LESSON G2 – PITOT STATIC INSTRUMENTS

Lesson Introduction

- The pitot-static system gives the ASI, VSI, and Altimeter access to the outside air through which the aircraft is moving
    - It is the source of air pressure for these three instruments
- What uses what
    - Static port vents the following 3 instruments to outside air
        - Altimeter
        - VSI
        - Airspeed indicator
    - Pitot tube supplies ram air pressure to:
        - Airspeed indicator
- A pitot-static system has two parts:
    - The impact pressure chamber and lines
    - The static pressure chamber and lines
        - In many aircraft, both the impact pressure and the static pressure come from the same source – the pitot-static tube, as in the Piper 180
        - Other aircraft split the pitot and static sources, as in the Cessna 172

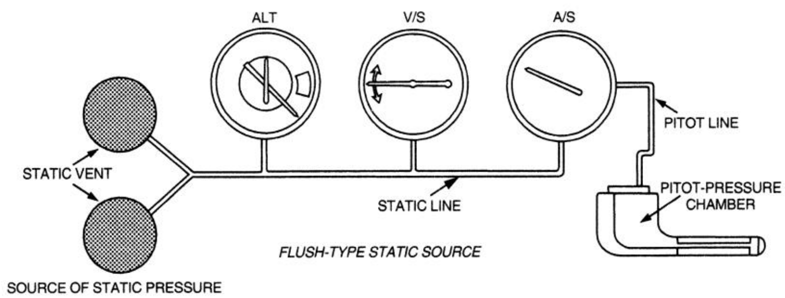

Figure 2-1. – *A typical pitot-static system.*

- The pitot tube measures impact air pressure (air striking the aircraft as it moves through the air)
    - The pitot tube is mounted where the airflow is undisturbed
        - Usually on the underside of the wing
    - The pitot tube is pointed directly into the relative wind

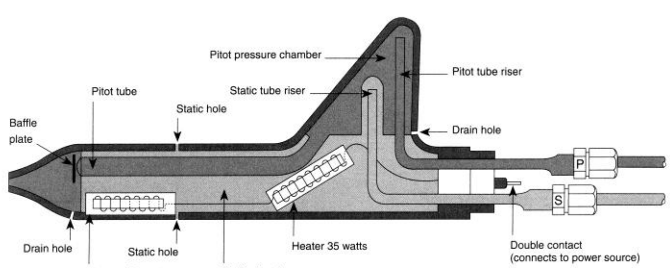

Figure 2-2. – *A typical electrically heated pitot-static head.*

- Static pressure (still air) is measured at:
  - A vent on the pitot tube that does not face into the relative wind
  - A vent or vents mounted flush with the side of the fuselage
    - Many aircraft have a flush static source vent on each side of the fuselage to ensure accuracy
- If the aircraft has one static port, unusual attitudes (a slip or skid) can force disrupted air past the static vents (and / or the pitot tube), causing the airspeed indicator to be inaccurate
- To Preflight the pitot-static system remove any coverings, visually inspect the holes for obstructions, and make sure the pitot heat works – touch it gingerly
  - Insects like to make their abode in the pitot tube
  - Static ports are often taped during maintenance or washing – check them carefully
  - Don't blow into any of these openings. If they are clogged, locate an aircraft technician
- As an aircraft moves through the air, the impact pressure on the pitot tube changes the pressure in the pitot chamber
  - This pressure is transmitted to the airspeed indicator by a tube
- The static chamber, whether in the pitot tube or on the fuselage, is vented through a small hole to undisturbed air
  - As the atmospheric pressure increases or decreases (as in an aircraft climbing or descending), the pressure in the static chamber goes up or down accordingly
- Ice can block either the static port and pitot tube in flight
  - Most aircraft have heated pitot tubes
    - Before entering areas of visible moisture – clouds included – turn on the pitot heat. This will prevent the accumulation of ice – better safe than sorry
      - The temperature in the pitot tube can lower quickly due to impact pressure and the Bernoulli effect – even in warm air
- Aircraft equipped for instrument flight have an alternate static source
  - A valve inside the cockpit can be opened if the outside static source becomes blocked
    - When using the alternate static source, the instruments will indicate differently because of the effect of the flow of air over the fuselage
      - The altimeter shows higher than the actual altitude
      - The airspeed indicates higher than the actual airspeed
      - The vertical speed shows a climb while in level flight

Altimeter

- The altimeter measures the height of the aircraft above a given level
  - Since it is the only instrument that gives altitude information, the altimeter is one of the most important instruments in the aircraft
- The pressure altimeter is an aneroid barometer that measures the pressure of the atmosphere at the level where the altimeter is located, and presents an altitude indication in feet
  - The altimeter uses static pressure as its source of operation

- The dial of a typical altimeter is graduated with numerals arranged clockwise from 0 to 9 inclusive
  - A change in atmospheric pressure is transmitted through a gear train to the three hands which sweep the calibrated dial to indicate altitude
    - The shortest hand indicates altitude in tens of thousands of feet
    - The intermediate hand in thousands of feet
    - The longest hand in hundreds of feet, subdivided into 20 foot increments
- Since atmospheric pressure continually changes, a means is provided to adjust the altimeter to compensate for nonstandard conditions
  - This is accomplished through a system by which the altimeter setting (local station barometric pressure reduced to sea level) is set to a barometric scale located on the face of the altimeter
    - Only after the altimeter is set properly will it indicate the correct altitude
  - The adjusted pressure is read in the small window on the face of the dial

Figure 2-3. – ***Sensitive altimeter. The instrument is adjusted by the knob (lower left) so the current altimeter setting (29.48) appears in the Kollsman window to the right.***

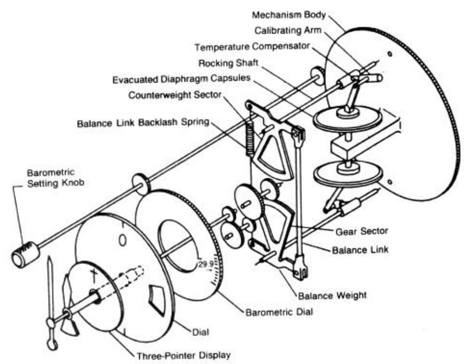

Figure 2-4. – ***Innards of a two aneroid altimeter.***

- Altimeter Construction
  - Modern altimeters contain sealed, flexible aneroid capsules or wafers (a stack of three or more) containing gas at a specified pressure. The capsules expand and contract with changes in atmospheric pressure

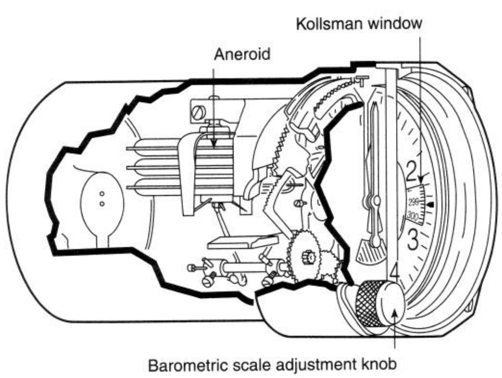

Figure 2-5. – ***Sensitive altimeter components.***

- One side of the stack is fixed in its position. The other side flexes and is connected to a spring and to a pointer
  - As the aneroid's movable side flexes in and out with changes in the surrounding air pressure, the pointer indicates the change on the instrument's faceplate, which is calibrated in either inches of mercury or millibars
- When there is more than one aneroid wafer, the altimeter is called "sensitive"
- The aneroid stack is inside a sealed chamber linked to the static port located on the outside of the aircraft
- The altimeter must be adjusted for nonstandard barometric pressures by twisting the knob on the bottom of the instrument
  - Turning the knob, simultaneously rotates the scale in the Kollsman window and the altimeter hands at a rate of 1" Hg per 1,000 feet
    - For practical purposes, this ratio can be considered the standard pressure lapse rate below 5,000 feet
- The Kollsman window scale is calibrated from 28.00" to 31.00" Hg. These two figures are the extremes in barometric change at sea level
- When flying IFR, remember to check the altimeter against the known field elevation to ensure that it is accurate to plus-or-minus 75 feet

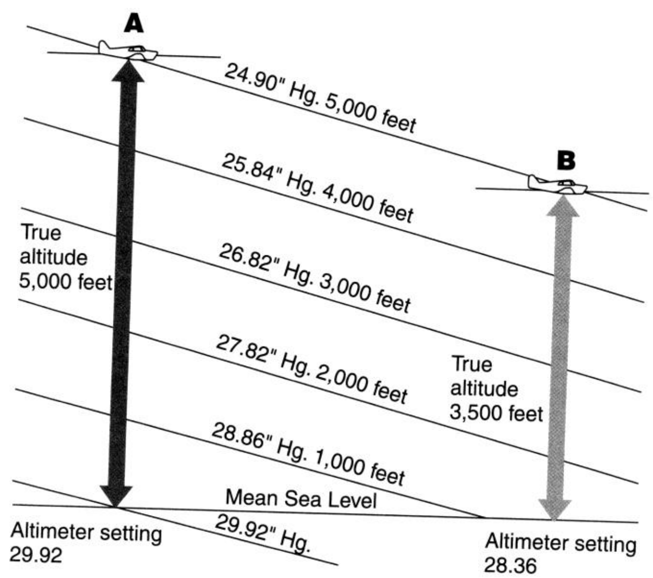

Figure 2-6. – ***Effects of nonstandard pressure on an altimeter.***

  - Nonstandard conditions can result in a difference of as much as 2,000 feet between true altitude (actual altitude above mean sea level) and the altitude indicated by the altimeter
- Temperature variations raise or lower the pressure levels that the altimeter is designed to sense

- The 4,000 foot pressure level (Figure 2-7) is higher on a warm day than it would be under standard conditions
- On a cold day the pressure level is lower than standard

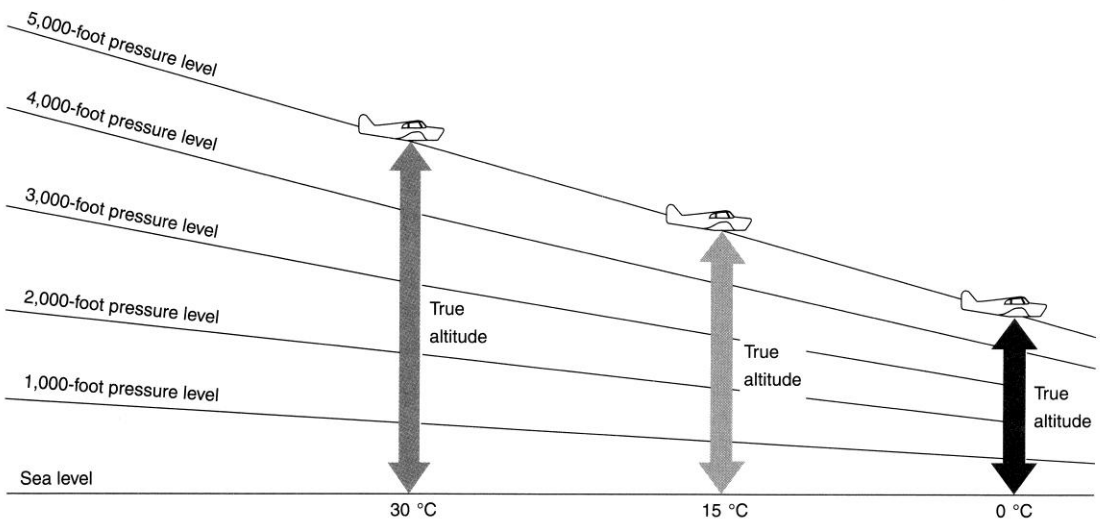

Figure 2-7. – ***Effects of nonstandard temperature on an altimeter.***

- The mnemonic device to remember here is, **"High to Low, Look Out Below"**
- If the aircraft is flying from an area of high temperature to one of low temperature, the true altitude will be lower than the indicated altitude

- The mnemonic works when flying from an area of high to low barometric pressure or high to low humidity as well
  - High, Hot, and Humid conditions cause the atmosphere to expand

- Unlike temperature and humidity changes, pressure changes can be corrected by adjusting the altimeter to the new pressure setting
  - Obtain the new setting by tuning in a nearby automatic terminal information service (ATIS) or automatic weather observation system (AWOS)
    - Each weather reporting station measures the atmospheric pressure hourly and, according to the station's elevation, corrects the pressure to sea-level pressure
- When flying cross-country below 18,000 feet MSL, adjust the altimeter to the local setting every 100 miles or so
- When flying at or above 18,000 feet, set the altimeter to 29.92 to maintain vertical separation of aircraft

Types of Altitude

- Absolute (AGL) – Height above ground level. The actual distance between an aircraft and the terrain over which it is flying

- Indicated – Face of the altimeter. The speed of an aircraft as shown on the airspeed indicator… “calibrated to reflect standard atmospheric adiabatic compressible flow at sea level uncorrected for airspeed system errors.” (14 CFR Part 1)
- True (MSL) – Actual height of an aircraft above mean sea level
- Pressure – Correlation to a standard atmosphere that would have the same pressure as current indicated or true altitude. Altitude above the standard 29.92” Hg plane
- Density – Correlation to a standard atmosphere that would have the same density (measured by pressure & temperature) as the current indicated or true altitude. Pressure altitude corrected for nonstandard temperature
    - Density altitude is used for computing the performance of an aircraft and its engines

Vertical Speed Indicator – VSI

- As a point of interest, 91.205 doesn’t require this instrument for IFR flight (or for VFR flight)
- The VSI is both a rate and trend instrument
    - It complements the primary pitch indicators in the panel during both takeoffs and landings in low visibility conditions

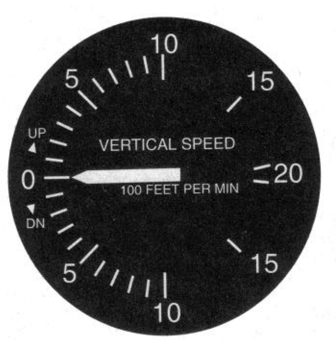

Figure 2-8. – ***Vertical speed indicator shows the rate of climb or descent in thousands of feet per minute.***

- The vertical speed indicator – also known as the vertical velocity or rate-of-climb indicator – is housed within a sealed case
    - It is connected to the static pressure line through a calibrated leak – also called a calibrated orifice
        - This is a hole of a specific diameter used to delay the pressure change in the case of the vertical speed indicator
    - Changing pressures expand or contract a diaphragm or aneroid wafer, which is connected to the indicating pointer by gears and levers
        - The mechanisms are similar to those found in an aneroid altimeter
        - A VSI compensates for changes in temperature without pilot input, so its indications are not subject to temperature errors – no adjustment knob needed
- Even though the vertical speed indicator operates from the static pressure source, it is considered a differential pressure instrument
    - The differential pressure is established between the instantaneous static pressure in the diaphragm (connected to the outside by the static system) and the trapped static pressure within the sealed instrument case
        - When the pressures equalize in level flight, the pointer reads zero on the face of the instrument

        - When the airplane begins a climb or descent, static pressure in the diaphragm changes, and the pointer moves up (climb) or down (descent)
            - It takes a few seconds for the differential pressure to stabilize at a constant rate because the calibrated leak restricts airflow into the sealed case

- The VSI needle should indicate zero when the aircraft is on the ground or maintaining a constant pressure altitude in flight
    - If not, have the instrument adjusted professionally
- If an out-of-adjustment VSI is disturbing, find something to cover it
    - As a rule, cover any instrument in the panel that malfunctions significantly during an IFR flight
        - This may prevent a bad case of vertigo
- Even though the VSI isn't required for IFR flight, it is one of the primary instruments scanned during every takeoff, especially during instrument conditions
    - The sequence of events and instrument indications during a takeoff are:
        - Engine power full, brakes release, airspeed indicator alive, engine instruments in the green, airspeed at rotation speed, rotate, and positive rate of climb as indicated by the VSI
    - The VSI is the only instrument that shows both the trend of the airplane's flight (climbing or descending) and the actual rate of climb or descent
- Some airports require that the aircraft be able to maintain a specific climb rate noted in feet per nautical mile
    - If the aircraft can't maintain the climb rate, the flight won't be able to meet the minimum altitude requirements for the departure
    - Both Jeppesen and NACO approach charts include rate of climb tables that convert feet per nautical mile requirements into a specific rate of climb and ground speed
    - Check the AFM/POH to see if the aircraft, as loaded, with that day's density altitude, can make the climb gradient. If the answer is no, lighten the payload or do whatever it takes to meet the climb requirements safely
- The VSI also is necessary for a constant-rate standard IFR climb or descent
- In smooth air the vertical speed indicator becomes the judge of how well the pilot maintains a steady altitude

Airspeed Indicator – ASI

- The modern ASI has a dial that is connected to the pitot-static system
    - This system gives the instrument access to the outside air through which the aircraft is moving

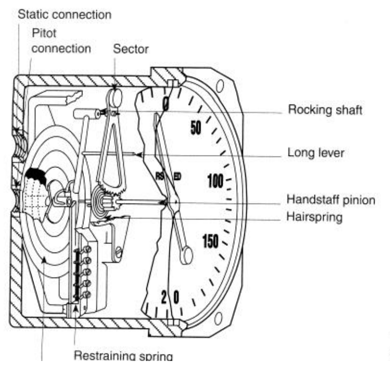

Figure 2-9. – ***Mechanism of an airspeed indicator.***

        - The ASI measures the speed at which the aircraft is moving through the air, NOT the speed over the ground
        - Airspeed is measured in knots or MPH

                - 1 Nautical Mile = 1.15 Statute Miles

- The ASI is a sensitive, differential pressure gauge that measures, with only a small delay, the difference between pitot pressure – or impact pressure, and static pressure – the undisturbed atmospheric pressure at the aircraft's altitude
    - These pressures are the same when the aircraft is on the ground in calm air
        - When the aircraft moves forward, however, the pressure on the pitot line becomes greater than the pressure in the static lines
- Most airspeed indicators consist of a sealed chamber or drum divided by a solid rubber diaphragm

Figure 2-10. – ***A true airspeed indicator allows the pilot to correct indicated airspeed for nonstandard temperature and pressure.***

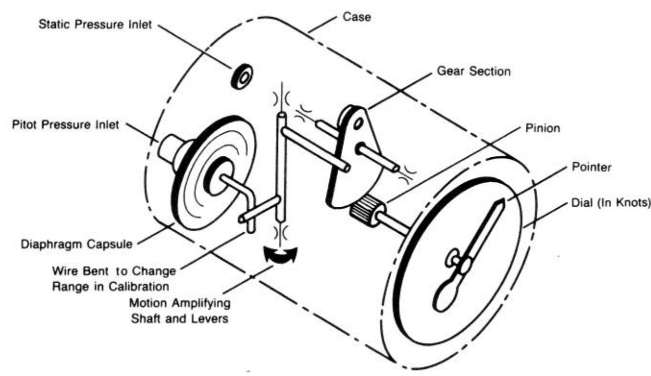

Figure ***2-11. – Mechanism of a simple airspeed indicator.***

- Static pressure is introduced into one side of the chamber and impact pressure into the other
    - When the airplane moves and the impact pressure increases, the diaphragm moves to accommodate the increased pressure
        - An arm on the diaphragm transfers this movement to a geared assembly that controls the ASI needle
            - The needle moves clockwise across the face of the instrument, which is calibrated in knots, miles per hour, or Mach number
- Many ASIs have a small circular slide-rule computer on the outer ring of the instrument that calculates true airspeed
    - The slide rule takes the altitude and outside air temperature into account to roughly determine the true airspeed from the indicated airspeed
    - At cruise speeds, indicated airspeed is essentially the same as calibrated airspeed in a properly installed system
- Airspeed Markings
    - White arc – Full flap operating range
    - Green arc – Normal operating range
    - Yellow arc – Operations in smooth air only

White arc Bottom Top	Flap operating range Flaps-down stall speed Maximum airspeed for flaps-down flight
Green arc Bottom Top	Normal operating range Flaps-up stall speed Maximum airspeed for rough air
Blue radial line	Airspeed for best single-engine rate-of-climb
Yellow arc Bottom Top	Structural warning area Maximum airspeed for rough air Never-exceed airspeed
Red radial line	Never-exceed airspeed

Figure 2-12. – ***Color codes for an airspeed indicator.***

- Red line – Never exceed speed

➢ Important V-speeds for an aircraft
- V_{S0} – Stall Speed in Landing Configuration
- V_S – Stall Speed in clean configuration
- V_{GLIDE} – Best Glide Speed
- V_X – Best Angle of climb
- V_Y – Best Rate of climb
- V_{FE} – Flaps extended speed
- V_A – Maneuvering Speed
- V_{NO} – Maximum structural cruising
- V_{NE} – Never Exceed

Types of Airspeed

➢ There are three kinds of airspeed that the pilot should understand:
- Indicated Airspeed (IAS) – the direct, uncorrected instrument reading obtained from the airspeed indicator
- Calibrated Airspeed (CAS) – the indicated airspeed corrected for installation error and instrument error
- True Airspeed (TAS) – the calibrated airspeed corrected for nonstandard pressure and temperature

➢ Indicated airspeed is shown on the dial of the instrument, uncorrected for instrument or system error

➢ Calibrated airspeed is the speed of the aircraft moving through the air, which is found by correcting IAS for instrument and position error
- Check the appropriate AFM/POH. It contains either a chart or graph to correct IAS for these errors and provides the correct CAS for the various flap and landing gear configurations

➢ True airspeed and CAS are the same in standard atmosphere at sea level
- Under nonstandard conditions, TAS is found by applying a correction for pressure altitude and temperature to the CAS
  - To find TAS, use the flight computer. The calibrated airspeed is corrected for temperature and pressure variation by using the airspeed correction scale on the computer
  - The pilot may also use a rule of thumb to determine the approximate TAS. Add to the IAS 2 percent of the IAS for each 1,000 feet of altitude

➢ There is a fourth airspeed for those flying faster aircraft – Equivalent Airspeed (EAS)
- EAS is CAS corrected for compression of the air inside the pitot tube

        - As the airspeed and pressure altitude increase, the CAS becomes higher than it should be and a correction for compression must be subtracted from CAS

Instrument Errors

- A blocked pitot tube causes the airspeed indicator to fail
    - The proper attitude and power setting automatically result in a safe airspeed
    - If the airspeed indicator starts to react in an unusual way, or the aircraft is flying in visible moisture, activate the pitot heat
    - A partially or completely blocked pitot head will give an erratic or zero reading
- A blocked static system causes the altimeter, airspeed, and vertical speed indicators to fail
    - If the external static port is clogged, activate the aircraft's alternate static source
    - A pressure differential exists between the normal and alternate static sources. The alternate source uses cabin air rather than outside air to function. The air flowing over the cabin causes a venturi effect inside the cockpit reducing the inside air pressure
    - Because of this pressure reduction, the altimeter will usually indicate a little higher than normal, the airspeed will register a little faster than normal, and the vertical speed indicator will indicate a climb even though the aircraft is in level flight
    - Check the owner's manual for calibration figures. Some aircraft have a correction card for this purpose in the cockpit, some use an airspeed calibration chart
    - Before the introduction of the alternate static source, the pilot created a source by breaking the glass face of the VSI. If, after the break, the VSI worked at all, it was backward. The airspeed indicator and altimeter worked as described above
- Most pressure altimeters are subject to mechanical, elastic, temperature, and installation errors
    - They lag in rapid climbs or descents because it takes time for the pressure changes to get from the static port to the instrument
        - The pilot can compensate for these lags by anticipating target altitudes and adjusting the climb or descent rates accordingly as the target altitude approaches
        - This technique gives the altimeter time to catch up and indicate properly
    - Altimeter errors also result if the instrument is incorrectly installed or if the static ports have not been properly placed
        - If the static port is blocked for some reason, the altimeter indication will freeze
            - Use the alternate static source
- In the Vertical Speed Indicator, the lag time from the calibrated leak can be a problem
    - Sudden or abrupt changes in aircraft attitude cause erroneous instrument readings as the airflow fluctuates over the static ports

    - Both pilot-induced turbulence and the kind caused by rough air cause several seconds (and sometimes longer) of unreliable needle indications
        - However, the VSI allows the pilot to establish and maintain level flight and specific-rate climbs or descents in normal flight
- The airspeed indicator must be calibrated in flight to determine system error
    - The system error, including position error but excluding the ASI instrument calibration error, may not exceed 3 percent of the calibrated airspeed or 5 kts, whichever is greater