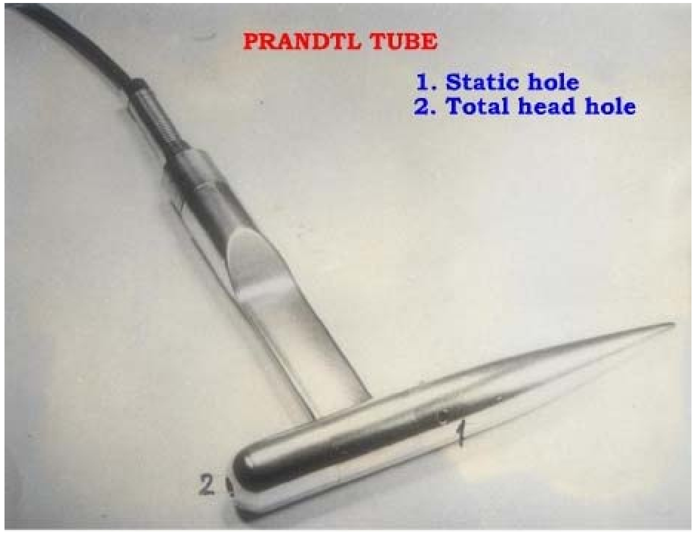
Total Pressure Measurements



Total Pressure Measurements

A correct total pressure measurement is a prerequisite for an accurate determination of velocity fields.

The total or stagnation pressure is defined as **the pressure obtained by isentropically decelerating the flow to rest**. The quality of the probe depends on how well it performs this process.

The main parameters influencing the measurements are:

- incidence
- Reynolds number
- Mach number
- velocity gradients
- proximity of walls
- unsteadiness of the flow and probe geometry

Total Pressure Measurements

An obstacle with a blunt nose decelerates the flow adequately at subsonic Mach number if the blunt nose is perpendicular to the flow direction.

This is not the case for supersonic flows because a bow shock will be formed and the entropy increase through this shock results in a measured pressure which is lower than the isentropic value.

Details of Pitot tube noses are shown on Fig 2.1. They can be circular (a), square (b, c) with different ratios of internal over external diameter d/D, with internal bevel (e,f,g).

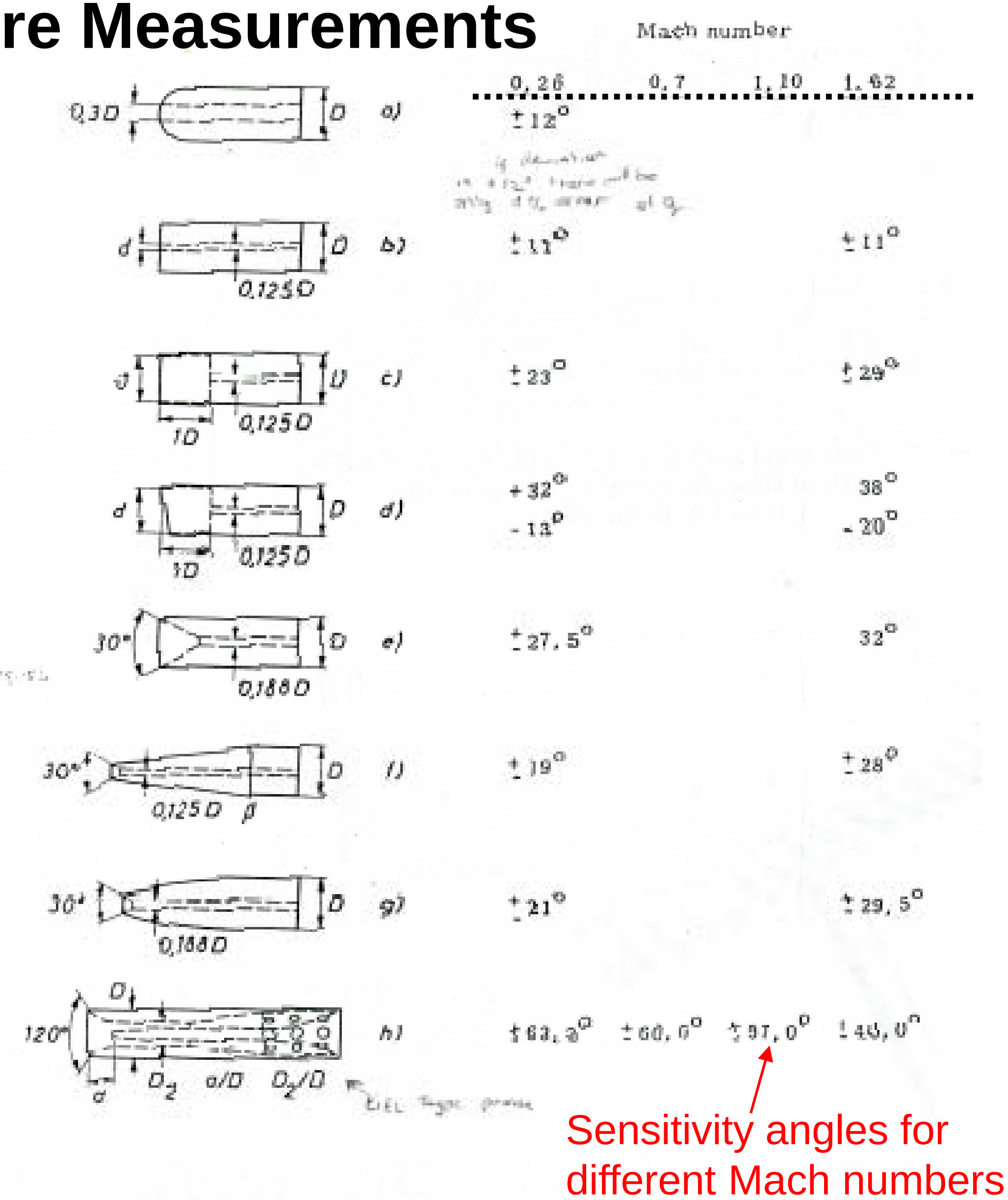
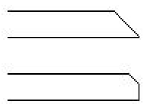


Fig. 2.1 - Influence of incidence angle on pitot-static tubes with different tip shapes. Deviations from the true pitot pressure are less than 1% of the dynamic pressure in the indicated angular range (W. Gracey, 1957)



Total Pressure Measurements

A. Incidence effect:

Pitot tubes are not very sensitive to angles of attack for which the measured total pressure deviates less than 1% of the dynamic pressure from the true one.

This sensitivity angle depends on the nose shape and Mach number.

The influence of orifice-over-external diameter is summarized on Fig. 2.2.

The sensitivity angle is normally increasing with Mach number

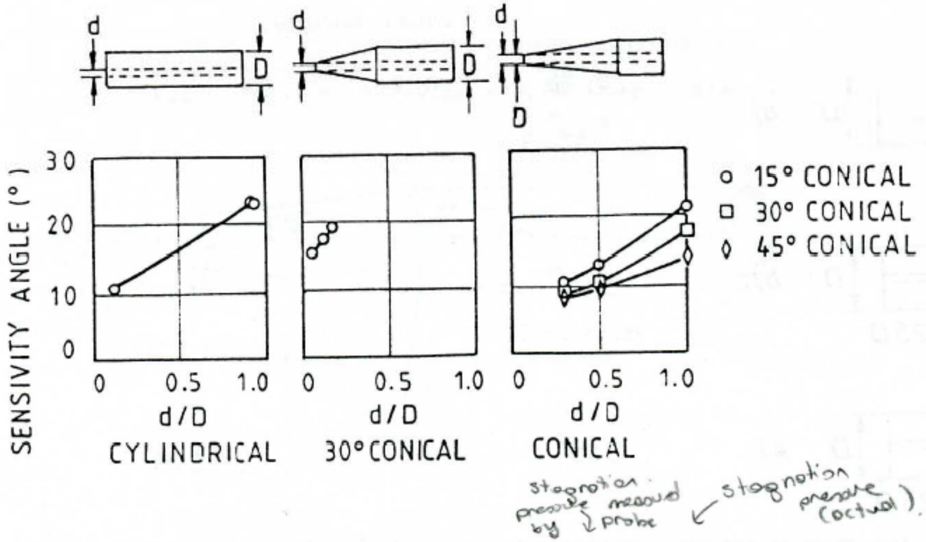


Fig. 2.2 - Variation of sensitivity angle ($(P_{op} - P_o)/q < .01$) with angle of attack for different probe geometries (J.R. Erwin, 1964)

Total Pressure Measurements

A. Incidence effect:

Extreme values of unsensitivity are reached with the Kiel probes.

They are well suited for total pressure measurements in flows of variable or unknown direction.

It allows to measure the radial or circumferential total pressure distribution downstream of a compressor or turbine or in the wake of bluff bodies.

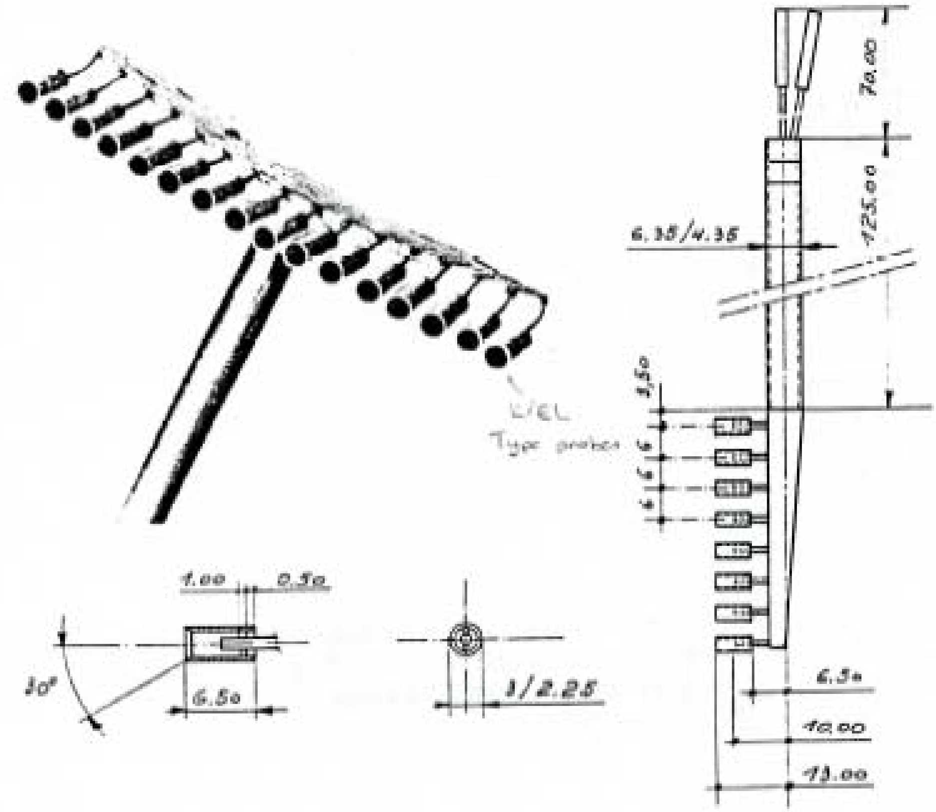


Fig. 2.3 - Total pressure rakes for turbomachinery application (F.A.E. Breugelmans, 1972)

Total Pressure Measurements

B. Reynolds number effect:

The viscous interaction between the free stream and stagnation fluid results in an energy transfer and as a consequence, in a pressure measurement which is too high.

Fig. 2.4 shows the calibration curves for different types of nose shapes. Measurements start to be incorrect for Re_d<100.

Such low Re number is reached if small probes are used or if the velocity is low (boundary layer measurements).

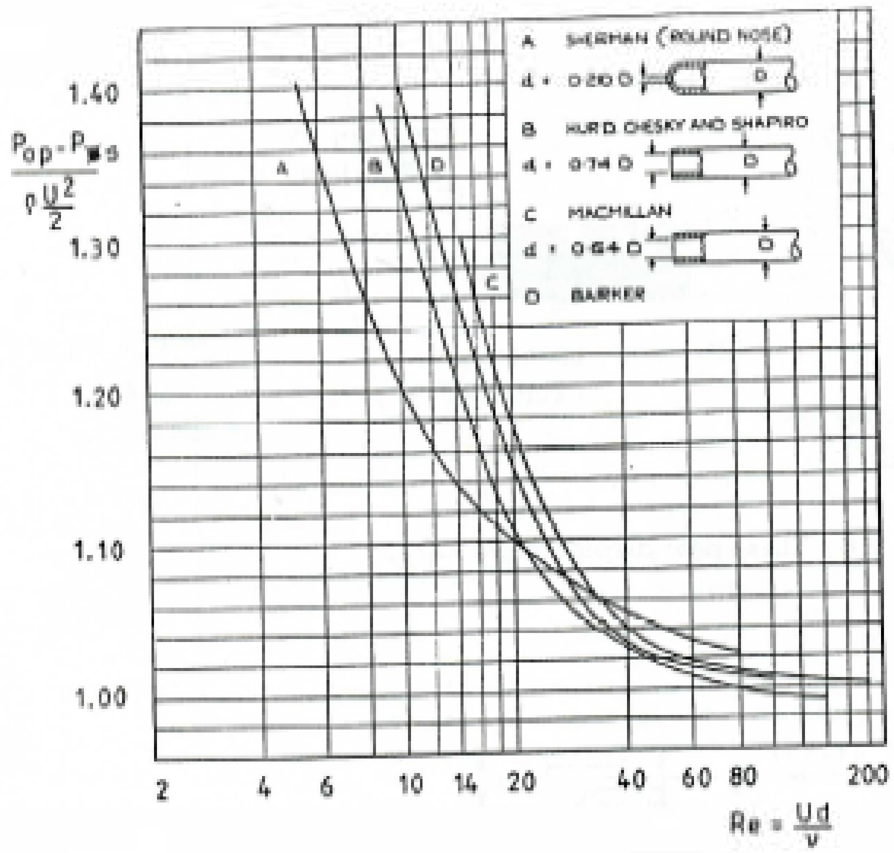


Fig. 2.4 - Calibration of pitot tubes at low Reynolds numbers (J.S. Thompson & D.W. Holder, 1958)

Total Pressure Measurements

B. Reynolds number effect:

Flattening the tube allows a decrease of the critical Reynolds number at which the viscous effects have an influence.

Flat Pitot tubes allow correct boundary layer measurements up to low Reynolds numbers.

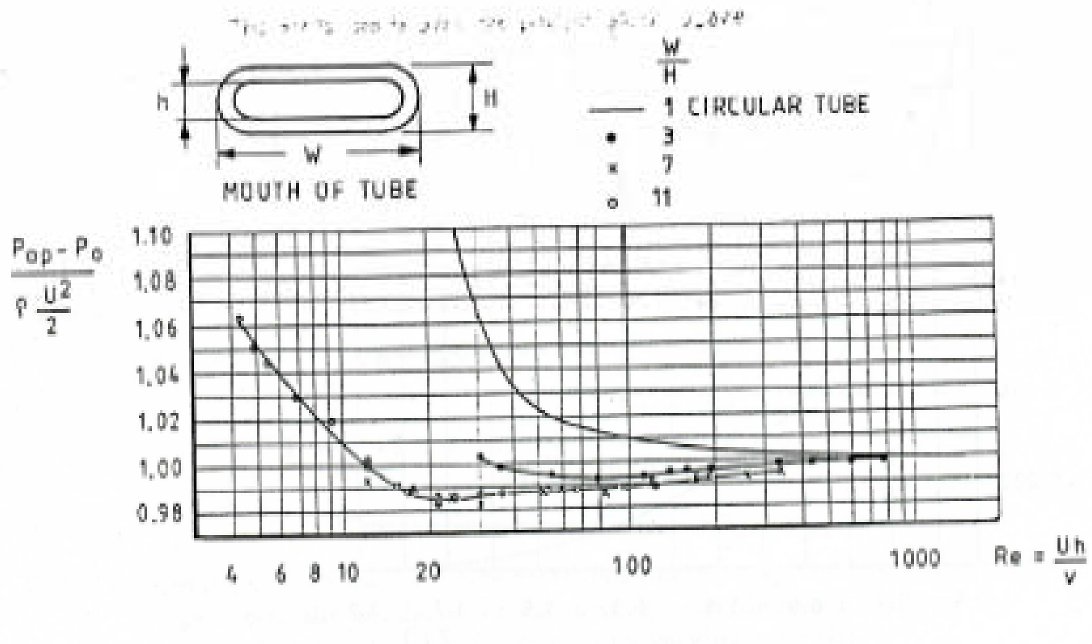


Fig. 2.5 - Calibration of flattened pitot tube at low Reynolds numbers (F.A. MacMillan, 1954)

Total Pressure Measurements

C. Velocity gradient effect:

The transverse velocity gradient will cause a measurement error which could be due to the following effects:

- The stagnation pressure is proportional to the square of the velocity. Integrating this over the orifice will result in a higher value than the stagnation pressure calculated from the square of the average velocity at the geometrical center of the orifice

- The presence of a probe in a velocity gradient causes deflection of the streamlines toward the region of lower velocity. This deflection causes the probe to indicate a bigger stagnation pressure than the existing at the probe location.

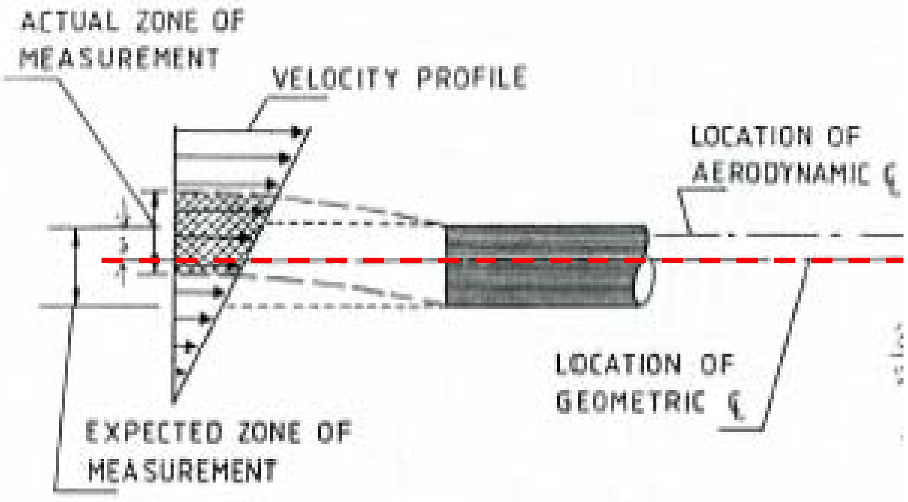


Fig. 2.6 - Shear flow displacement effect

Velocity profiles obtained from Pitot measurements in a wake close to the trailing edge using probes of similar geometry but with varying diameter.

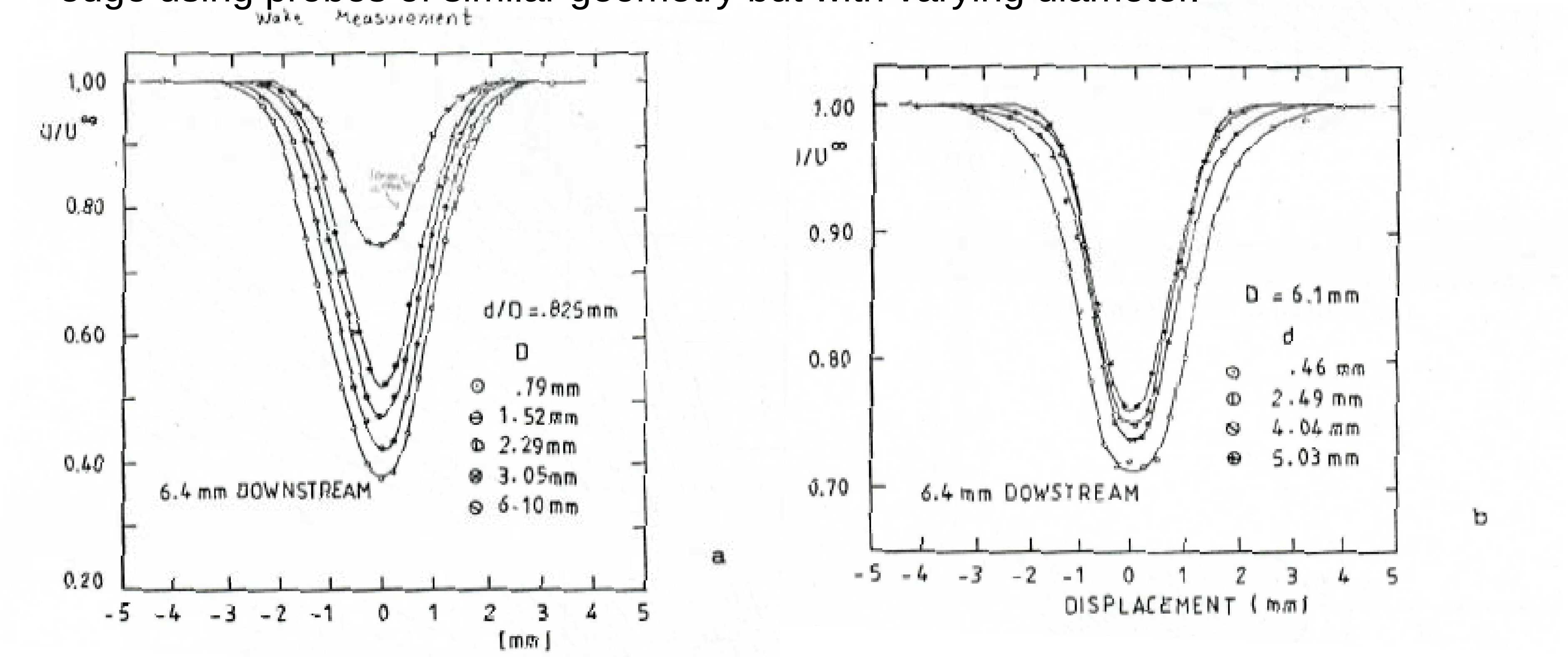
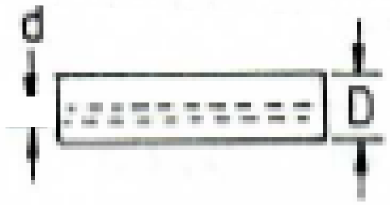


Fig. 2.8 - Comparison of wake profiles measured behind a symmetric airfoil using geometrically similar pitots of varying outer diameter (a) and constant outer diameter with varying bore (b)



Total Pressure Measurements

D. Wall proximity effect:

The streamline shift due to the velocity gradient in the boundary layer is limited by the proximity of the wall and the measured total pressure is closer to the exact value.

Fig. 2.7 indicate the velocity correction for Z/D<2. This correction has to be deduced from the velocity.

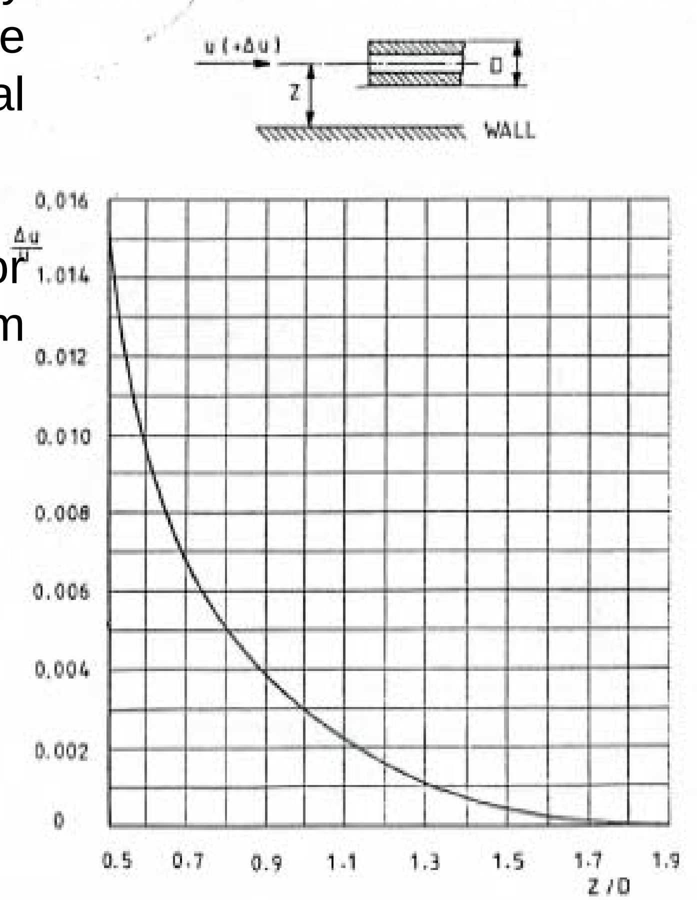


Fig. 2.7 - Velocity correction for a circular pitot tube near a wall (F.A. MacMillan, 1956)

Total Pressure Measurements

D. Wall proximity effect:

Preston (1954) has indicated that a Pitot tube resting on the wall can be used for skin friction measurements.

$$C_f = f\,(U_P/U,\ UD/\nu)$$

U_p is the velocity corresponding to the dynamic pressure defined by the Preston tube measurement minus static pressure measurement on the wall. U is the free stream velocity.

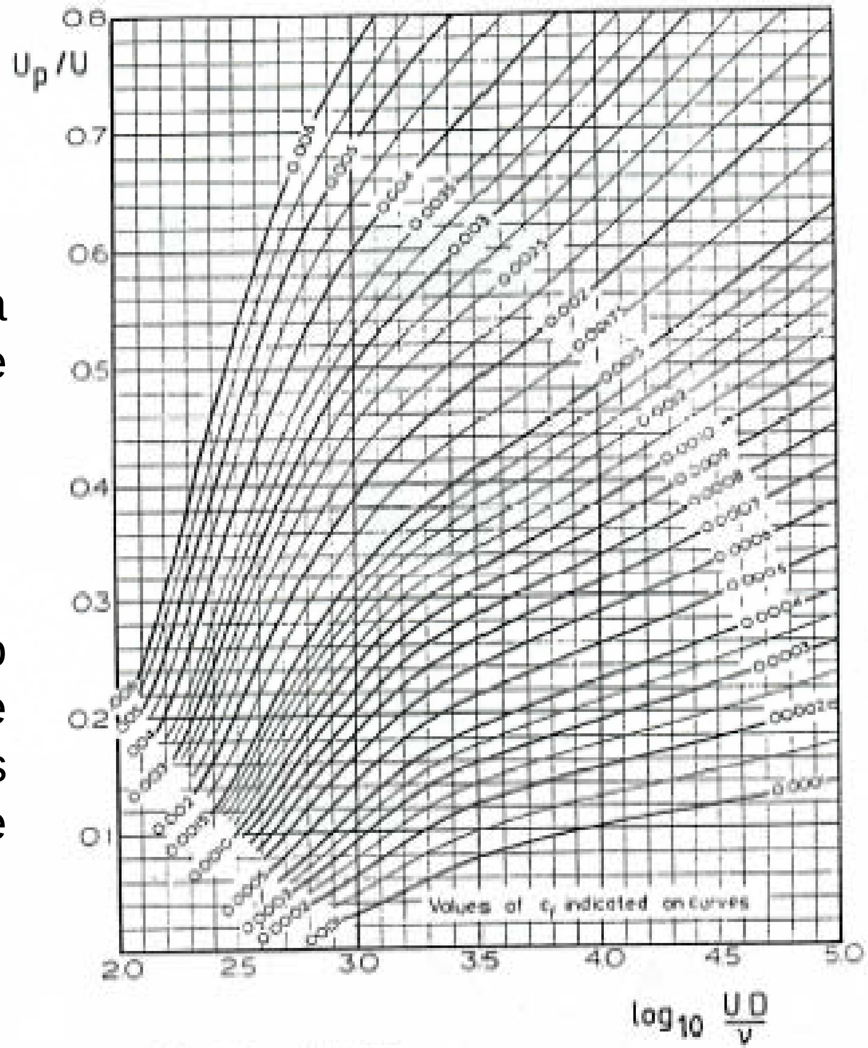


Fig. 2.9 - Calibration curves for the Preston tube showing skin friction coefficient as a function of U_P/U and tube Reynolds number (M.R. Head & V.V. Ram, 1971)

Total Pressure Measurements

E. Turbulence effects:

Turbulence or flow unsteadiness may influence Pitot tube readings in two ways:

A. The fluctuating velocity component influences the direction of the flow approaching the orifice (like effect of incidence).

B. The fluctuating velocity components may contribute to the stagnation pressure. Expressing the velocity as the sum of the mean velocity and the fluctuating components u', v' and w'

$$\mathbf{U}_{\mathbf{total}}=U_{mean}+\mathbf{u'}+\mathbf{v'}+\mathbf{w'}$$

results for incompressible flows, into a stagnation pressure defined by

$$P_o=P_s+1/2\rho\, U^2_{total}$$

Turbulence intensities of 20%, which are high, will result into a maximum total pressure change of 2%.

Total Pressure Measurements

F. Mach number effect:

A Mach number variation does not substantially affect the Pitot tube pressure measurements if the flow is subsonic. However, shocks appearing at supersonic Mach numbers, result in pressure losses and a Pitot pressure reading below the isentropic stagnation pressure.

Total pressure measurement corrections in supersonic flows are based on the assumption that the shock is normal to the flow.

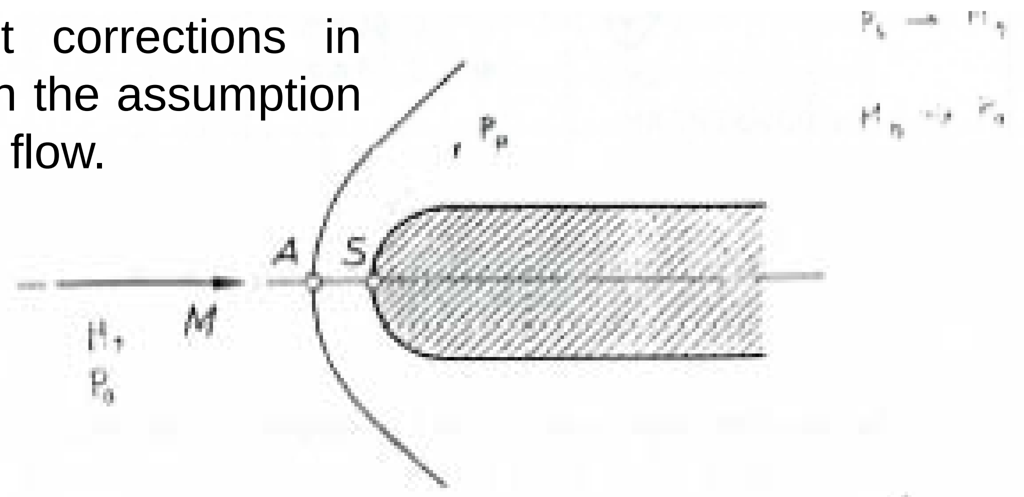
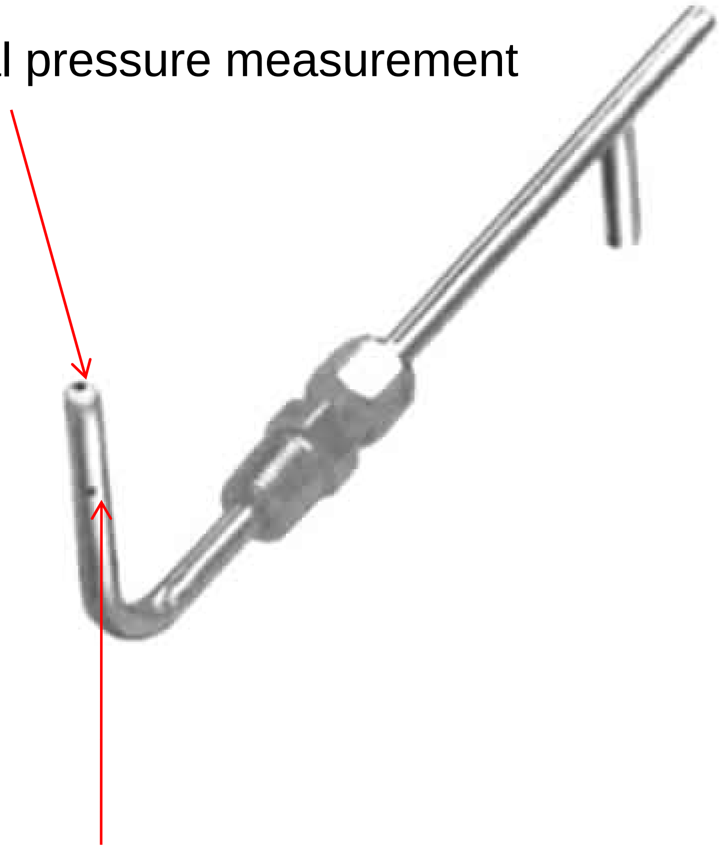


Fig. 2.10 - Probe tip in supersonic flow with detached shock wave with S = stagnation point, A = vertex of the shock wave

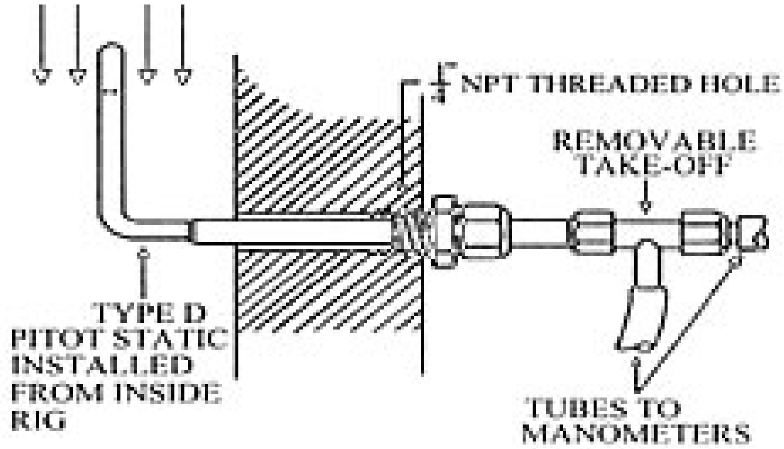
PITOT-STATIC PRESSURE PROBES

Total pressure measurement

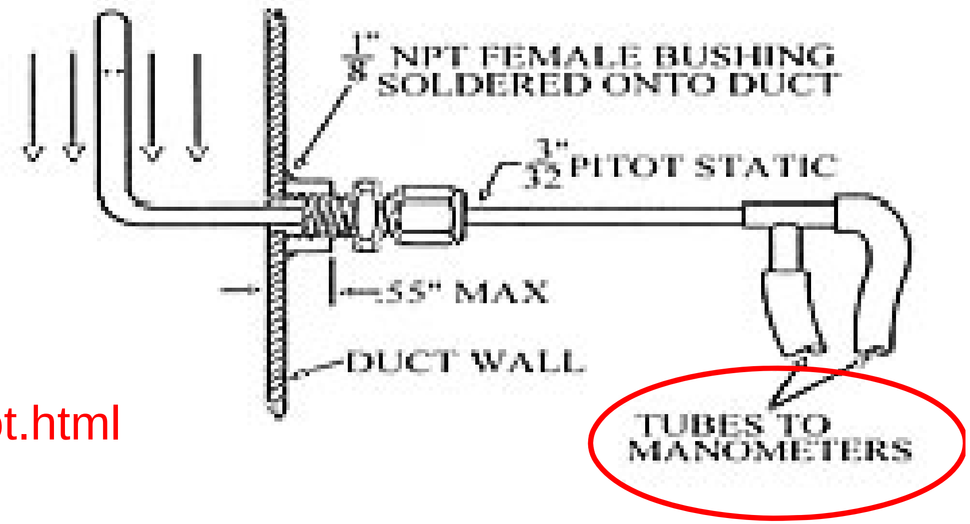


Static pressure measurement

Thick wall installation



Thin wall installation

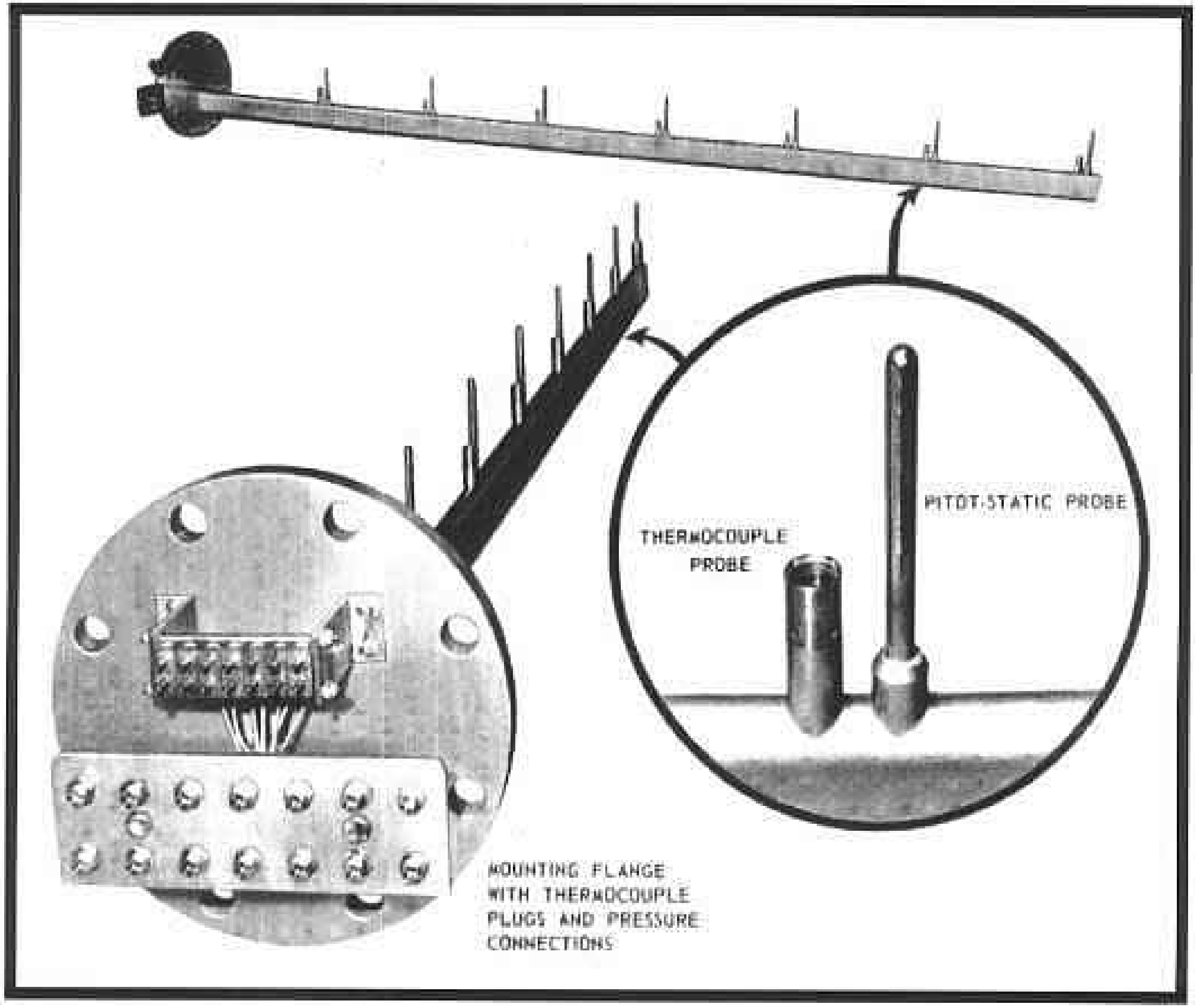


Read: http://www.unitedsensorcorp.com/pitot.html

United Sensor stainless steel Boundary Layer Probes measure total pressure of a fluid near solid boundaries.

A Traverse unit measures distance in increments of 0.01" on a scale graduated in divisions of 0.1" with a vernier.

Angle of rotation of the probe, used for measuring flow direction, is measured in movements of 0.2° over a full 360° on a protractor graduated in 2° divisions for easy readability and a special large scale vernier.



United Sensor Pressure and / or Temperature Rakes measure a cross-section of total pressure, static pressure and / or total temperature of a moving fluid. Rakes offer the advantage of providing many separate readings simultaneously or a simple average of many readings.