Private Pilot (ASEL) Ground School Course

Lesson 07 | Aircraft Flight Instruments

Lesson Overview

Lesson Objectives:

- Develop an understanding of how the flight instruments work on an aircraft.

Lesson Completion Standards:

- Student demonstrates satisfactory knowledge of aircraft flight instruments by answering questions and actively participating in classroom discussions.

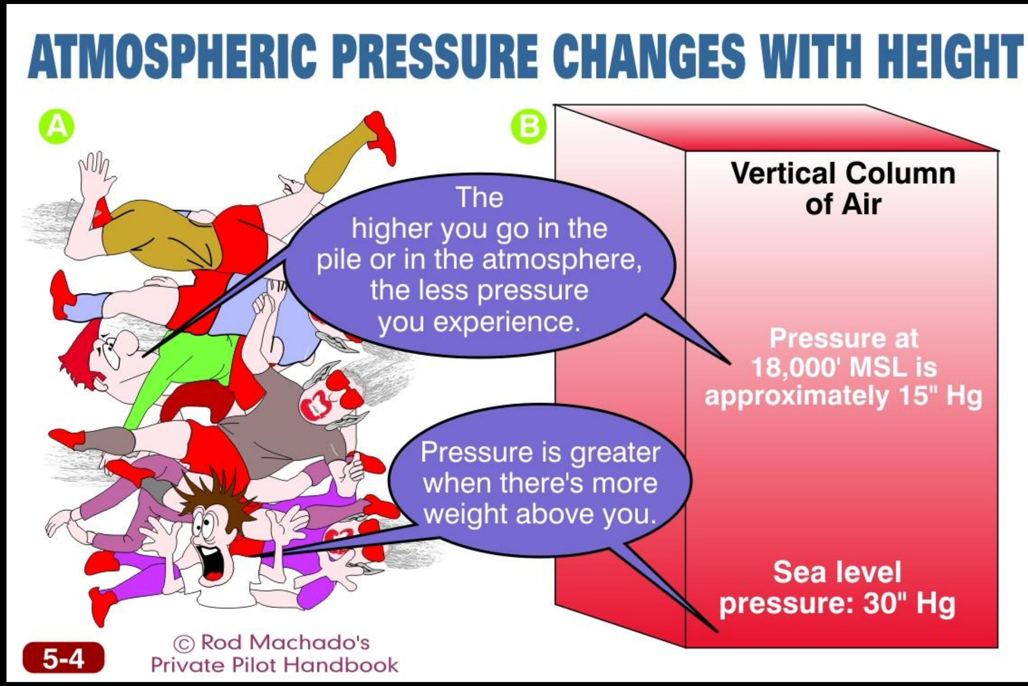
Pitot-Static Instruments

Aircraft Flight Instruments

BASIC SIX PACK

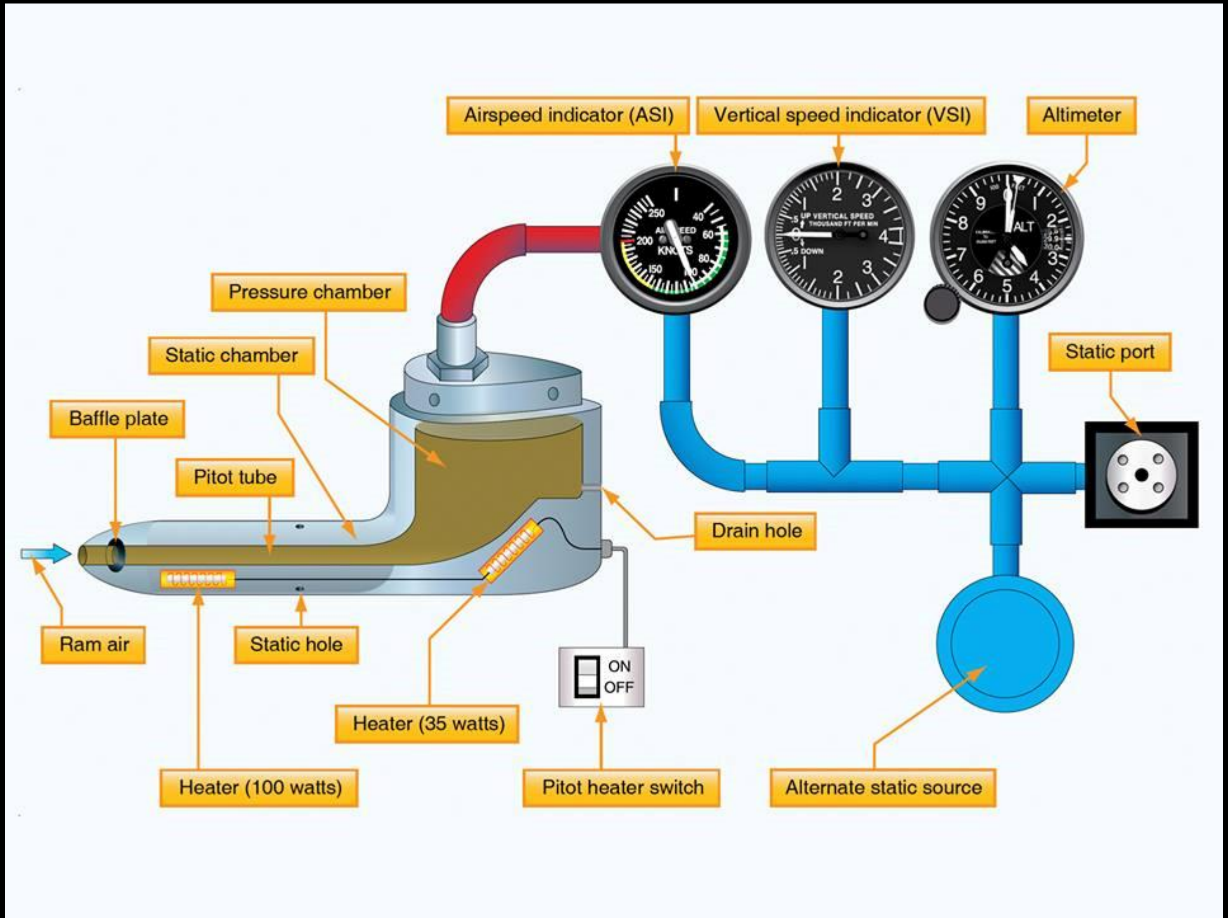
Atmospheric Pressure and Density

- Air molecules are piled on top of one another
- At sea level there is a great deal of static air pressure or weight because there are more air molecules at the top of the pile
- As you ascend, there are fewer air molecules above you
- Atmospheric pressure or weight (and density) decreases with a gain in altitude

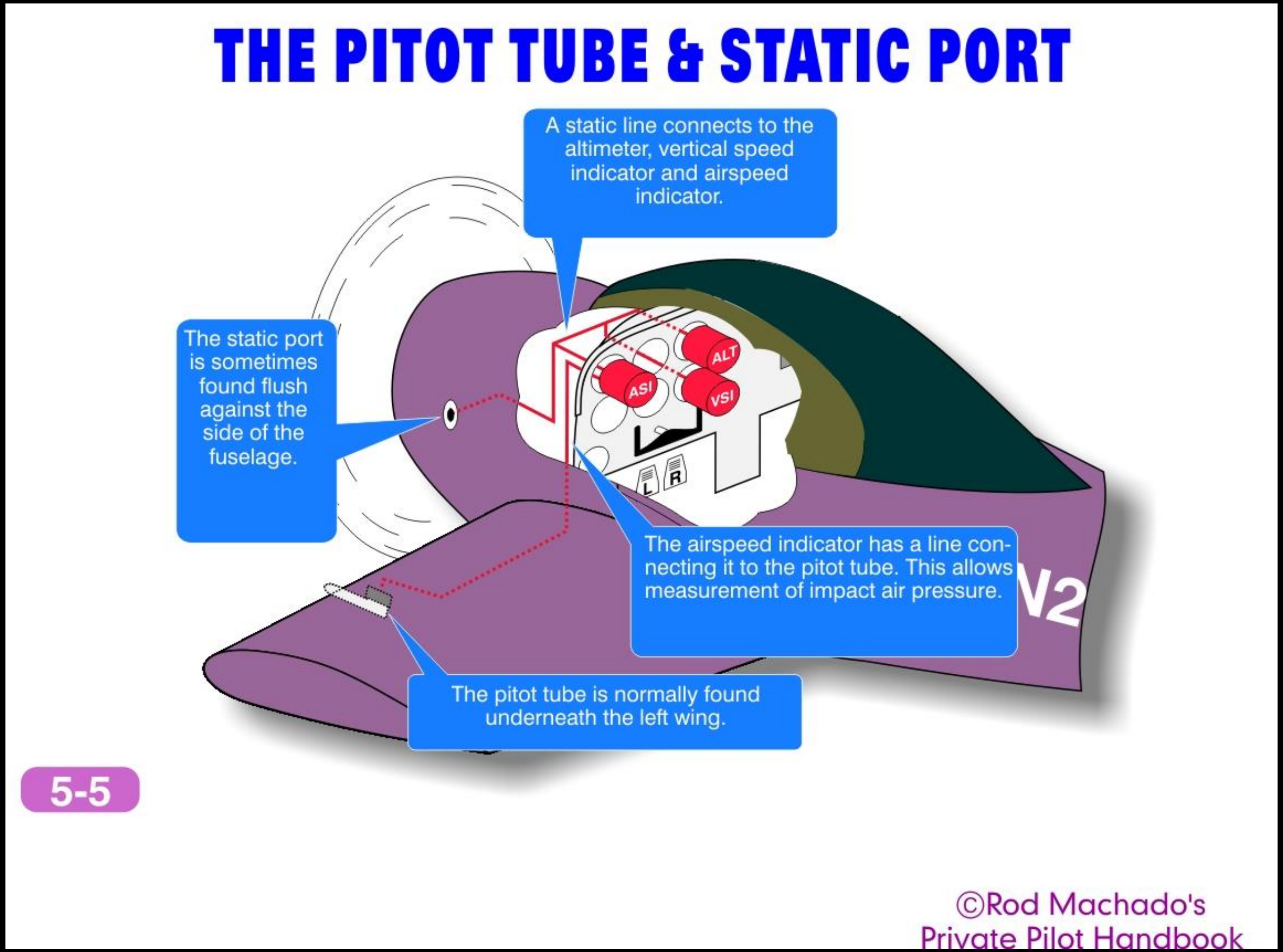


Pitot-Static System

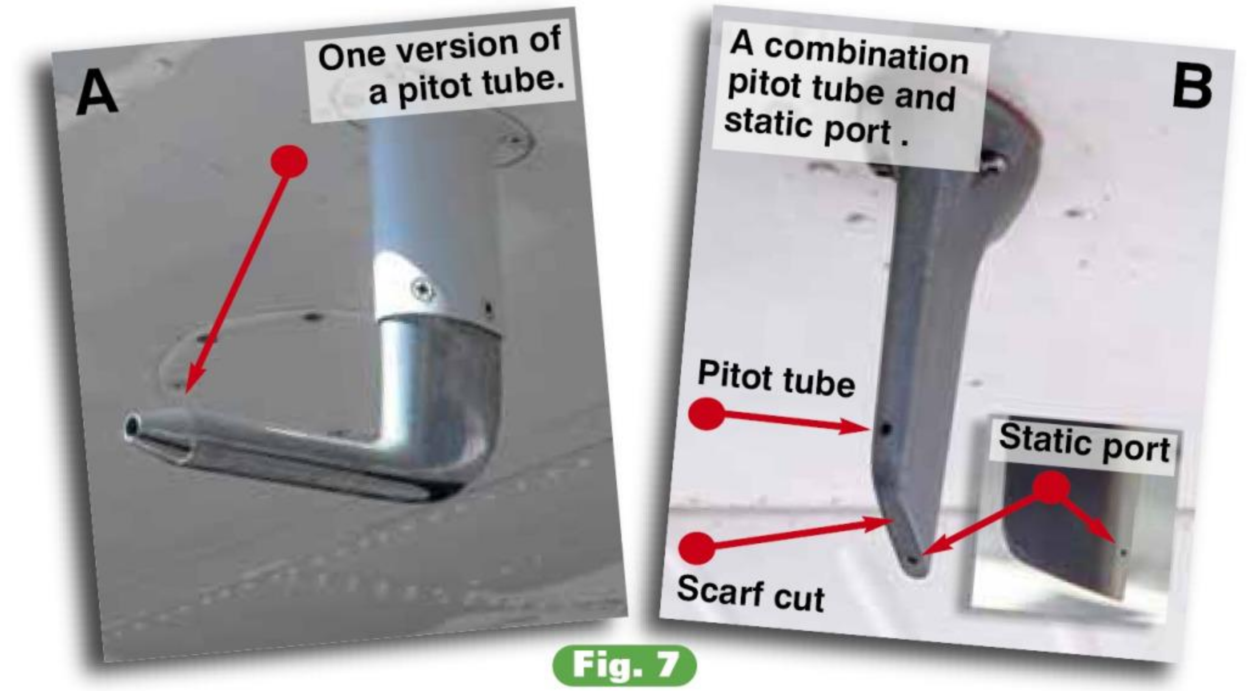
- ASI – Pitot & Static
- Altimeter – Static only
- VSI – Static only



Pitot Tube Static Port Locations



Pitot Tube Static Port



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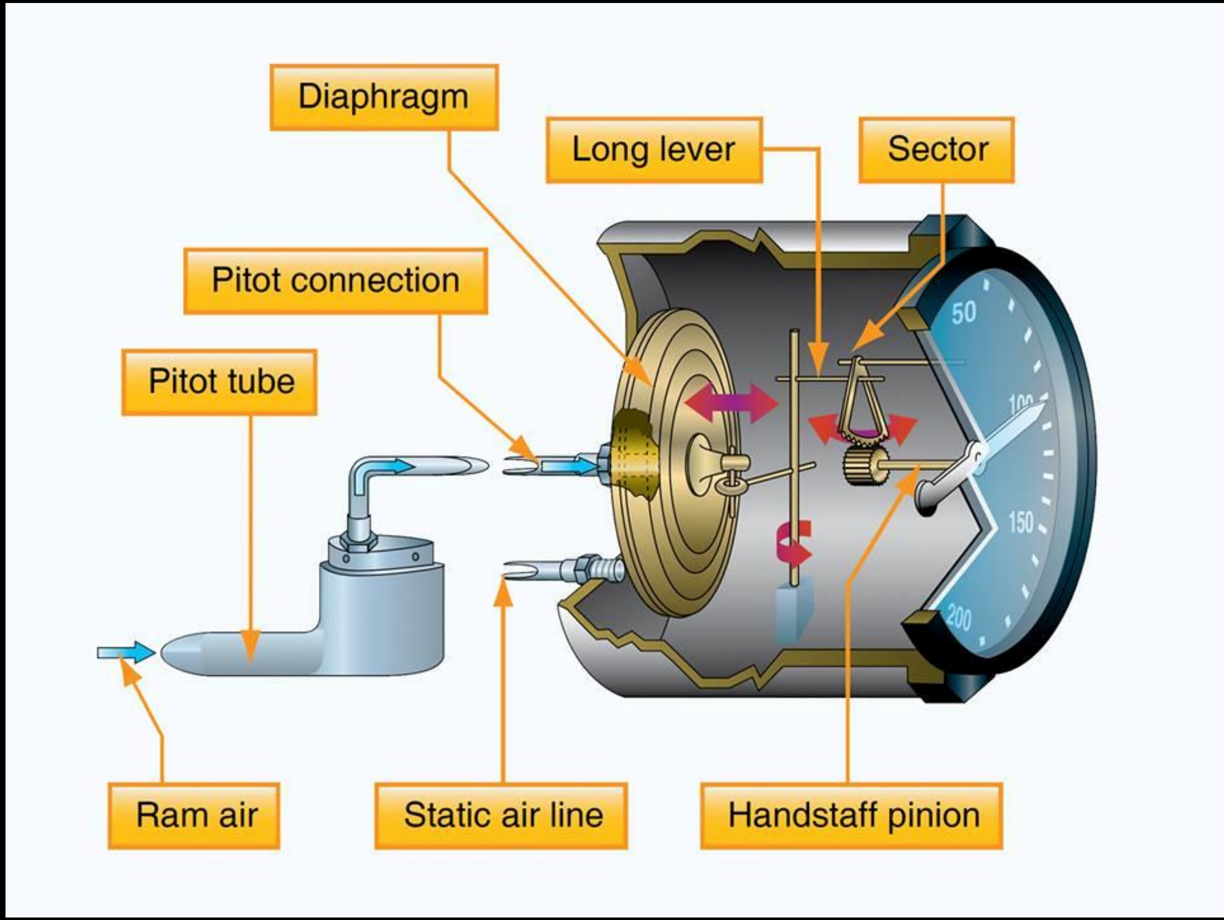
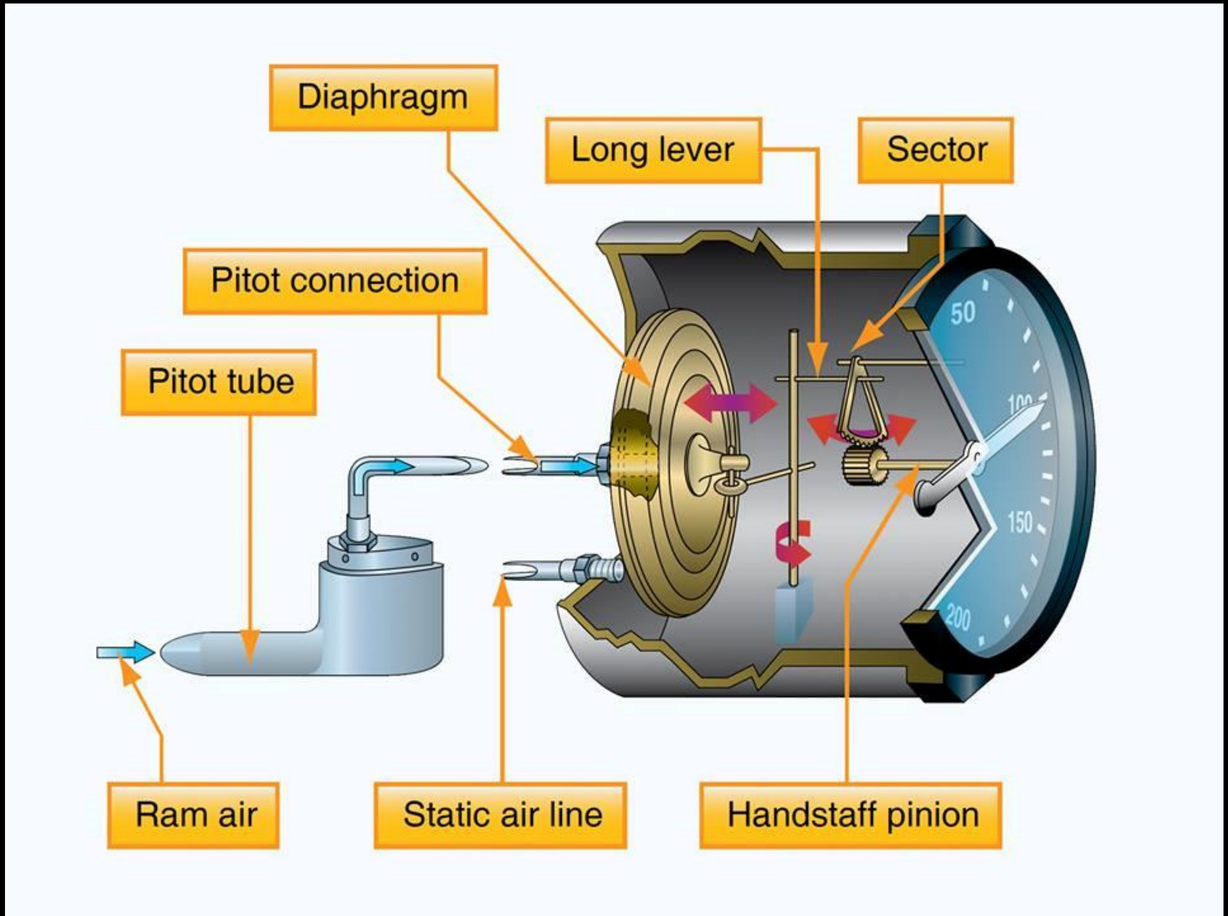
Airspeed Indicator

- <u>*Differential*</u> pressure gauge that measures the dynamic pressure of the air
- Dynamic pressure is the <u>difference</u> in the ambient static air pressure and the total, or ram, pressure caused by the motion of the aircraft through the air

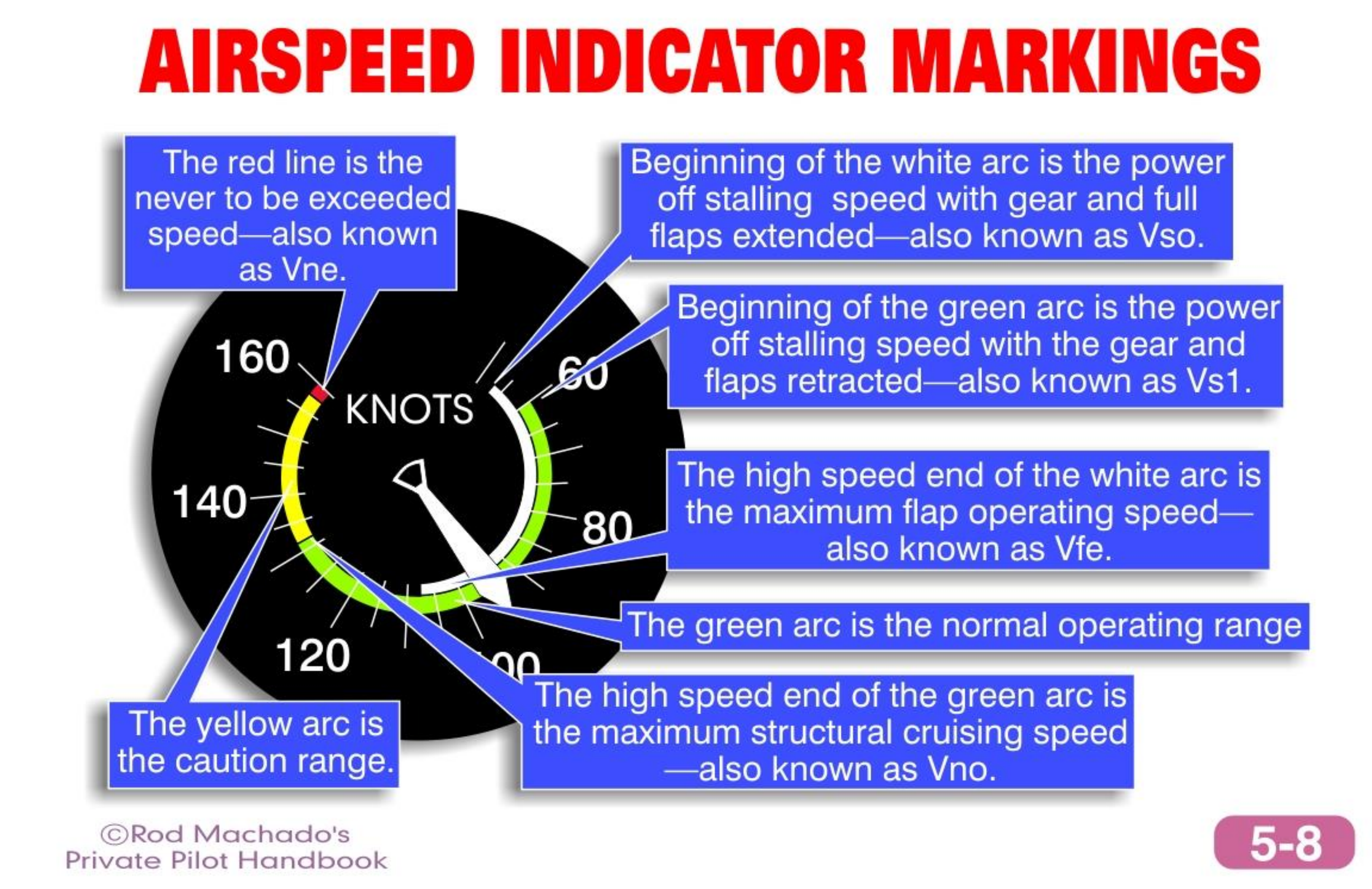


Airspeed Indicator

- Thin diaphragm receives its pressure from the pitot tube
- Instrument case is sealed and connected to the static ports
- As the pitot pressure increases *or* the static pressure decreases, the diaphragm expands
- This change is measured by a shaft and gears driving a pointer across the instrument dial
- Calibrated in knots, statute miles per hour, or both

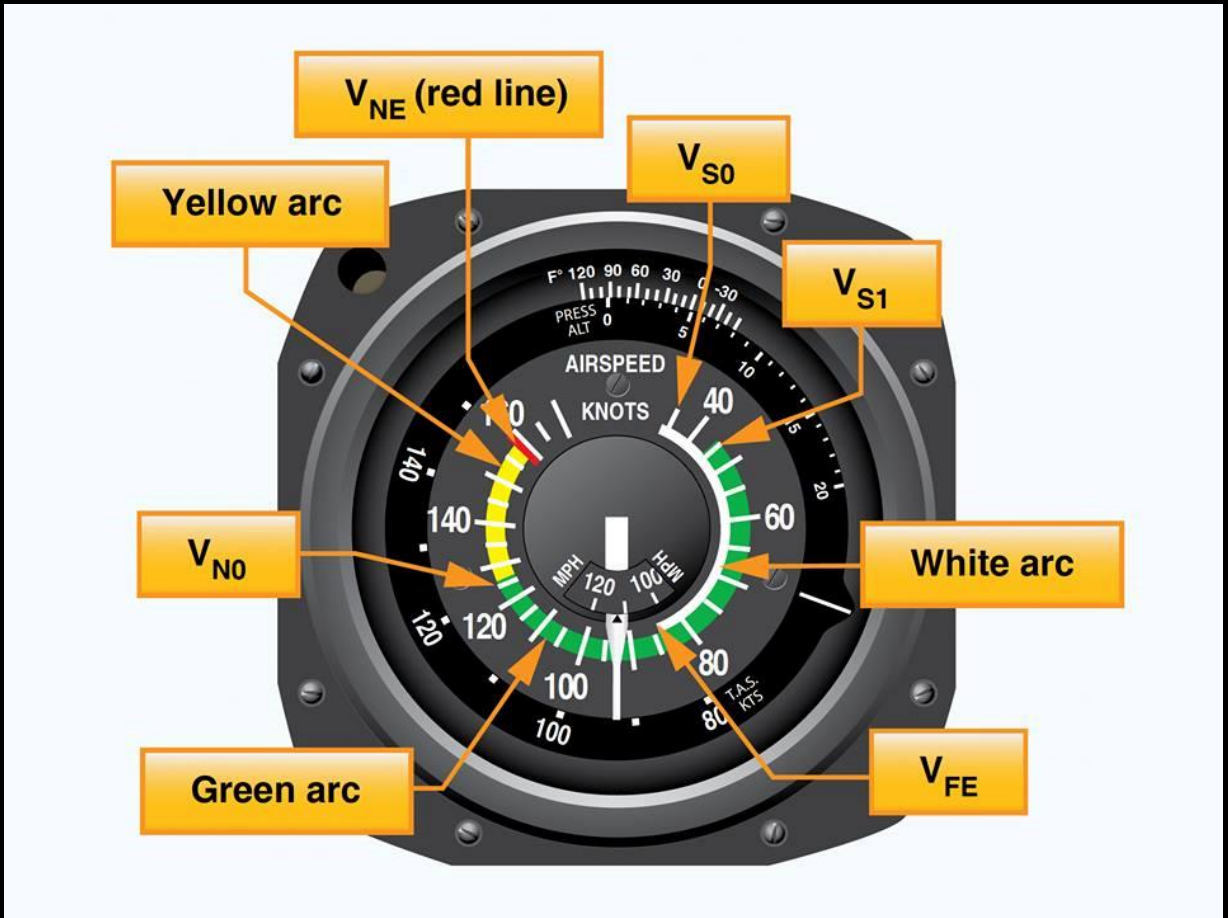


Airspeed Indicator Markings



Airspeed Indicator Markings

- V_{NO} – Maximum Structural Cruising Speed
- V_A – Maneuvering Speed not shown (decreases with GW)



Stall Speed: V_S

V_S - Stall speed or minimum steady flight speed at which the airplane is controllable

- Generic term and usually does not correspond to a specific airspeed

Stall Speed: V_{S1}

V_{S1} - Stall speed or minimum steady flight speed in a specific configuration

- Normally regarded as the “clean” (gear and flaps up) stall speed
- Lower limit of the green arc
- Is a clean stall, but definition of “clean” could vary

Stall Speed: V_{S0}

V_{S0} - Stall speed in landing configuration

- Lower limit of white arc
- Stalling speed or the minimum steady flight speed at which the airplane is controllable in landing configuration (engines at idle, props in low pitch, usually full flaps, cowl flaps closed, CG at maximum forward limit (i.e., most unfavorable CG) and MGLW

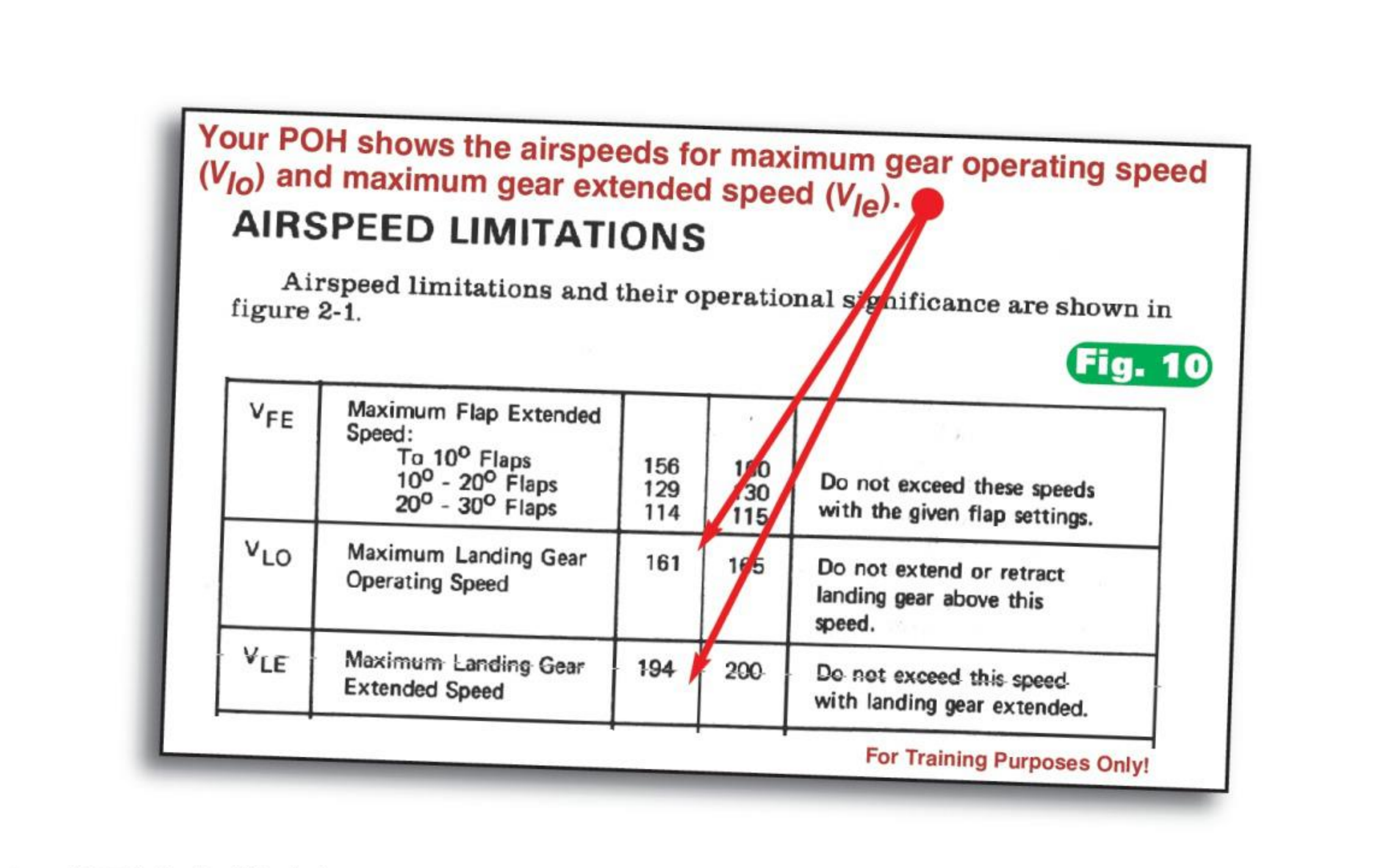
Design Maneuvering Speed V_A

- Speed below which you can move a single flight control, one time, to its full deflection, for one axis of airplane rotation only (pitch, roll or yaw), in smooth air, without risk of damage to the airplane
- V_A must be entered in the FAA-approved AFM/POH of all recently designed airplanes
- Design maneuvering speed does <u>not</u> provide structural protection against multiple full control inputs in one axis or full control inputs in more than one axis at the same time

Speed Limitations *not* Color-Coded on ASI

- V_{LE} - Maximum landing gear *extended* speed
- V_{LO} – Maximum landing gear *operating* speed
- V_A - Design maneuvering speed
- V_O – Operating maneuvering speed (below GW)

POH Airspeed Limitations



V_{FE}	Maximum Flap Extended Speed: To 10° Flaps 10° - 20° Flaps 20° - 30° Flaps	 156 129 114	 160 130 115	Do not exceed these speeds with the given flap settings.
V_{LO}	Maximum Landing Gear Operating Speed	161	165	Do not extend or retract landing gear above this speed.
V_{LE}	Maximum Landing Gear Extended Speed	194	200	Do not exceed this speed with landing gear extended.

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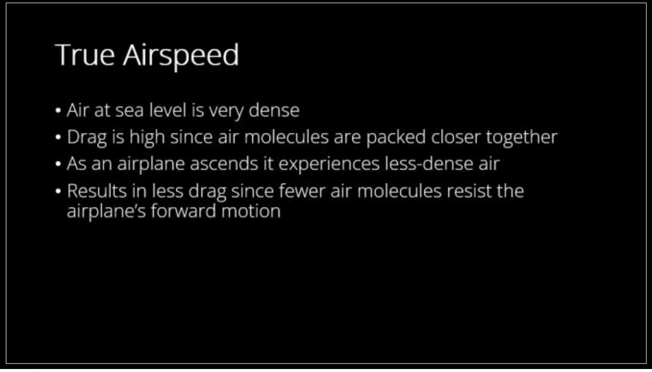
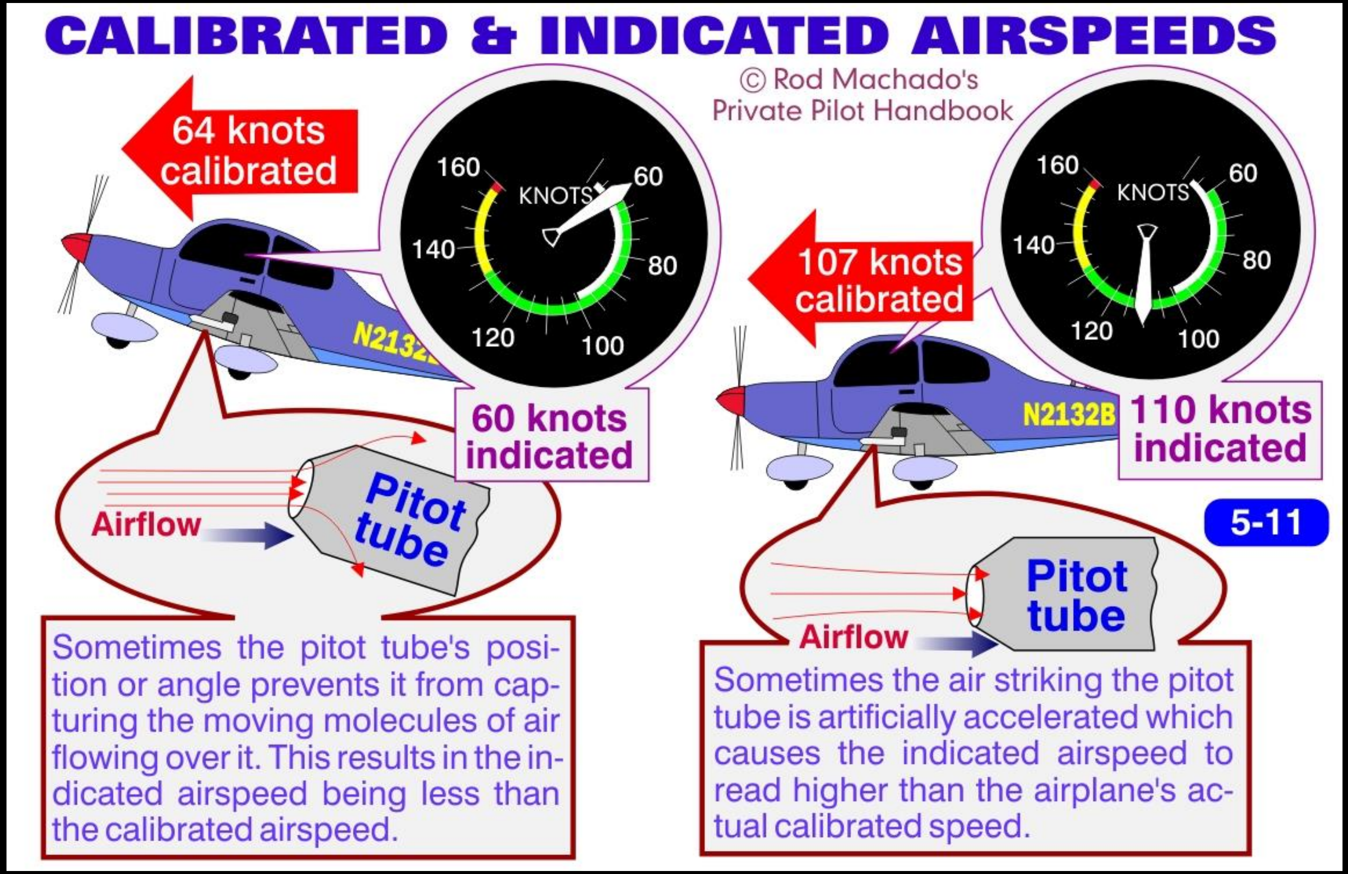
Airspeed Definitions

- Indicated Airspeed (IAS) - Airspeed that is shown on the airspeed indicator, uncorrected for instrument or system errors
- Calibrated Airspeed (CAS) - Indicated airspeed corrected for position or installation error
- True Airspeed (TAS) - Calibrated airspeed corrected for temperature and pressure altitude



Calibrated vs. Indicated

- Pitot tubes are not always installed where they can accurately sample impact-air pressure
- At variable angles of attack, the pitot tube sometimes does not accurately reflect the airplane's speed



Converting IAS to CAS

- Chart from POH allows you to calibrate your indicated airspeed readings for accuracy

KIAS = Knots Indicated AirSpeed/KCAS = Knots Calibrated AirSpeed

AIRSPEED CALIBRATION CHART

FLAPS UP											
KIAS	50	60	70	80	90	100	110	120	130	140	150
KCAS	50	64	72	81	89	98	107	116	126	135	153
FLAPS 10°											
KIAS	40	50	60	70	80	90	100				
KCAS	55	58	64	72	81	90	107				
FLAPS 30°											
KIAS	40	50	60	70	80	85					
KCAS	54	57	62	71	80	85					

Condition: Power required for level flight or maximum rated RPM dive

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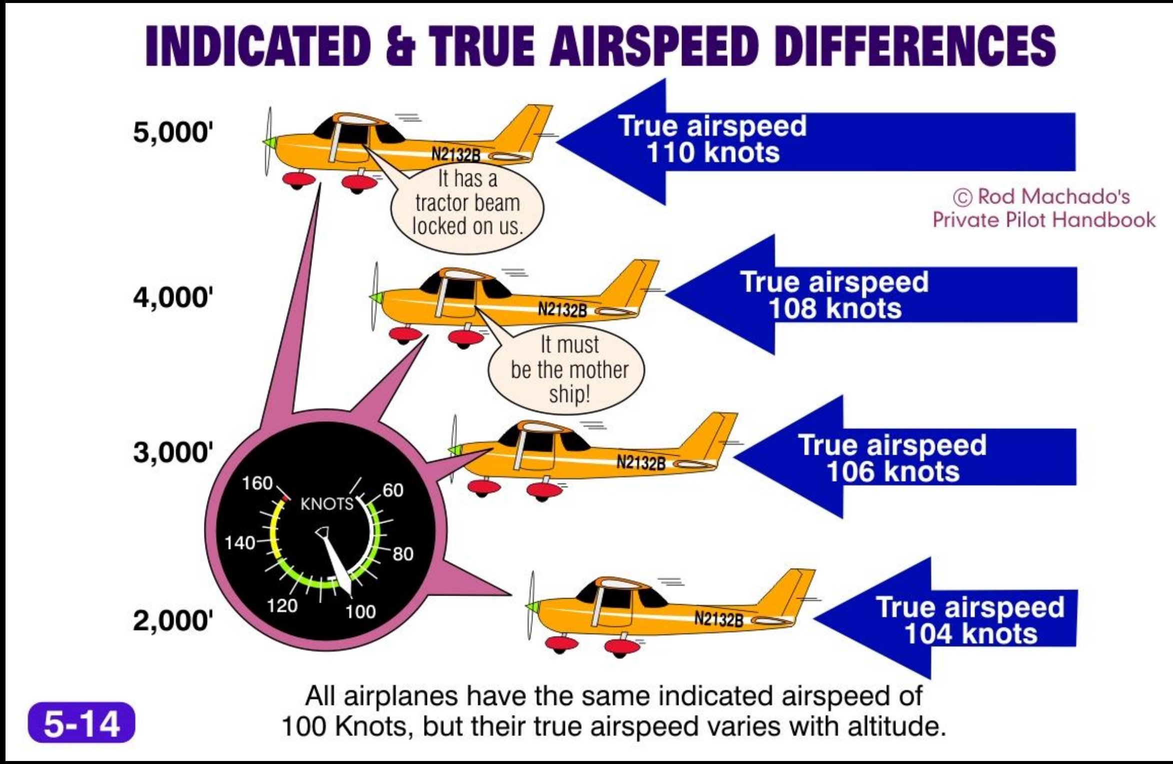
True Airspeed

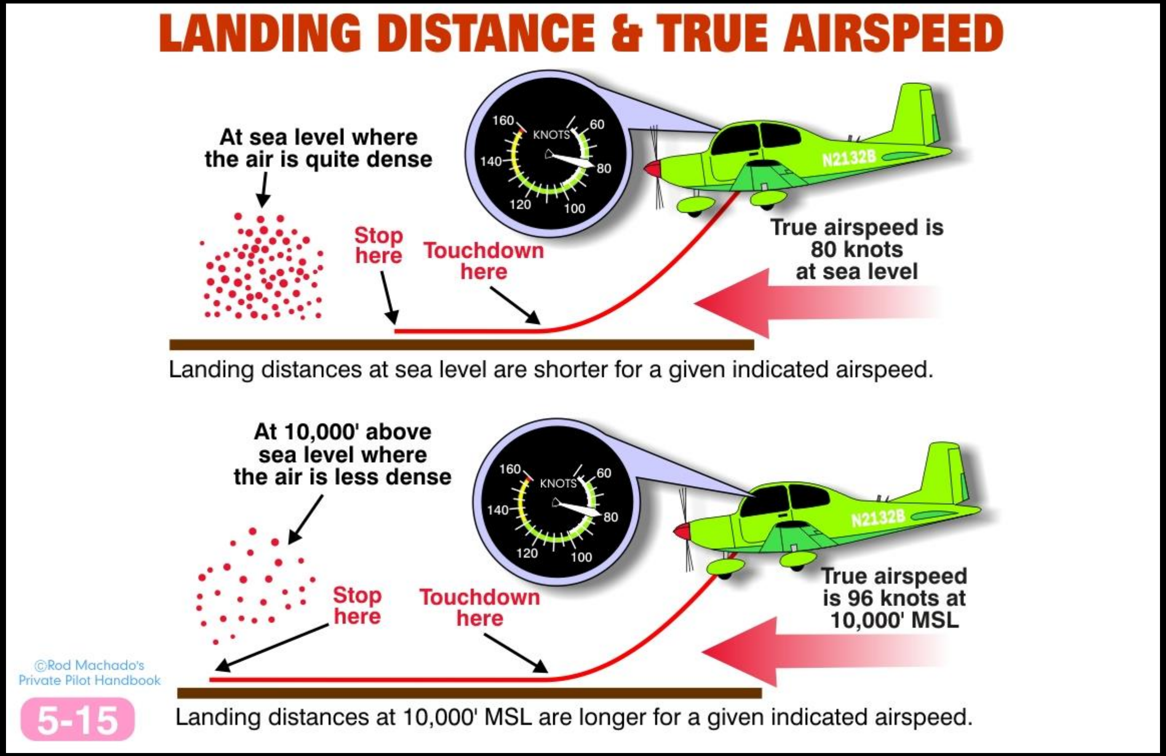
- Air at sea level is very dense
- Drag is high since air molecules are packed closer together
- As an airplane ascends it experiences less-dense air
- Results in less drag since fewer air molecules resist the airplane’s forward motion

True Airspeed

- Airplanes flying at higher altitudes move faster through the air for a given power setting because of the decrease in density
- While the airplane goes faster through the thinner air, there are fewer air molecules striking the pitot tube and expanding the bellows of the airspeed indicator
- Result is at higher altitudes you are moving faster than your airspeed indicator shows

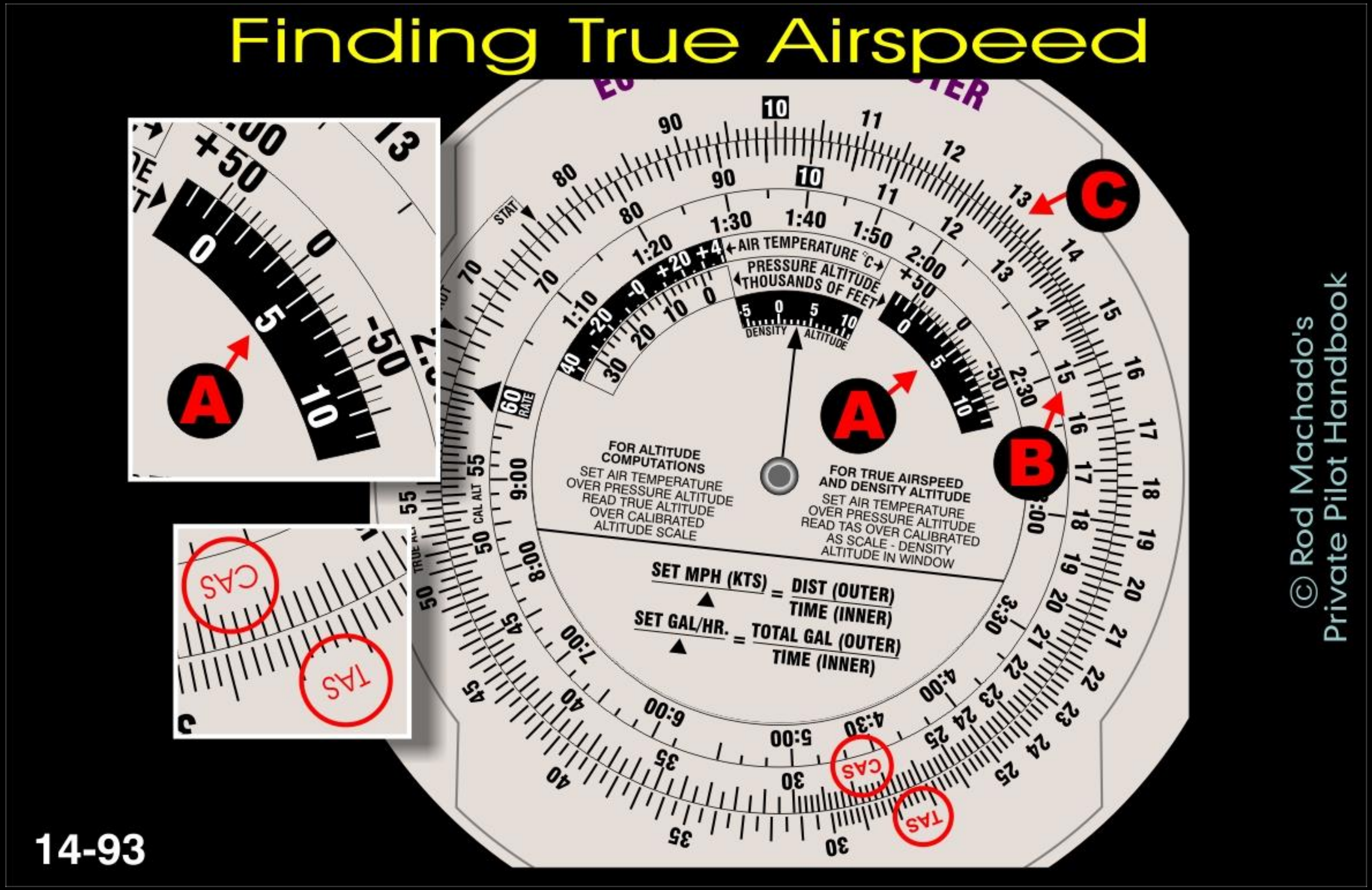


TAS vs. Landing Distance



- In thinner air you will be moving faster (higher TAS) to achieve the same indicated airspeed
- The airplane stalls at the same indicated airspeed whether you're at 1,000 feet or 10,000 feet
- To lift off and accelerate requires a longer-than-normal takeoff distance at high altitude airports

Finding True Airspeed Using E6B



- Calibrated airspeed corrected for temperature and pressure altitude
- A - Line up PA on inner scale opposite OAT on outer scale
- B – CAS on inner scale and resulting TAS on outer scale C

True Airspeed on E6B

	Pressure Altitude	Temp °C	CAS knots	TAS knots	Density Altitude
1	14,000	5	160		
2	20,000	-20	200		
3	8,000	15	150		

- Calibrated airspeed corrected for temperature and pressure altitude
- Pressure Altitude when 29.92 In Hg set in altimeter

True Airspeed on E6B

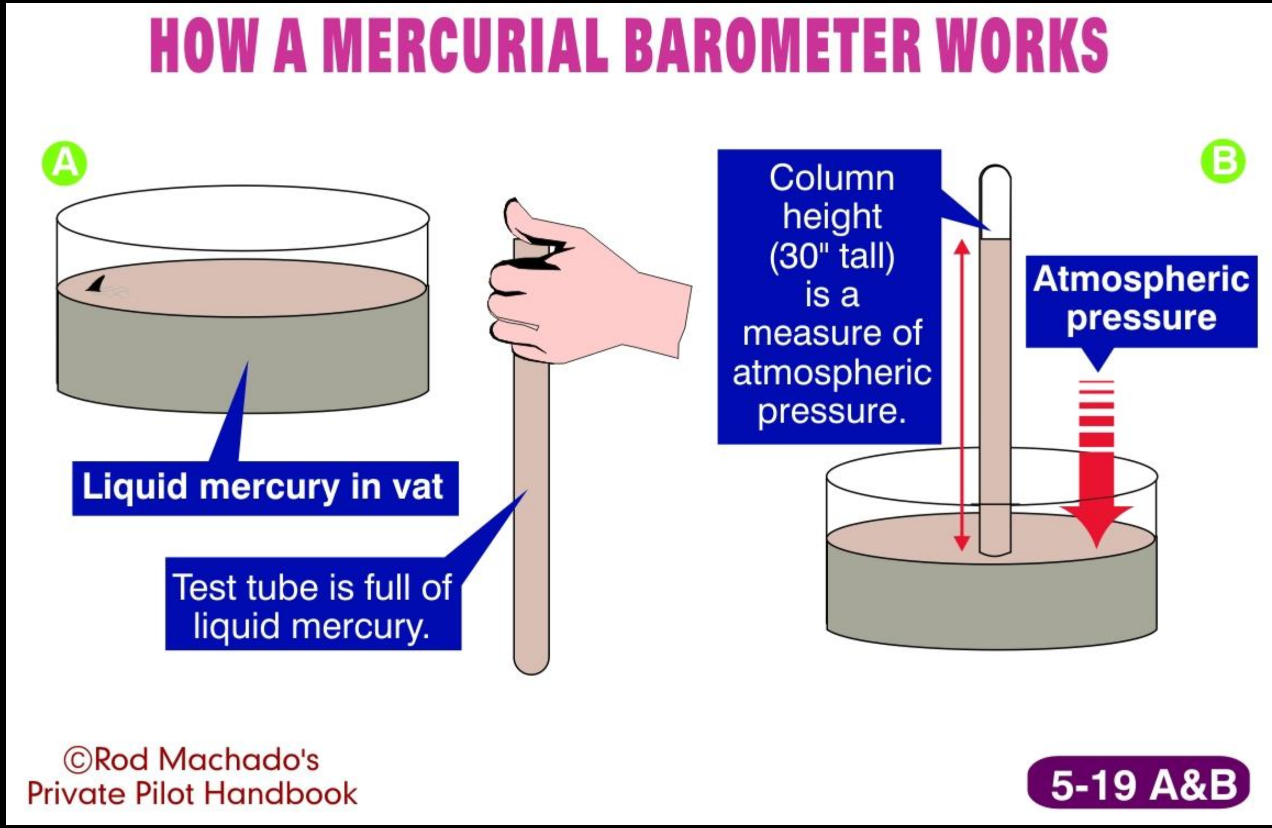
	Pressure Altitude	Temp °C	CAS knots	TAS knots	Density Altitude
1	14,000	5	160	204	
2	20,000	-20	200	273	
3	8,000	15	150	174	

TAS Indicator

- Provides both True and IAS
- Has the conventional airspeed mechanism, with an added subdial visible through cutouts in the regular dial
- Knob on the instrument allows pilot to rotate the subdial and align an indication of the OAT with the PA being flown
- Indicates the TAS on the subdial

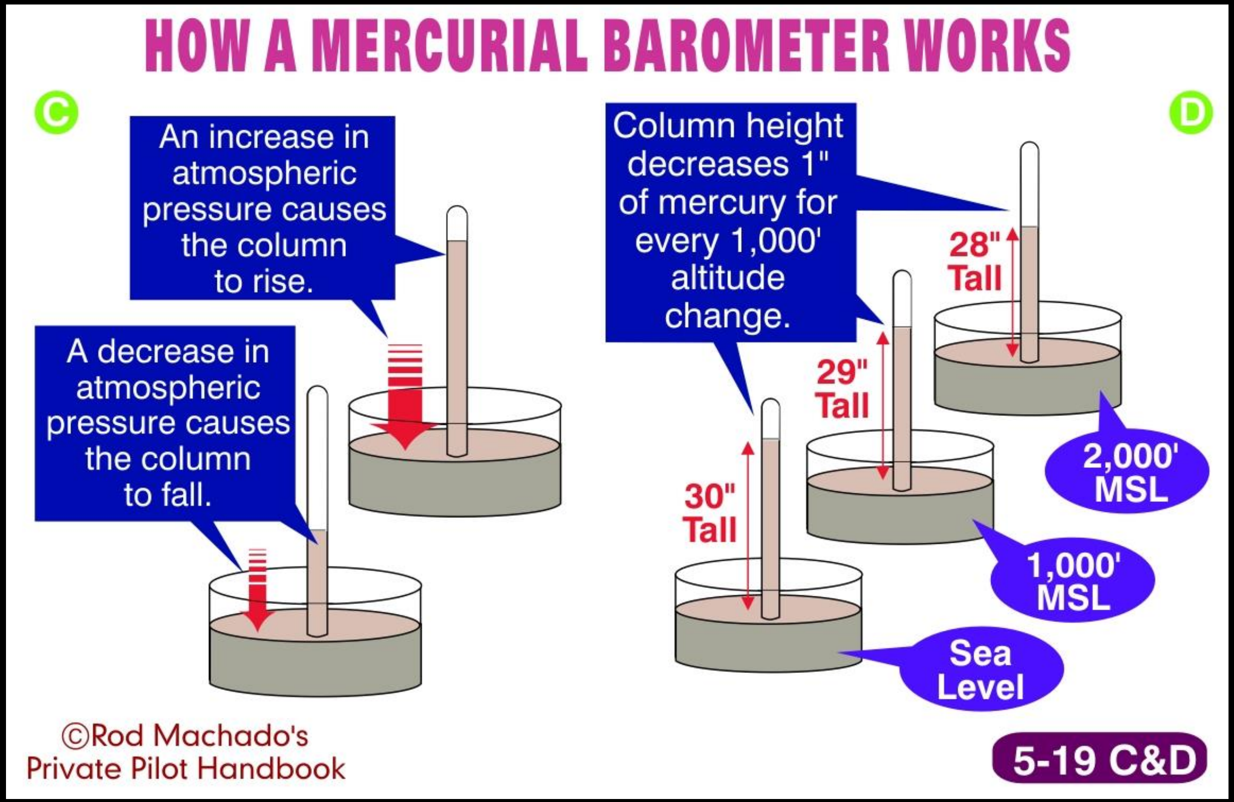
Mercurial Barometer

- A tube of the liquid metal mercury is filled and placed upside down in a vat of mercury
- Weight of the mercury inside the tube creates a small vacuum as the column attempts to sink out of the tube and into the vat
- The vacuum prevents the mercury from entirely sinking into the reservoir
- The column finally stabilizes at a certain height



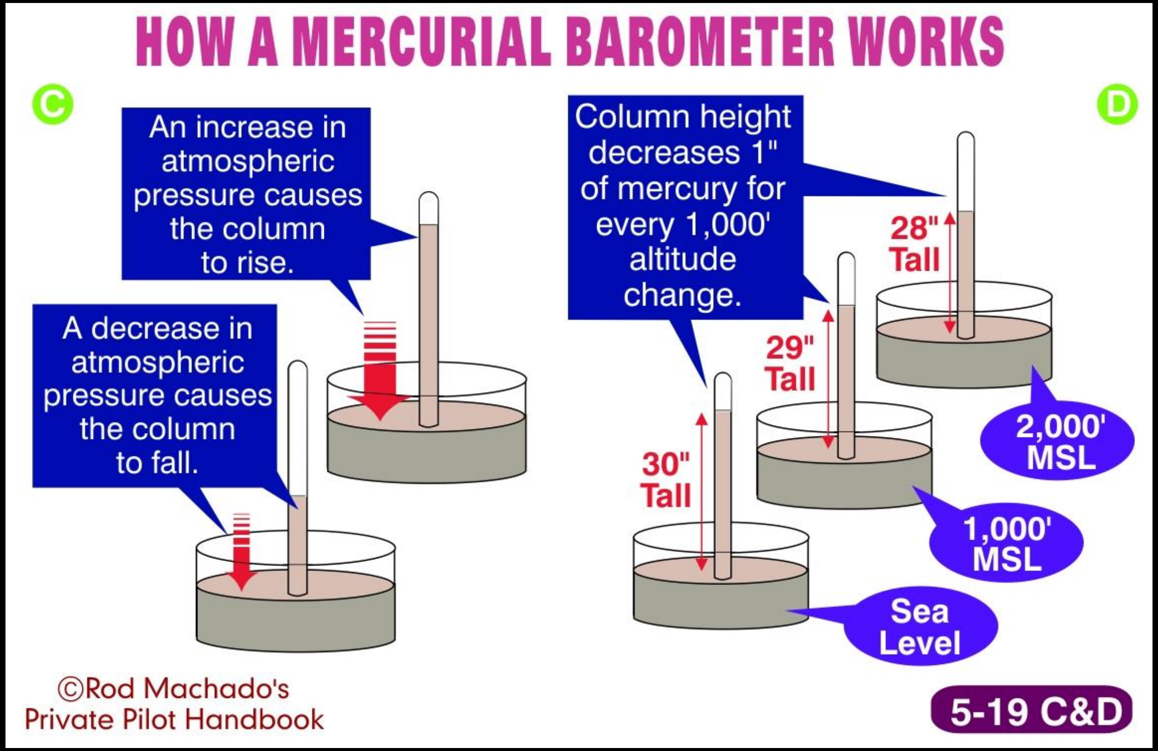
Mercurial Barometer

- Decreasing the atmosphere’s pressure on the reservoir surrounding the tube allows the column to decrease in height
- Increasing atmospheric pressure pushes on the reservoir, moving the column upward into the tube and increasing its height



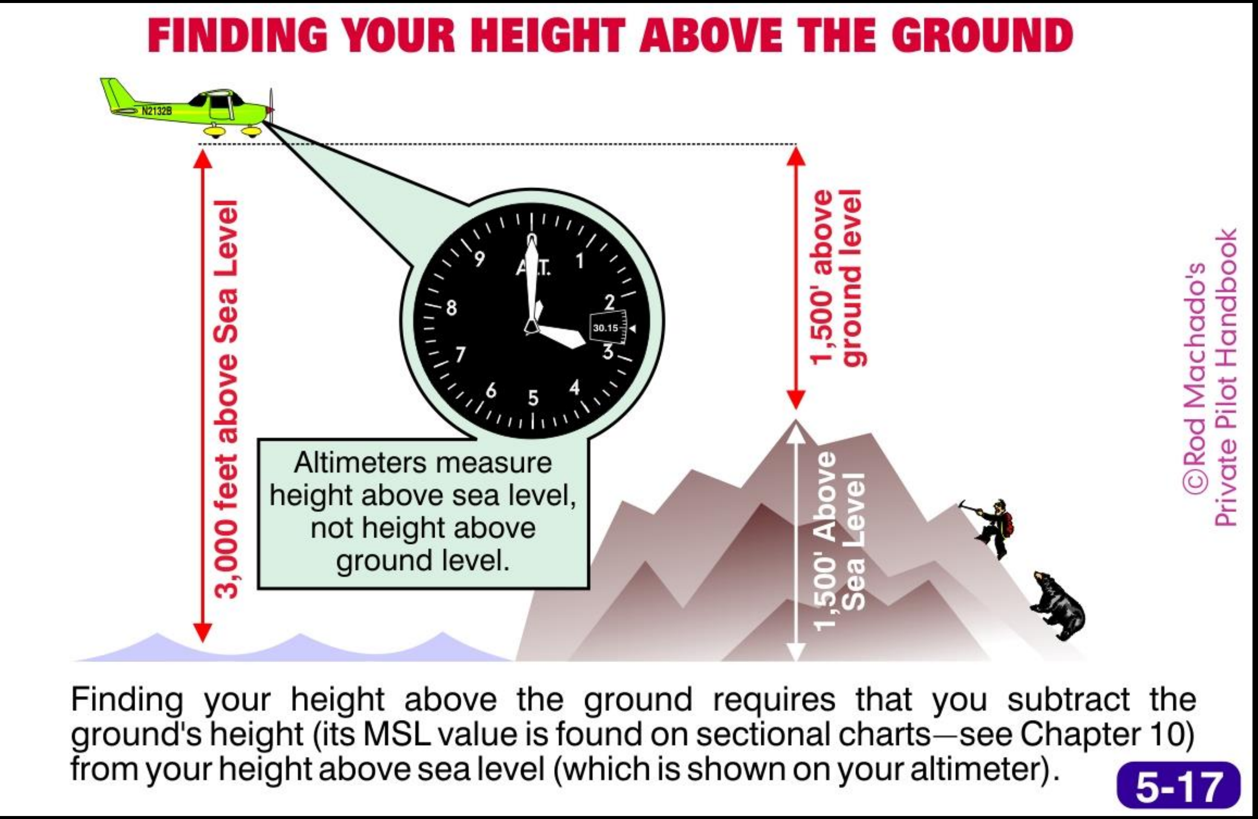
Mercurial Barometer

- Since the weight of the atmosphere changes with height, this pressure change should be reflected by a lengthening or shortening of the mercury column
- A column of mercury changes about one inch in height per thousand feet of altitude change
- This is the standard used to calibrate altimeters

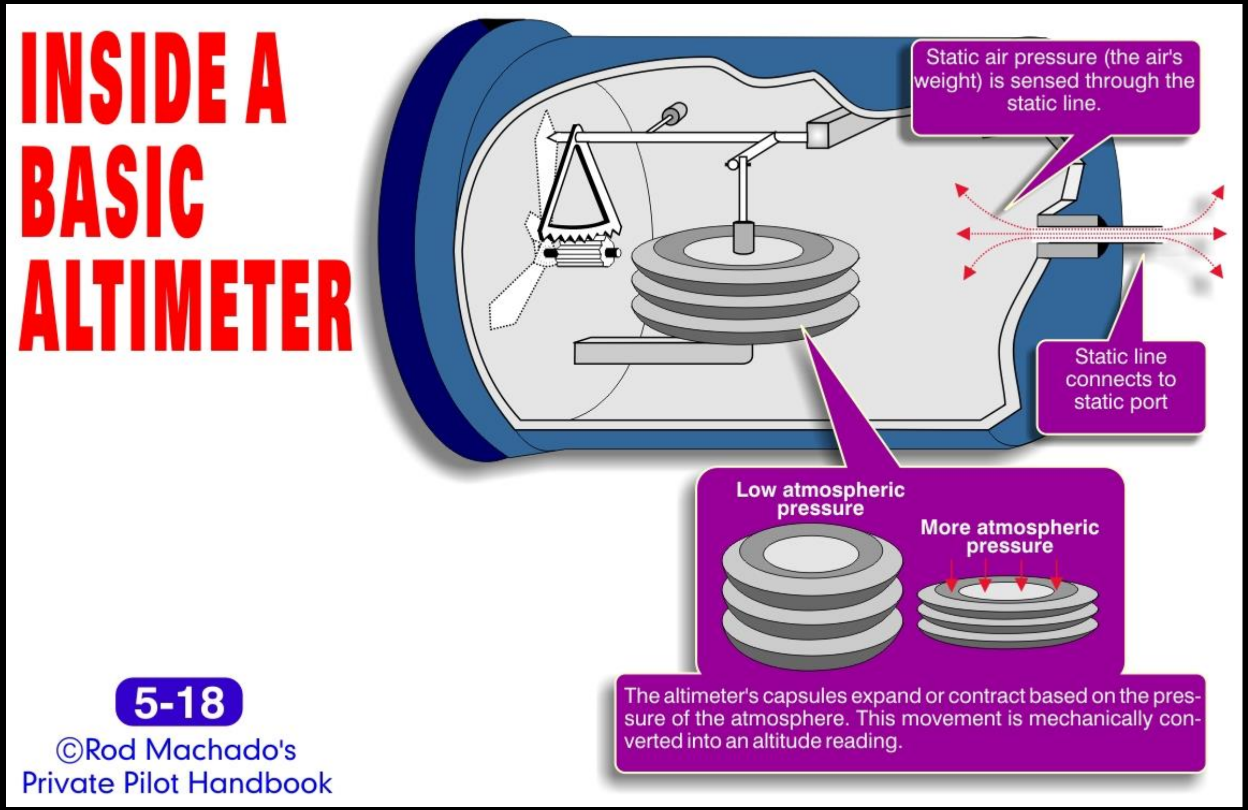


What Do Altimeters Show?

- Altimeters do not directly show your height above the ground
- Provides you with your height above sea level (true altitude)

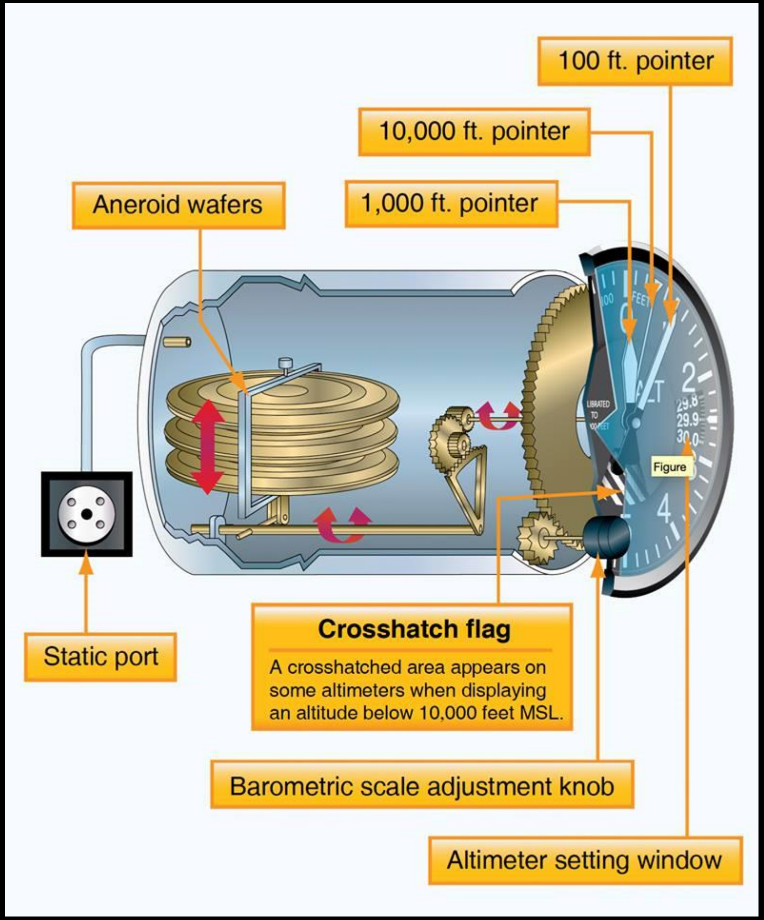


Inside A Basic Altimeter



- Altimeter's case is connected to the static port
- This allows static air pressure to surround the sealed capsule
- Any change in static air pressure is reflected by an expansion or contraction of the capsule, providing the altitude reading

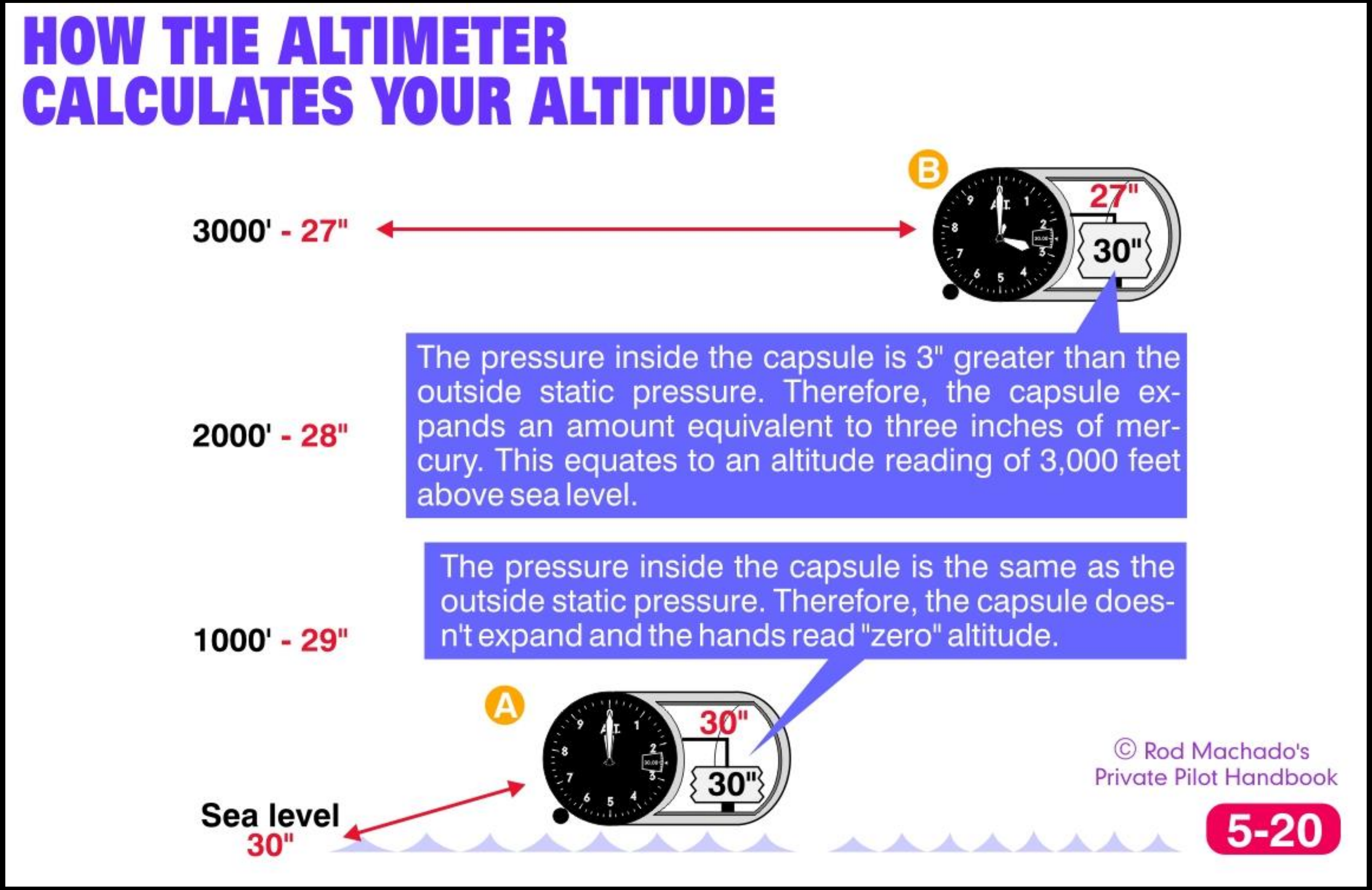
Principle of Operation



- The sensitive element is a stack of evacuated, corrugated bronze aneroid capsules
- Air pressure acting on these aneroids tries to compress them against their natural springiness, which tries to expand them
- The result is their thickness changes as the air pressure changes

How The Altimeter Determines Altitude

- Measures the difference between sea level pressure and pressure at the airplane's present altitude
- Assume the pressure inside sealed capsule is at 30" Hg
- Altimeter is calibrated so that a 1" Hg change in pressure is equivalent to a change of 1000 feet in altitude

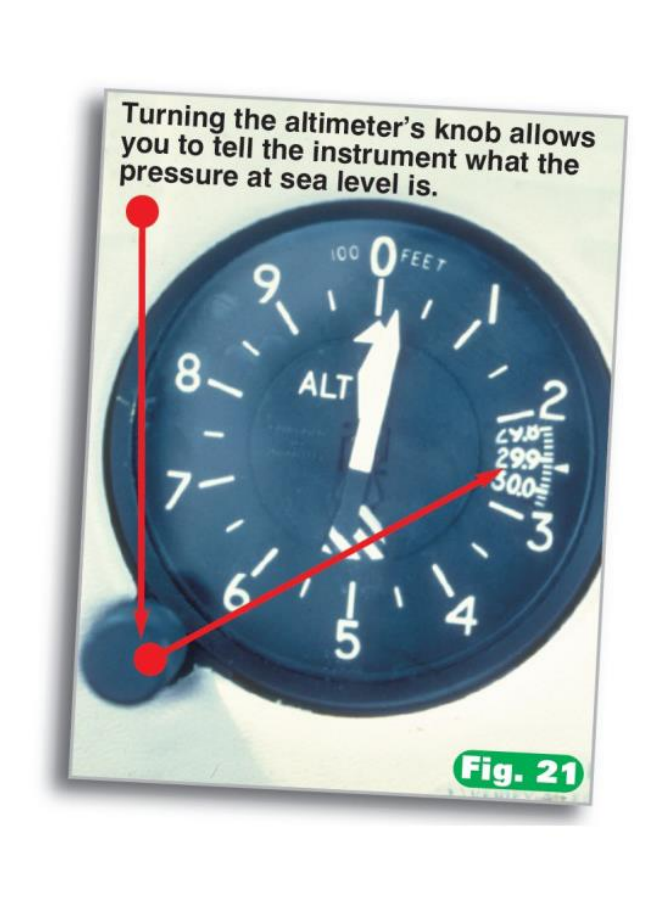


Non-Standard Pressure on an Altimeter

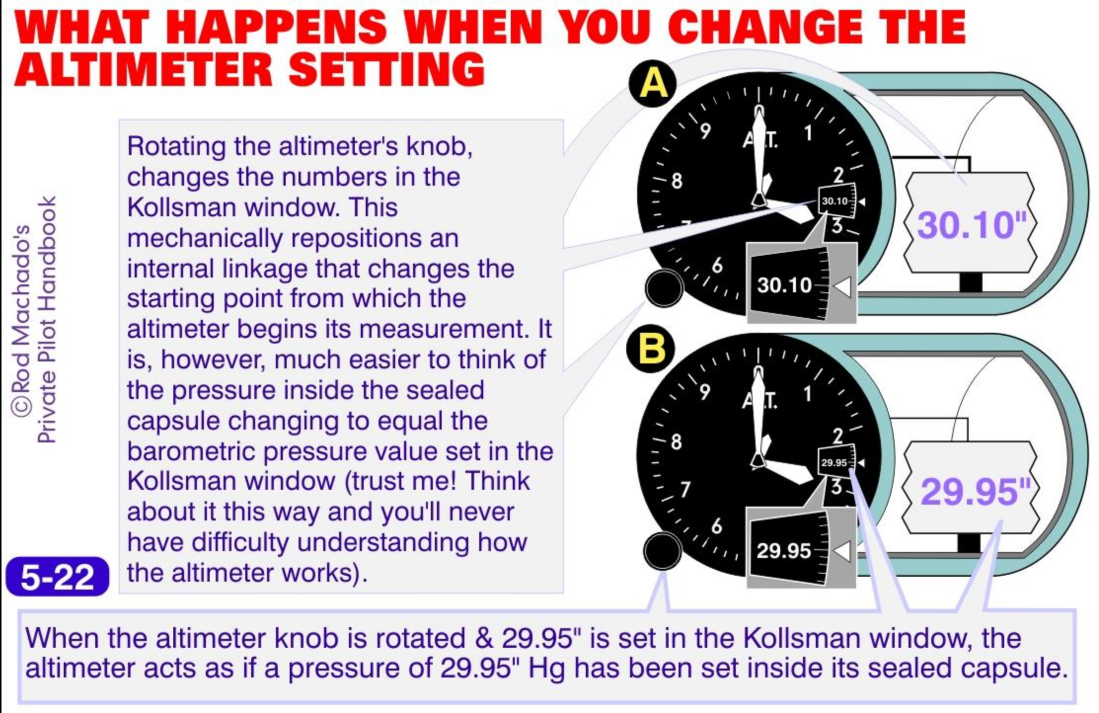
- The standard pressure lapse rate is a decrease of 1" Hg for each 1,000 feet of increase in altitude (lower atmosphere)
- Maintaining a current altimeter setting is critical because the atmosphere pressure is not constant
- In one location the pressure might be higher or lower than the pressure just a short distance away

Pressure Variations And The Altimeter

- The altimeter measures the difference between sea level pressure and the outside static pressure at your altitude
- Sea level pressure changes at a fixed location, as well as between locations
- You need a way to keep your altimeter informed about the changing pressure at sea level



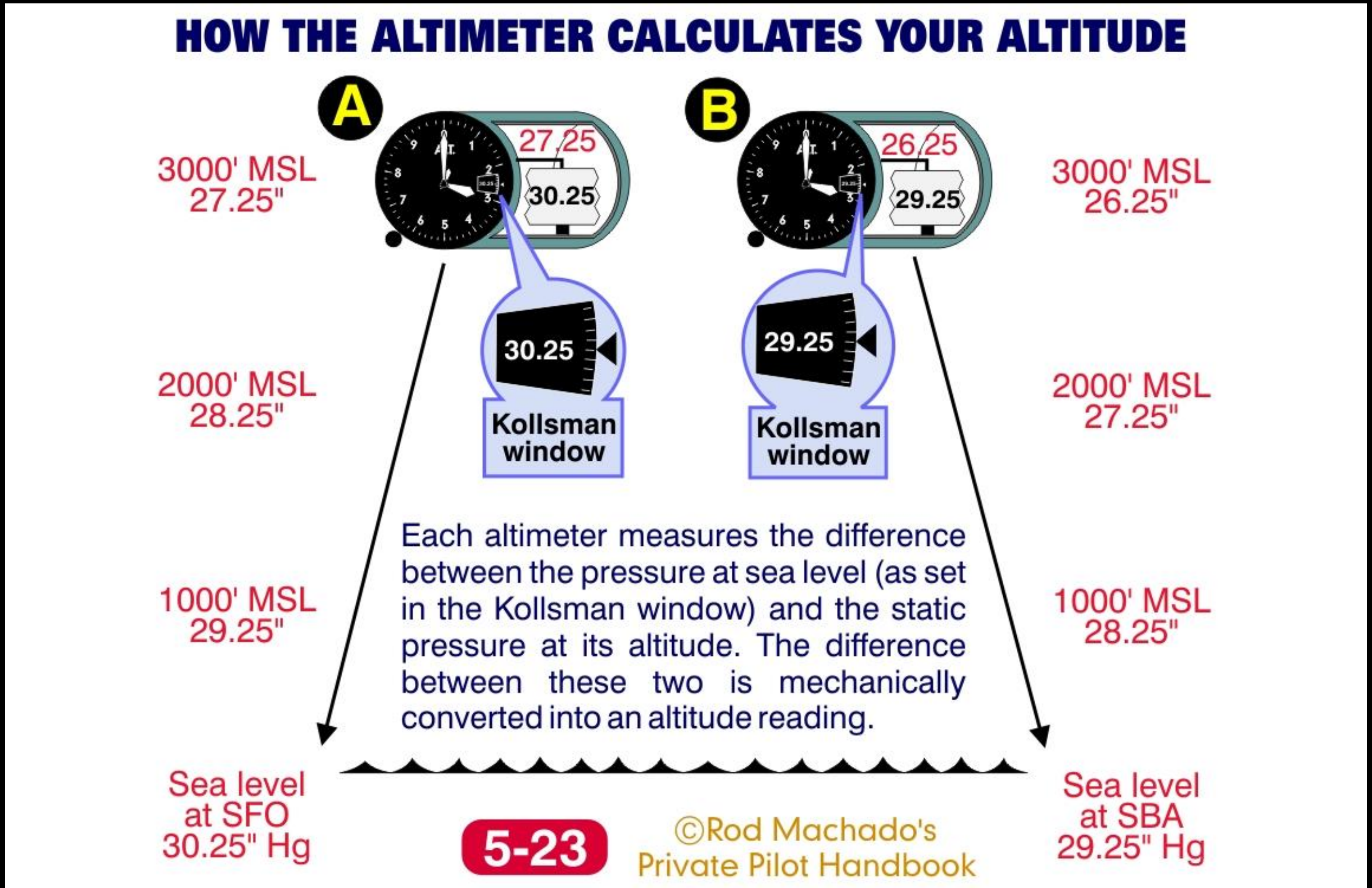
Altimeter Setting



- Twisting the knob rotates the numbers in the Kollsman window
- This is how the pilot sets the altimeter to what the pressure is at sea level
- Recalibrates the pressure inside the altimeter’s expandable capsule

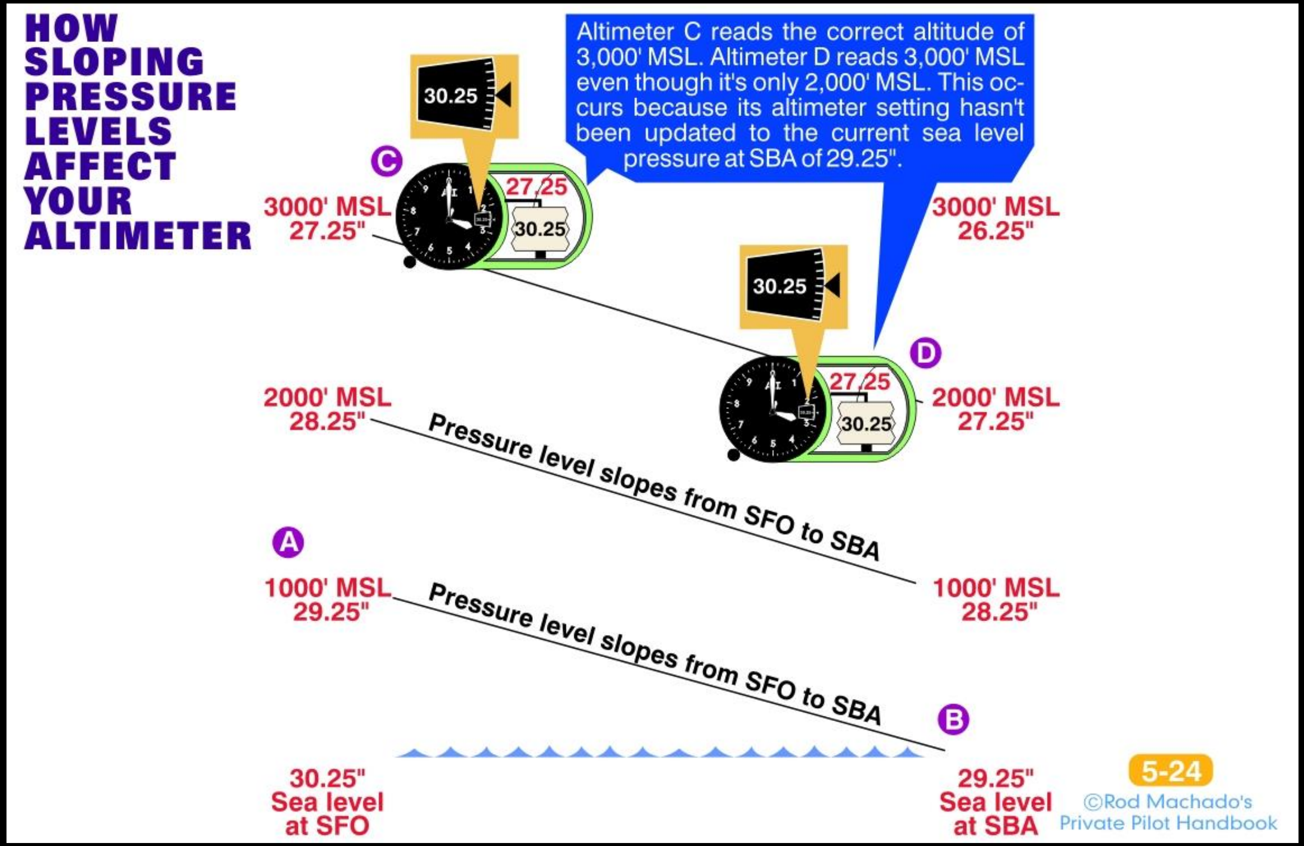
Correcting For Sea Level Pressure Change

- Setting the Sea Level pressure (altimeter setting) corrects the altimeter for non-standard pressure

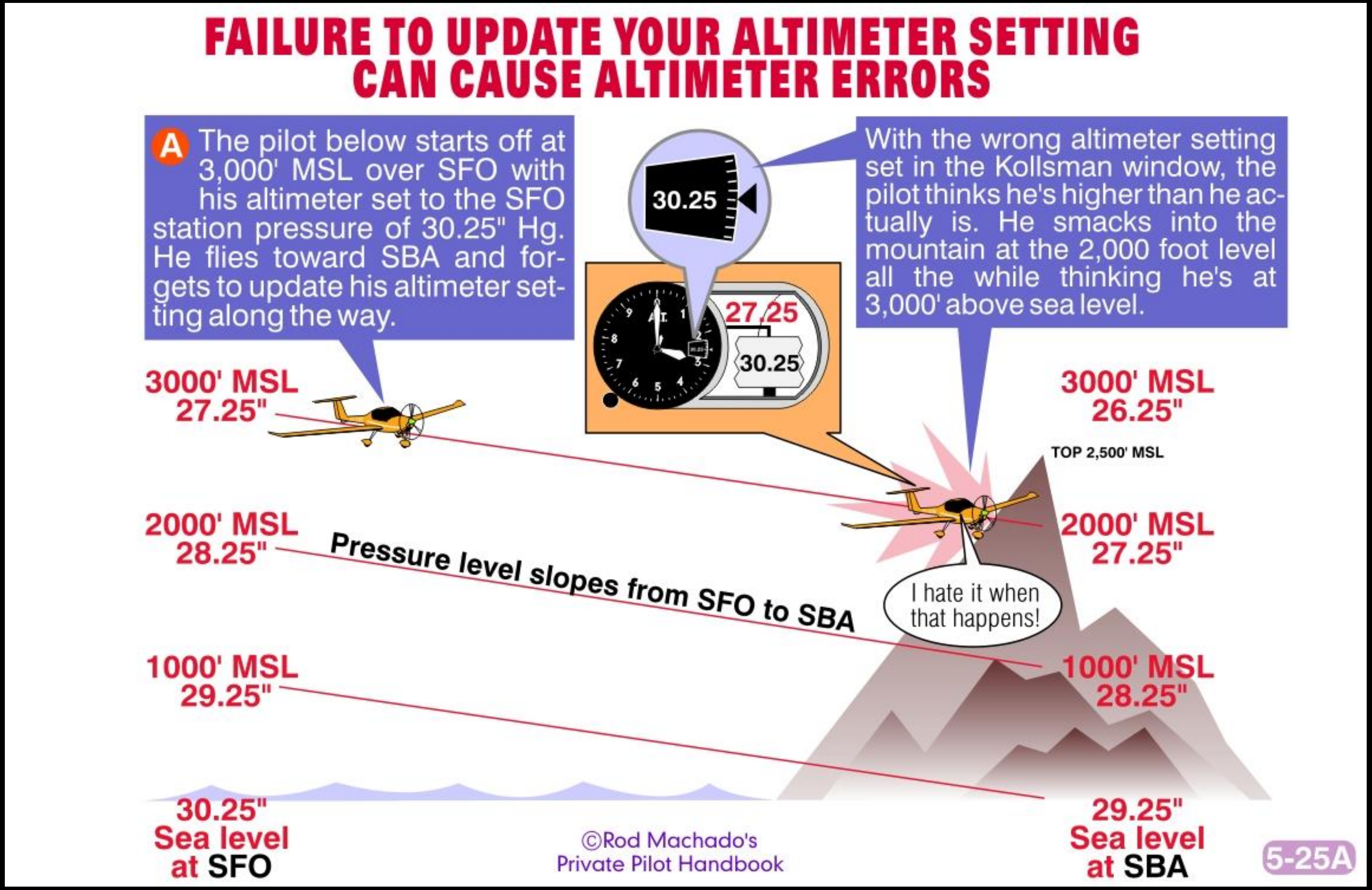


How Sloping Pressure Levels Affect Altimeter

- If we don't update the altimeter setting, the indicated altitude (what's shown on the altimeter's face) becomes different from our true altitude (our actual height above sea level)
- 1 in Hg = 1000 feet

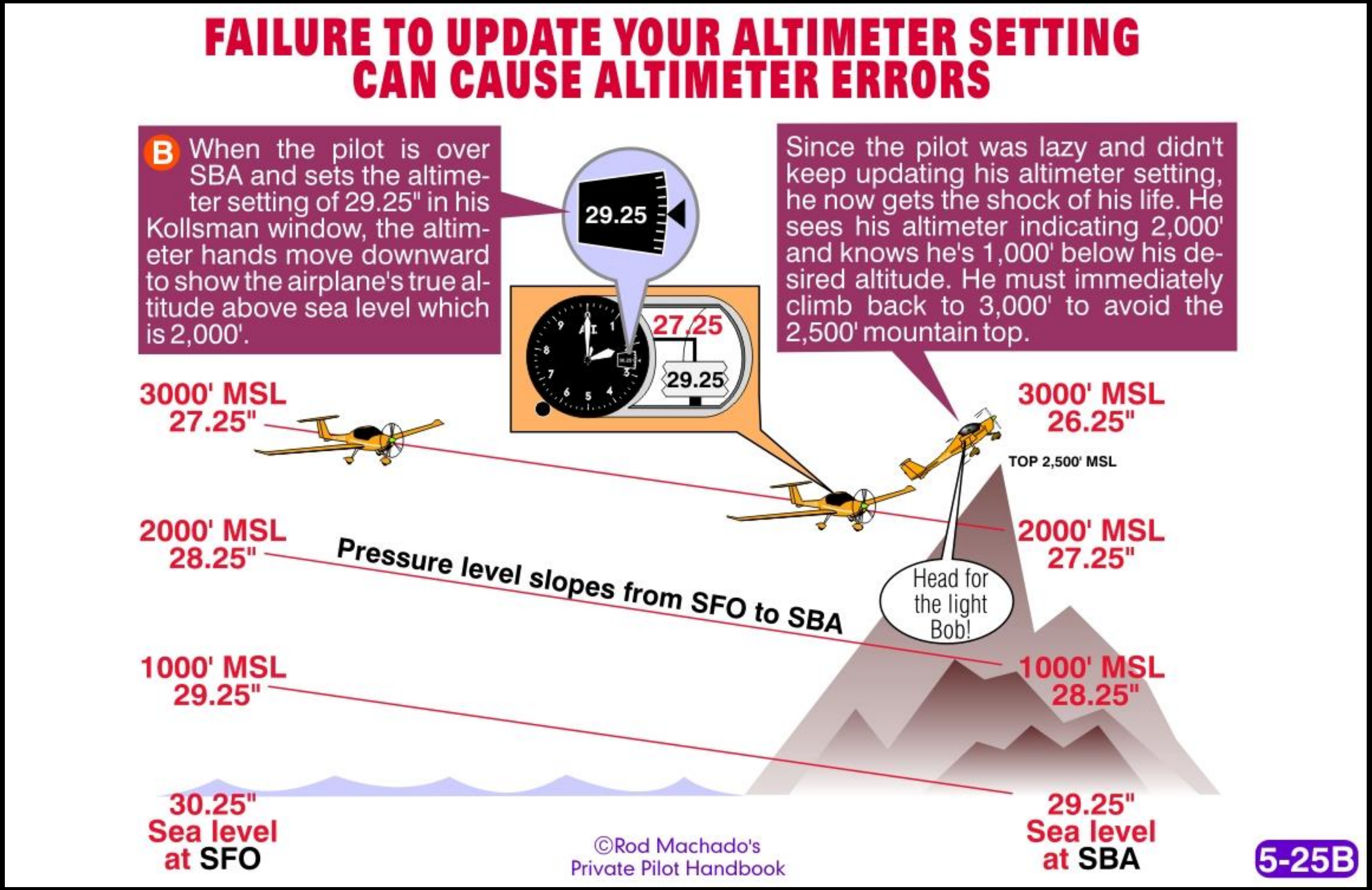


Failure to Update Altimeter Setting



- Flying from a higher to a lower sea level pressure, you will be lower than what your altimeter shows
- 1 in Hg = 1000 feet

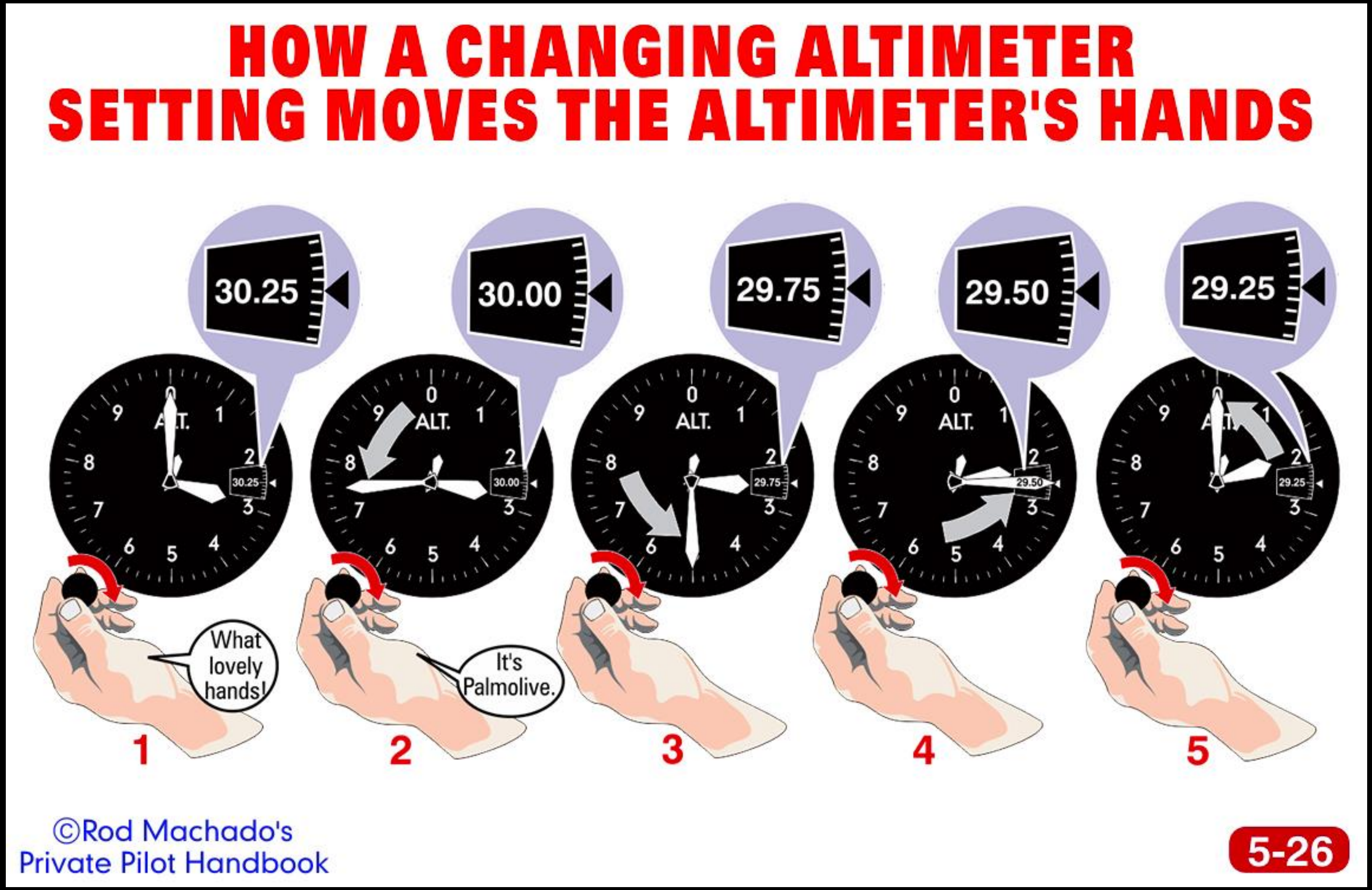
Updated Altimeter Setting



- With the corrected altimeter setting, the pilot realizes he is 1000 feet low
- 1 in Hg = 1000 feet

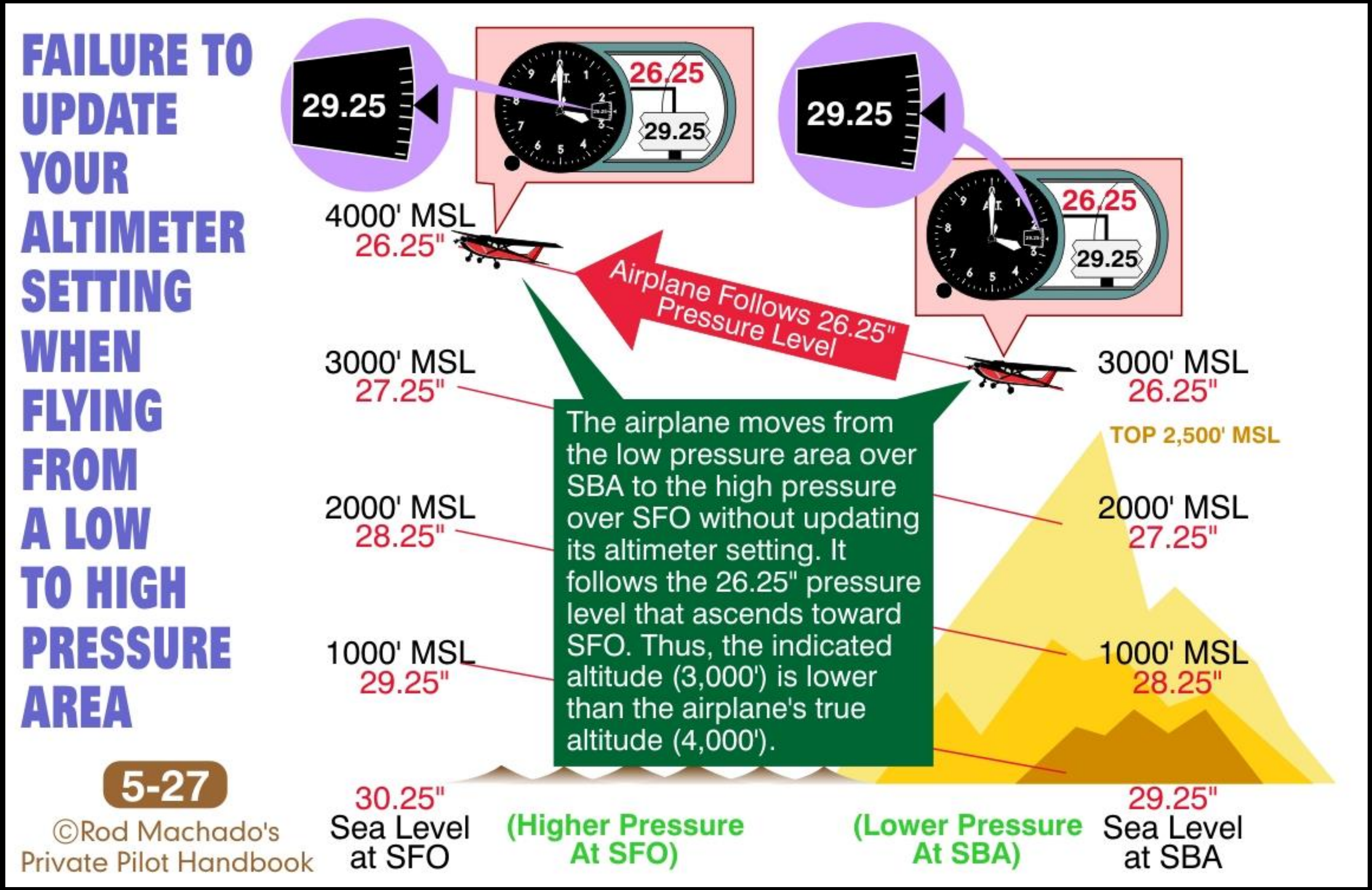
Changing The Altimeter Setting

- Decreasing the altimeter setting causes the altitude hands to decrease
- Opposite is true when increasing the altimeter setting
- 1 in Hg = 1000 feet



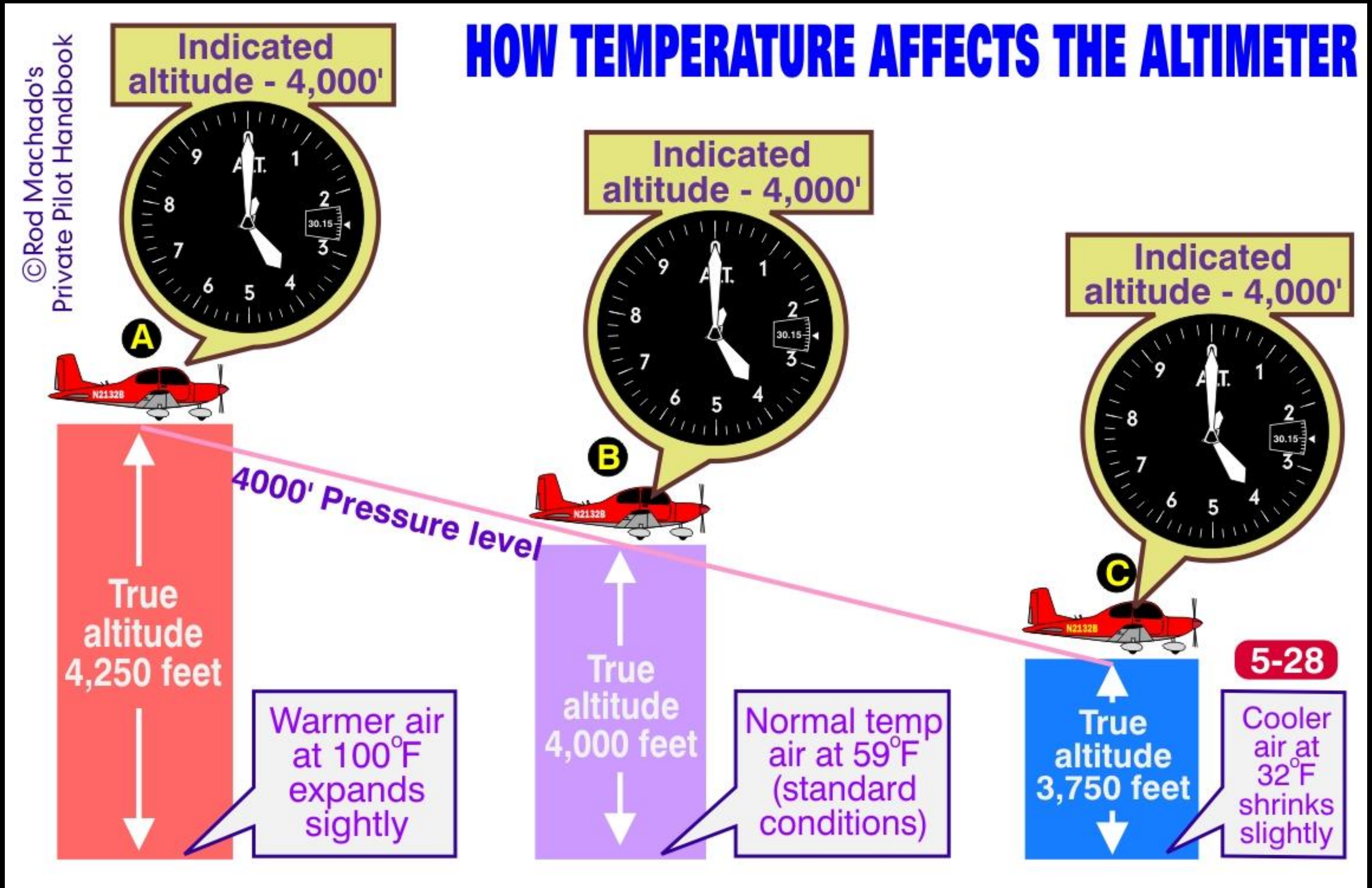
Failure to Update Altimeter Setting

- Flying from a lower to a higher sea level pressure, you will be higher than what your altimeter shows
- 1 in Hg = 1000 feet



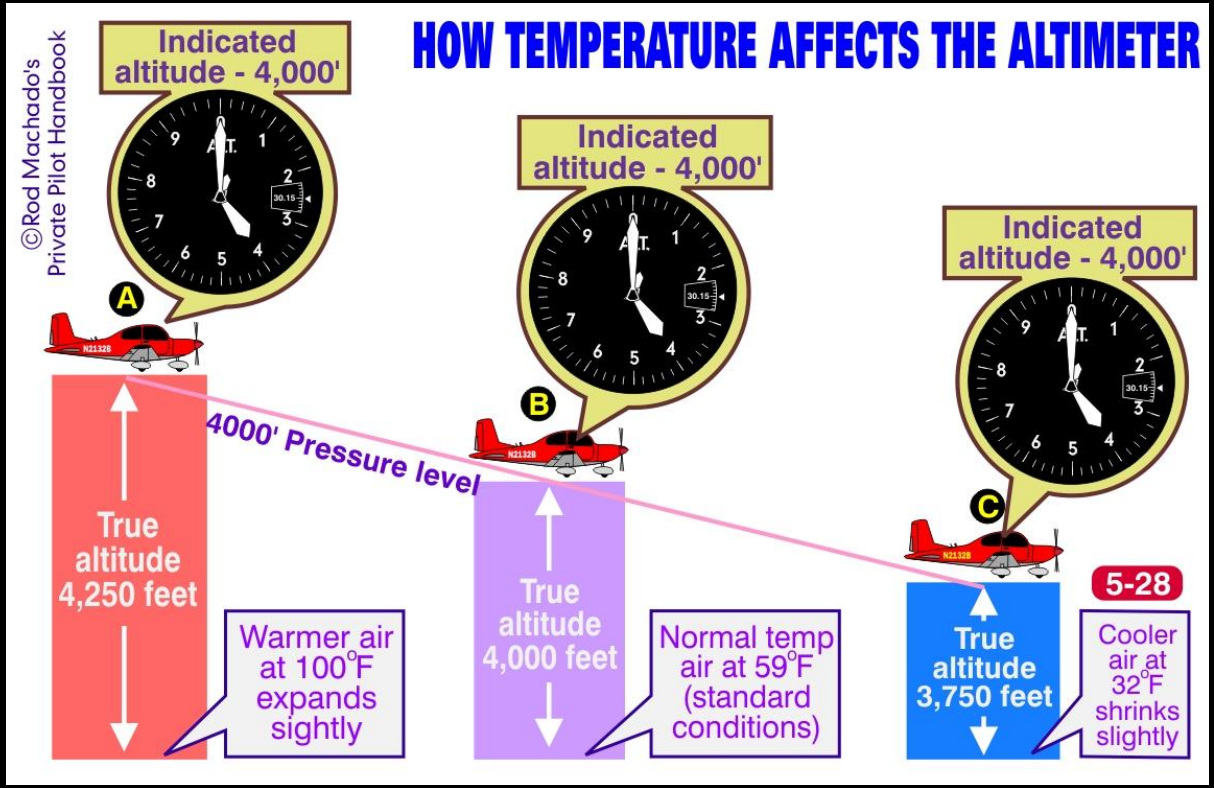
Effect of Temperature

- When air is at standard temperature (59°F/15°C at SL) the altimeter experiences no temperature error
- Airplane B, sitting on top of a column of normal temperature air, has an indicated altitude (4,000 feet) which is equal to its true altitude (4,000 feet)

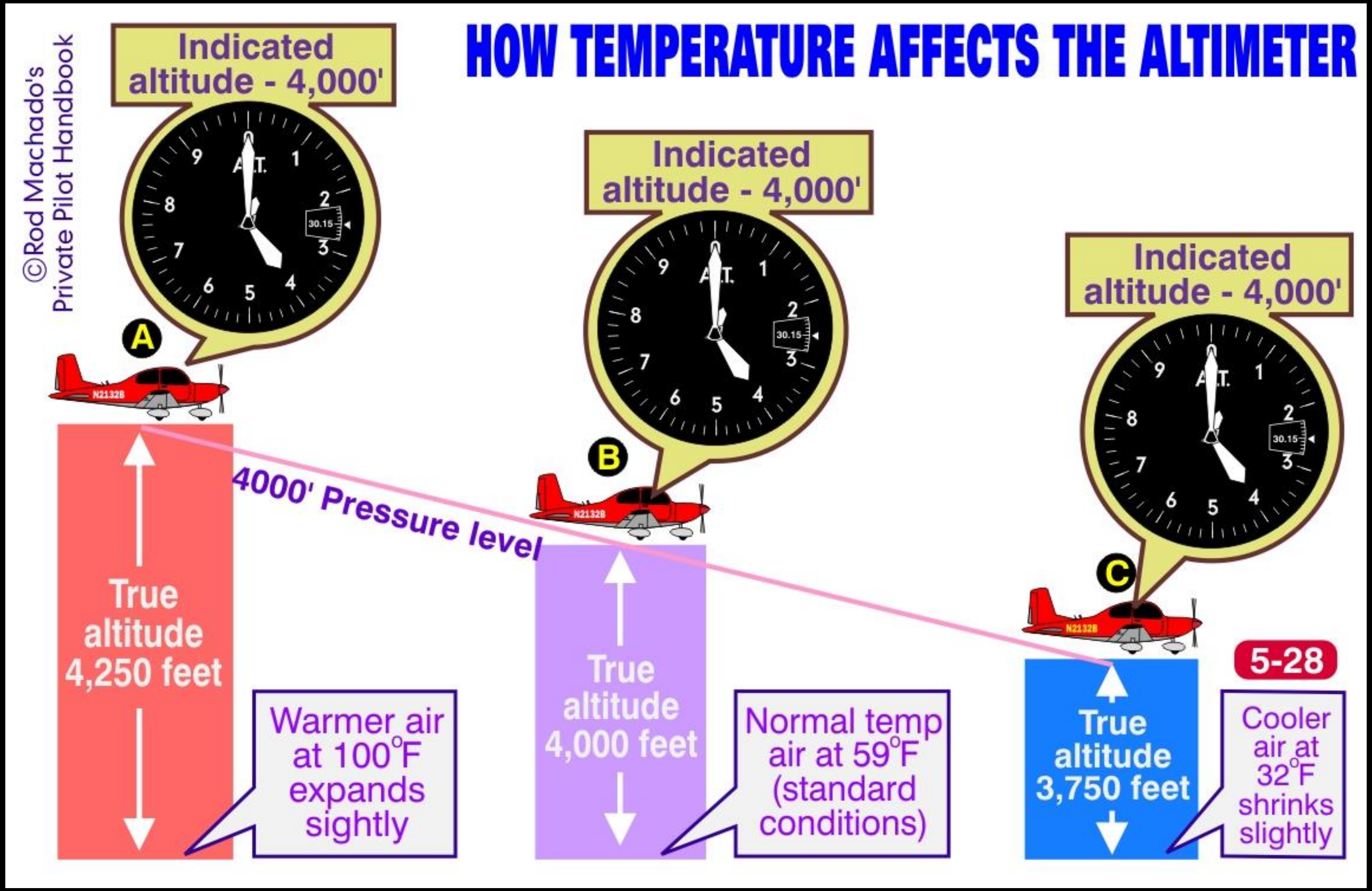


Effect of Temperature

- A mass of air having temperatures different from standard distributes its weight differently in the vertical direction
- When temperatures are warmer air expands and the expanded column of air is taller
- The pressure level is taller in warmer air
- Airplane A's indicated altitude is 4,000 feet and its true altitude is 4,250 feet

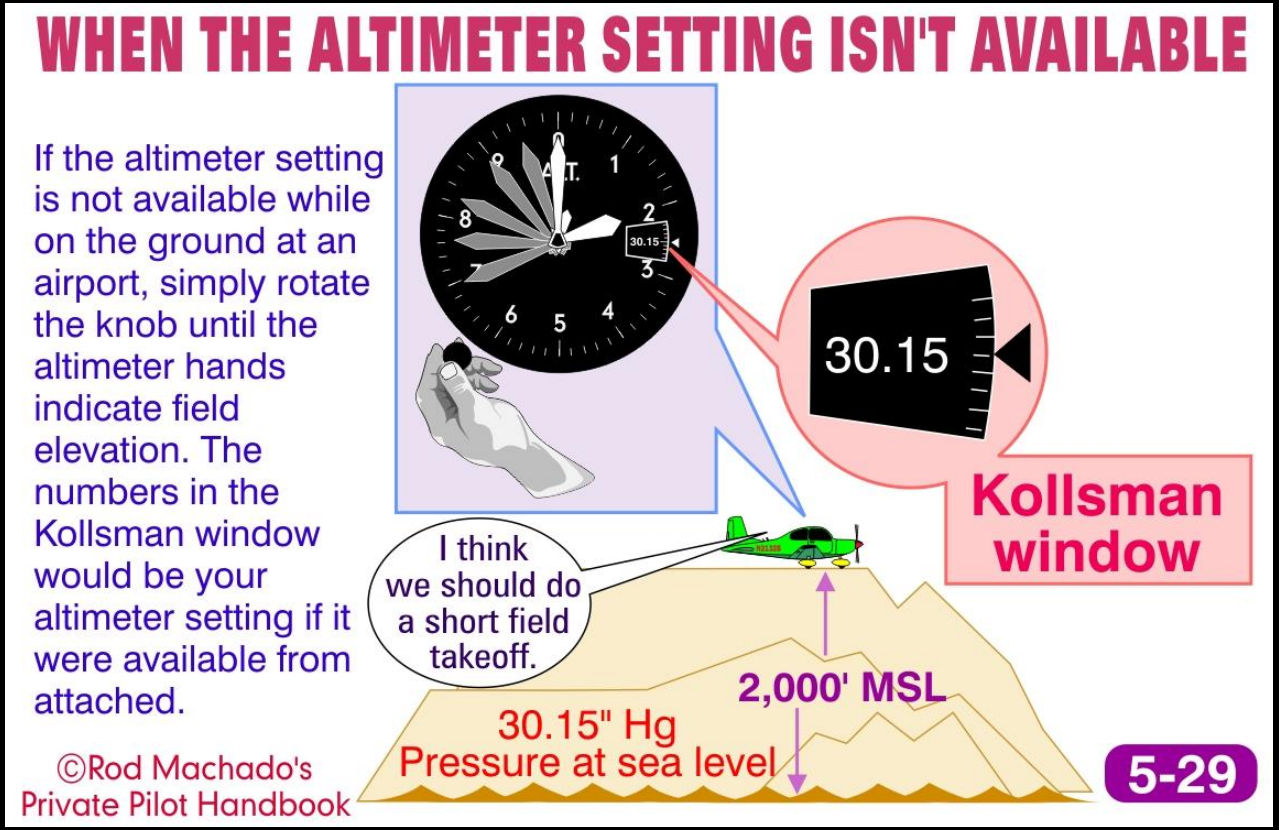


Effect of Temperature



- Colder air produces shorter or more closely spaced pressure levels
- Airplane C's indicated altitude is 4,000 feet and its true altitude is 3,750 feet.

Altimeter Setting Not Available



- Rotate the altimeter knob until the hands point to field elevation
- The numbers in the Kollsman window give you an approximate altimeter setting for that location

Altimeter Settings

- Before departure the pilot should obtain the altimeter setting given for the local airport
- Enroute, the pilot should set the altimeter to the closest station within 100 NM
- At or above 18,000 feet all aircraft use 29.92 (Flight Levels)

Sensitive Altimeter

- Has adjustable barometric scale allowing the pilot to set the reference pressure from which the altitude is measured
- This scale is visible in a small window called the Kollsman window
- A knob on the instrument adjusts the scale
- Range of the scale is from 28.00 to 31.00 inches of mercury

Sensitive Altimeter

- Rotating the knob changes both the barometric scale and the altimeter pointers
- A change in the barometric scale of 1" Hg changes the pointer indication by 1,000 feet

Sensitive Altimeter

- When the barometric scale is adjusted to 29.92 In Hg the pointers indicate the pressure altitude
- Displays indicated altitude by adjusting the barometric scale to the local altimeter setting
- The altimeter then indicates the height above the existing sea level pressure (MSL)

Altimeter Indications

- Altimeter indicates true altitude above MSL when operating within International Standard Atmosphere (ISA) parameters of pressure and temperature
- Standard Atmosphere: Temperature 15°C/59°F; Pressure 29.92

Altimeter Indications

- Nonstandard pressure conditions are corrected by applying the correct local area altimeter setting
- Temperature errors from ISA result in true altitude being higher than indicated altitude whenever the temperature is warmer than ISA, and true altitude being lower than indicated altitude whenever the temperature is colder than ISA
- True altitude variance under conditions of colder than ISA temperatures poses the risk of inadequate obstacle clearance

Altimeter Errors

- A sensitive altimeter is designed to indicate standard changes from standard conditions (29.92 / 15°C)
- Most flying involves errors caused by nonstandard conditions and the pilot must be able to modify the indications to correct for these errors
- There are two types of errors:
  - Mechanical
  - Inherent

Mechanical Altimeter Errors

- Preflight check to determine the condition of an altimeter consists of setting the barometric scale to the local altimeter setting
- Altimeter should indicate the surveyed elevation of the airport
- If the indication is off by more than ±75 feet from the airport elevation, the instrument should be recalibrated
- Differences between ambient temperature and/or pressure causes an erroneous indication on the altimeter

Pressure Altitude

- Pressure altitude is used for performance computations
- A standard day occurs when the sea level temperature is 59°F (15°C) and pressure is 29.92" Hg
- Airplane performance charts are based on these conditions
- Climb rate chart requires two variables: pressure altitude and temperature

HOW TO FIND AND USE PRESSURE ALTITUDE

A Think of pressure altitude as the altitude the engineers were at when they created the airplane's performance charts. This is the altitude your altimeter reads when 29.92" of Hg is set in your Kollsman window.

WEIGHT LBS	PRESS ALT FT	CLIMB SPEED KIAS	RATE OF CLIMB - FPM			
			-20°C	0°C	20°C	40°C
2550	S.L.	73	795	730	665	600
	2000	73	705	645	585	525
	4000	73	625	565	510	450
	6000	72	540	485	430	370
	8000	72	460	405	350	295
	10,000	72	380	325	275	
	12,000	72	300	250		

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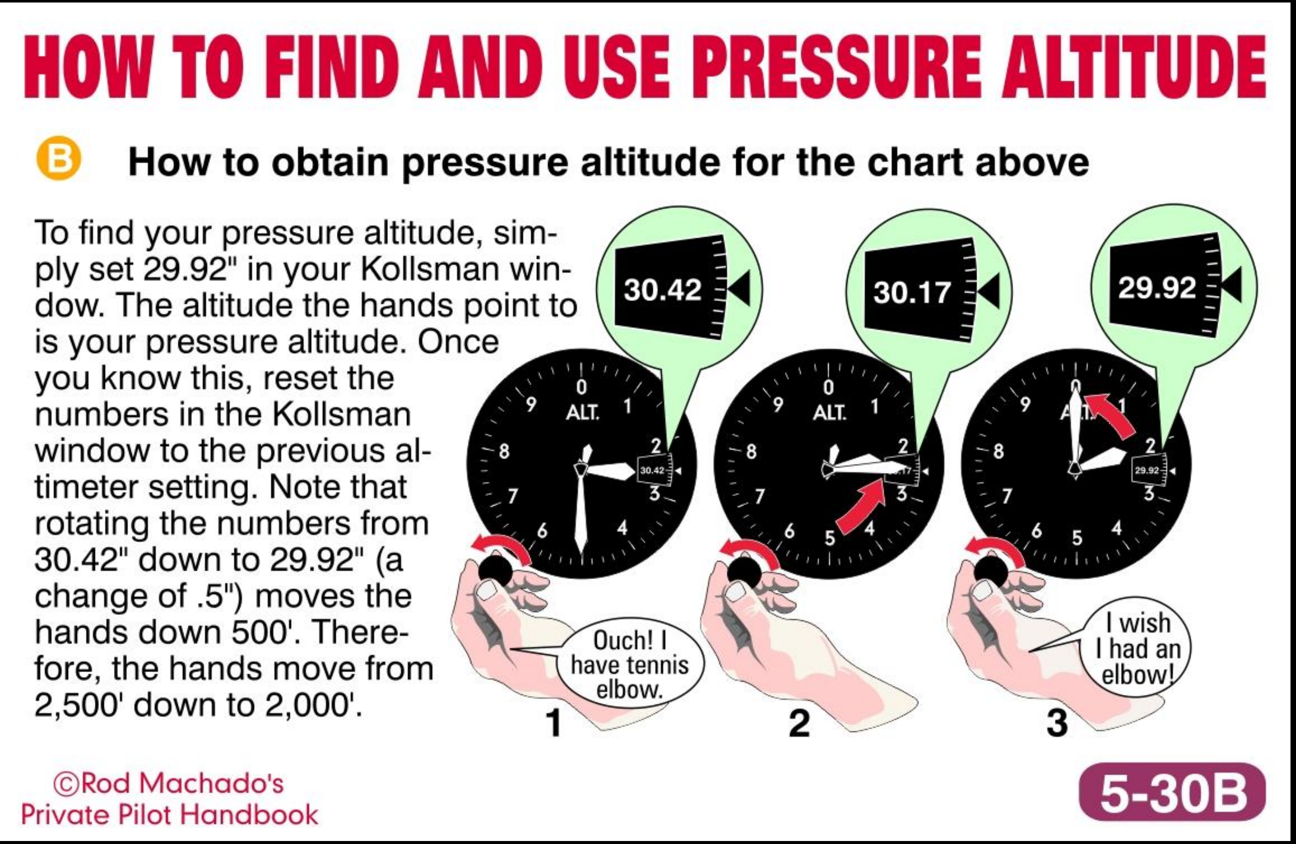
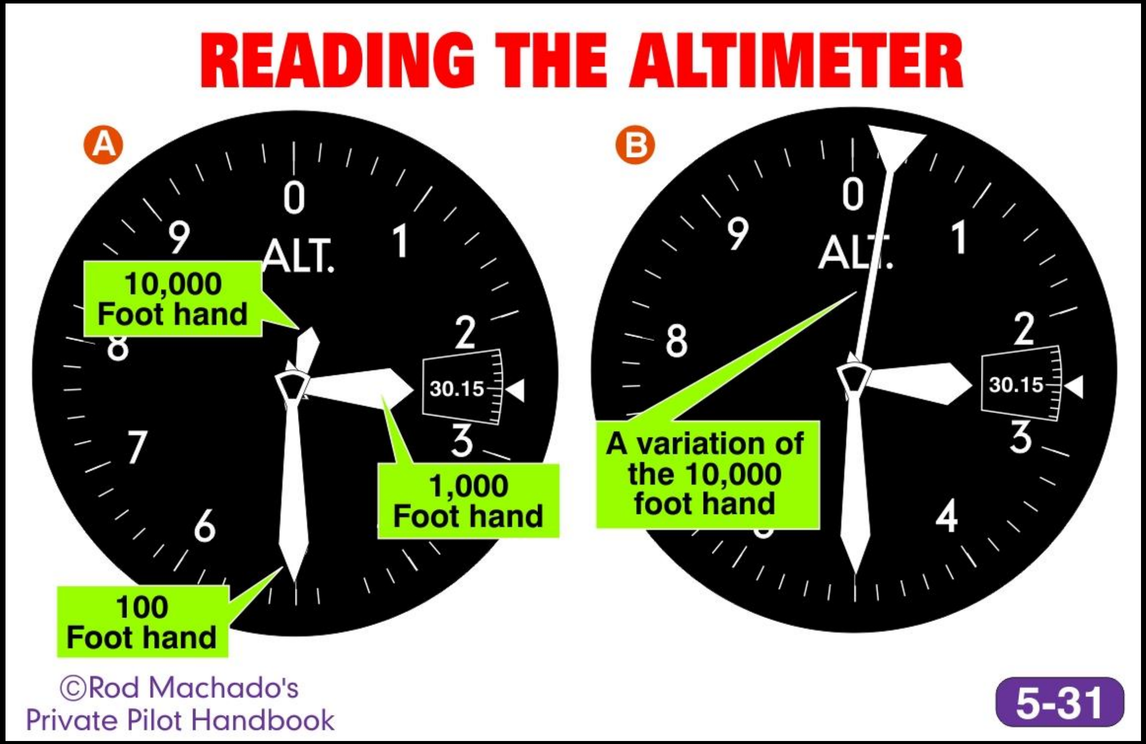
Finding Pressure Altitude

- To determine pressure altitude set the altimeter’s Kollsman window to 29.92” Hg and read the indicated altitude



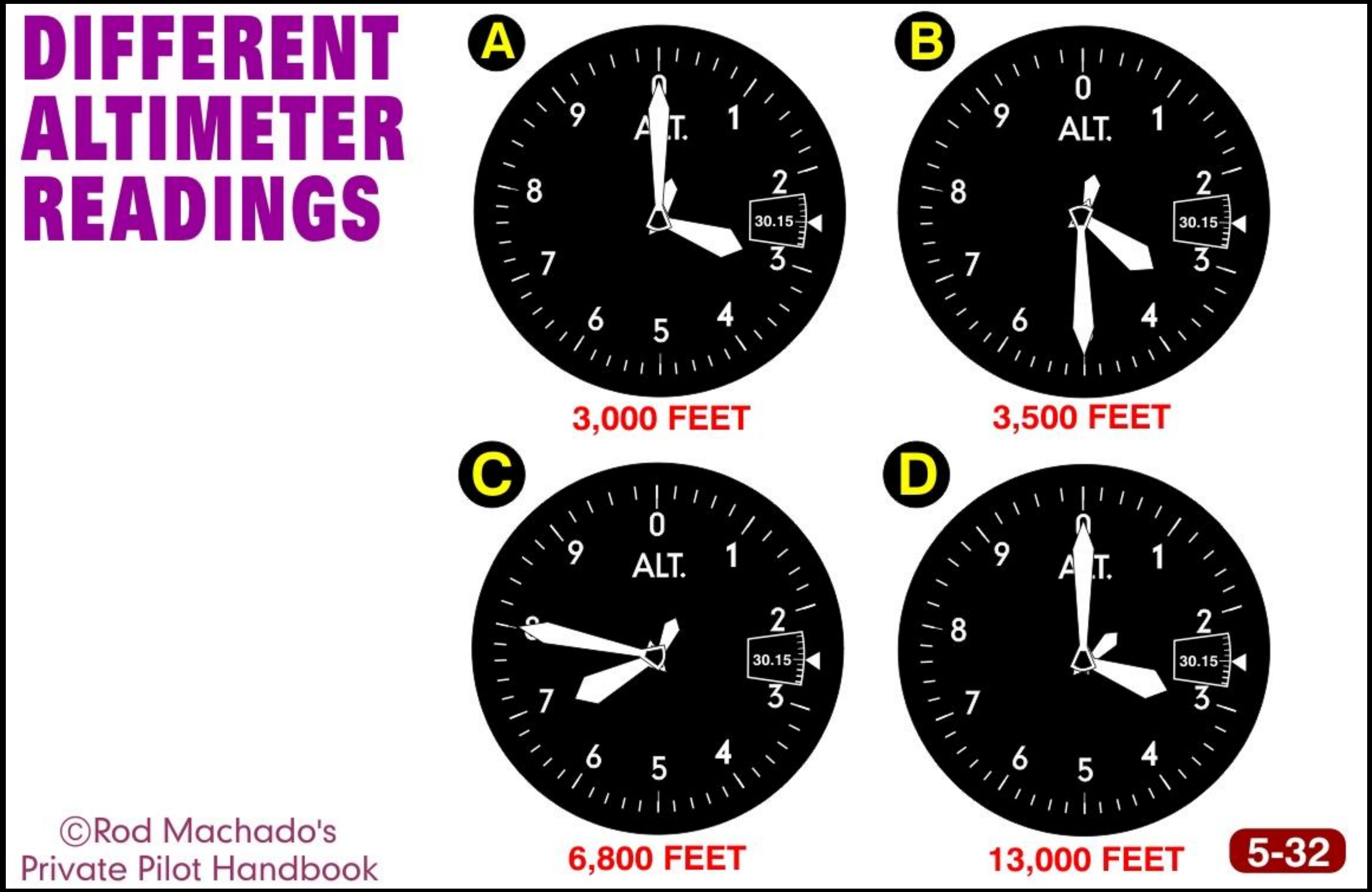
Altimeter Hands



- Shortest hand points to numbers representing the airplane's height in tens of thousands of feet
- Medium, thicker hand represents altitude in thousands of feet
- Long thin hand represents the airplane's altitude in hundreds of feet

Different Altimeter Readings

- Keep an eye on the 10,000 foot hand, especially on FAA tests



Different Altimeter Readings

Figure 82. Altimeter

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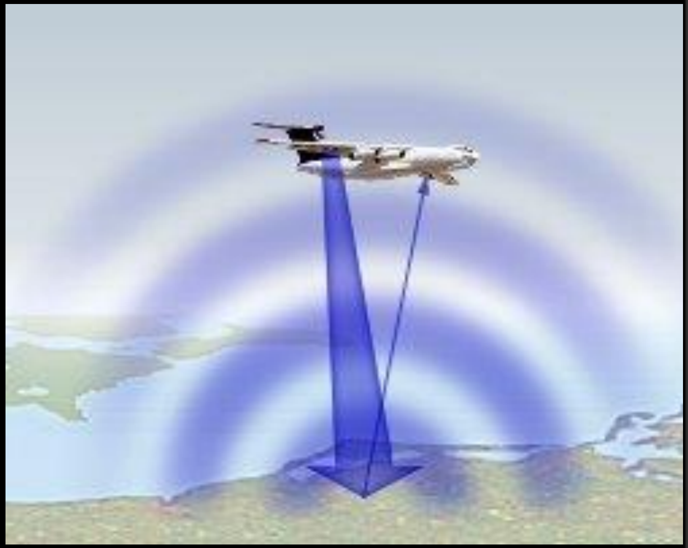
Different Altimeter Readings

Figure 3. Altimeter ©ASA

Absolute Altitude

- **Absolute Altitude** - Height directly above terrain (Radar Altimeter)

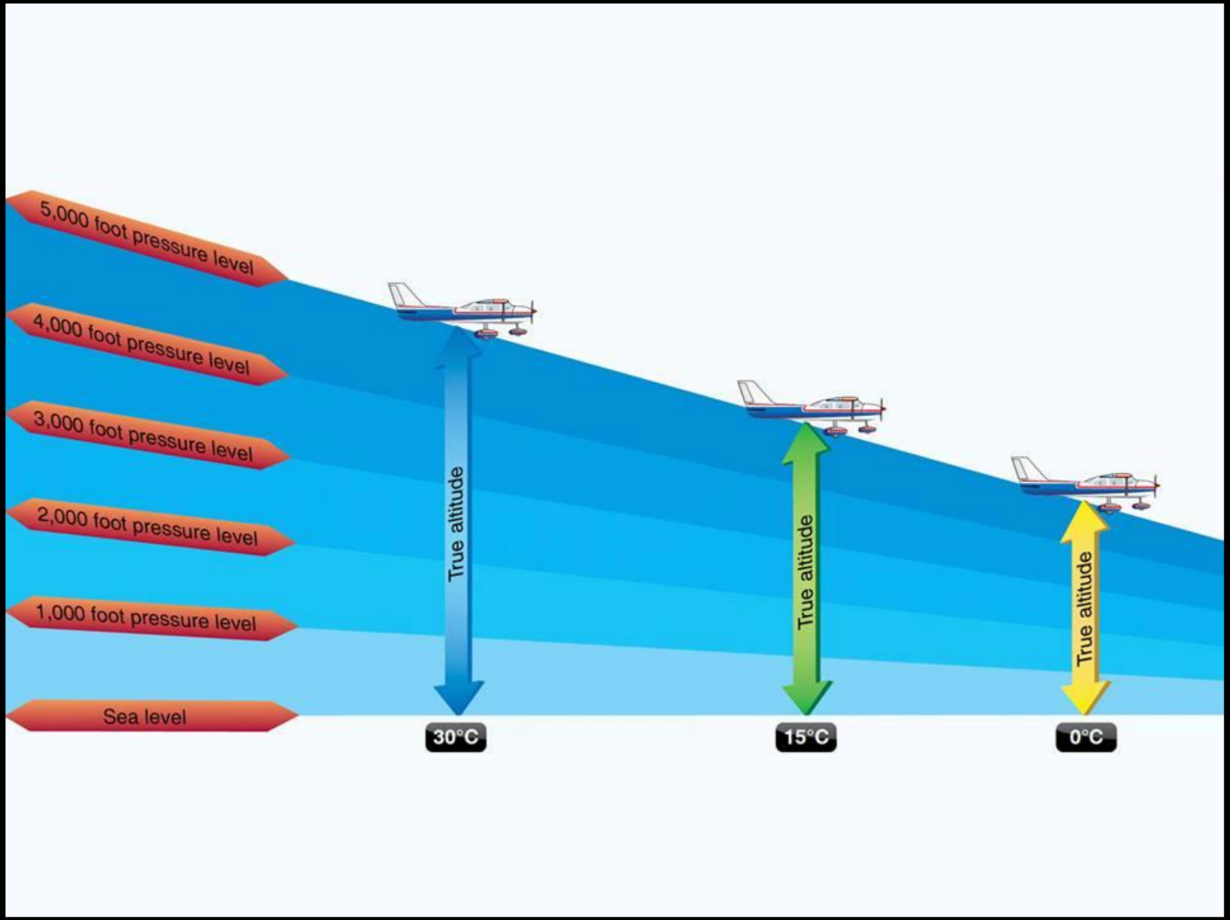


Altitude Definitions

- **Indicated Altitude** - Altitude above MSL indicated on an altimeter that is set to the current local altimeter setting
- **Pressure Altitude** - Altitude indicated on an altimeter when it is set to the standard sea level pressure of 29.92 inches of mercury
- **True Altitude** - Exact height above sea level (The altimeter setting yields true altitude at field elevation)
- **Absolute Altitude** - Height directly above terrain (Radar Altimeter)
- **Density Altitude** - Pressure altitude corrected for a nonstandard temperature

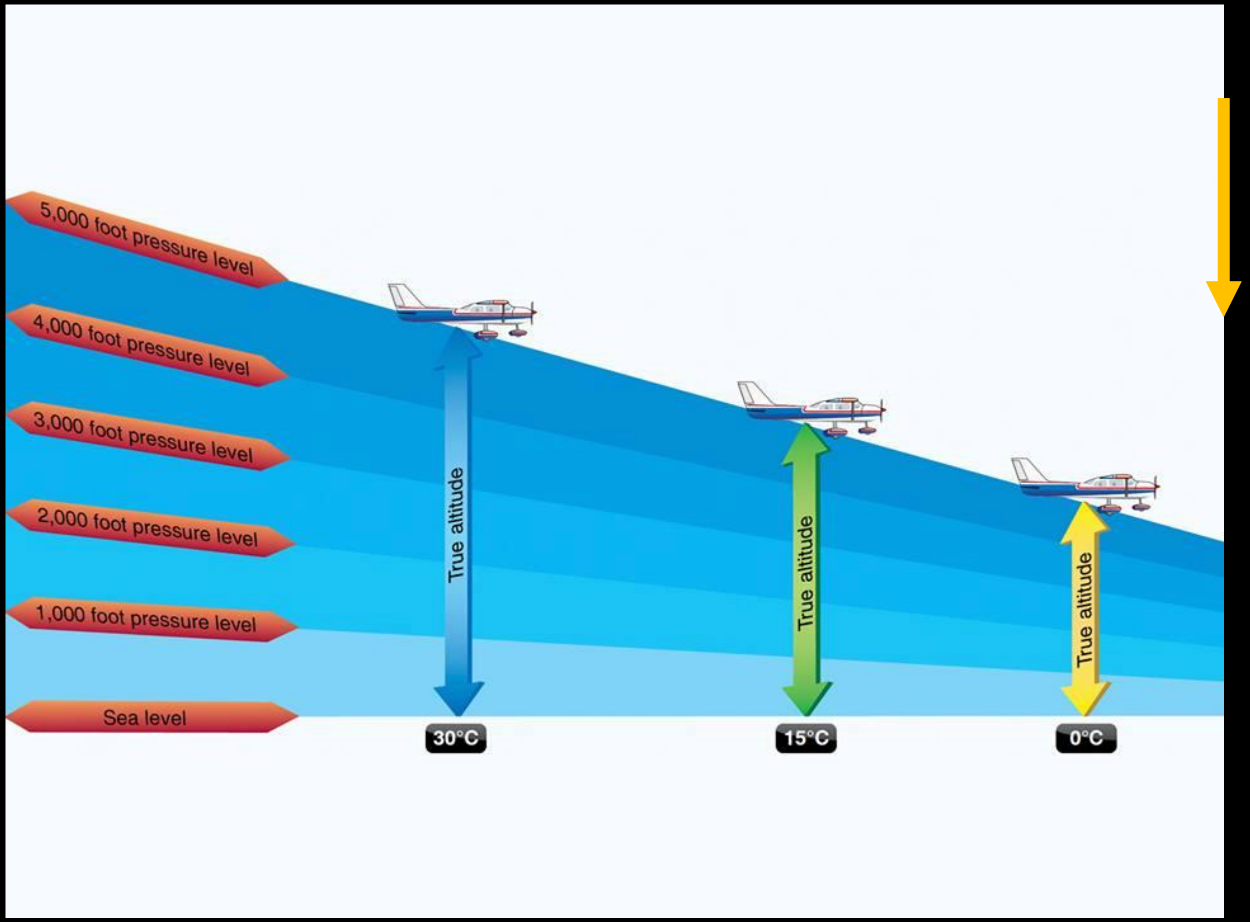
Altimeter Error- Temperature

- When the aircraft is flying in air that is warmer than standard the air is less dense, and the pressure levels are farther apart
- When flying at an indicated altitude of 5,000 feet, the pressure level for that altitude is higher than it would be in air at standard temperature, and the aircraft is higher than it would be if the air were cooler



Altimeter Error- Temperature

- If the air is colder than standard, it is denser, and the pressure levels are closer together
- When flying at an indicated altitude of 5,000 feet, its true altitude is lower than it would be if the air were warmer



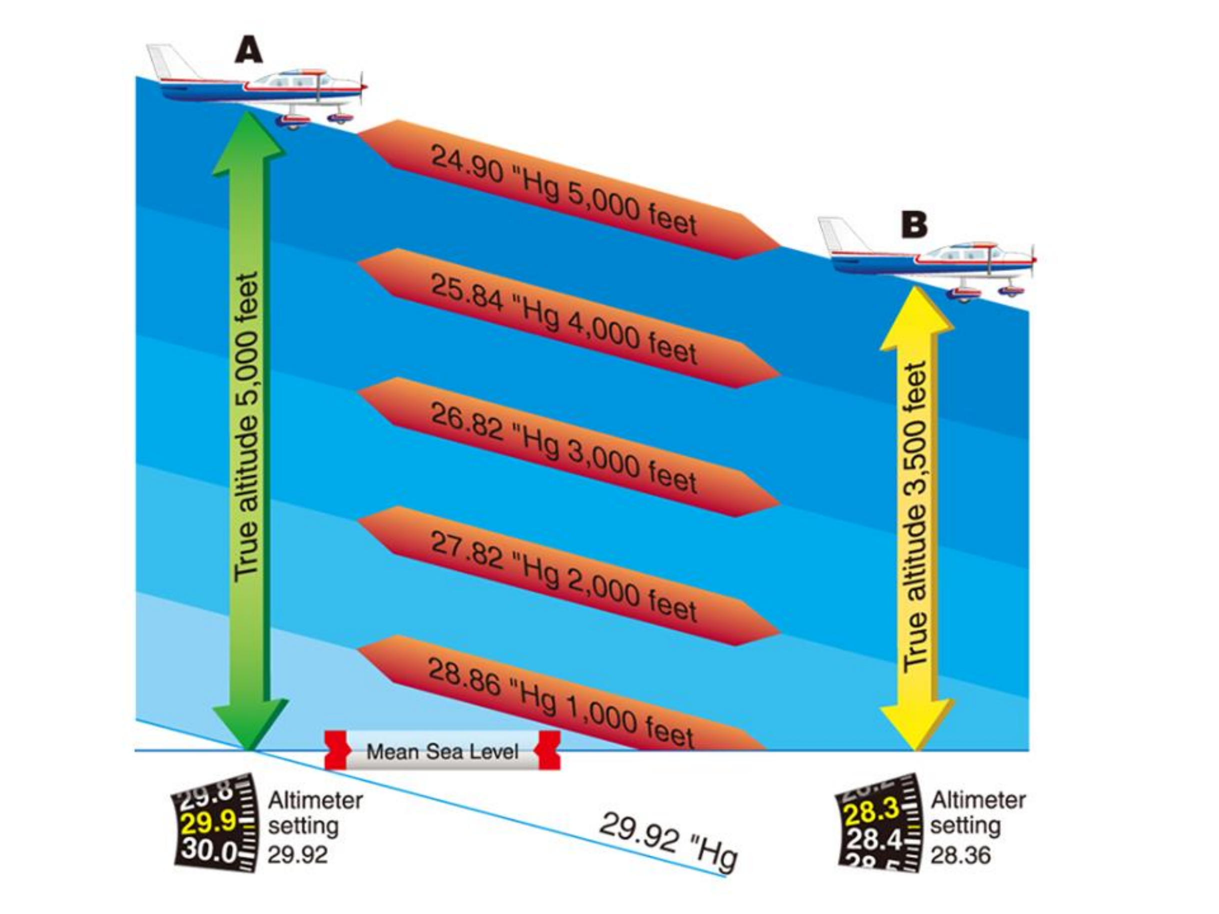
Temperature Corrections

- Under *extremely* cold conditions, pilots may need to add an appropriate temperature correction determined from the correction chart to charted IFR altitudes to ensure terrain and obstacle clearance with the following restrictions:
- Altitudes specifically assigned by ATC shall not be corrected

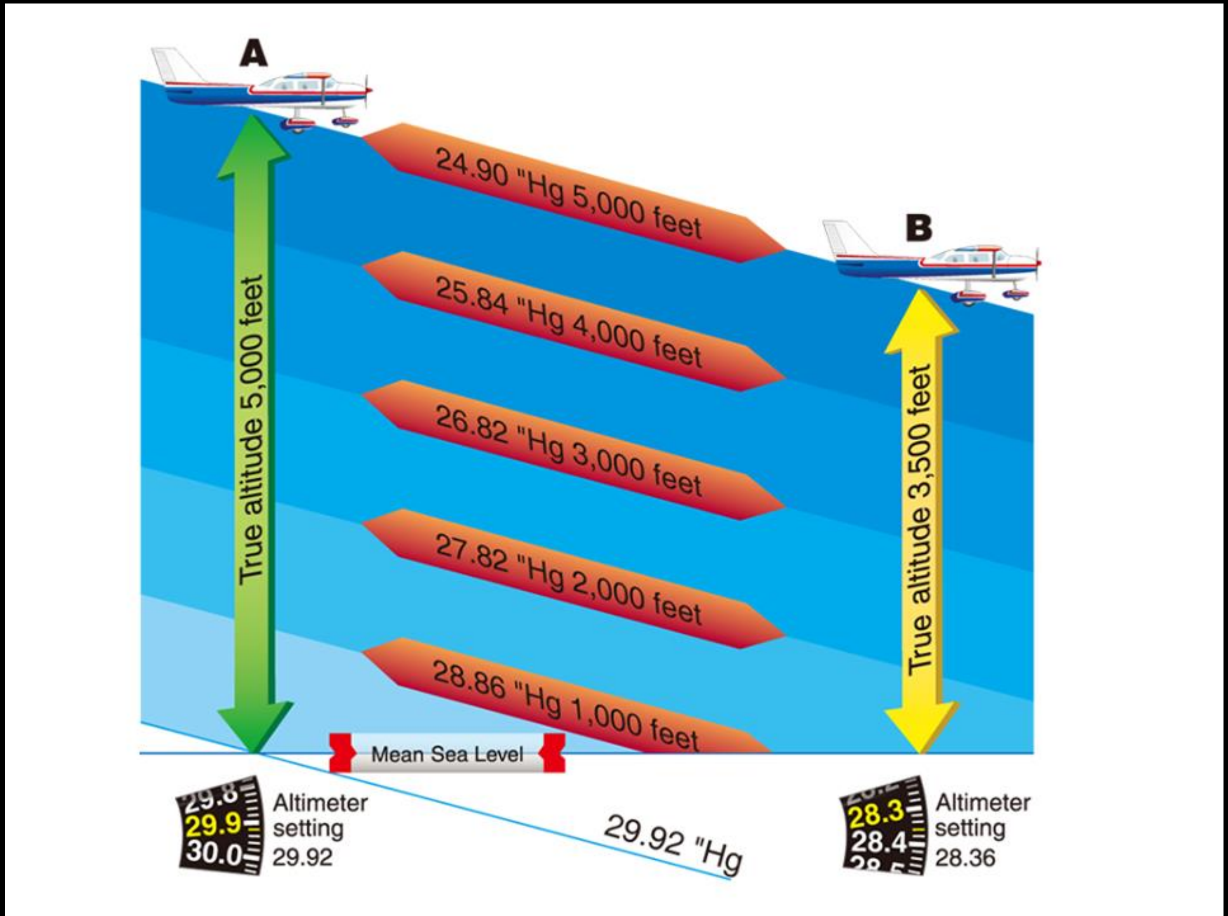
Reported Temp 0 °C	Height Above Airport in Feet: 200	300	400	500	600	700	800	900	1,000	1,500	2,000	3,000	4,000	5,000
+10	10	10	10	10	20	20	20	20	20	30	40	60	80	90
0	20	20	30	30	40	40	50	50	60	90	120	170	230	280
-10	20	30	40	50	60	70	80	90	100	150	200	290	390	490
-20	30	50	60	70	90	100	120	130	140	210	280	420	570	710
-30	40	60	80	100	120	140	150	170	190	280	380	570	760	950
-40	50	80	100	120	150	170	190	220	240	360	480	720	970	1,210
-50	60	90	120	150	180	210	240	270	300	450	590	890	1,190	1,500

Non-standard Pressure on an Altimeter

- Take an aircraft whose altimeter setting is set to 29.92" of local pressure
- As the aircraft moves to an area of lower pressure the pilot fails to readjust the altimeter setting
- As the pressure decreases, the true altitude is lower



Non-standard Pressure on an Altimeter



- Adjusting the altimeter settings compensates for this
- When the altimeter shows an indicated altitude of 5,000 feet, the true altitude at Point A (the height above MSL) is only 3,500 feet at Point B

When flying:

High to Low (Pressure)

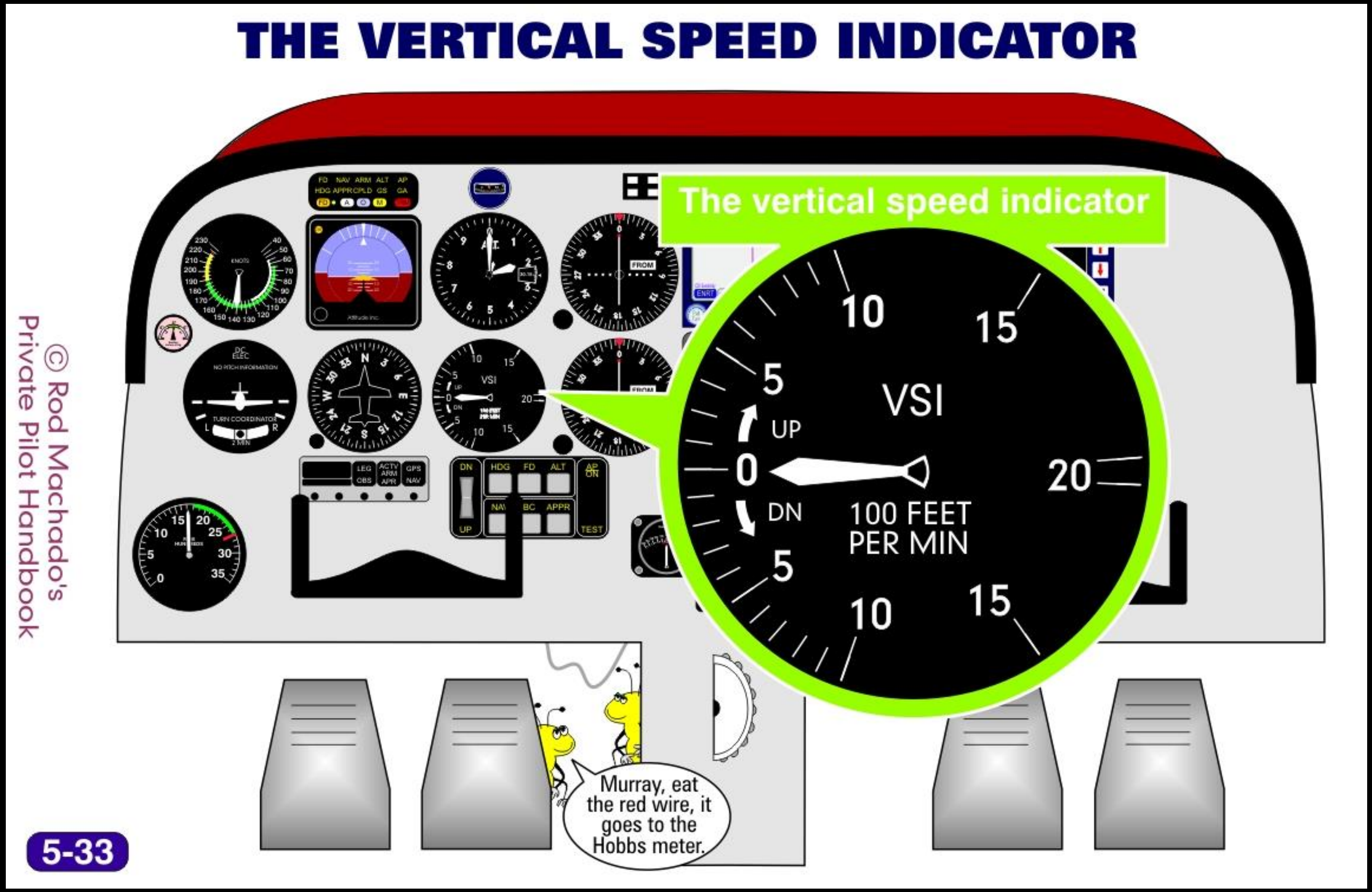
or …

Hot to Cold (Temperature)

Look out below!

Vertical Speed Indicator

- Indicates climb or descent in feet per minute (FPM)

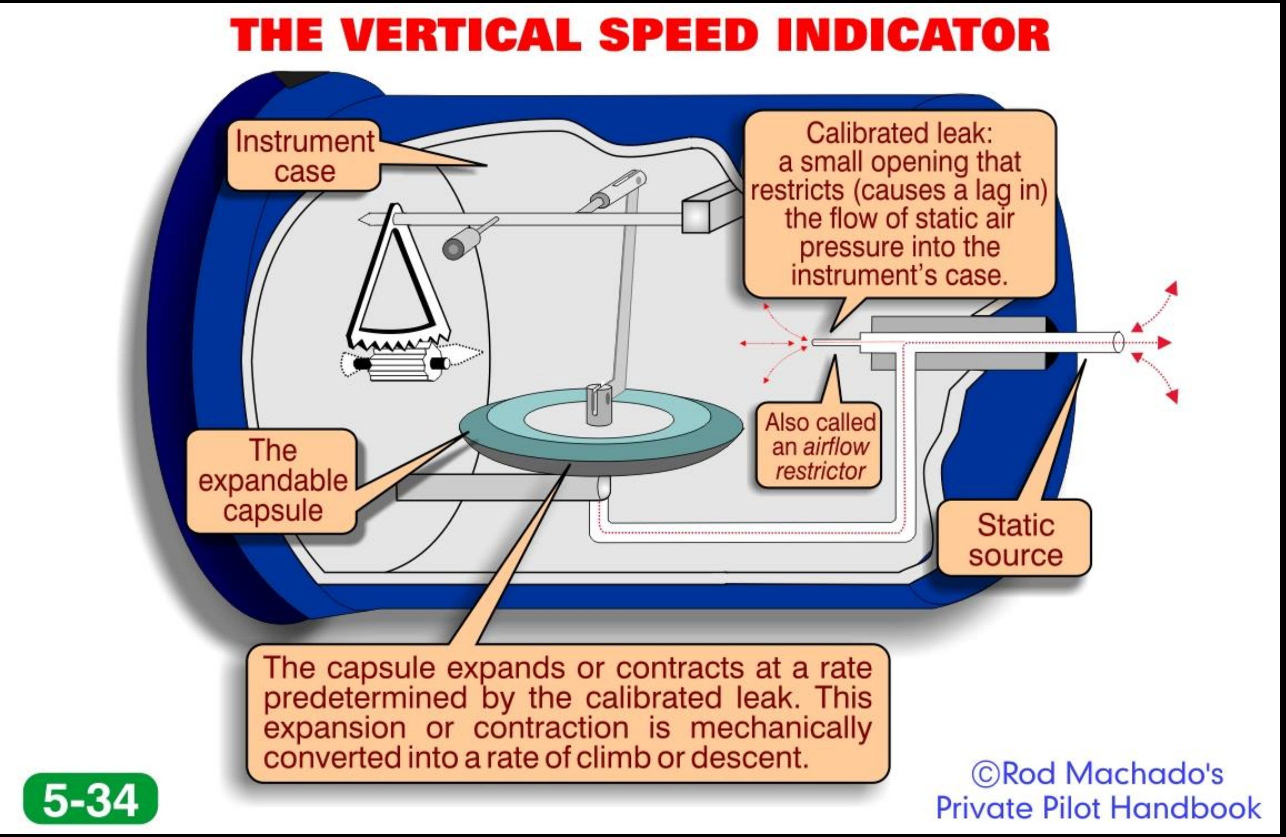


Vertical Speed Indicator (VSI)

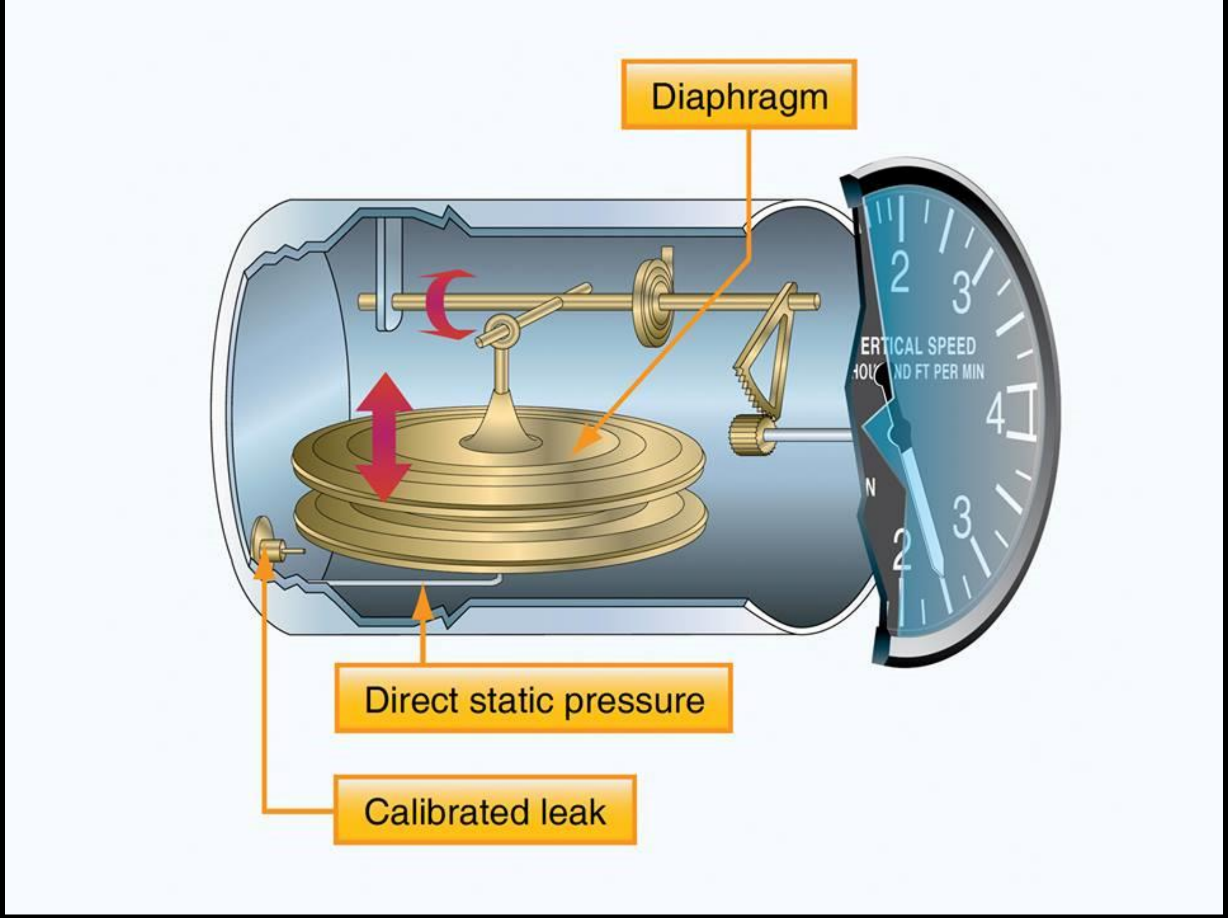
- A *rate-of-pressure change* instrument that gives an indication of any deviation from a constant pressure level
- Indicates climb or descent in feet per minute (FPM)
- The pointer indication in a VSI lags a few seconds behind the actual change in pressure
- Is more sensitive than an altimeter and is useful in alerting the pilot of an upward or downward trend, thereby helping maintain a constant altitude

VSI Operation

- Inside the aneroid and the inside of the instrument case are both vented to the static system
- The case is vented through a calibrated orifice that causes the pressure inside the case to change more slowly than the pressure inside the aneroid
- As the aircraft ascends, the static pressure becomes lower
- The pressure inside the case compresses the aneroid, moving the pointer upward, showing a climb indicating (FPM)



Vertical Speed Indicator



- Inside the aneroid and the inside of the instrument case are <u>both</u> vented to the static system
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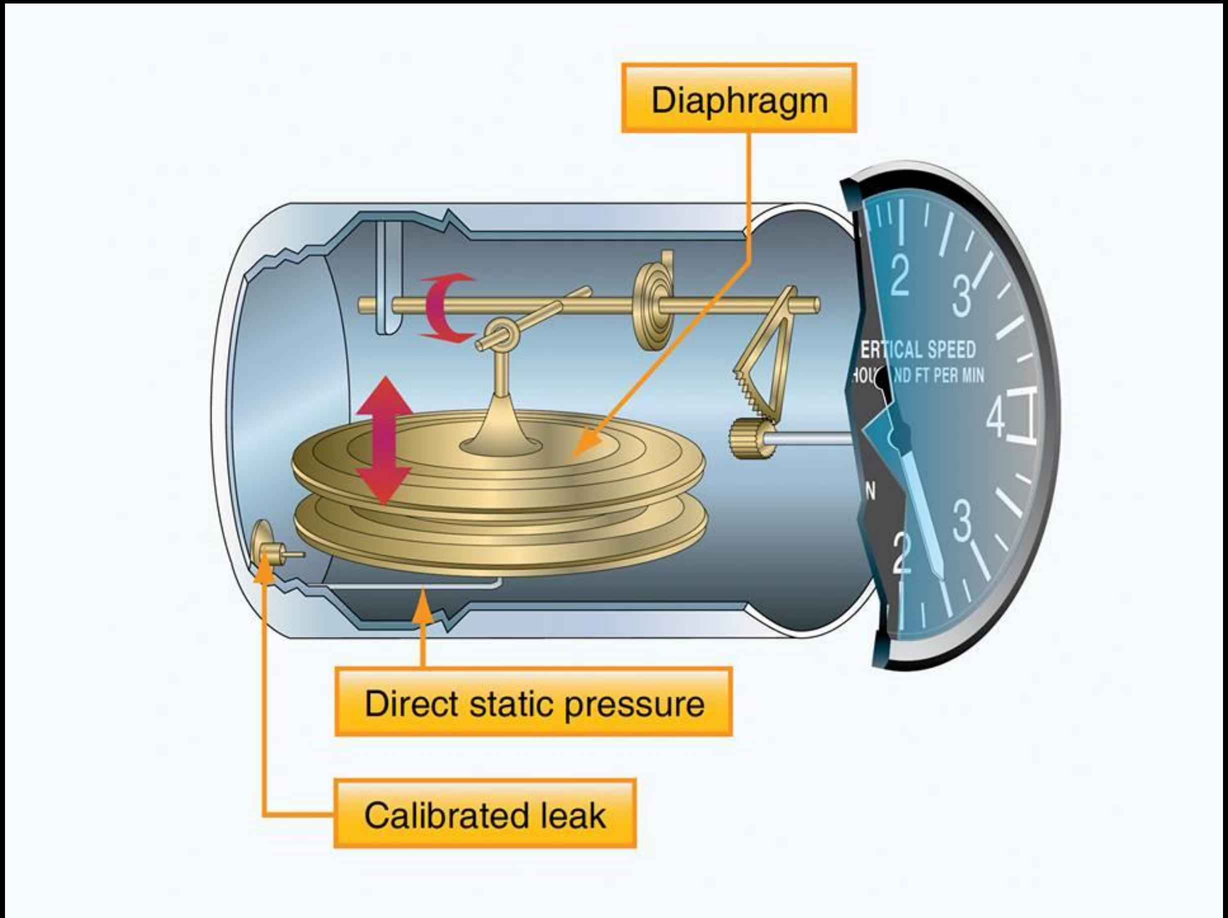
Vertical Speed Indicator



- When the aircraft levels off, the pressure no longer changes
- The pressure inside the case becomes equal to that inside the aneroid, and the pointer returns to the zero position
- When the aircraft descends, the static pressure increases
- The aneroid expands, moving the pointer downward, indicating a descent

Vertical Speed Indicator Checks

- *Not* required by regulation to be on board, but is commonly found on instrument airplanes
- A VSI pre-takeoff check is made to check for a “zero” reading
- If it is indicating a climb or descent, note the error and apply it to readings in flight

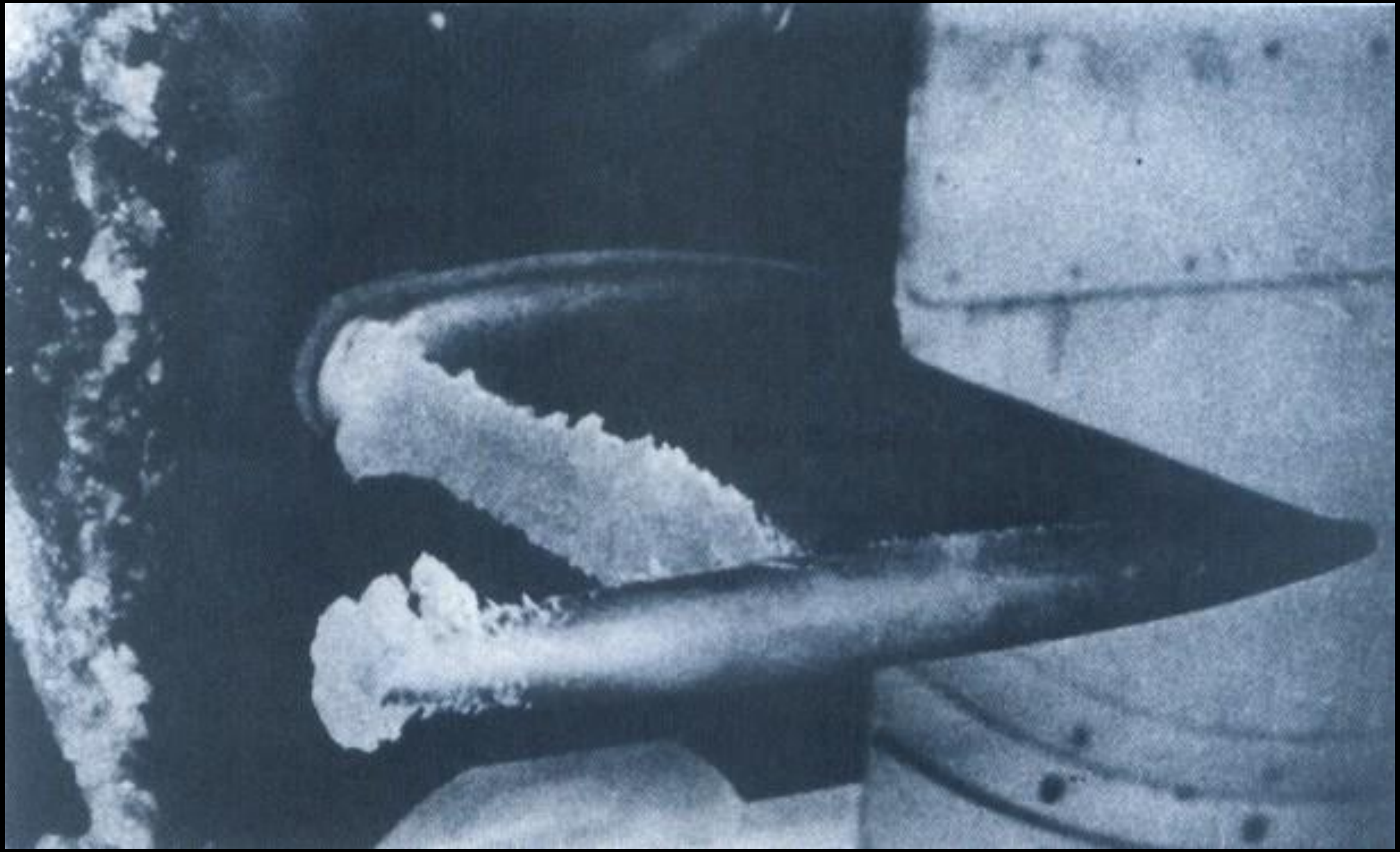
Blockage of the Pitot-Static System

- Errors in the ASI, ALT, and VSI almost always indicate a blockage of the pitot tube, the static port(s), or both
- Moisture (including ice), dirt, or insects can cause a blockage in both systems

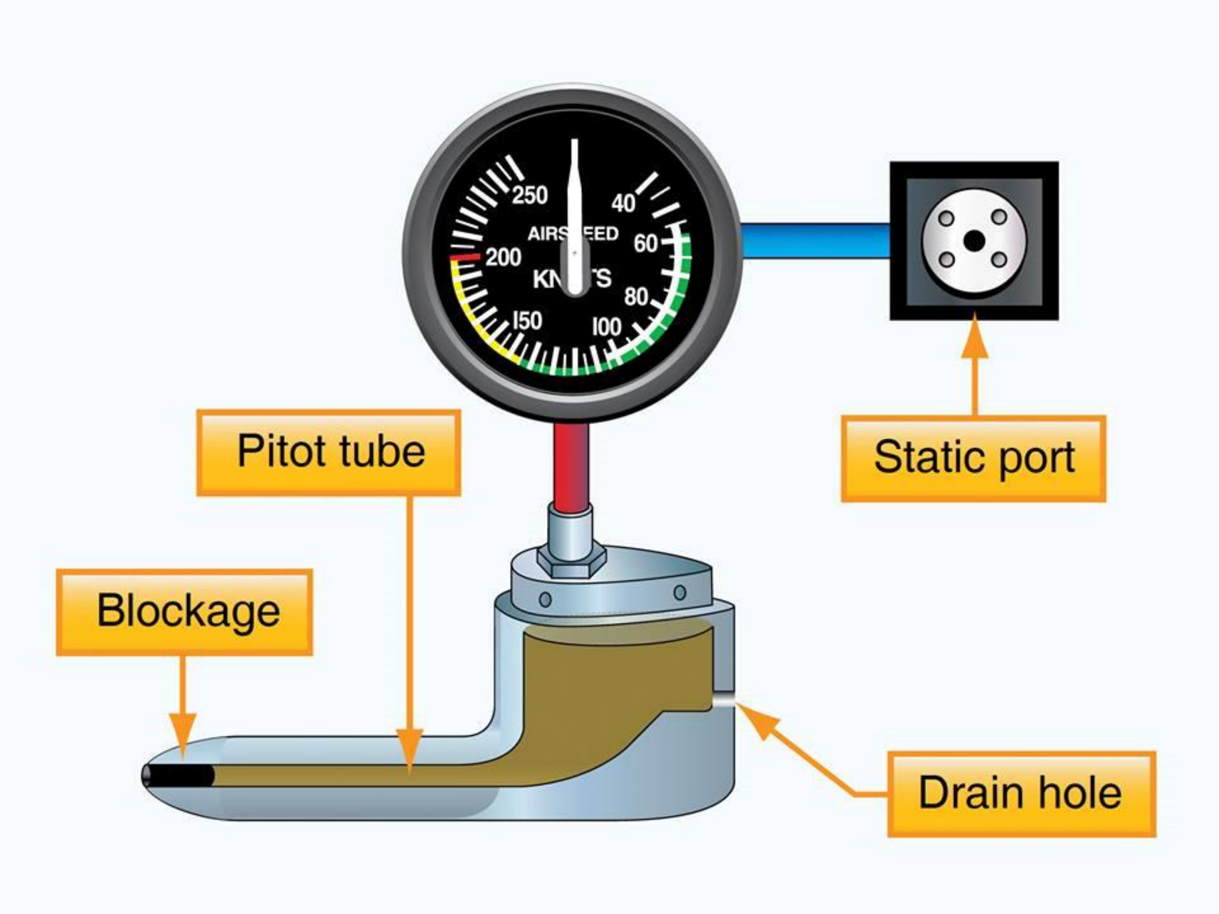
Blockage of the Pitot-Static System

- During preflight make sure pitot tube cover is removed and static port openings are checked for blockage and damage
- Check operation of pitot heat during preflight
- The pitot tube is particularly vulnerable to icing because of the position of the ram air input in the airflow, hence most IFR aircraft have a pitot heater to prevent it from icing up
- Drain holes prevent moisture accumulating in the probe

Pitot Tube Icing



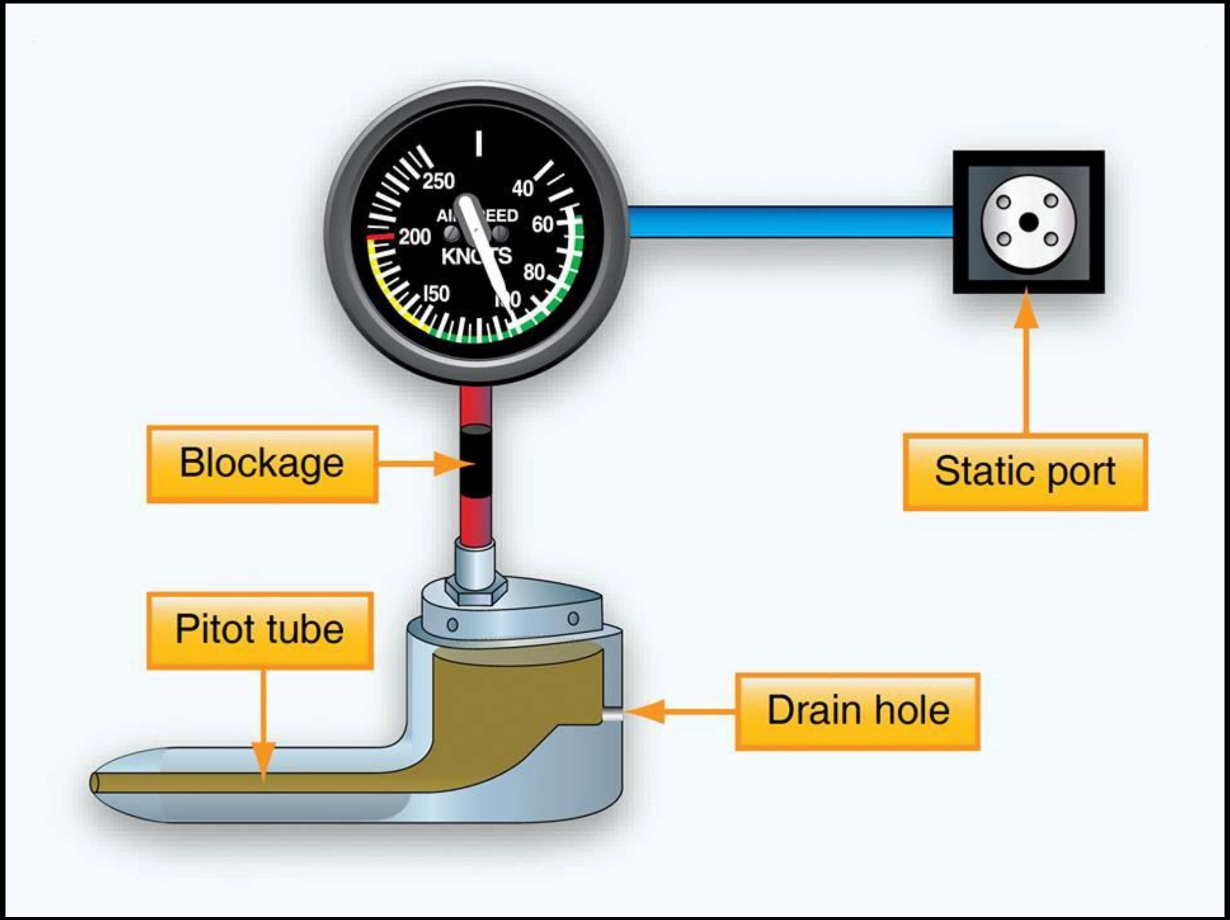
Blocked Pitot System



- If the pitot tube becomes obstructed, the pitot system can become partially or completely blocked
- When dynamic pressure cannot enter the pitot tube opening, the ASI no longer operates
- If the drain hole is open, static pressure equalizes on both sides of the diaphragm in the ASI and the indicated airspeed slowly drops to zero

Totally Blocked Pitot System

- If both the pitot tube ram pressure hole and drain hole become obstructed, the ASI operates like an altimeter as the aircraft climbs and descends



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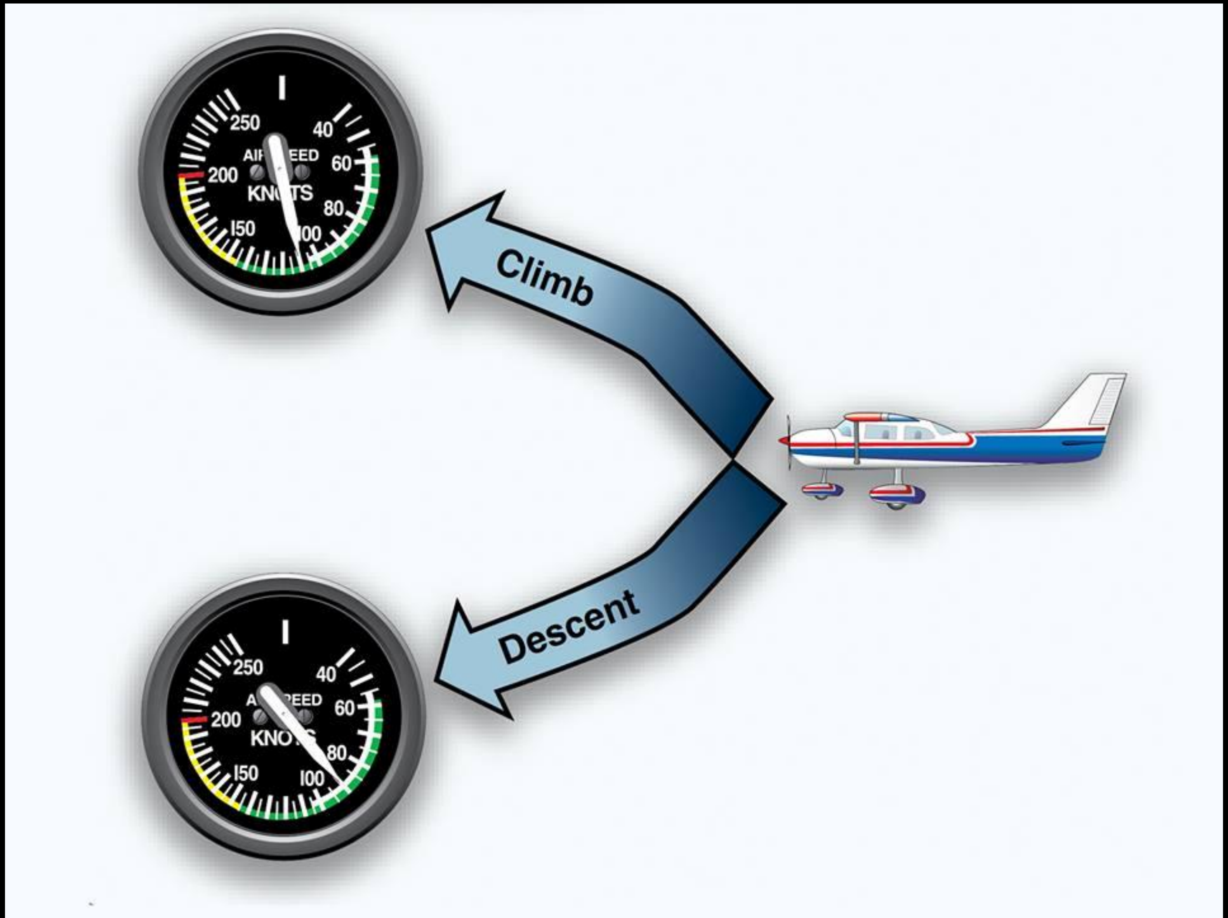
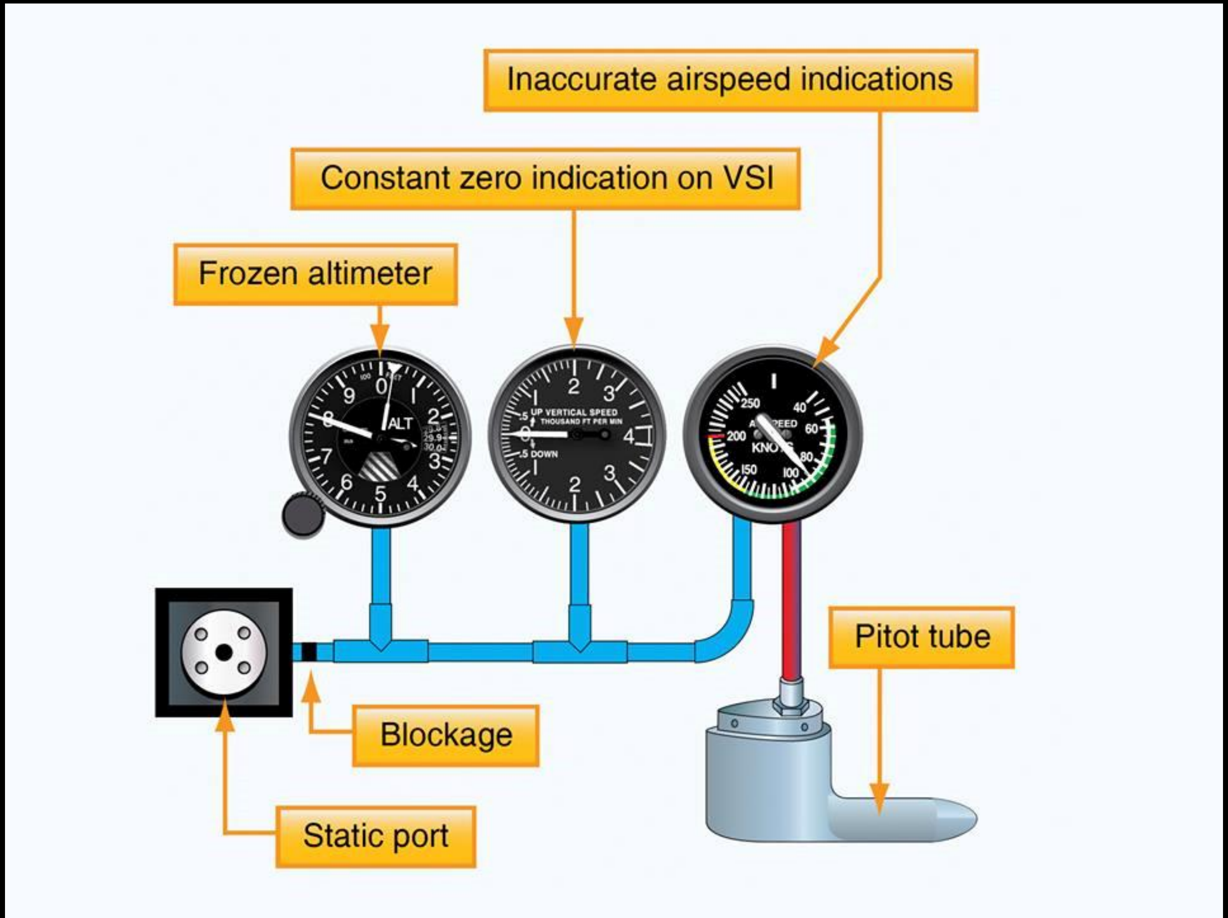


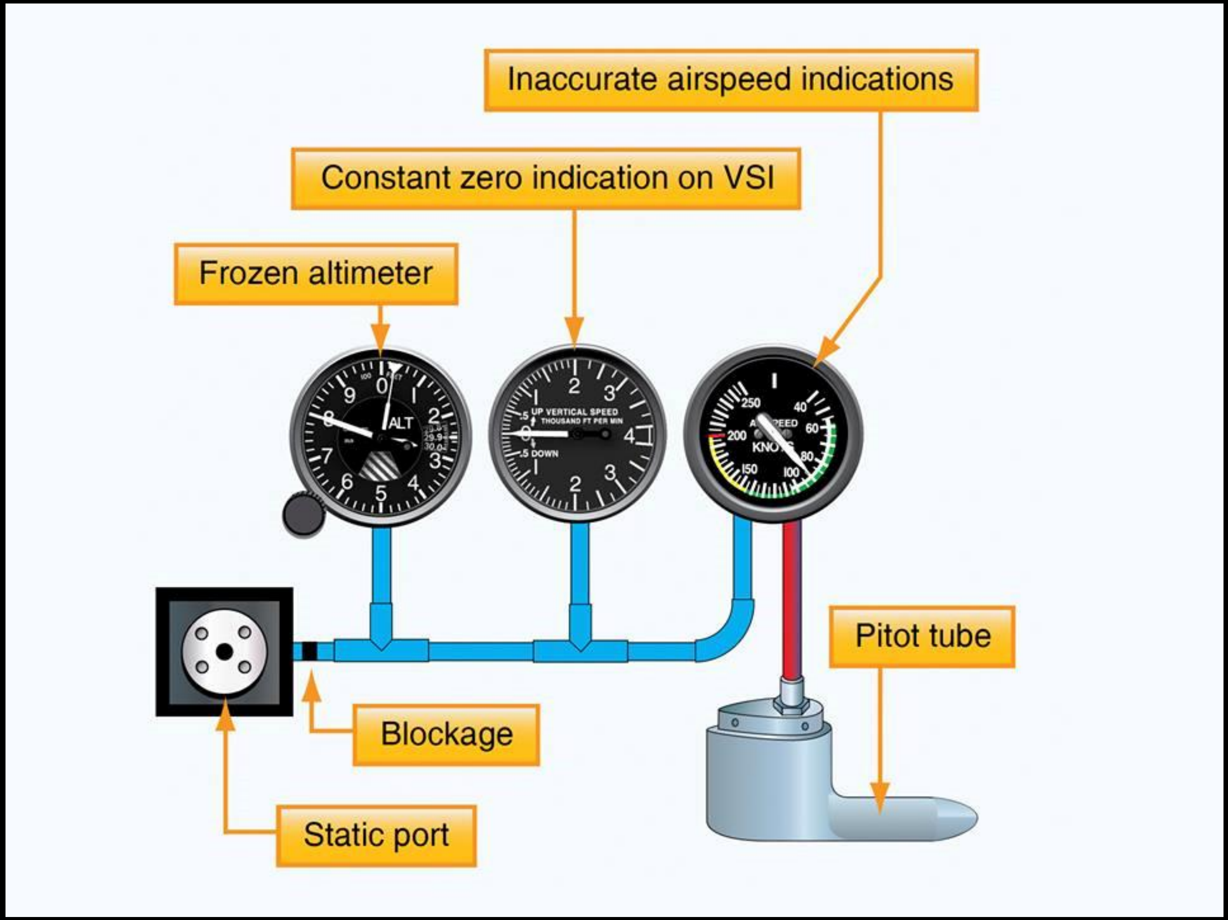
- If the pitot tube and the drain holes become clogged with ice while flying in icing conditions the total pressure in the pitot tube will stay constant
- In a climb, the static pressure reduces, and so the ASI will read higher than it should
- In a descent, the ASI will read less than it should
- ASI behaves like an altimeter - it reads high as the airplane climbs, and reads low as the airplane descends

Blocked Static System



- When aircraft is above the altitude where the static ports became blocked the airspeed indicates lower than the actual airspeed because the trapped static pressure is higher than normal for that altitude
- For operations at lower altitudes, a faster than actual airspeed is displayed due to the relatively low static pressure trapped in the system

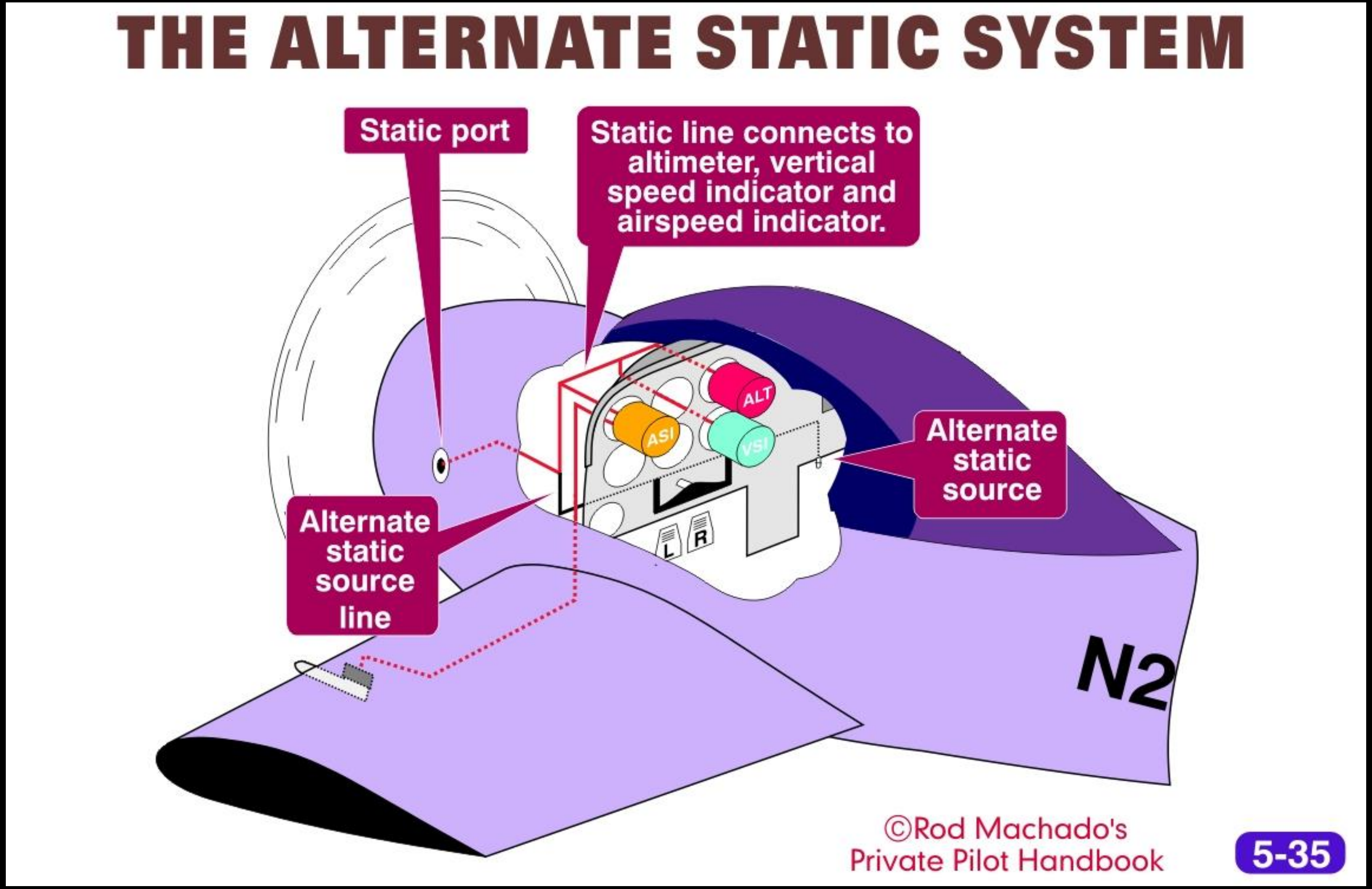
Blocked Static System



- Trapped static pressure causes the altimeter to freeze at the altitude where the blockage occurred
- For the VSI, a blocked static system produces a continuous zero indication

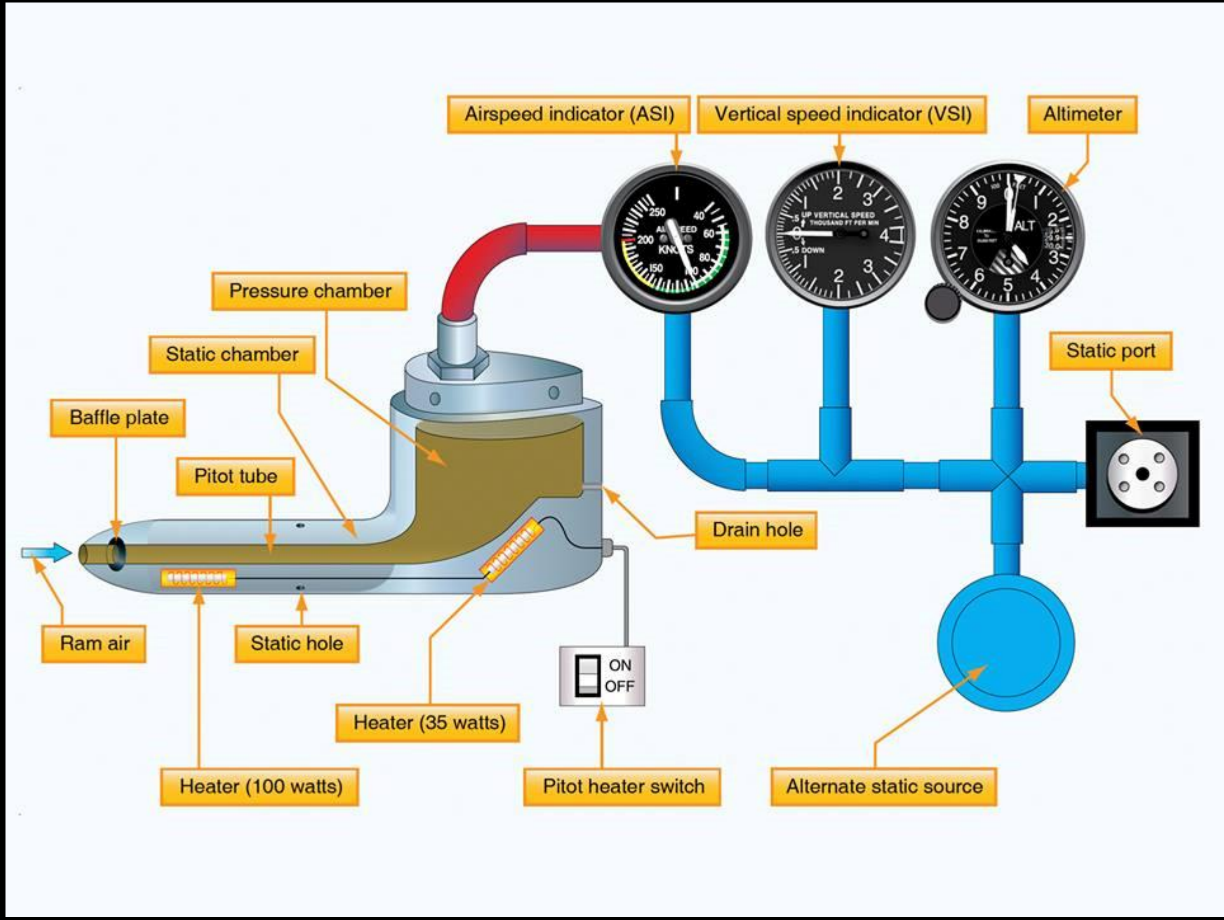
Alternate Static Source

- An alternate static source may be available in the event of a blockage



Alternate Static Source

- Usually measures the pressure in the cockpit, which is less than the external static pressure due to venturi effect
- If both normal and alternate sources of static pressure were blocked breaking the glass of the VSI will introduce the cockpit pressure into the system



Alternate Static Source Activation

- *Altimeter* will read slightly high
- *Airspeed Indicator* will read slightly high
- *VSI* will momentarily show a climb before settling down

Knowledge Check

Which of the following represent the stalling speed in the landing configuration?

A. V_{S1}
B. V_S
C. V_{STALL}
D. V_{SO}

Knowledge Check

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Knowledge Check

What flight instruments are a part of the Pitot-Static system?

A. Airspeed Indicator, Altimeter, and Vertical speed indicator
B. Altimeter, Vertical speed indicator, and attitude indicator
C. Heading Indicator, Turn coordinator, and Altimeter
D. Vertical speed indicator and Airspeed Indicator

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Knowledge Check

Which of the following is the definition of True Airspeed?

A. Airspeed that is shown on the airspeed indicator, uncorrected for instrument or system errors
B. Calibrated airspeed corrected for temperature and pressure altitude
C. Indicated airspeed corrected for position or installation error
D. None of the above

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~~D. None of the above~~

Knowledge Check

Which airspeed is not displayed on an airspeed indicator?

A. V_{NE}
B. V_{NO}
C. V_A
D. V_S

Knowledge Check

Which airspeed is not displayed on an airspeed indicator?

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~~B. V_{NO}~~
C. V_A
~~D. V_S~~