

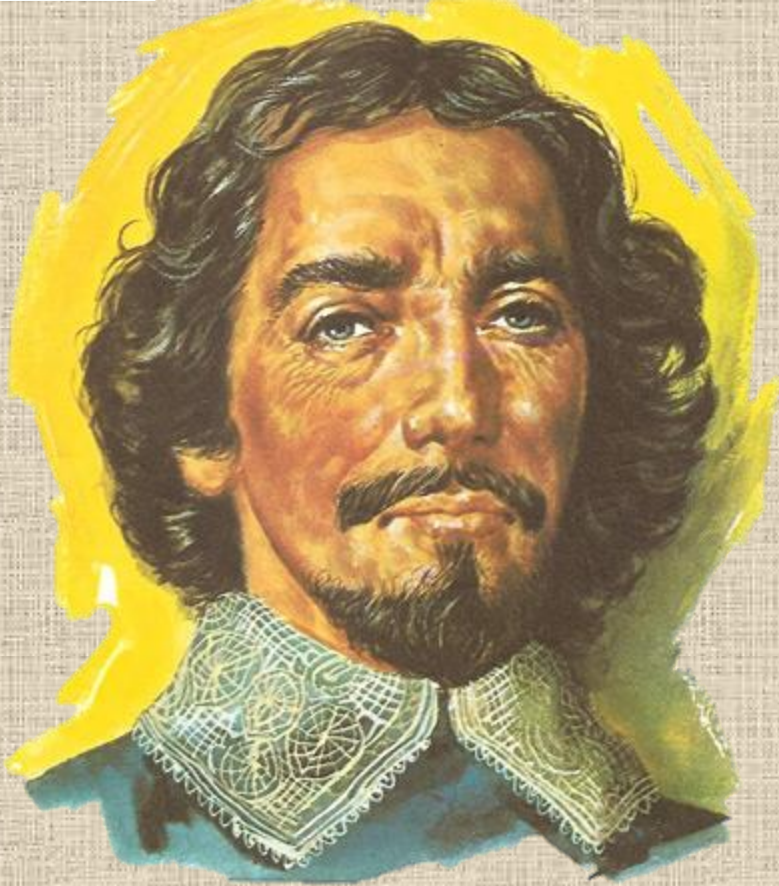
AE-705: Introduction to Flight Pressure & Airspeed Measurement



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Outline

- ❑ Pressure Measurement
- ❑ Airspeed Measurement
- ❑ Types of Airspeeds

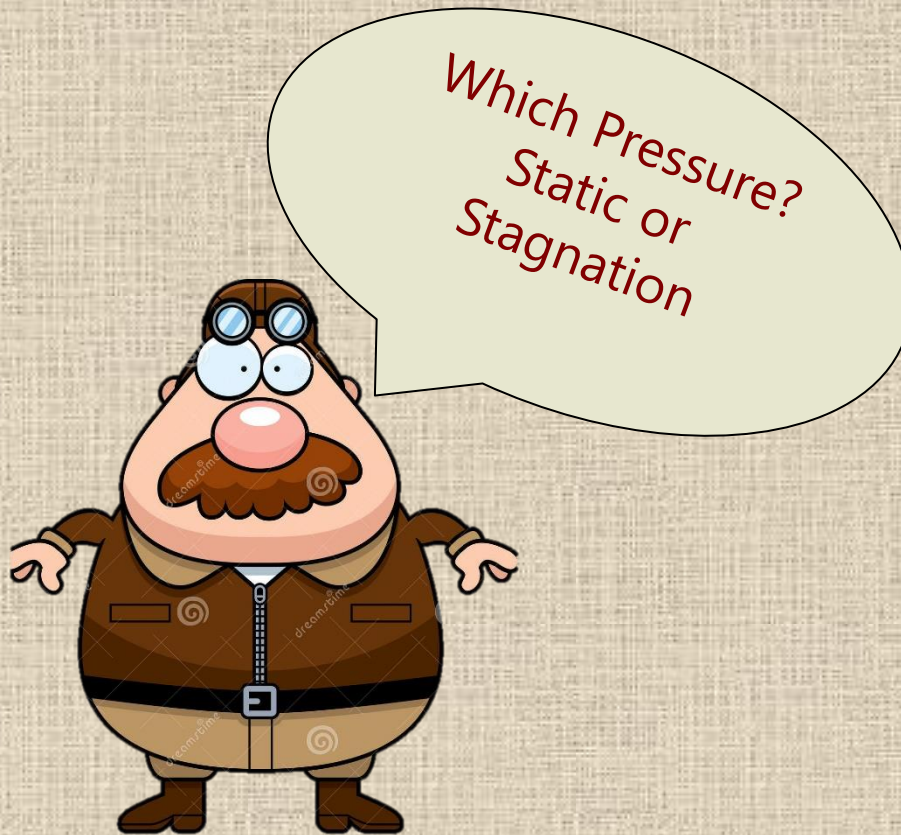


Source: http://www.daviddarling.info/images2/von_Guericke.jpg

PRESSURE MEASUREMENT

PRESSURE MEASUREMENT

Mechanism that can change sense in pressure



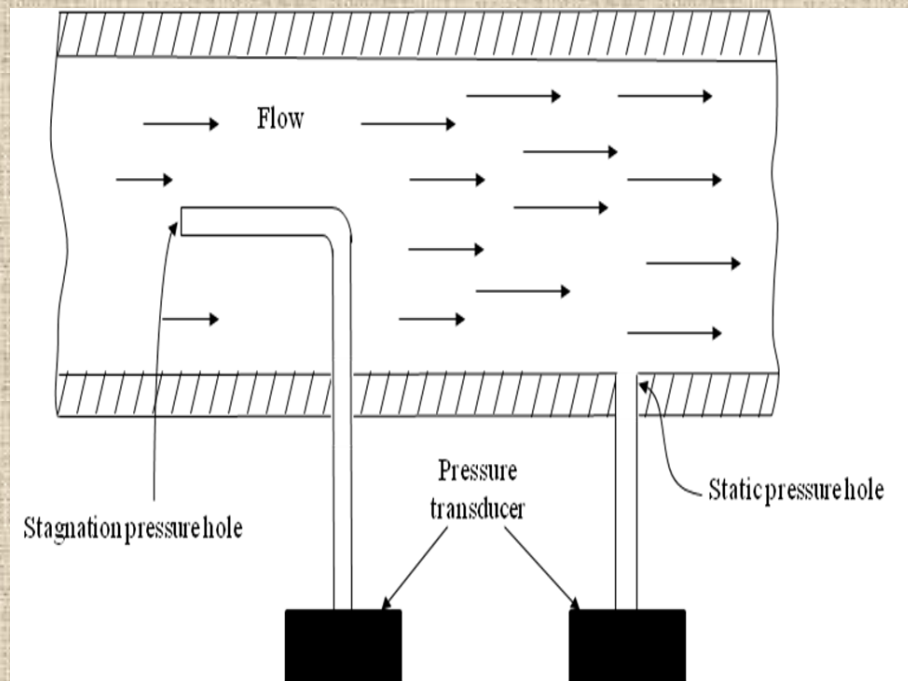
Source: <https://thumbs.dreamstime.com/z/cartoon-pilot-mustache-illustration-47714733.jpg>



Source: <https://s-media-cache-ak0.pinning.com/736x/2f/b2/d0/2fb2d079d23f32df9574b6c02ecc46ab.jpg>

STATIC PRESSURE

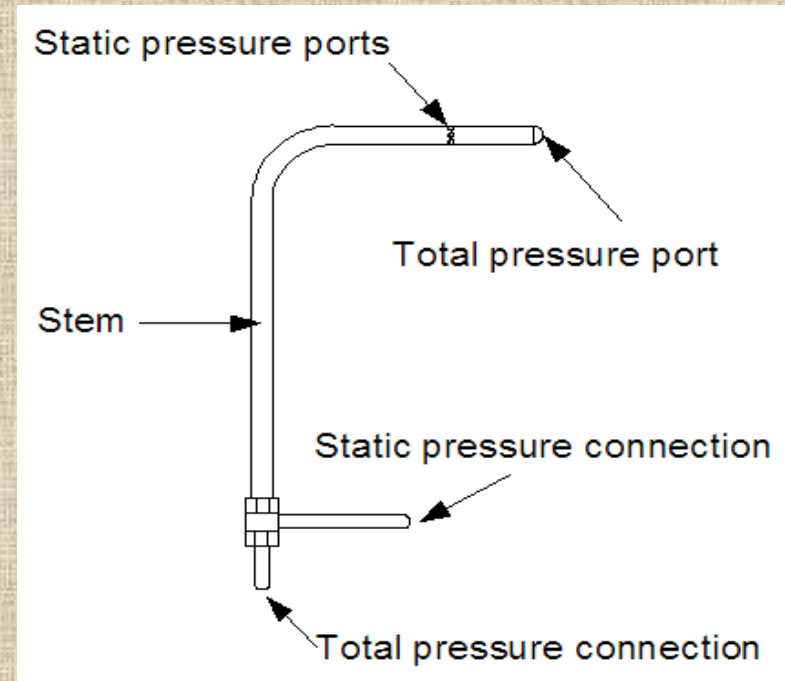
Measurement made such that V_{flow} isn't disturbed



Source: <http://nptel.ac.in/courses/101103004/module7/lec6/1.html>

STAGNATION PRESSURE

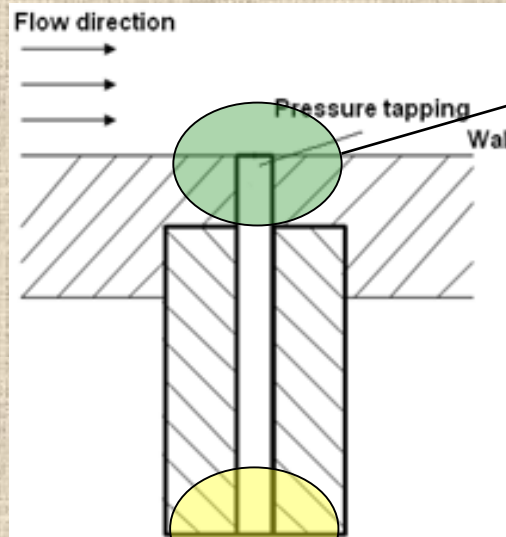
Measurements made when $V_{flow} \rightarrow 0$ isentropically



Source: <http://www.flowkinetics.com/images/generic-pitot-static-pitot-configuration.png>

STATIC PRESSURE MEASUREMENT

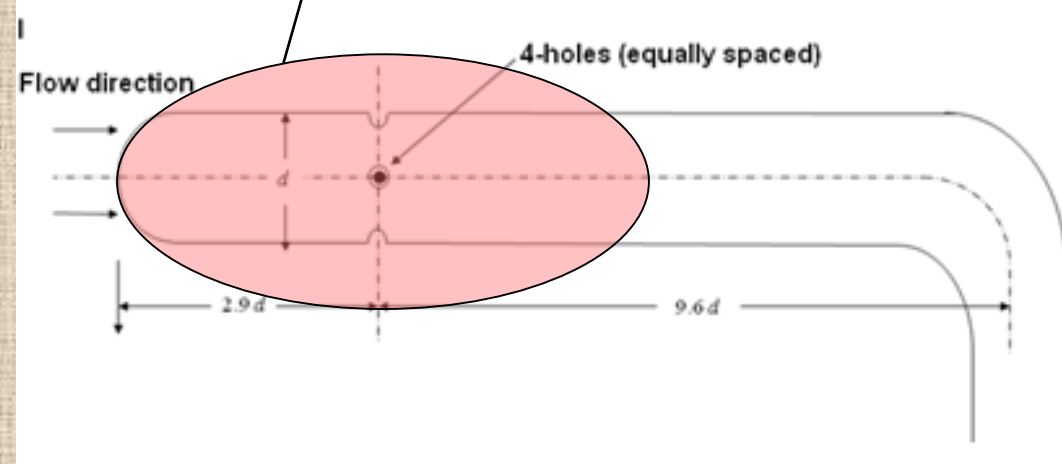
PRESSURE TAPPING



small hole drilled normal to the surface

Connection to the pressure measurement instrument

P_{static} probe inserted without disturbing flow streamlines



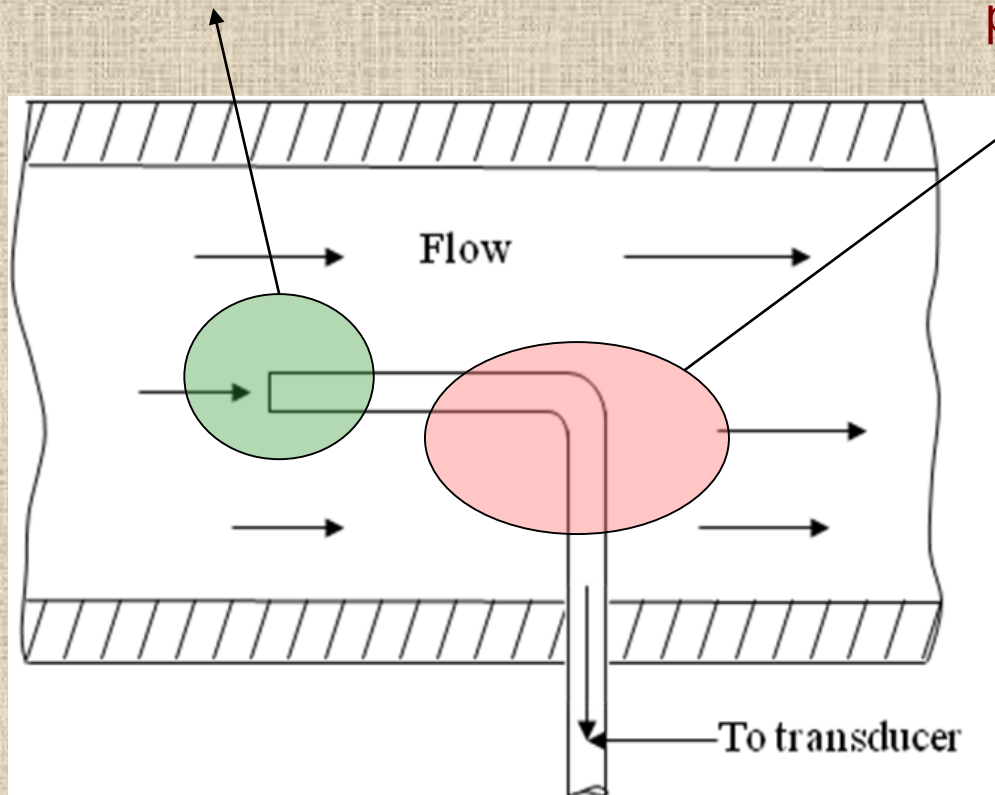
Source: <http://nptel.ac.in/courses/101103004/module7/lec6/1.html>

STAGNATION PRESSURE MEASUREMENT

Pitot tube used for measurement of $P_{stagnation}$

Fluid decelerated
isentropically to rest

Stagnation probe placed
parallel to the flow



Source: <http://nptel.ac.in/courses/101103004/module7/lec6/1.html>



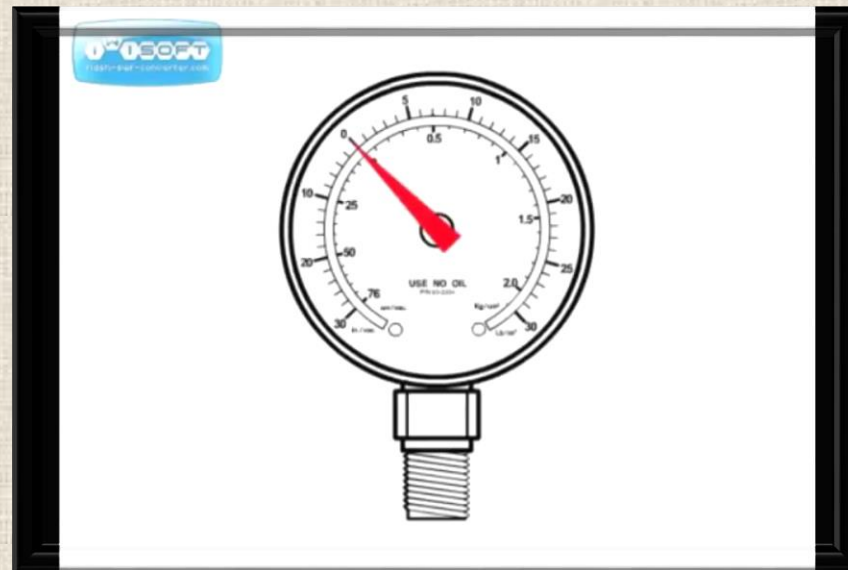
Source: <https://azcamsmedia.azureedge.net/media/themes/fab-four/article-content-images/life-insurance/movember-pilot-main.jpg?la=en-GB>

The Bourdon Tube



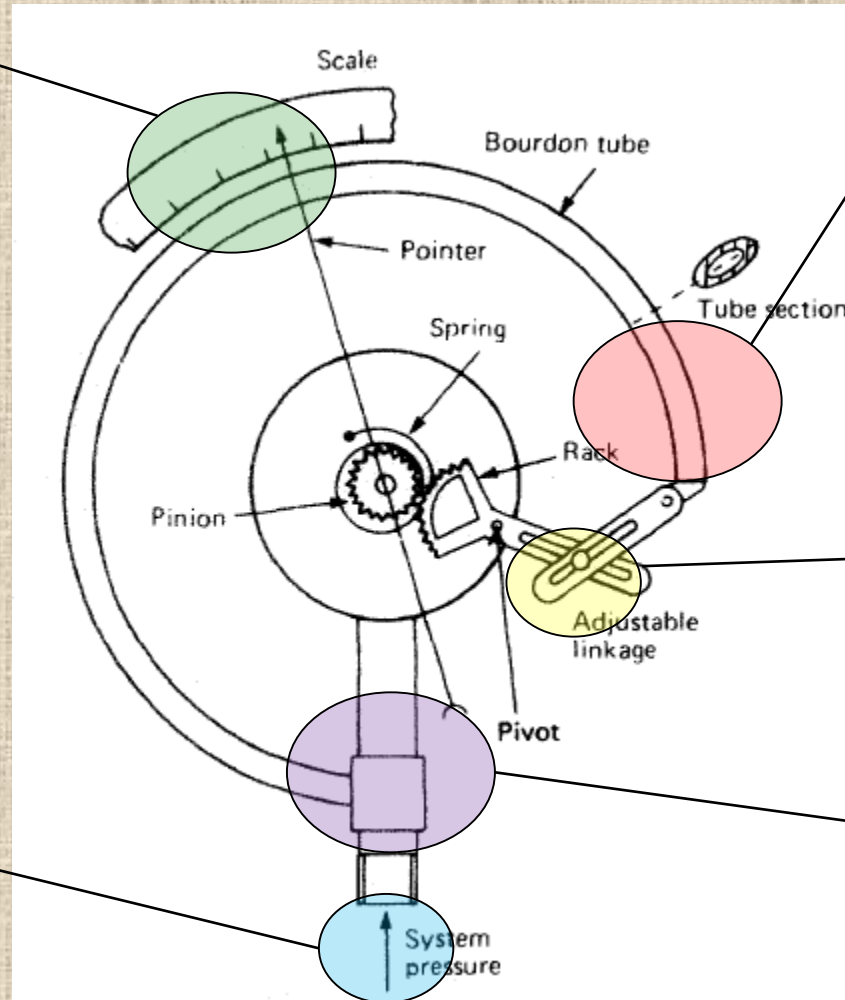
Source: <https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32df9574b6c02eec46ab.jpg>

BUT HOW DOES THE PILOT SEE THE PRESSURE??



BOURDON TUBE

Pointer movement
along scale
observed by pilot



- Closed end
- Free to move
- $P_{fluid} \uparrow$ tube straightens
- $P_{fluid} \downarrow$ tube recoils

Pointer attached
via adjustable
linkages

Fluid entry

- Open end
- Fixed in place

Source: <http://www.machineryspaces.com/Bourdon-tube-pressure-gauge.PNG>



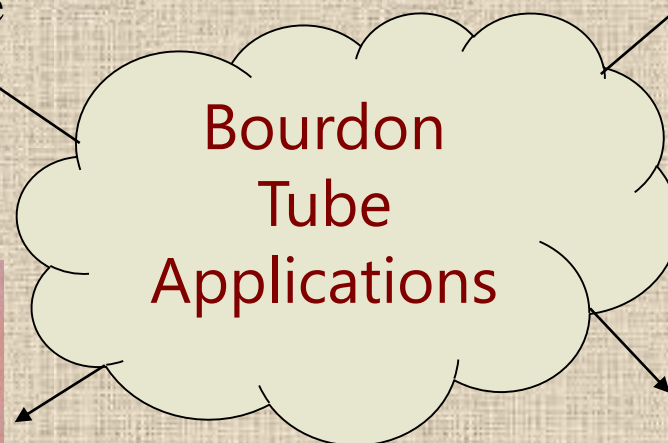
Source: <https://www.aviationengines.com.au/wp-content/uploads/OilPressure-300x300.jpg>

engine oil pressure gauge



Source: http://www.umastruments.com/images/2_25_Electronics/225HydraulicP.jpg

hydraulic pressure gauge



Source: http://aircraftpartsandsalvage.com/images/50-380105-3_937.JPG

deice boot pressure gauge



Source: <http://i.ebayimg.com/images/g/dG0AAOSwZKBZEgCS/s-l300.jpg>

oxygen tank pressure gauge

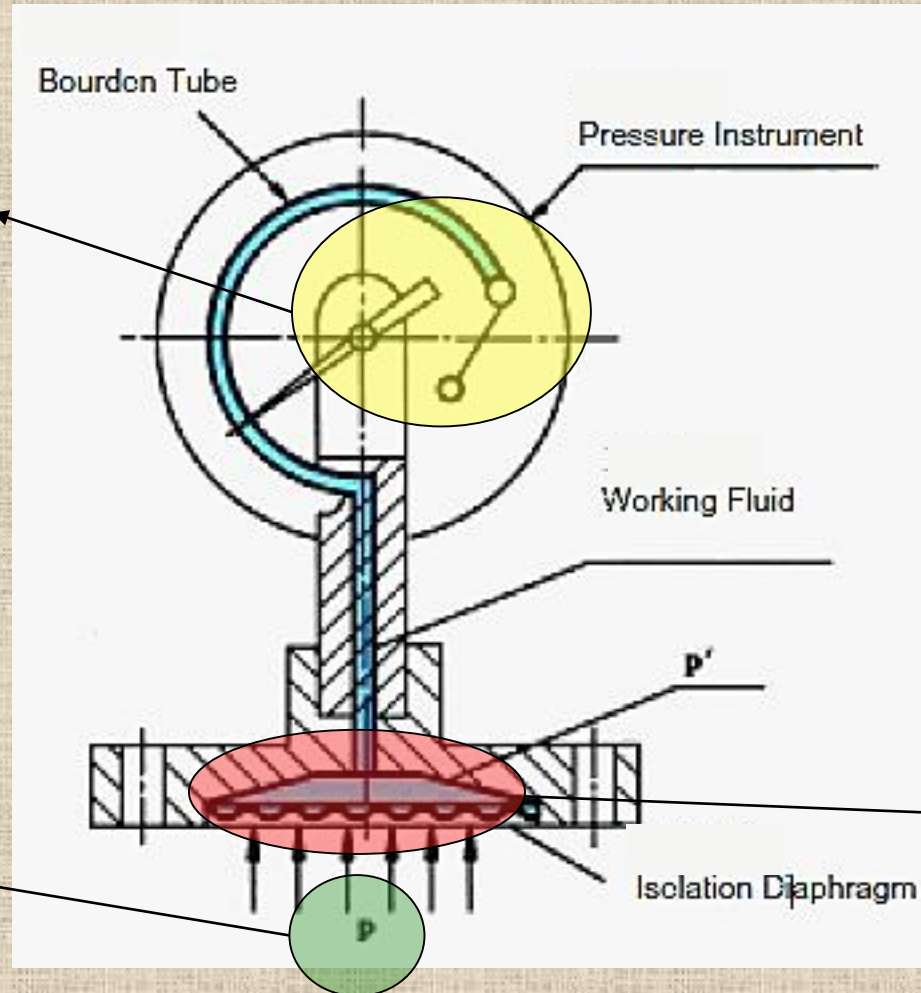
Source: https://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/amt_airframe_handbook/media/ama_Ch10.pdf

DIAPHRAGM

Diaphragms and Bellows can also be used for pressure measurement



Source: <https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32d9574b6c02ec46ab.jpg>



Movement of diaphragm linked to the pointer

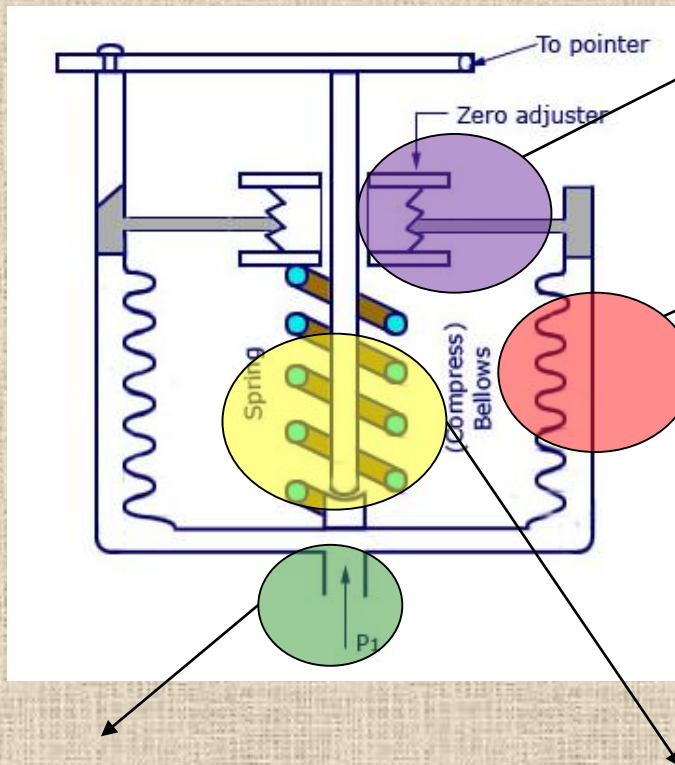
Pressure introduced through opening

- Hollow thin walled corrugated disk
- pressure $\uparrow \leftrightarrow$ diaphragm expands

Source: http://3.bp.blogspot.com/_SEJ_mMmfxvU/TKhqC2QPzuI/AAAAAAAAAH8/vvmwO_zCOq0/s400/elastic+diaphragm+gauges.gif

BELLOWS

a collection of diaphragm chambers connected together



Pointer linked to a scale

movement of the side walls
correlates with change in pressure

Lets see how
Bellows
work

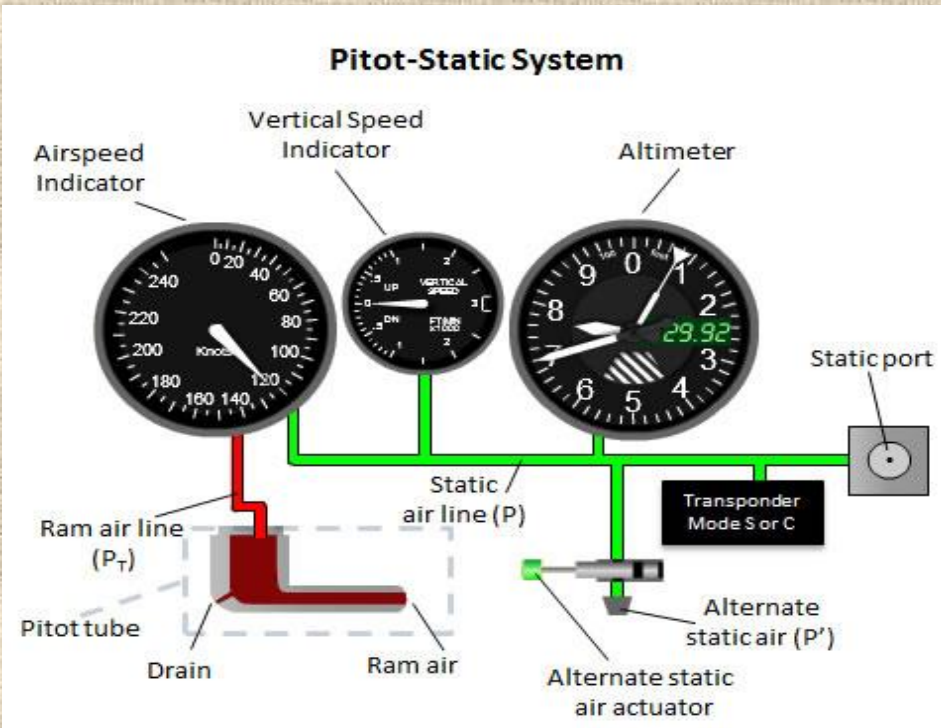


Source: <http://www.instrumentationtoday.com/bellows/2011/09/>

Source: <https://i-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32d9574b6c02ecc46ab.jpg>

PITOT STATIC SYSTEM

system of pressure-sensitive instruments used to determine an aircraft's airspeed



Source: http://www.luizmonteiro.com/images/ImagesArticles/PitotBlockages/Art_Pitot_Blockage_b11.gif

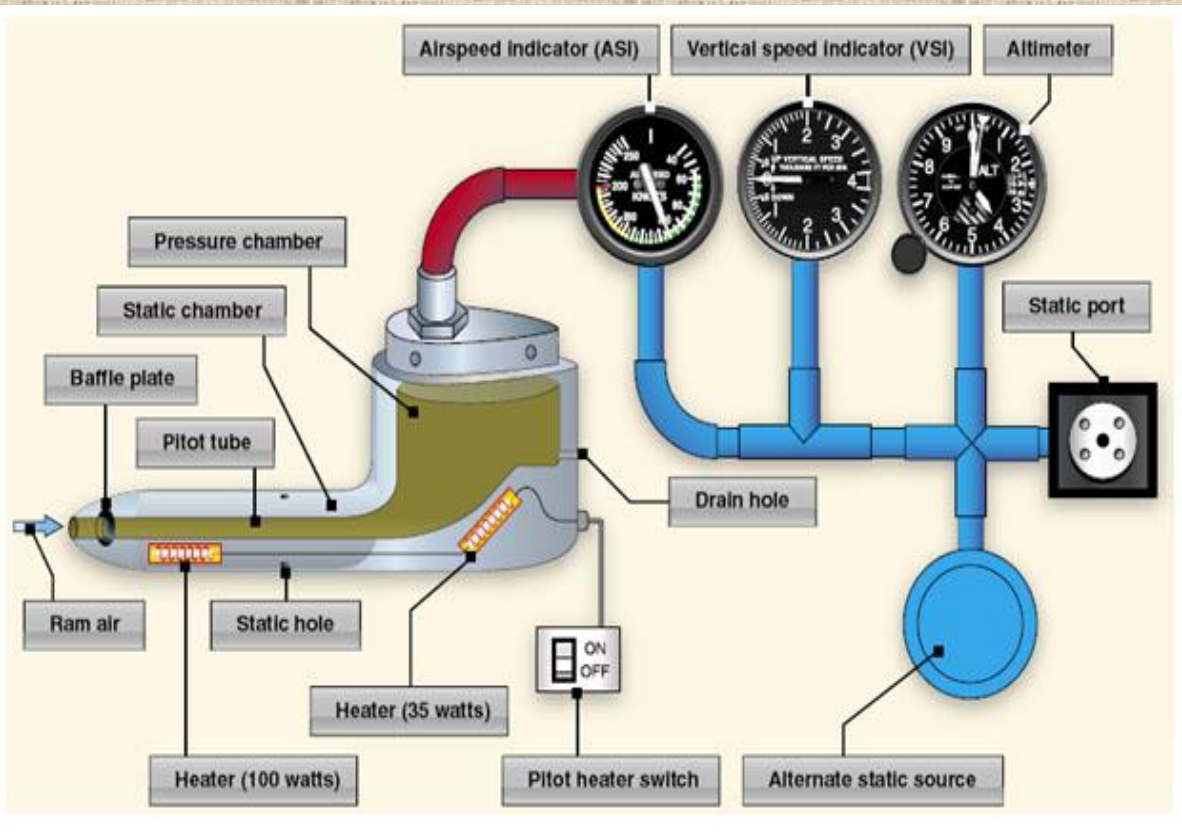
Lets see how a
Pitot Static System
works



Source: <https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32d9574b6c02ee46ab.jpg>

- measures ram air pressure and compares it to static pressure
- Measures altitude and tells rate of climbing or descending in feet per minute

PITOT STATIC SYSTEM



COMPONENTS

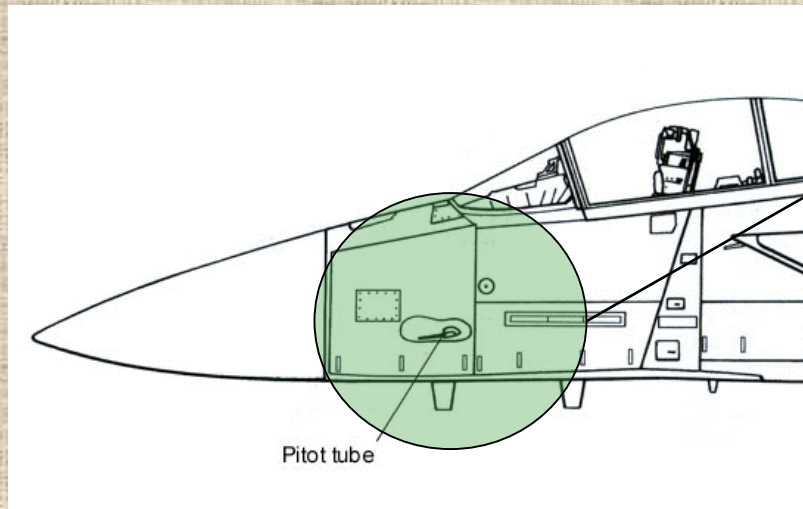
- Pitot Tube
- Static Port
- Instruments
- Alternate Static Port

Source: <http://www.myairlineflight.com/images/pitot-staticsyslg.jpg>

Source: <https://www.thebalance.com/g00/aircraft-systems-pitot-static-system-2826057110c.referrer=>

PITOT STATIC TUBES

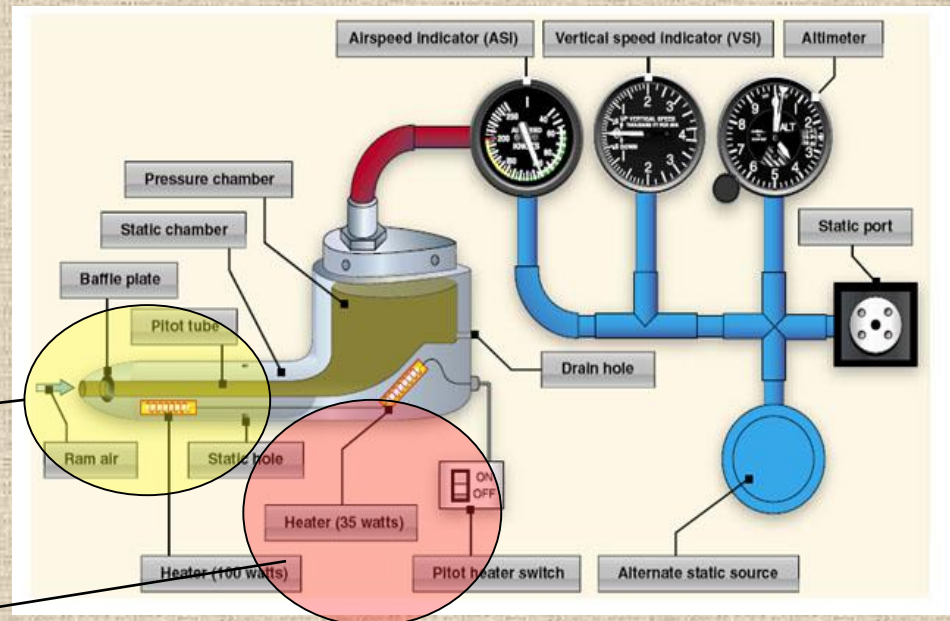
instrument used to measure fluid flow velocity



Source: http://www.f-15e.info/technology/sensors/pitot/graphics/pitot_placement.gif

L-shaped device located on the exterior of the aircraft

ram air pressure enters the tube

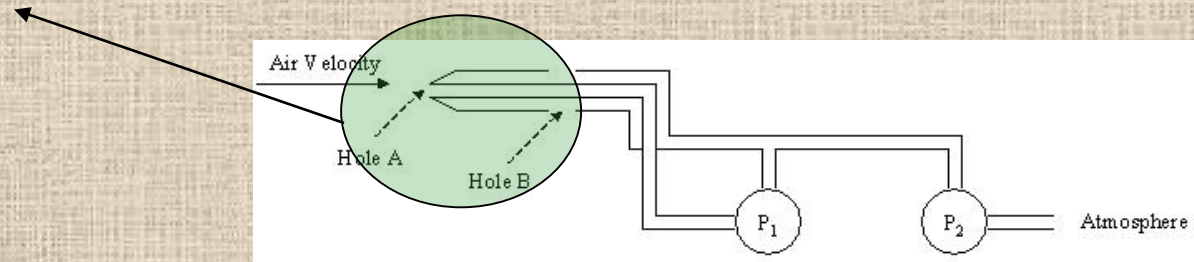


Source: <http://www.myairlineflight.com/images/pitot-staticsyslg.jpg>

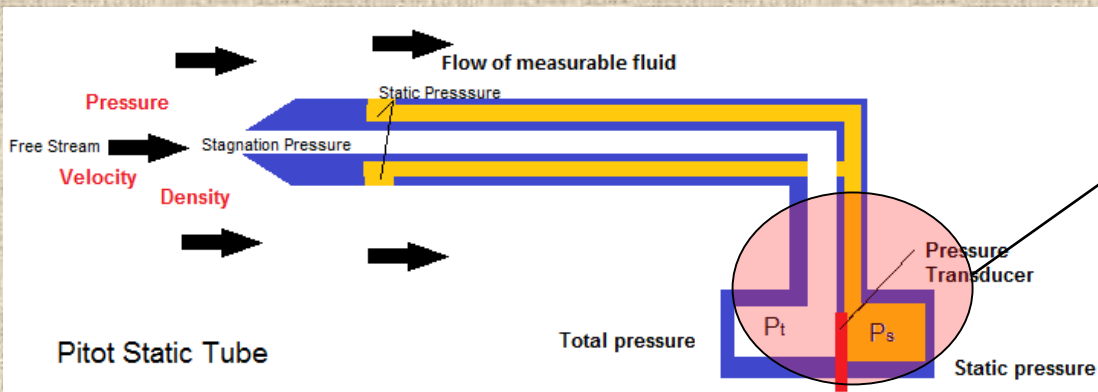
prevents ice from blocking the air inlet
or drain hole

PITOT STATIC TUBES

Several small holes drilled around the outside of the tube



Source: <http://d2v1cm6117u1fs.cloudfront.net/media%2F49d%2F49d20187-5804-4953-b1a3-bcef775149c%2FphpL9ng4B.png>



Source: http://forums.ni.com/legacyfs/online/15039_Pitot%20Tube.png

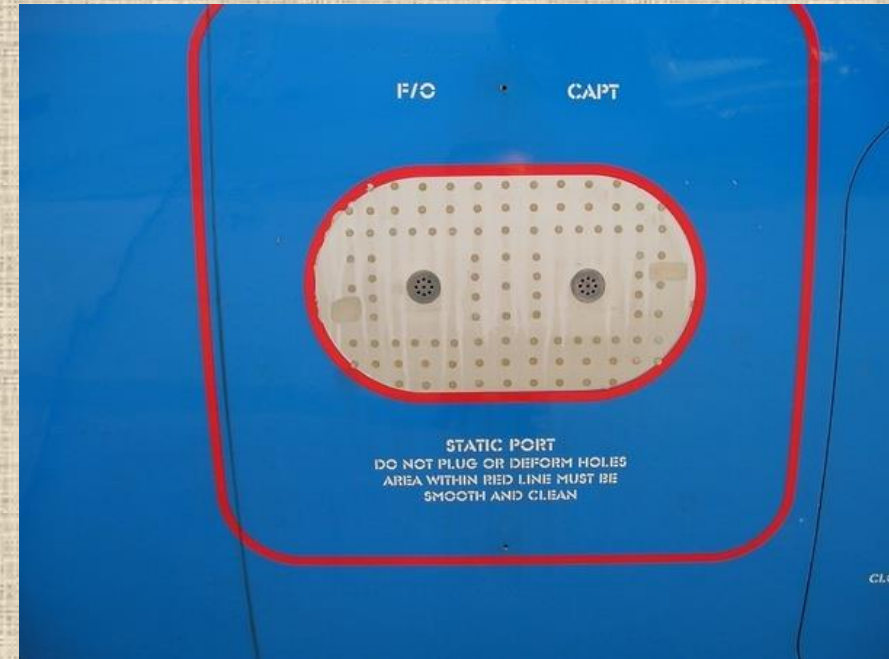
holes connected to one side of the pressure transducer

The pressure transducer measures dynamic pressure q

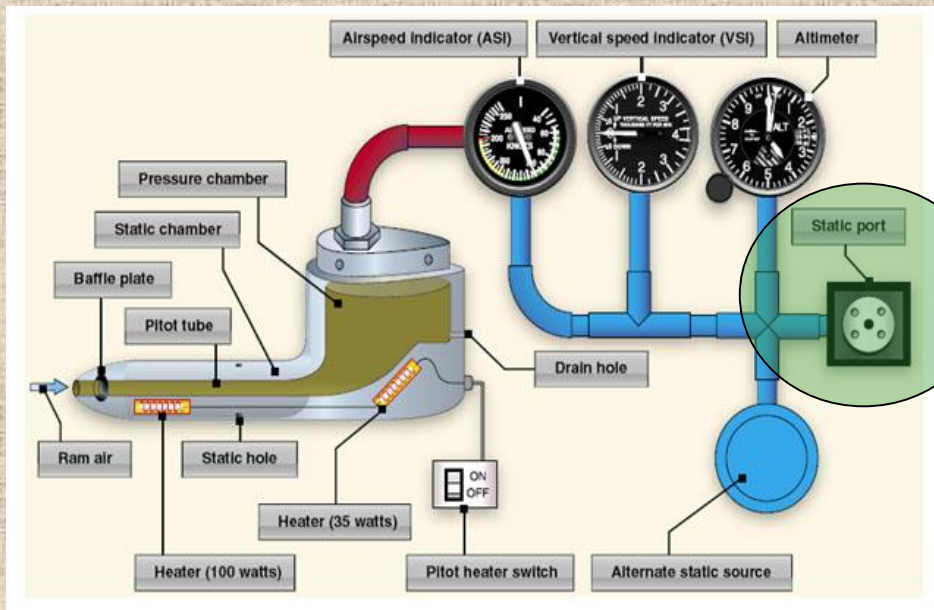
Source: <http://www.flowkinetics.com/images/generic-pitot-static-pitot-configuration.png>

STATIC PORT

small air inlet located on the side of the aircraft



Source: <https://qph.ec.quoracdn.net/main-qimg-c884d8a697540d1b661f37581582c2f3-c>



Source: <http://www.myairlineflight.com/images/pitot-staticsyslg.jpg>

measures static air pressure

ALTERNATE STATIC PORT

Used when the main static port experiences a blockage

causes slightly inaccurate readings on the instruments



Source: <http://www.myairlineflight.com/images/pitot-staticsyslg.jpg>

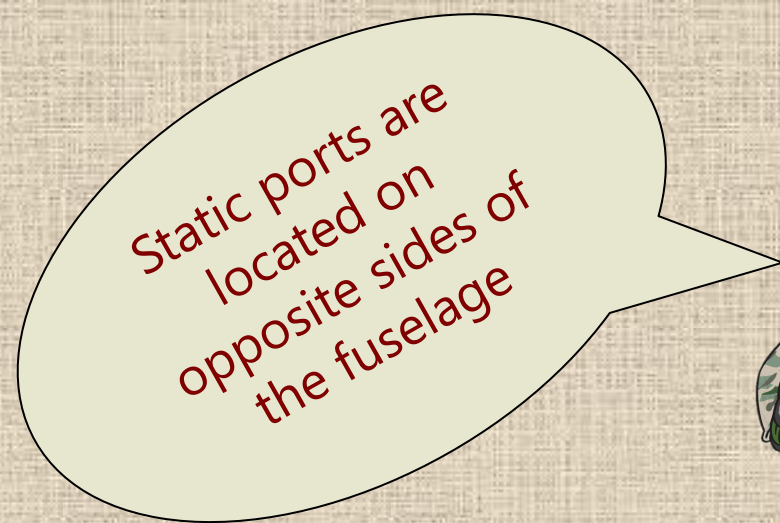
Static ports are positioned perpendicular to the airflow to avoid errors due to variations in wind speed



Source: <https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32df9574b6c02eec46ab.jpg>



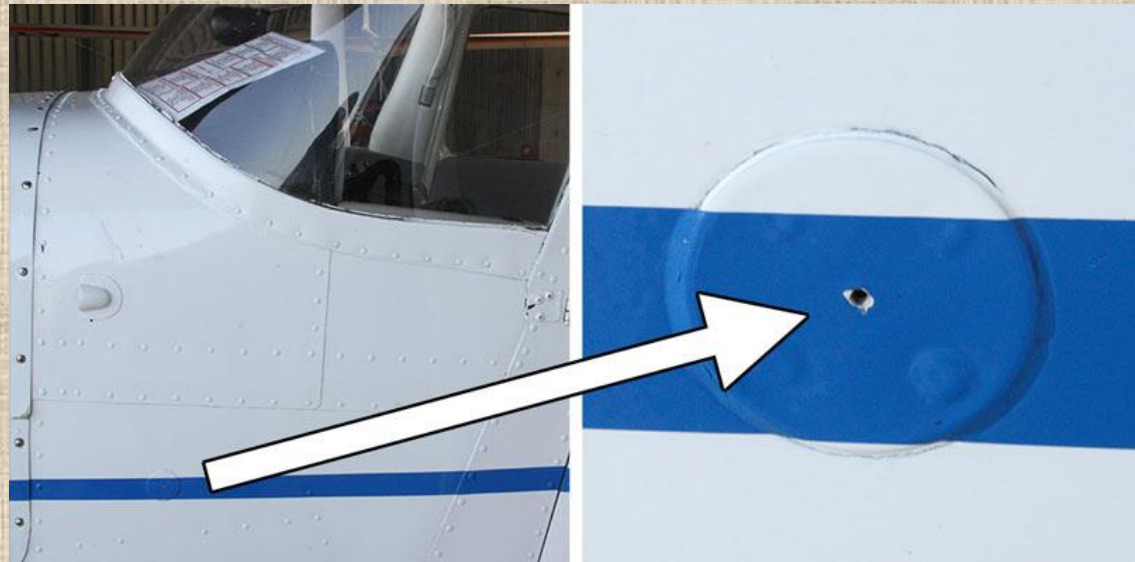
Source: http://www.airteamimages.com/pics/168/168077_800.jpg



Source: <https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32df9574b6c02ec46ab.jpg>

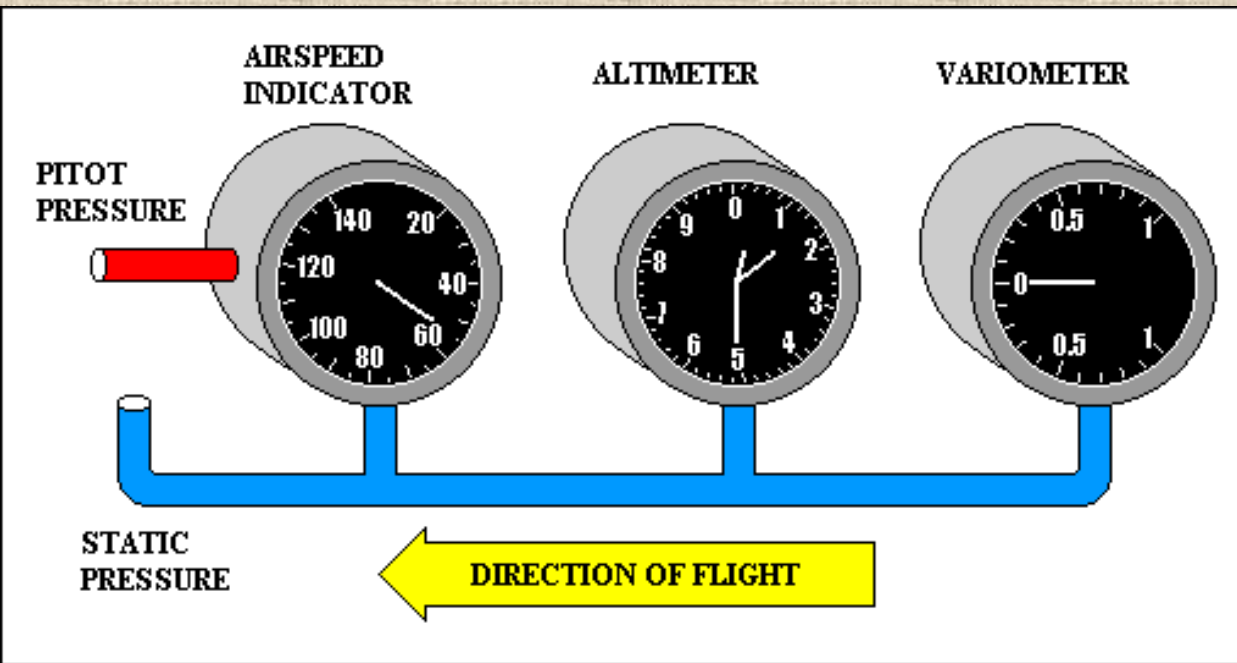


Source: <https://thumbs.dreamstime.com/z/cartoon-pilot-mustache-illustration-47714733.jpg>



Source: <http://www.boldmethod.com/images/blog/quizzes/2014/11/can-you-answer-these-7-systems-questions/stem-3.jpg>

INSTRUMENTS



Source: http://www.5c1.net/Systems_files/pitot.gif

Pitot-static system involves three instruments

- Airspeed indicator
- Altimeter
- Variometer

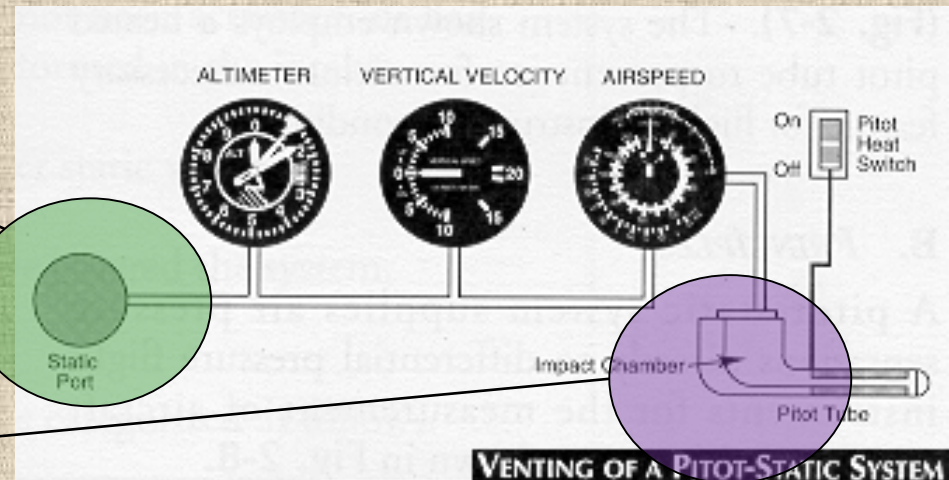
AIRSPEED INDICATOR



a differential pressure system that measures both dynamic air pressure and static pressure

P_{static} → Static port

P_{dynamic} → Pitot tube

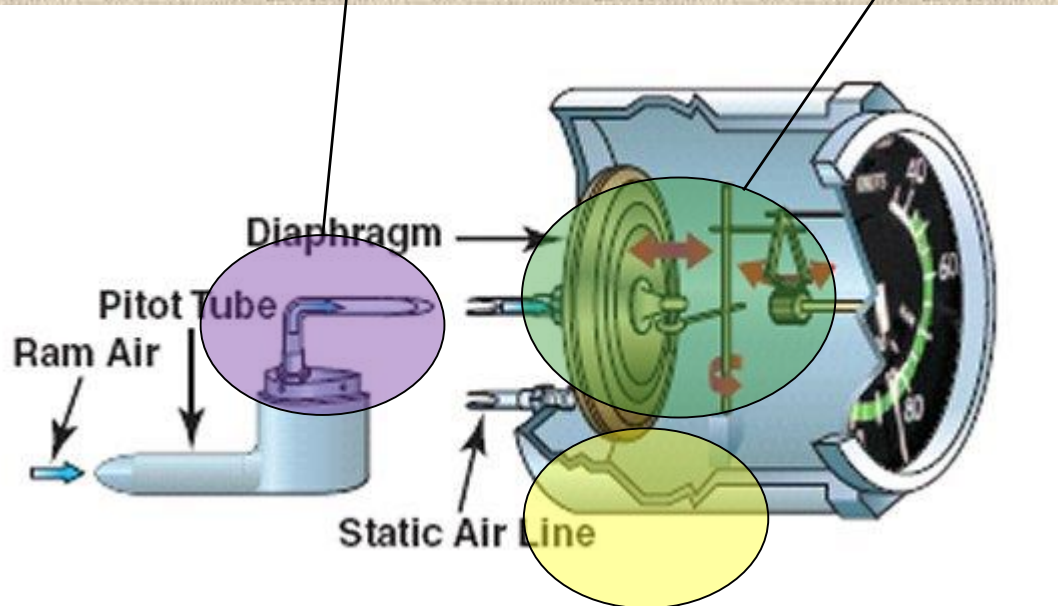


Source: <http://www.allstar.fiu.edu/aero/images/2-7.gif>

AIRSPEED INDICATOR

diaphragm receives both P_{static} and P_{dynamic} from the pitot tube

sealed case with an aneroid diaphragm



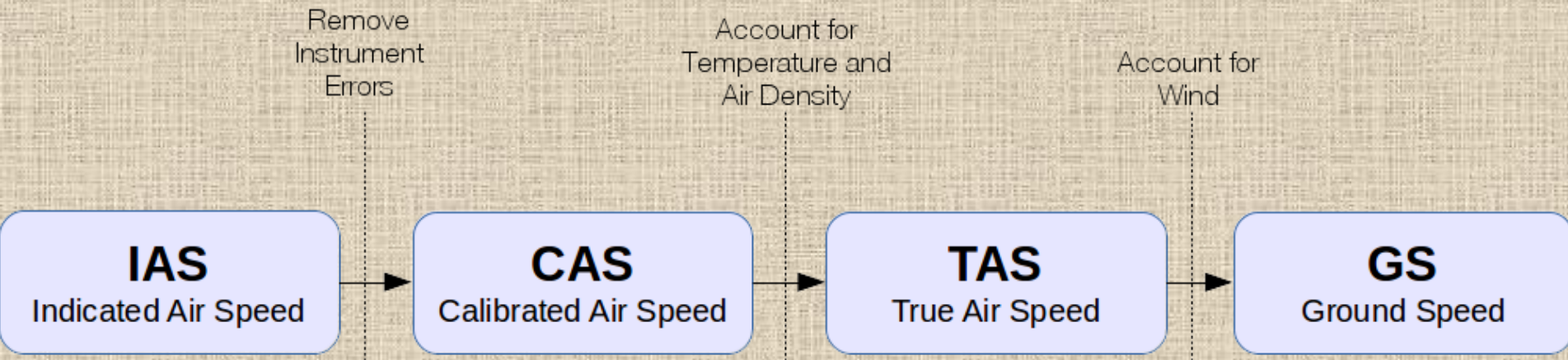
Lets see
how ASI
works



P_{static} measured from inside the casing but outside the diaphragm

Source: <https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32df9574b6c02ec46ab.jpg>

AIRSPEED CORRECTIONS



Source: <https://i.stack.imgur.com/matiD.png>

Indicated Airspeed

Calibrated Airspeed

Equivalent Airspeed

True Airspeed

Groundspeed



Source: <https://medicacheckup.com/57562/1732110/38d07972313212087574e032ed646d.jpg>

INDICATED AIRSPEED (IAS)



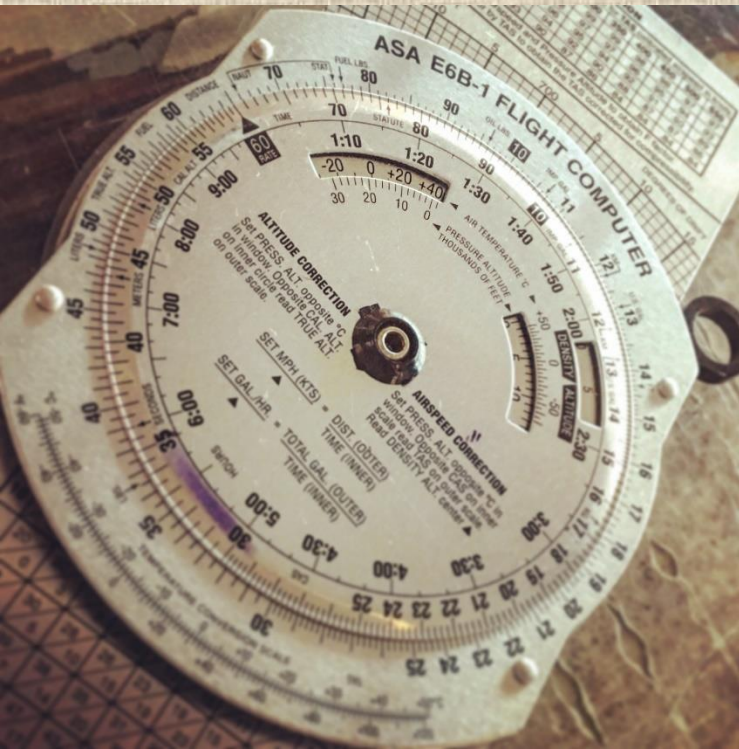
airspeed read directly from the indicator

ASI errors can creep in due to a variety of reasons

- obstructions or leaks in the pitot static plumbing
- improper placement of the pitot tube or static source
- sloppy ASI gauge

Source: https://upload.wikimedia.org/wikipedia/commons/8/8c/FAA-8083-3A_Fig_12-1.PNG

CALIBRATED AIRSPEED (CAS)

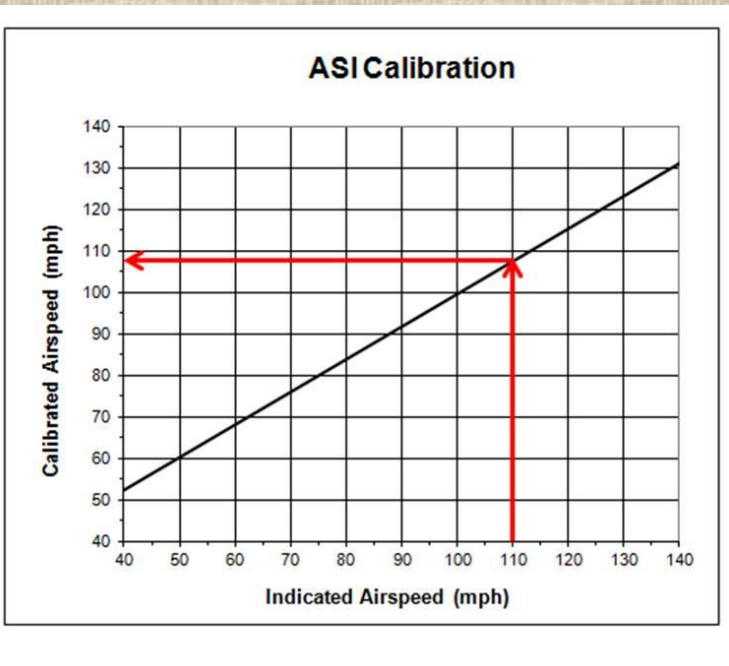


indicated airspeed corrected for instrument errors and position error

describes the $P_{dynamic}$ acting on aircraft surfaces regardless of existing of temperature, pressure, altitude or wind

The calibrated airspeed can be found in the aircraft's operating handbook

CALIBRATED AIRSPEED (CAS)



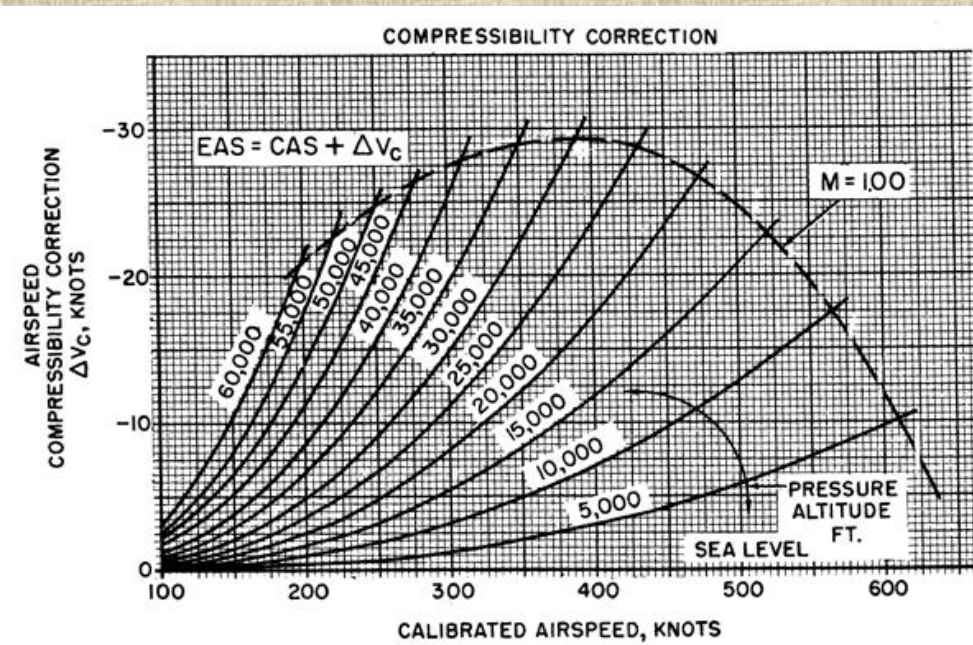
Source: <http://www.sonex604.com/images/asi/CAS.jpg>

ASI calibration is done using a handheld GPS

The GPS calibration involves flying at a constant indicated airspeed at three different headings

Data is plugged into a spreadsheet, and graph of indicated airspeed vs. calibrated airspeed is plotted

EQUIVALENT AIRSPEED (EAS)



calibrated airspeed adjusted for compressibility errors

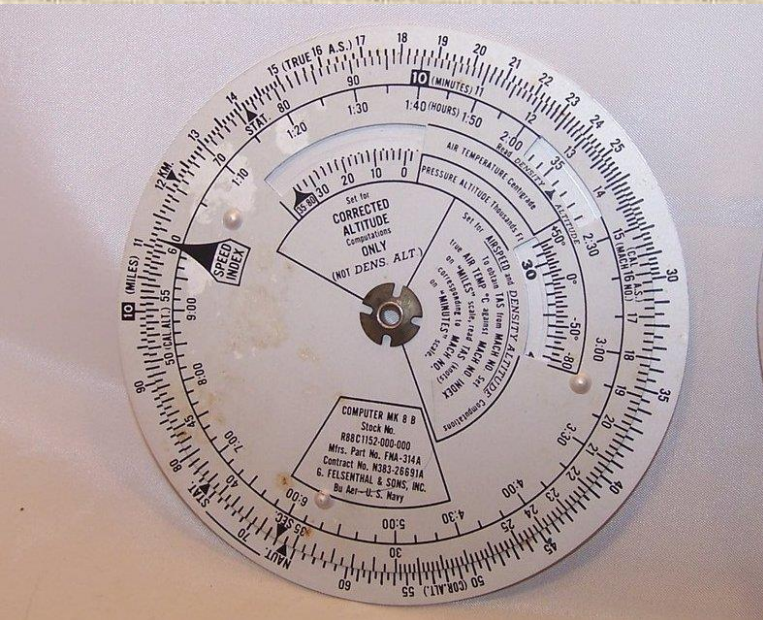
useful for predicting aircraft handling, aerodynamic loads and stalling

EAS is a function of dynamic pressure(q)

$$EAS = \sqrt{\frac{2q}{\rho_0}}$$

standard sea level density

TRUE AIRSPEED (TAS)



Source: http://www.prestoimages.net/imagecapture/images/rd10335/10335_1984681.pjpep

Dalton Computer

CAS adjusted for nonstandard pressure and temperature

TAS cannot be measured directly

For slow speeds it is calculated using a Dalton Computer

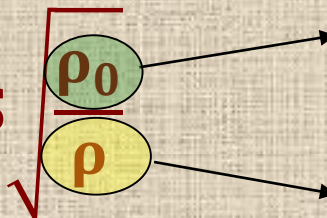
At high speeds the compressibility error rises significantly

TAS is calculated using the Mach speed

TRUE AIRSPEED (TAS)

Low-speed flight

At low speeds and altitudes, IAS and CAS are close to EAS

$$TAS = EAS \sqrt{\frac{\rho_0}{\rho}}$$



The diagram shows the formula $TAS = EAS \sqrt{\frac{\rho_0}{\rho}}$. The term ρ_0 is enclosed in a green oval, and the term ρ is enclosed in a yellow oval. An arrow points from the green oval to the text "Density at ISA". Another arrow points from the yellow oval to the text "Density at which aircraft is flying".

Density at ISA

Density at which aircraft is flying

High-speed flight

TAS can be calculated as a function of Mach number and static air temperature:

$$TAS = a_0 \sqrt{\frac{T_0}{T}}$$


The diagram shows the formula $TAS = a_0 \sqrt{\frac{T_0}{T}}$. The term T_0 is enclosed in a blue oval, and the term T is enclosed in a purple oval. An arrow points from the blue oval to the text "Air Temp at sea level". Another arrow points from the purple oval to the text "Static air temperature".

Air Temp at sea level

Static air temperature

TRUE AIRSPEED (TAS)

TAS as a function of impact pressure (q_c), static pressure (P) and static air temperature (T_0) (valid for subsonic flow):

$$TAS = a_0 \sqrt{\frac{5T}{T_0} \left[\left(\frac{q_c}{P} + 1 \right)^{\frac{2}{7}} - 1 \right]}$$

where

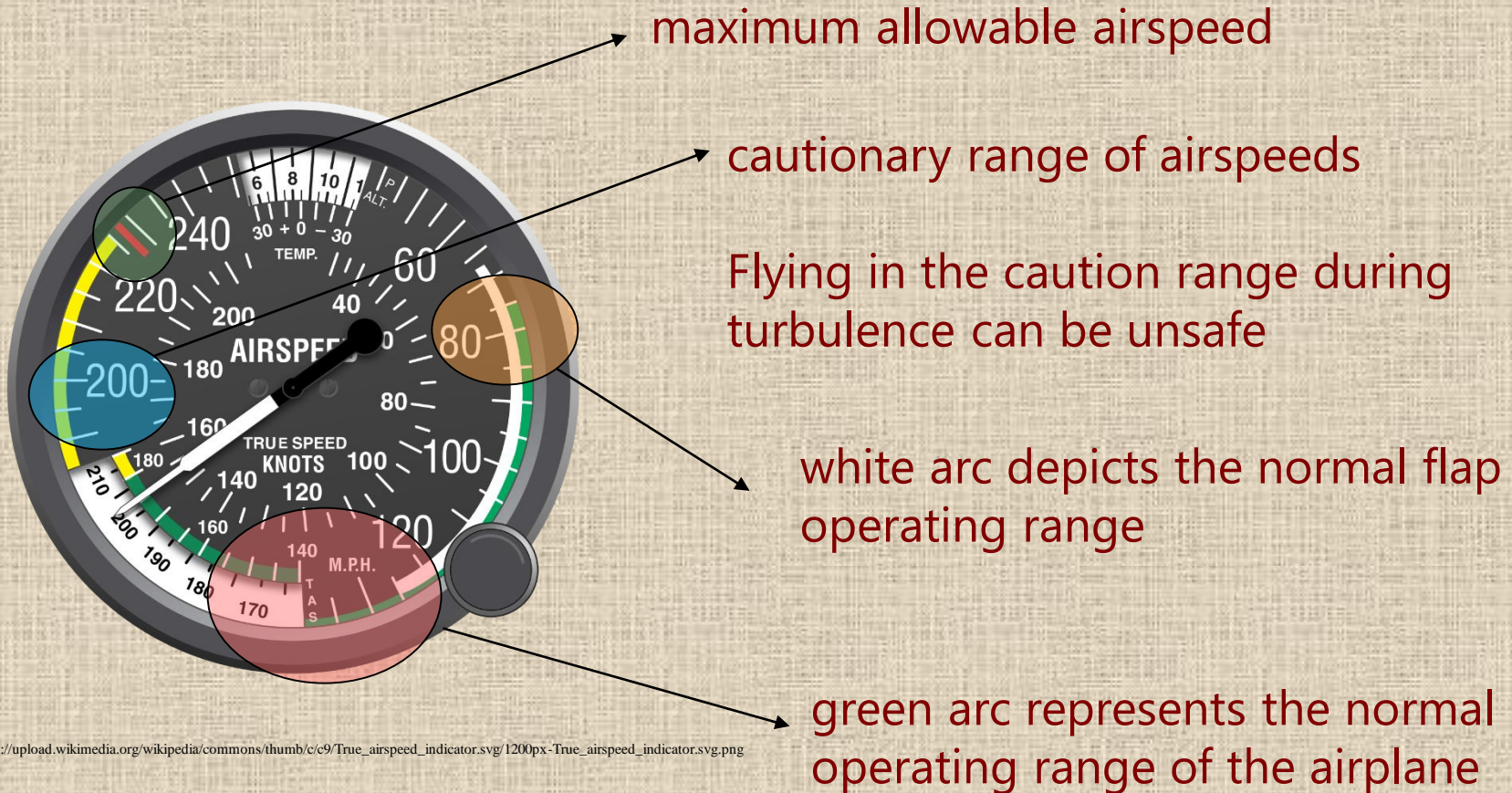
$$T = \frac{T_t}{1 + 0.2M^2}$$

Diagram illustrating the variables in the equation:

- T_t (Total air temperature) is the numerator.
- M (Mach Number) is the variable in the denominator.

AIRSPEED INDICATOR MARKINGS

color-coded airspeed markings on ASI for the pilot's safety



Source: https://upload.wikimedia.org/wikipedia/commons/thumb/c/c9/True_airspeed_indicator.svg/1200px-True_airspeed_indicator.svg.png