AE-705: Introduction to Flight
Pressure & Airspeed Measurement

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Outline

- Pressure Measurement
- Airspeed Measurement
- Types of Airspeeds
PRESSURE MEASUREMENT

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

Mechanism that can change sense in pressure

Which Pressure?
Static or Stagnation

Why not both

Source: https://thumbs.dreamstime.com/z/cartoon-pilot-mustache-illustration-47714733.jpg
Source: https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32d9574b6f02rec46ab.jpg
**STATIC PRESSURE**

Measurement made such that $V_{flow}$ isn’t disturbed

**STAGNATION PRESSURE**

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

Source: http://nptel.ac.in/courses/101103004/module7/lec6/1.html
Source: http://www.flowkinetics.com/images/generic-pitot-static-pitot-configuration.png
STATIC PRESSURE MEASUREMENT

PRESSURE TAPPING

- Small hole drilled normal to the surface
- \( P_{\text{static}} \) probe inserted without disturbing flow streamlines

Connection to the pressure measurement instrument

Source: http://nptel.ac.in/courses/101103004/module7/lec6/1.html
STAGNATION PRESSURE MEASUREMENT

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

Fluid decelerated isentropically to rest

Stagnation probe placed parallel to the flow

Source: http://nptel.ac.in/courses/101103004/module7/lec6/1.html
BUT HOW DOES THE PILOT SEE THE PRESSURE??

Source: https://s-media-cache-ak0.pinimg.com/736x/21/b2/d0/2fb2d079d23f32df9574b6c02eec46ab.jpg

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

- Fluid entry
- Open end
- Fixed in place

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

- Pointer attached via adjustable linkages

- Pointer movement along scale observed by pilot

Source: http://www.machineriespaces.com/Bourdon-tube-pressure-gauge.PNG
Bourdon Tube Applications

- Engine oil pressure gauge
- Hydraulic pressure gauge
- Deice boot pressure gauge
- Oxygen tank pressure gauge

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


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

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

Source: http://aircraftpartsandsalvage.com/images/50_380105-3_937.JPG
DIAPHRAGM

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

Movement of diaphragm linked to the pointer

Pressure introduced through opening

Diaphragms and Bellows can also be used for pressure measurement

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

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

a collection of diaphragm chambers connected together

Pressure entry

Spring in a compressed shape

Pointer linked to a scale

movement of the side walls correlates with change in pressure

Let's see how Bellows work

PITOT STATIC SYSTEM

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

- 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

**PITOT STATIC TUBES**

Instrument used to measure fluid flow velocity

L-shaped device located on the exterior of the aircraft

Ram air pressure enters the tube

Prevents ice from blocking the air inlet or drain hole
PITOT STATIC TUBES

Several small holes drilled around the outside of the tube

holes connected to one side of the pressure transducer

The pressure transducer measures dynamic pressure $q$
STATIC PORT

small air inlet located on the side of the aircraft

measures static air pressure

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

Source: http://www.myairlineflight.com/images/pitot-staticsylg.jpg
ALTERNATE STATIC PORT

Used when the main static port experiences a blockage

causes slightly inaccurate readings on the instruments

Static ports are positioned perpendicular to the airflow to avoid errors due to variations in wind speed.
Static ports are located on opposite sides of the fuselage.

But where are static ports located?

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

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

Source: https://media-cdn.pinterest.com/upload/295284212477386922_161ox0rY_f.jpg

Pitot-static system involves three instruments:

- Airspeed indicator
- Altimeter
- Variometer
Airspeed indicator is a differential pressure system that measures both dynamic air pressure and static pressure.

\[ P_{static} \rightarrow \text{Static port} \]

\[ P_{dynamic} \rightarrow \text{Pitot tube} \]
AIRSPEED INDICATOR

Diaphragm receives both $P_{\text{static}}$ and $P_{\text{dynamic}}$ from the pitot tube.

Sealed case with an aneroid diaphragm.

$P_{\text{static}}$ measured from inside the casing but outside the diaphragm.

Source: http://www.aerospaceweb.org/question/instruments/airspeed/pitot-static-system.jpg

Source: https://s-media-cache-ak0.pinimg.com/736x/2f/b2/d0/2fb2d079d23f32df9574b6c02eec94ab.jpg

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**Airspeed Corrections**

- **Indicated Airspeed**
- **Calibrated Airspeed**
- **Equivalent Airspeed**
- **True Airspeed**
- **Groundspeed**

*Source: https://i.stack.imgur.com/matiD.png*
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/8/8e/FAA-8083-3A_Fig_12-1.PNG
CALIBRATED AIRSPEED (CAS)

indicated airspeed corrected for instrument errors and position error

describes the $P_{dyamic}$ 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


E6B, Whiz Wheel used for CAS calibration
CALIBRATED AIRSPEED (CAS)

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

Source: http://www.sonex604.com/images/asi/CAS.jpg
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 \( q \).

\[
EAS = \sqrt{\frac{2q}{\rho_0}}
\]

Compressibility correction chart used for EAS.

Source: http://code7700.com/images/compressibility_correction.png
TRUE AIRSPEED (TAS)

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

\[ \text{TAS} = \text{EAS} \sqrt{\frac{\rho_0}{\rho}} \]

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:

\[ \text{TAS} = a_0 \sqrt{\frac{T_0}{T}} \]

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

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

Total air temperature

Mach Number

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AIRSPEED INDICATOR MARKINGS

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

- maximum allowable airspeed
- cautionary range of airspeeds
- white arc depicts the normal flap operating range
- green arc represents the normal operating range of the airplane

Flying in the caution range during turbulence can be unsafe

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