Flow Measurement

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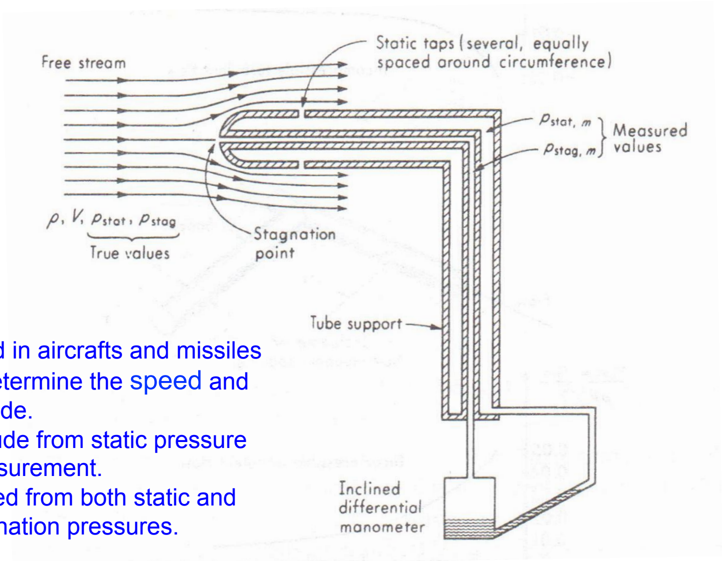
Velocity Measurement using Pitot Static Tube

- If the direction of flow is known, a Pitot static tube can be aligned with this direction
- Measure p_{stag} (stagnation or total pressure) and p_{stat} (static pressure)
- Assume steady, one-dimensional, incompressible, inviscid flow
- Obtain flow velocity as:

$$V = \sqrt{\frac{2(p_{stag} - p_{stat})}{\rho}}$$

Pitot-static tube



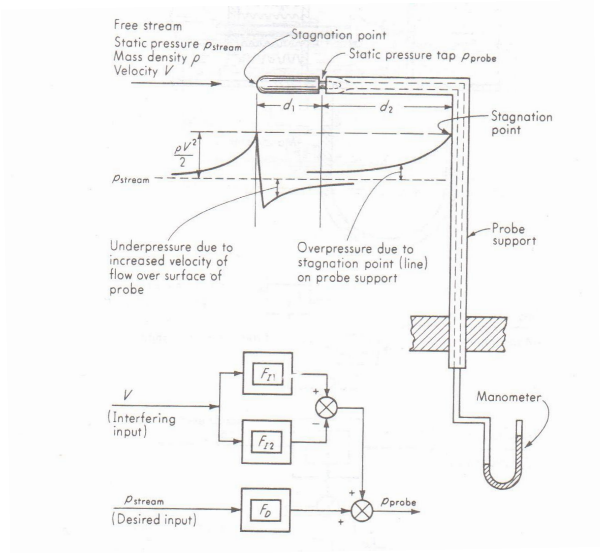
Used in aircrafts and missiles to determine the speed and altitude.
Altitude from static pressure measurement.
Speed from both static and stagnation pressures.

Sources of Error in p_{stat}

- Misalignment of tube axis and velocity vector: This exposes the tap to a component of velocity
- Non-zero tube diameter: Flow accelerates around the tube (due to blockage by tube). This causes decrease in static pressure
- Influence of tube support: Flow stagnates on tube support leading edge. Pressure increases at the stagnation point. This effect propagates upstream

Note that the last two errors can be made to cancel each other by proper design – done in Prandtl pitot tube

Prandtl pitot tube



Sources of Error in p_{stag}

- Misalignment: This prevents formation of true stagnation point at the measuring hole, since the velocity is no longer zero
- Two- and three-dimensional velocity fields: Due to finite probe size, and non-uniform velocity field, there is actually a range (and not a single value) of velocity at the tube tip. This variation leads to error in p_{stag} measurement
- Effect of viscosity: Due to finite viscosity of fluid, correction in (p_{stag} – p_{stat}) is required
- $$p_{stag} - p_{stat} = \frac{C\rho V^2}{2}$$
- $$C = 1 + \frac{4}{\mathrm{Re}}, 10 < \mathrm{Re}(= \frac{\rho VR}{\mu}) < 100$$

R is (outer) radius tube

Variation of pressure with altitude in our atmosphere

- Air pressure above sea level can be calculated as http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html

  $$p = 101325\,(1 - 2.25577\,10^{-5}\,h)^{5.25588} \qquad (1)$$

  where, p = air pressure (Pa), h = altitude above sea level (m) (default temperature is taken as 15 °C)
- So, if altitude resolution of 30 m is required, the pressure has to be measured within 360 Pa at sea level; and 121 Pa at 10 km altitude

Pitot tube for compressible flows

- If flow is compressible, earlier expression does not apply, rather use

  $$V = \sqrt{\frac{2\gamma}{\gamma - 1}\frac{p_{stat}}{\rho_{stat}}\left[\left(\frac{p_{stag}}{\rho_{stag}}\right)^{(\gamma-1)/\gamma} - 1\right]}$$

  γ: ratio of specific heat
- An alternate expression, without involving ρ_{stag}, since ρ_{stag} is dependent on T_{stag} and therefore difficult to measure, is

  $$p_{stag} = p_{stat}\left[1 + \frac{\gamma - 1}{2}\left(\frac{V}{c}\right)^2\right]^{\gamma/(\gamma-1)}$$

  $$c = \sqrt{\gamma RT}$$

  c: speed of sound, R: gas constant, T: free-stream static temperature