the fluid velocity.

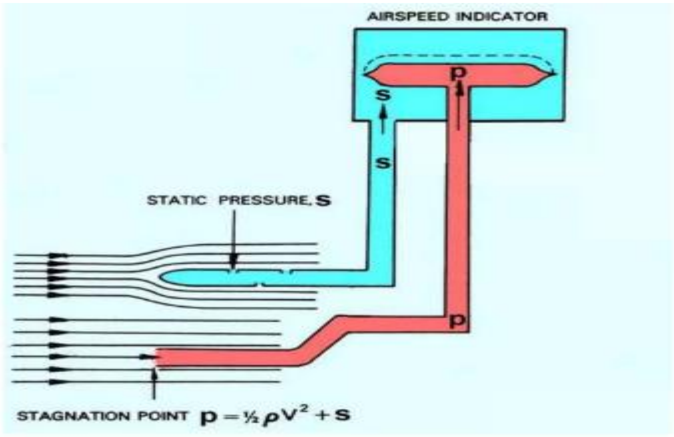
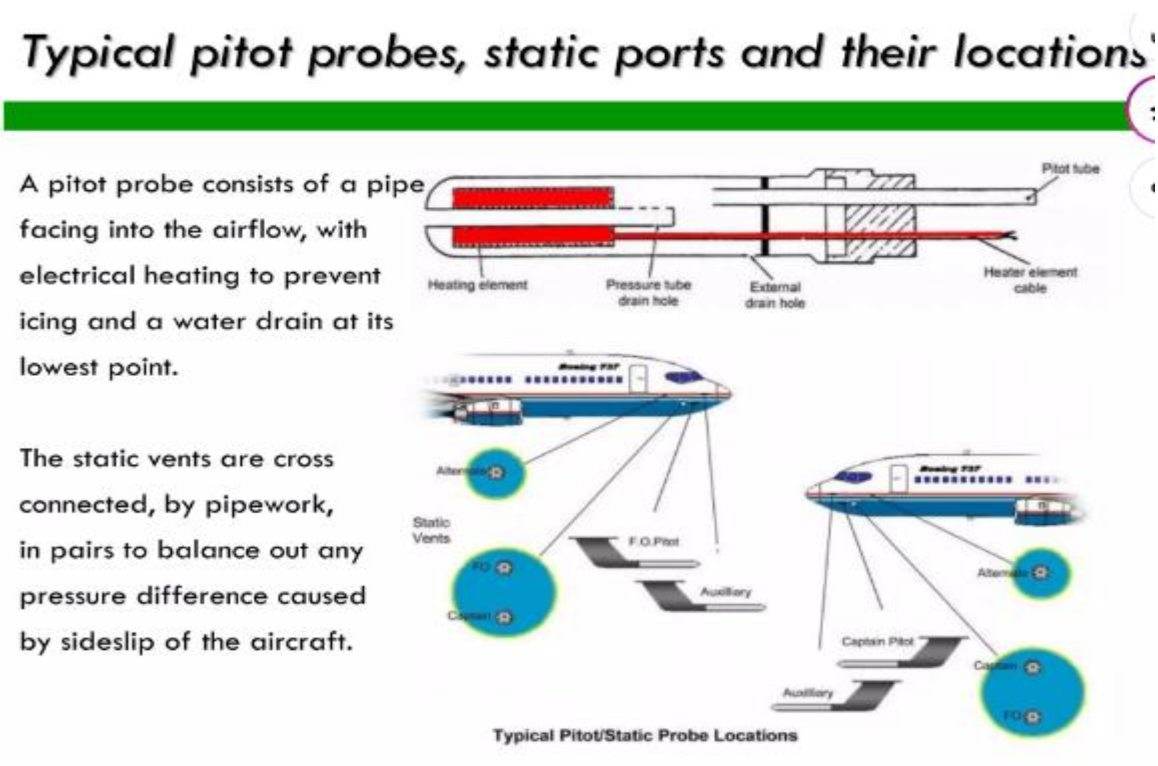


Figure: Measuring airspeed by using pitot and static pressures



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Working of Pitot-Static System

1. **Pitot Tube:** Faces forward to capture "total pressure" (ram air pressure) from the aircraft's movement through the air.

Note: Ram air pressure is the pressure produced by the forward motion of the aircraft**,** when outside air is compressed at an intake.

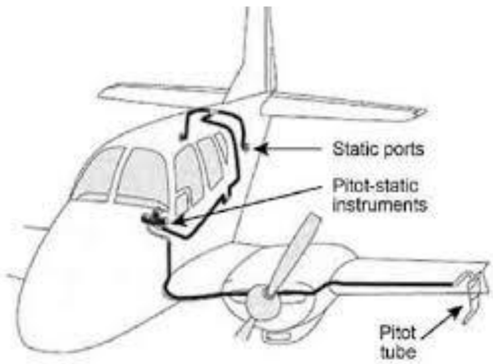
2. **Static Ports:** Located on the fuselage, they sense "static pressure," which is the undisturbed atmospheric pressure at the aircraft's altitude.
3. **Pressure Difference:** The difference between total and static pressure is used to calculate airspeed. Static pressure alone determines altitude and vertical speed.

Key Instruments & Their Functions

- **Airspeed Indicator (ASI):** Shows how fast the aircraft is moving through the air, calculated from pitot and static pressure.
- **Altimeter:** Measures altitude (height above sea level) using static pressure.
- **Vertical Speed Indicator (VSI):** Indicates the rate of climb or descent by sensing changes in static pressure over time.
- **Machmeter:** Shows the aircraft's speed as a function of the speed of sound, often combined with the ASI.

Modern Advancements (Air Data Computer - ADC)

- Modern systems use an ADC to centralize data from pitot tubes, static ports, and total air temperature (TAT) probes.
- The ADC processes these inputs to provide highly accurate airspeed, altitude, Mach number, and vertical speed, correcting for errors and feeding data to digital flight displays (EFIS).



Static Pressure:

Static pressure, is the absolute pressure (pressure referenced to a vacuum) of the air surrounding the aircraft.

This is obtained while the aircraft is stationary on the ground, but will be affected as the aircraft moves through the air, giving rise to errors. Modern aircraft sample static pressure through pairs of static vents.

Pitot (Total) Pressure

The pitot probe is located in a region of undisturbed airflow and consists of a cylindrical tube open on one side to the airstream. The forward motion of the aircraft forces air into the tube which is then brought to rest by the geometry of the probe. The pressure measured by the pitot tube is known as stagnation pressure or total pressure in accordance with the Bernoulli equation. This measured pressure is the sum of the static and dynamic pressures acting on the aircraft at the location of the probe.

Wing mounted Pitot Tube on a Cessna 172

https://commons.wikimedia.org/wiki/File:Cessna_172_Skyhawk_II_-_Pitot_tube.jpg

The pitot pressure is a measure of ram air pressure (the total air pressure created by aircraft motion).

To understand this, let us consider a probe placed in a flowing fluid. When the fluid flows at a certain velocity, *v*, over the probe, it will be brought to rest at the nose known as the stagnation point.

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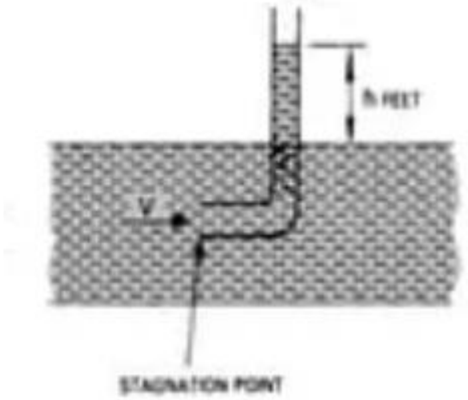

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So, by measuring dynamic pressure we can determine the fluid velocity.

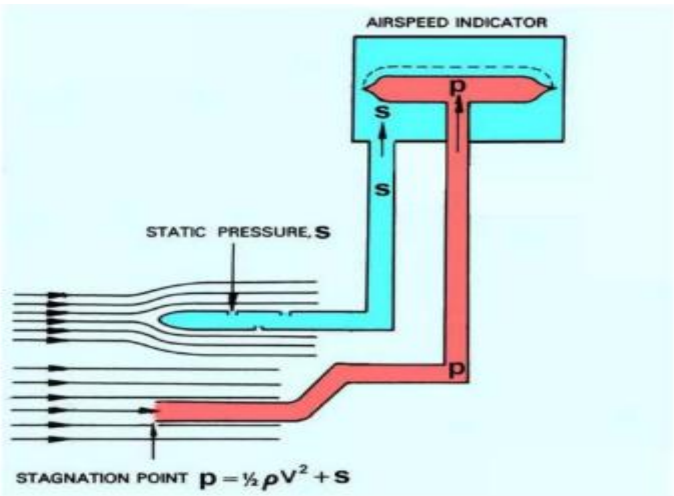


Figure: Measuring airspeed by using pitot and static pressures

Air Data Instruments

The basic air data instruments used in aircraft are:

1. Airspeed Indicator (ASI) – to measure airspeed of the aircraft
2. Altimeter – to measure altitude of the aircraft
3. Machmeter – to measure Mach number of the aircraft
4. Vertical Speed Indicator (VSI) – to indicate rate of climb or descent

These air data instruments, namely ALT, ASI, and VSI, are based on the measurements of pitot and static pressures.

Pitot tube is used to sense the total or pitot pressure, Pt. A static port (either combined with a pitot tube or separate) is used to measure the ambient atmospheric static pressure, Ps. Static pressure sensing is more complicated and difficult.

Recall that

$$p_t = p_s + \frac{1}{2}\rho V^2$$

i,e q = Pt – Ps where q is differential / dynamic pressure

As already discussed, pitot pressure, also called total pressure, is defined as the pressure of air brought to rest (stagnation pressure) is entropically (without change in internal energy).

Static pressure is defined as the undisturbed (ambient) air pressure through which the aircraft is moving. It is the absolute pressure which would be present locally, without any presence of flow. Static pressure measurement is more difficult and challenging than pitot pressure measurement. There will be significant influence of the moving aircraft on the atmospheric pressure through which it flies. Measuring static pressure accurately in this dynamic environment has always posed severe measurement problems.

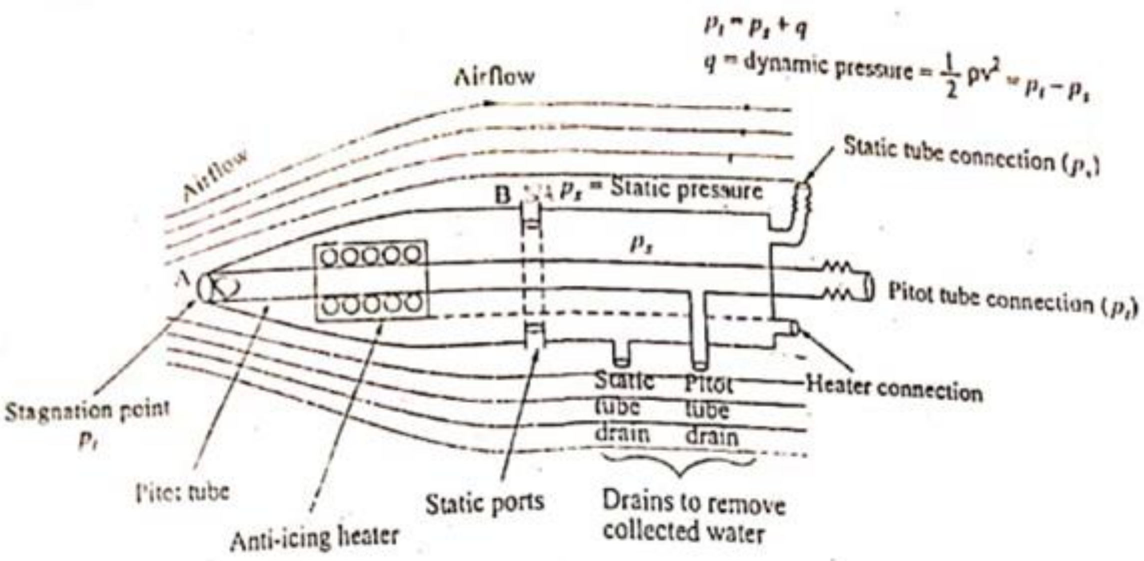
There are two types of probes based on static port configuration, namely:

1. **Combined pitot–static probe**
2. **Separate pitot and static probe**

Combined Pitot -Static Probe

In this probe shown in Figure 3.7, both total pressure and static pressure are sensed in the same pitot–static tube. Static ports are co-located with the pitot tube and are not separate.

Note that the total pressure P_t is severally called total pressure**,** pitot pressure**,** or stagnation pressure**.** The basic pitot tube consists of a capillary tube with a smaller diameter opening A, which faces the airflow moving at a certain velocity V. The flow is brought to rest at the tip of the probe and the flow velocity gets converted into a pressure head.



Details of combined pitot-static probe.

The tip of the probe and the flow velocity gets converted into a pressure head. Note that the dynamic pressure

$$q = \frac{1}{2}\rho V^2$$

is over and above the ambient static pressure Ps. Thus, the basic pitot tube senses the total of **(**1) static pressure and (2) dynamic pressure, caused by the fluid flow**.** If the flow velocity is zero, then dynamic pressure will be zero, and Pt (the total pressure) is equal simply to Ps, the static pressure.

$$p_t = p_s$$

The static pressure, in a combined pitot–static probe, is sensed by admitting the air through small ports B, around the circumference of the pitot tube as shown in Figure 3.7. Ideally, static ports should not sense the dynamic pressure.

Note in Figure 3.8 that wherever there are abrupt changes in the aircraft (such as leading edges of fuselage, wing, horizontal tail), the position error is more because of the pressure build-up.

The total and static pressures are made available to air data instruments through metallic tubes with airtight pneumatic connectors. Total pressure, Pt, is sampled through central port A of Figure 3.7, which is connected to the output pneumatic connector. A static pressure chamber is formed concentric to the total pressure port, sensing ambient atmospheric pressure through holes around its circumference at a suitable point along the pitot tube.

The flow past the static port must be laminar, without any turbulence, and there should be no cross-flows into the static ports. The selection of static port location is done very carefully based on wind-tunnel studies to minimize what is known as position error.

The static chamber and the restricted small-diameter static ports together act as an analogous RC filter, to smooth out any turbulent air flowing through the static ports, particularly when the aircraft does maneuver like yawing. We must, ideally, locate the static pressure port in the aircraft at a place which is least disturbed by the airflow past the aircraft. Any error resulting due to positioning of the static port is called the position error, which is discussed next.

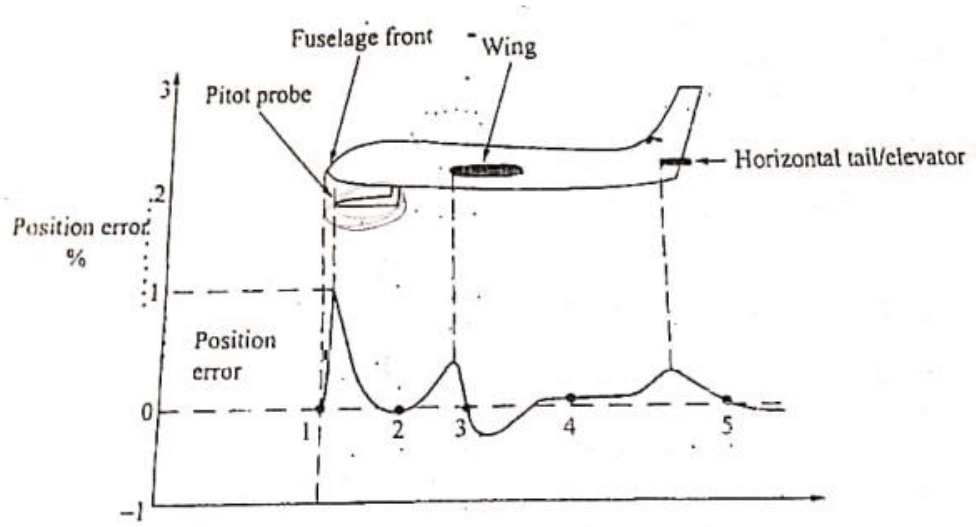


Fig. 3.8 Percentage position error along the length of the aircraft points 1 to 5 indicate positions of least error and therefore are the best possible locations of pitot-static probe in an aircraft.

3.4.1 Position Error

Position error is caused by the difference between the local static pressure (at the point of sensing) and the free-stream static pressure. Some difference always exists because the aircraft is moving in the static atmosphere, causing flow disturbances, and we are attempting to measure static atmospheric pressure. However, the difference should be minimized to as great an extent as possible.

Figure 3.8 shows how this error changes along the length of a subsonic aircraft. This pressure distribution is not constant and varies with Mach number and angle of attack. The following steps minimize the position error:

1. **Aerodynamically shaping the probe** so that it does not cause any disturbance to the airflow and also nulls out any local position error, i.e., by aerodynamic compensation over the flight envelope of the aircraft (i.e., Mach number and angle of attack).
2. **Locating the probe in the aircraft** such that maneuvers like pitching, rolling, and yawing of the aircraft do not have a significant effect on the pressure sensing.

Figure 3.9 shows some more common pitot and pitot-static probes. Static ports are worst affected by wrong positioning of the probe in the aircraft.

Consider first the probe shape. Shock waves (abrupt pressure changes) are caused by high speed air flowing past an abrupt change in shape of the probe, which should be minimized.

The airflow past the probe must be "laminar"-i.e. airflow must be in smooth lines (need not be straight) past the aerodynamically shaped body of either the probe or even the aircraft. Laminar, flow is the air flow in which neighboring layers do not mix, but flows at different velocities. It is also known as **streamline flow**, with no disruption between the layers. Laminar flow, generally speaking is smooth, while turbulent flow is rough, accompanied by violent mixing between layers.

Static ports are meant to sense the prevalent atmospheric pressure under zero-airflow conditions. Any deviation due to static ports being at an angle to the airflow will cause an error. The pressure developed at different angles of attack is a function of the location of the static holes along the probe axis, their position around the circumference of the probe, and also the diameter of the probe.

In addition, combined pitot–static probes can be aerodynamically compensated against errors caused by variations in the speed of aircraft (Mach number) and angle of attack. This compensation is achieved by properly contouring the probe and locating the static ports such that the opposing static pressure compensates for the position error caused by changes in speed and angle of attack.

Aerodynamically compensated probes are a result of on-site evaluation in wind tunnels. The experience of probe manufacturers on different types of subsonic as well as supersonic aircraft plays a major role in achieving effective compensation.

Combined pitot–static probes are preferred in high-speed fighter aircraft.

Separate Static Ports

Thus, from the foregoing discussions, combining static ports in the pitot probe introduce to position error:

(i) caused by probe vibrations, and

(ii) errors introduced at different angles of attack.

Therefore separate static ports, located at the main body of the aircraft (fuselage) offers distinct advantages. In fact, separate static ports are used in almost all civil transport aircraft. A typical static port is shown fig.

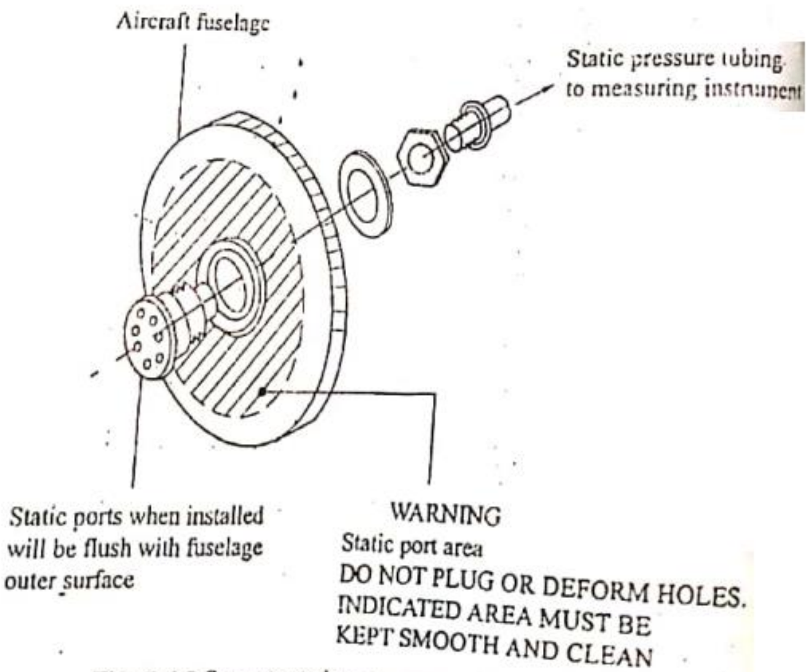


Fig. 3.10 Separate static port, mounted flush with fuselage.

Goodrich of USA specializes in automatically compensating for position error. The aerodynamically compensated design is achieved by appropriately contouring the static probe to minimize local pressure disturbances.

The Static Source Error (SSE) correction is generally done in the Air Data Computer (ADC). The SSE is an airframe-dependent error and is evaluated by conducting extensive flight tests. The correction values obtained are stored in the ADC memory and are applied to correct the indicated airspeed, altitude, and climb rate.

In some aircraft, the SSE correction is performed using lookup tables implemented through computer software in the ADC. Figure 3.12 shows a typical schematic of an ADC.

The SSE correction module receives the factory-set SSE correction data, which is automatically applied to the CAS (Calibrated Airspeed) module. Consequently, the ADC corrects the pitot–static signals of altitude and CAS transducers. This will be further discussed later.

Pneumatic-type Air Data Instruments

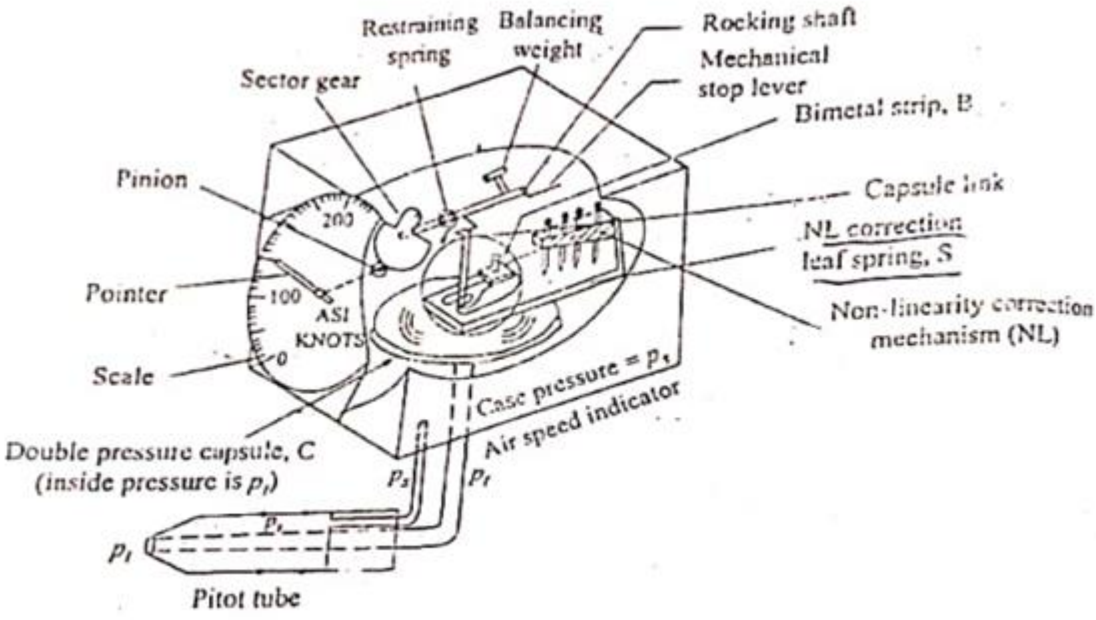
- ASI
- ALTI
- VSI

Pneumatic Airspeed Indicator (ASI)

A Pneumatic Airspeed Indicator (ASI) is a crucial flight instrument that measures an aircraft's speed through the air by sensing pressure differences from the pitot-static system, displaying it as Indicated Airspeed (IAS) on a dial, vital for safe operation like preventing stalls and ensuring proper lift, using a diaphragm that expands with dynamic pressure from the pitot tube against static pressure in the instrument case.

Working (Pitot-Static Principle)

- **Pitot Tube:** Senses "ram air" (total pressure = static + dynamic) as the aircraft moves forward.
- **Static Ports:** Measure ambient "static pressure" (air pressure around the aircraft).
- **Diaphragm:** Inside the ASI, static pressure fills the case, while pitot pressure flexes a sealed diaphragm. The difference (dynamic pressure) causes the diaphragm to expand or contract, moving a needle.
- **Zero Reading:** On the ground, pressures are equal, showing zero speed.



(a) Combined pitot and static probe connected to air speed indicator (ASI)

Pressure inputs:

- The pitot tube supplies total pressure Pt to the instrument.
- The static port supplies static pressure Ps.
- These pressures act on a double pressure capsule (C), where the inside pressure is Pt and the outside pressure is Ps.
- The pressure difference (Pt−Ps), i.e., dynamic pressure, causes capsule expansion or contraction.

Mechanical transmission:

- The capsule movement is transmitted through a capsule link to a rocking shaft.
- A sector gear attached to the rocking shaft meshes with a pinion.
- The pinion drives the pointer, which moves over a calibrated scale marked in knots to indicate airspeed.

Control and correction elements:

- A restraining spring and balancing weight provide restoring force and stability.
- A mechanical stop lever limits excessive movement and protects the mechanism.
- A bimetal strip (B) provides temperature compensation.

- A non-linearity correction mechanism (NL) and NL correction leaf spring (S) correct the non-linear relationship between dynamic pressure and airspeed, ensuring accuracy across the speed range.

Overall function:

- As aircraft speed increases, dynamic pressure increases, causing greater capsule deflection.
- This deflection is mechanically amplified and converted into pointer rotation.
- The pointer position on the scale directly indicates the airspeed of the aircraft**.**

Mechanical and Design Compensation

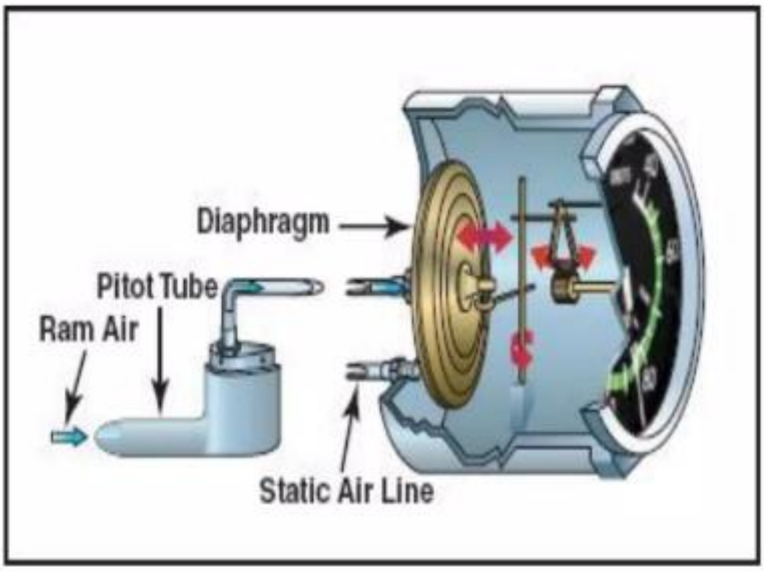
- **Square Law Compensation:** Because dynamic pressure increases with the square of speed

$(q = \frac{1}{2}\rho V^2)$,

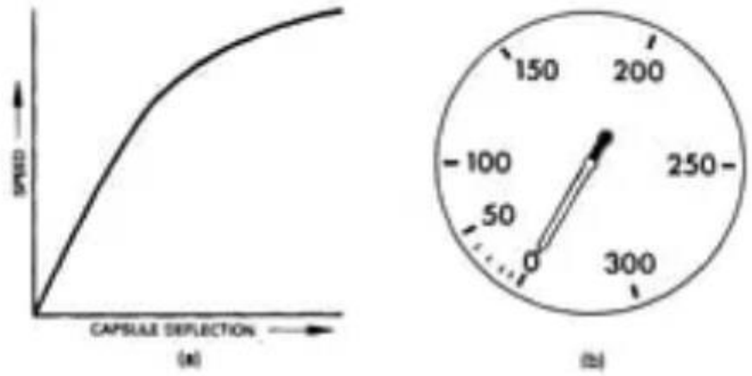
a simple capsule would expand non-linearly. Internal mechanical linkages use custom-shaped cams or levers to linearize this expansion, ensuring the dial's needle moves in uniform increments.

- **Bi-metallic Strips:** To compensate for instrument errors caused by temperature changes affecting the metal capsule's elasticity, some ASIs incorporate a bi-metallic strip that adjusts the linkage mechanism as temperatures shift.
- **Dual Static Vents:** To minimize position error, many aircraft utilize two static ports (one on each side of the fuselage). This cancels out pressure disturbances caused by side-slipping, as an increase in pressure on one side is offset by a decrease on the other.

AIRSPEED Indicator



Airspeed indicator measures the difference between the pitot and static pressures in terms of the $^{1}/_{2}\rho V^2$ formula i.e. it measures a differential pressure which varies with the square of the airspeed.



Pointer movement means capsule deflection. At low speeds, small pointer deflection means large speed variations and vice versa.

So direct magnification of deflection would give a non-linear scale reading which is inconvenient to read.

To make the dial linear, an arrangement is needed so that the pointer movement is increased for small deflections and decreased for large deflections, i.e., a variable magnification, which is called, in this case, the square-law compensation.

Square-law-compensation

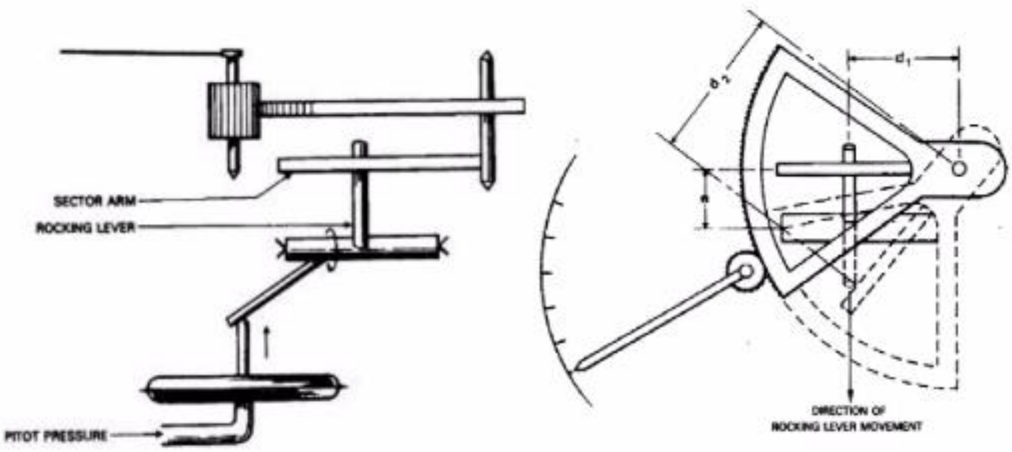


Figure: Square-law-compensation by rocking lever/sector-arm mechanism

Pressure Altitude Indicator-ALTI

A Pressure Altitude Indicator (Altimeter) shows an aircraft's height above a standard datum plane (29.92 inHg/1013.2 hPa) by sensing atmospheric pressure, crucial for performance calculations and high-altitude flight, especially above 18,000 ft where all aircraft use this standard setting for consistent separation. Pilots set their altimeter's Kollsman window to 29.92 inHg to get the Pressure Altitude (PA), indicating height relative to the International Standard Atmosphere (ISA) rather than actual terrain.

Working:

- **Sensing Pressure**: An aneroid barometer inside the instrument detects changes in air pressure from the aircraft's static port.
- **Mechanism**: As altitude increases, pressure drops, causing the aneroid to expand and move needles on the gauge.
- **Kollsman Window**: A setting allows pilots to adjust the instrument for local conditions (QNH/QFE) or to the standard pressure (29.92 inHg) for Pressure Altitude

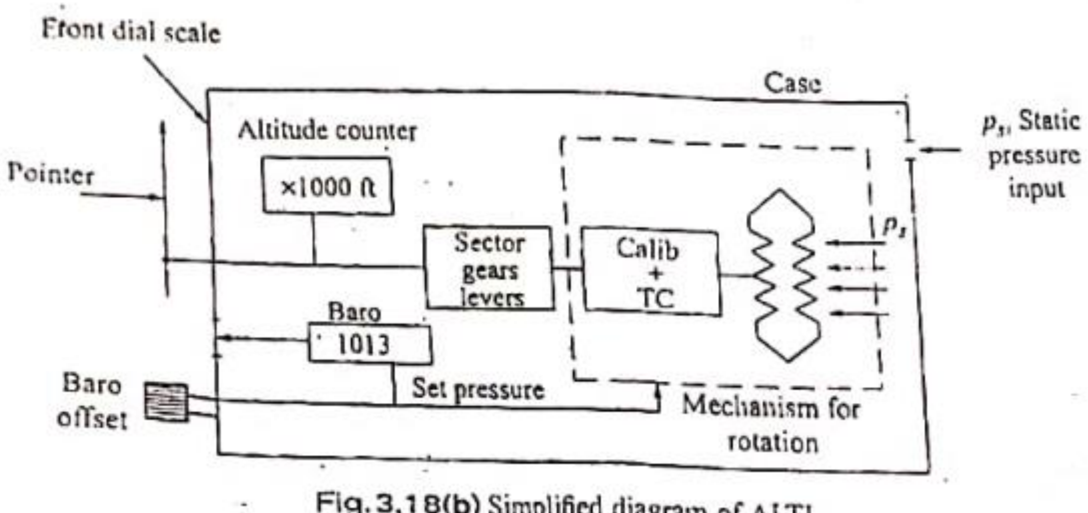


Fig. 3.18(b) Simplified diagram of ALTI.

An altimeter is an aircraft instrument used to measure the altitude (height) of the aircraft above mean sea level. It works on the principle that atmospheric pressure decreases with increase in altitude.

Main Parts and Their Functions

1. Static Pressure Input (Ps)

- Static pressure from the atmosphere enters the altimeter through the static port.
- As the aircraft climbs, static pressure decreases; as it descends, pressure increases.

2. Aneroid Capsule (Pressure-Sensitive Element)

- Inside the case is a sealed aneroid capsule.
- When static pressure decreases (climb), the capsule expands.
- When static pressure increases (descent), the capsule contracts.

3. Case

- The case is connected to static pressure.
- The pressure difference between the capsule interior and the case causes capsule movement.

4. Mechanical Linkage / Sector Gears & Levers

- The expansion or contraction of the capsule is transmitted through levers and sector gears.
- This mechanism converts small capsule movements into rotational motion.

5. Calibration + Temperature Compensation (Calib + TC)

- Ensures accurate altitude indication.
- Compensates for:
    - Non-linear pressure changes
    - Temperature effects on the capsule

6. Altitude Counter / Dial Scale

- Displays altitude on the front dial.
- Commonly shows:
    - x1000 ft counter
    - Pointer for hundreds of feet

7. Barometric Pressure Setting (Baro Set / 1013 hPa)

- The baro setting knob allows the pilot to set reference pressure:

- 1013 hPa (29.92 inHg) → Standard pressure (Flight Levels)
- Local QNH for true altitude

- Baro offset adjusts the altitude reading according to atmospheric conditions.

Note: hPa stands for hector pascal
inHg stands for inches of mercury

Working Principle

1. Static pressure enters the altimeter.
2. Change in pressure causes the aneroid capsule to expand or contract.
3. Capsule motion is transferred through gears and levers.
4. This rotates the pointer and counter on the dial.
5. Altitude is displayed in feet above mean sea level.

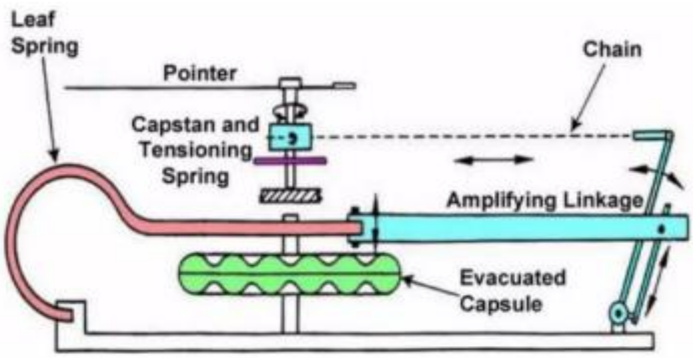


Figure: Aneroid Barometric altimeter

An altimeter operates on the aneroid barometer principle, I,e it responds to changes in atmospheric pressure. The Altimeter has a sealed evacuated capsule inside a sealed case.

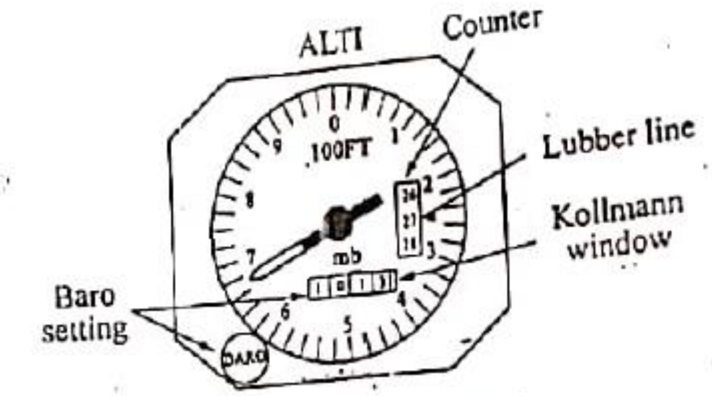
The air pressure on the outside of the capsule tends to squash it, this being opposed by the leaf spring and the spring action of the corrugated metal itself. As barometric pressure increases or decreases, the capsule will be compressed or expanded respectively.

By the use of an amplifying lever and chain linkage, the expansion and contraction of the capsule is transmitted to a pointer that moves over a scale, calibrated to show barometric pressure, with the leaf and tensioning springs maintaining tension in the linkage.

ALTIMETER DIAL

Altimeters used to have three pointers rotating at different rates, one revolution of a pointer indicating one hundred thousand feet of altitude respectively.

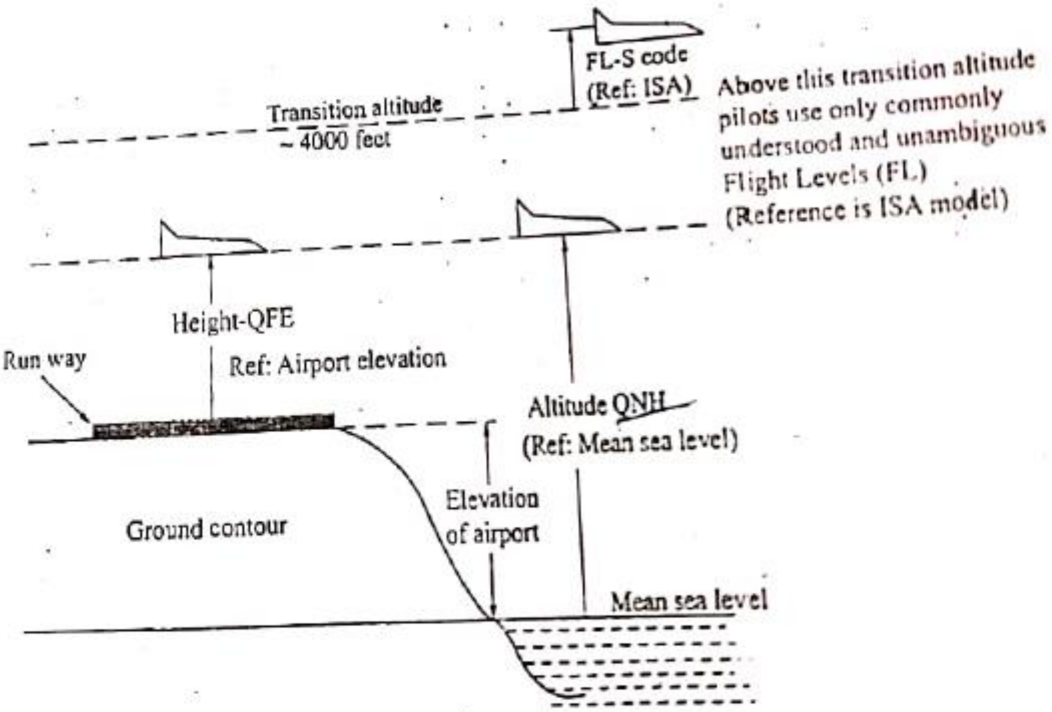
https://www.slideshare.net/slideshow/pitot-static-system/48826464



(a) Baro adjust in ALTI

1. The pilot can manually offset the zero of ALTI, using BARO knob, usually located at bottom left of front dial side of ALTI.

2.The window displaying the set baro pressure is called Kollsmann window, named after US-German immigrant, who manufactured high quality air data instruments.



(b) QFE, QNH and S code define.

Fig.3.19 ALTI, baro knob and flight levels.

QFE, QNH and standard pressure settings define different altitude references in an aircraft altimeter.

QFE gives height above the airfield with zero indication on the runway.

QNH gives altitude above mean sea level and shows airport elevation on ground. Above the transition altitude, altimeter is set to standard pressure (1013 hPa) and altitude is expressed as flight levels to maintain safe vertical separation.

1. QFE shows the aircraft flight altitude above the local airport level. When the aircraft lands at the airport, the ALT reads zero feet. This prevalent atmospheric pressure is requested by the pilot and provided by the ATC or even broadcast periodically by the airport. This setting corresponds to 28 feet if the airport is 560 feet high; the difference between sea level and ground pressure is 0.1 mb. A common mnemonic (memory aid) for QFE is “Field Elevation.”

2. QNH (mnemonic: Nautical Height) is a more common pressure setting used by pilots to indicate aircraft flight altitude with respect to sea level. It will cause the altimeter to read altitude above mean sea level, within a certain defined region. QNH is in millibars (mb) or hectopascals (hPa) (1 hPa = 1 mb). QFE and QNH are in inches of mercury (1 inHg = 29.92 inHg = 1013.2 mb = 1013.2 hPa).

In North America, however, QFE and QNH are in inches of mercury. It is a good idea to stick to millibars to avoid ambiguity. ATC will pass on QNHs on clearing them to descend below the transition altitude. As part of ATC clearance, QNH ensures smooth landing of aircraft on the runway.

3. S (or SAS): When the aircraft has crossed the transition altitude, they must be referenced to 1013.2 mb — the ISA standard pressure — to facilitate maintenance of flight levels of the aircraft. This is a definite requirement in a busy air corridor, such as the trans-Atlantic route. This code is also known as Standard Altimeter Setting (SAS).

In S code, the barometer is set to 1013.2 mb (or 29.92 inHg). It is used for aircraft flying above a predetermined transition altitude. Since all aircraft use the same S code in the air corridor and flying with the same zero offset of 1013.2 mb, the air traffic controller ensures vertical separation of aircraft (usually 1000 feet) issued between any two aircraft. The transition altitude — the switch-over point — is usually 4000 feet. Above this datum altitude, the aircraft uses flight levels (FL) to establish flight altitudes. For example, FL 40 = 4000 feet, FL 300 = 30,000 feet.

Figure 3.19(b) shows clearly the distinction between QFE, QNH, S, as well as elevation, height, and altitude with respect to aircraft flying at certain altitude. Minimum vertical separation of 1000 feet is maintained by all aircraft flying in the air corridor. Recent trend is to reduce the vertical separation to lower than 1000 ft by using GPS (Global Positioning System) and this is known as RVSM (Reduced Vertical Separation Minima). This reduced separation is increasingly in use in air traffic, particularly over the Atlantic Ocean between Europe and USA. Further, in addition to vertical separation, some attempt is being made to include lateral (side-wise) separation also.

Errors in ALTI (Altimeter)

Sensitive altimeters are manufactured to extremely tight and close tolerances. Yet there are certain inherent errors, which make the ALTI reading depart from the true value. They are explained below:

(i) Friction error

Friction in the mechanical system causes irregular and jumpy motion of the pointer, when the pressure is changing uniformly. Friction also causes hysteresis the readings while going up and coming down will be different for the same steady-state altitude.

By using jewel bearings, precision engineering of push rods, bell cranks, sectors, pinions, gears, cams, etc., friction can be reduced to a minimum. The fine mechanism technology of the precision advantage in ALTI is used to advantage.

(ii) Errors due to vibration

Changes in aircraft attitude (pitch, roll, yaw) and vibration cause shaking of mechanical parts, resulting in errors in indication.

(iii) Errors due to improper balancing

Improper balancing of mechanical parts causes error in altimeter indication.

(iv) Elastic error (springiness)

Elastic changes resulting in lag and hysteresis occur due to internal stresses of mechanical parts.

Errors with respect to time are caused by release of internal stresses of the pressure-sensing capsules.

This is minimized by proper stress relieving and heat treatment of parts during the manufacture of ALTI.

(v) Temperature error

With ambient temperature changes, the elastic constant of the capsule changes. For example, when the temperature decreases, the spring constant increases, giving less expansion of capsules. This results in erroneous reading of ALTI. In sensitive altimeters, this error is minimized by the opposing expansion of a bimetallic strip, as has already been explained.

(vi) Pressure leak error

Pressure leaks cause an erroneous reading. A leaky ps connection introduces error.

At high rates of ascent or descent, there will be a lag between the pressure within the ALTI's case and the pressure in the static tube. The two pressures, however, equalize when the aircraft reaches steady flight altitude.

Vertical Speed Indicator (VSI)

Vertical Speed Indicator is also known as Rate of Climb Indicator (RCI) or Vertical Velocity Indicator (VI).

VSI indicates the rate of change of height, in feet per minute (fpm), of an aircraft.

VSI is one of the three primary air data instruments (other two are ALT and ASI), which indicates to the pilot if the aircraft is in level flight, or ascending or descending and, if so, at what rate (fpm).

The static pressure gives information about the flight altitude and is indicated by ALT. VSI, on the other hand, measures the rate of change of barometric pressure, by measuring the differential pressure between the static pressure and the delayed static pressure.

The delay or lag is introduced by a metered orifice (restriction). The only input to VSI is the static pressure, just like in ALTI. VSI indicates vertical speed in feet per minute directly.

A pictorial view of VSI is shown in Figure 3.21(a).

Construction and Working of VSI

VSI primarily comprises three main parts (Figure 3.21(a)):

1. Pressure-sensing capsule (1)
2. Metered orifice (2)
3. Pointer and scale (3)

The entire instrument case (4) is sealed except for a hole to receive Ps (static pressure). The front-face dial, as shown in Figure 3.21(a), is in the 9 o'clock position when the aircraft is on ground or in straight and level flight.

Most of the dial indicators have a logarithmic scale, as readings near zero are well expanded. The expanded lower scale provides good readability near zero marking, which corresponds to straight and level flight of the aircraft.

Pressure Lag Principle

The inlet static pressure Ps is fed to:

(1) Pressure-sensing capsule via a capillary tube, to minimize pressure surges reaching the capsule, and also to

(2) a metered orifice, analogous to resistance in electrical circuits.

The metered orifice provides the lag or delay in building up pressure inside the instrument case (analogous to capacitance). The system behaves like an RC network, and $\tau = RC$

where τ is the time taken to reach 63% $(1 - e^{-1})$ of the pressure step input, as shown in Figure 3.22.

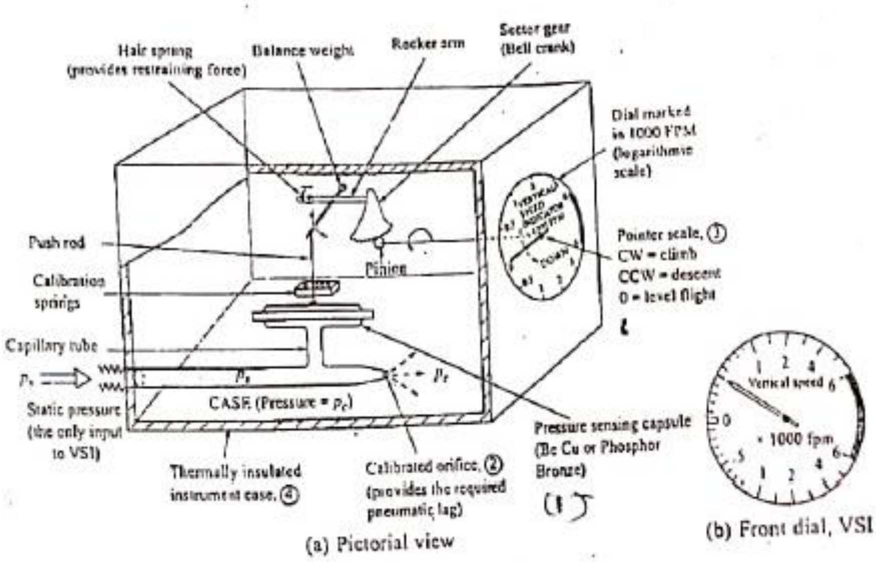


Fig. 3.21 Vertical speed indicator.

Note: VSI – Theoretical Aspects

The following assumptions are made in this analysis:

1. ISA standard atmospheric conditions are assumed.
2. Change of case pressure is adiabatic, meaning that there is no heat loss during the pressure changes. To facilitate this adiabatic process, the instrument case should be thermally well insulated.
3. VSI is well sealed, so that aircraft cabin pressure does not influence its reading.
4. The pressure change between diaphragm pressure pdp_dpd and case pressure pcp_cpc is very small,

   $\Delta p = pc - pd$ is very small

5. Volume of the case is constant.

Pointer Deflection Relation

Under the above assumptions, it can be shown that the pointer deflection x of VSI is a linear function of the pressure drop Δp across the orifice (Figure 3.21), which in turn is proportional to the aircraft's vertical speed.

$x = K \Delta p$ (3.18)

$x = a V(1 - e - t/\tau)$ (3.19)

Where:

- x = VSI needle displacement
- K = constant of proportionality
- $\Delta p = pc - pd$
- a = another constant of proportionality
- η = vertical speed of aircraft (in fpm)
- t = elapsed time
- τ = time constant (in seconds)

Dynamic Response of VSI

When the aircraft starts climbing with a constant vertical velocity η (as shown in Figure 3.22):

- The initial error is 100%
- After one time constant ($t=\tau$), the error reduces to 23%
- After 3τ seconds, the error is reduced to 5%

This shows that the VSI behaves like a first-order system (RC-type response) with a finite response time.

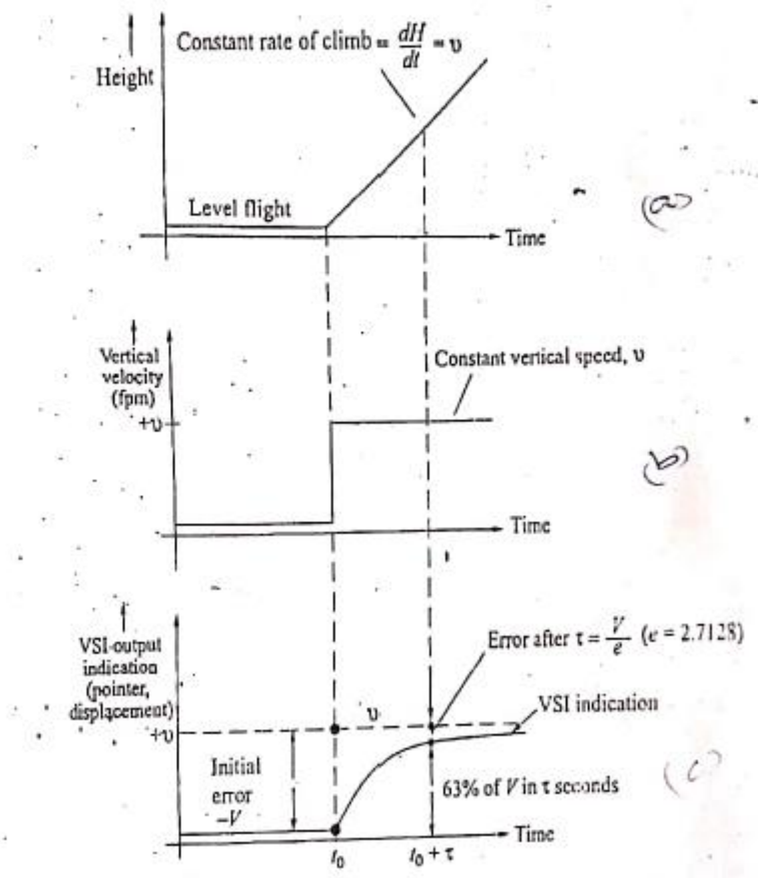


Fig. 3.22 VSI plots of H, dH/dt and needle displacement vs time.

VSI – Time Constant and Working (Practical Considerations)

Selection of the lag time constant is very important in VSI. Time constant is a strong function of the volume of the VSI chamber. For fast response, the volume should be as small as practicable. However, reducing the volume also reduces the sensitivity of the VSI. Hence, the chamber volume must be selected as a compromise between speed of response and sensitivity.

Taking all the above factors into consideration, a time constant of about 5 seconds will give satisfactory performance of VSI. This also ensures stable readings during flight through turbulent weather.

In general aviation aircraft such as Cessna 182, the lag time τ of VSI is 5 seconds. This means the VSI shows the vertical speed of the aircraft 5 seconds ago. More expensive aircraft use Instantaneous Vertical Speed Indicator (IVSI), which is discussed in Subsection 3.4.4.

VSI Working in Different Flight Conditions

1. Straight and level flight

If the aircraft is flying straight and level, ps = pc

and there will be no differential pressure for the capsule.
The pointer reads zero rate of climb or descent and is at the 9 o'clock position (Figure 3.22(b)).

2. Aircraft climbing

When the aircraft is climbing:

- ps (static pressure) decreases, case pressure will be more
- Pressure is felt immediately inside the capsule
- Outside the capsule, case pressure pc - ps decreases more slowly due to the restricted orifice
- A differential pressure develops:

  Pc-Ps exists to operate the needle to show climb up position.

Since pc>ps, the capsule is compressed, producing a movement that operates the needle to show climb.

This movement is transmitted to the pointer via push rod, bell crank, torque bar, etc. The needle moves up to show climb in the correct sense to the pilot. For example, if the aircraft is ascending at 500 fpm, the needle moves up to the +0.5 mark, as shown in Figure 3.23.

3. Aircraft descending

Opposite to climbing:

- The aircraft descends into higher pressure
- pcp_cpc becomes lower than psp_sps
- The capsule expand**s**
- The pointer moves to show descent below zero

Thus, the needle moves below zero to indicate descent. For example, if the aircraft is descending at 500 fpm, the VSI indicates –0.5.

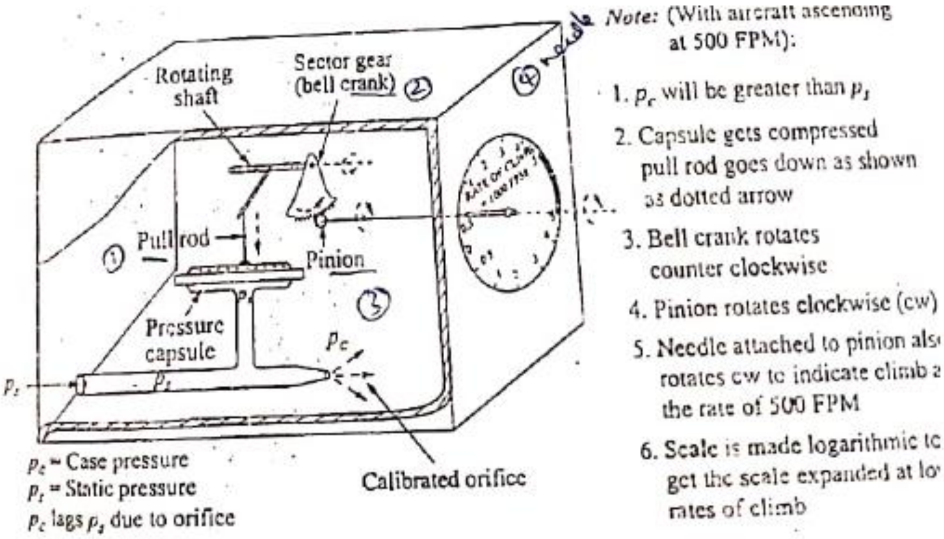


Fig.3.23 Simplified diagram of vertical speed indicator. Aircraft is climbing at 500 FPM (say

If the aircraft is flying at a constant rate of climb or descent, there will be a constant rate of increase or decrease of pressure in the capsule and, because of the metered orifice, there will be a constant rate of pressure change in the case also, but with a time lag. The time constant of the leak causes the pressure in the case always to lag behind the pressure in the capsule, thus maintaining a constant differential pressure.

This results in the VSI indicating a constant rate of ascent or descent.

As soon as the aircraft stops climbing or descending and starts flying straight and level, the pressure difference Δp becomes zero, and the needle returns to zero indication.

When indicating level flight, the pressure differential Δp is very small, of the order of 0.03 cm (or mm) of water, even for full-scale deflection. This requires high manometric precision and accuracy of the VSI.

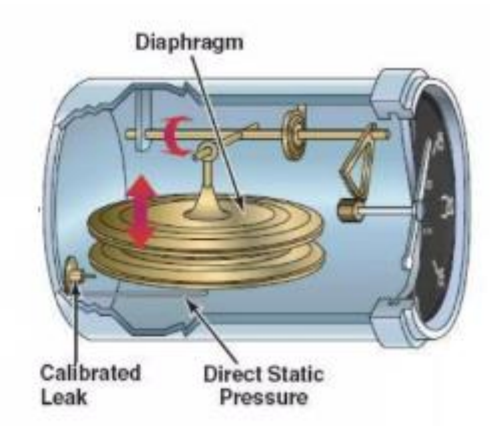
Errors and Compensation in VSI

There will be some error in VSI introduced due to changes in:

- **Altitude**
- **Viscosity**
- **Temperature**

In more sensitive VSI, these effects are compensated by special compensation techniques. For example:

- Temperature compensation is achieved by a bimetallic strip
- Viscosity compensation is achieved by maintaining an optimum mix of laminar and turbulent flow, with turbulence being generated by sharp-edged orifices.

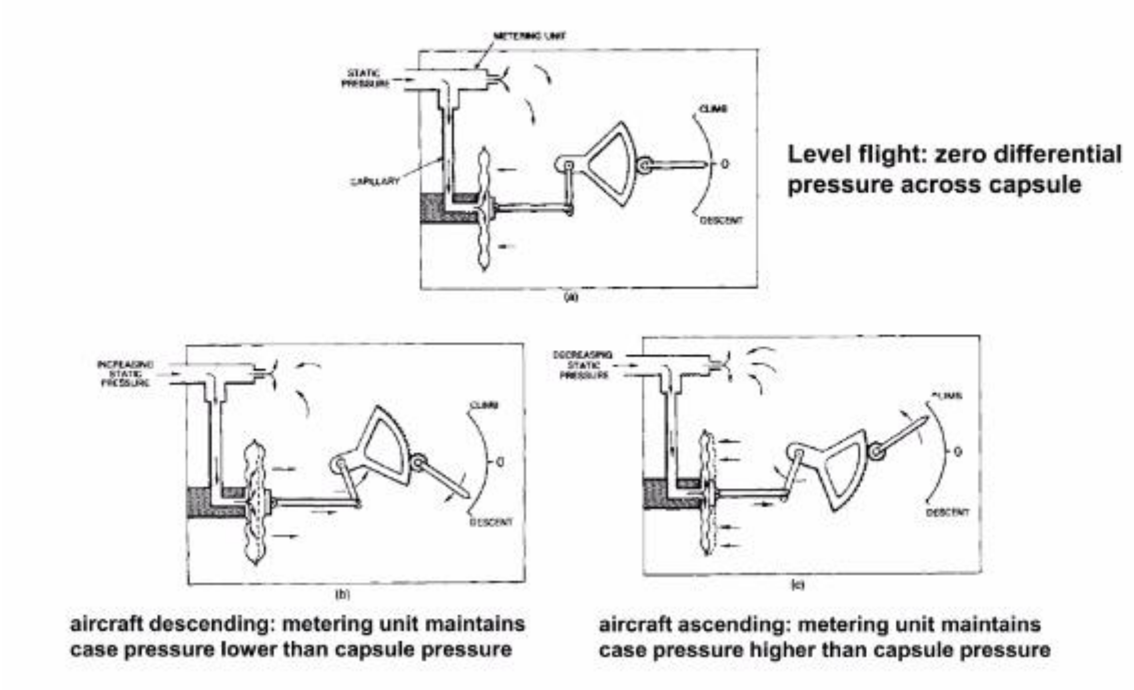


VSI is a very sensitive differential pressure gauge, designed to indicate the rate of altitude change from the change of static pressure alone.

This indicator consists basically of three main components:

1. A capsule,
2. An indicating element, and
3. A metering unit with an orifice/calibrated leak.

The orifice is opened to the interior of the case to apply static pressure to the exterior of the capsule. It has a time-lag response characteristic.



3.4.5 Instantaneous Vertical Speed Indicator (IVSI)

In a conventional VSI, there is a time lag of about 5 seconds, which is unacceptable in certain types of aircraft.

IVSI displays a very rapid rate of ascent or descent**,** and such instantaneous response is highly desirable in agile aircraft such as F-16 (USA) or LCA (India). Figure 3.24 shows the simplified schematic of IVSI.

Principle of Operation of IVSI

In order to reduce the lag time, IVSI uses one or two accelerometer pumps in the static pressure line ps leading to the pressure capsule, as shown in Figure 3.24.

IVSI uses the same modules as VSI. Further, it incorporates one or two accelerometer units, which help to create a faster build-up of differential pressure, particularly at the beginning of climb and descent.

The accelerometer is almost identical to a conventional accelerometer**,** consisting of a seismic piston mass and spring within the accelerometer cylinder, which is connected along the static pressure line**.**

When the pilot changes vertical speed, vertical acceleration occurs.

- Due to this acceleration, the seismic mass (piston) is instantaneously displaced.
- The piston action pumps air into the pressure capsule.
- **During descent**:
  - Seismic piston moves upward.
  - Capsule pressure increases.
  - Pointer deflects along the descent scale.
- **During ascent**:
  - Seismic piston moves downward.
  - Capsule pressure decreases.
  - Pointer deflects along the climb scale.
- The accelerometer response is transient (temporary). After a short time, the accelerometer effect decays. Then the conventional Vertical Speed Indicator (VSI) operates normally.
- A restriction in the bypass line is provided:
  - Minimizes loss of pressure fluctuations caused by acceleration pumping.
  - Ensures pressure changes act mainly on the capsule.
- The bypass restriction improves pumping efficiency of the accelerometer.
- Instantaneous VSI (IVSI) is used in:
  - All fighter aircraft
  - Most modern airliners

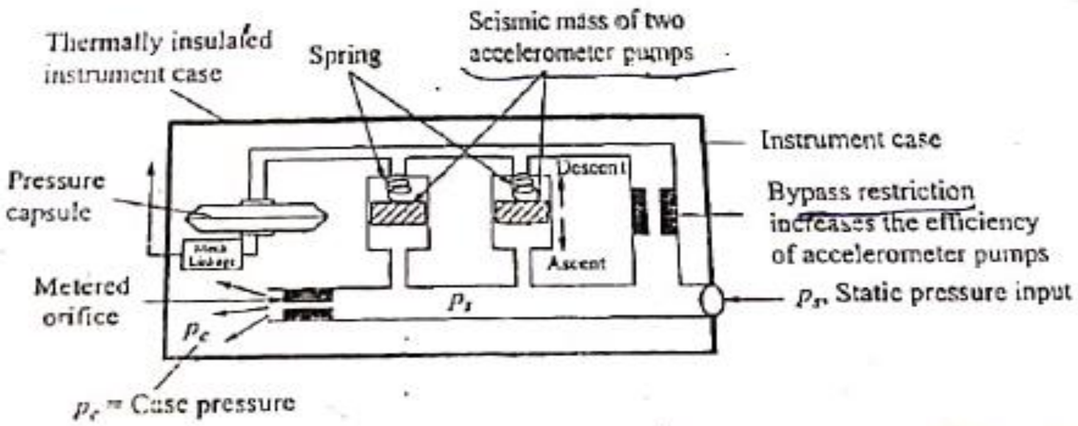


Fig. 3.24 IVSI–schematic diagram.