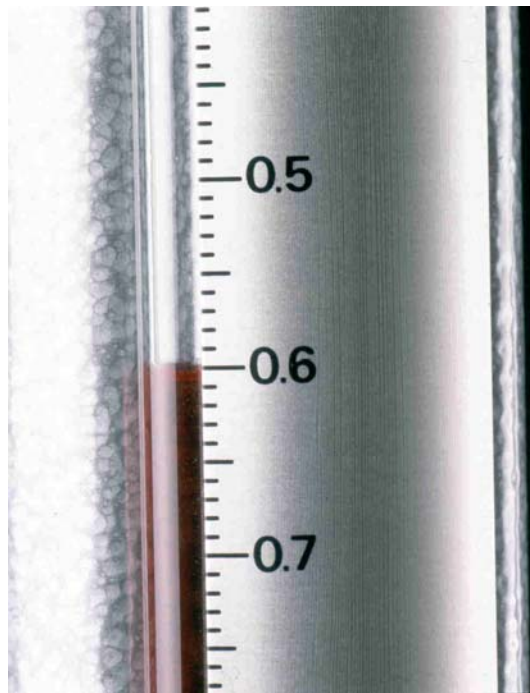# HOW TO MEASURE PRESSURE

HOW TO MEASURE FLOW

by
G.J.Matthews

HOW TO MEASURE PRESSURE.

FUNDAMENTAL PRINCIPLES.

Due to the depth of the earth's atmosphere the air around us exerts a pressure, known as atmospheric pressure. This can be measured with a barometer and varies depending upon the weather conditions. It also varies according to altitude above or below sea level at which it is made.

Pressure measurements in heating systems are usually made relative to atmospheric pressure, and may be corrected to 'Standard Conditions' to make possible a comparison between readings. The internationally agreed 'Standard Conditions' are for an air density of 1.2 kg/m³.
(Atmospheric air at a temperature of 16°C, a pressure of 100,000 Pa. and a relative humidity of 65% has a density of 1.2 kg/m³, but these conditions are not part of the definition.)

The only pressure acting at any point in a stationary fluid is Hydrostatic pressure which acts equally in all directions. If the fluid is set in motion the pressure still persists, but may change in magnitude.
If we consider a very thin disc placed in the fluid, and moving with it, the static pressure as it is called will act on the two faces of the disc.

P_S

INFINITELY THIN DISC.

P_S
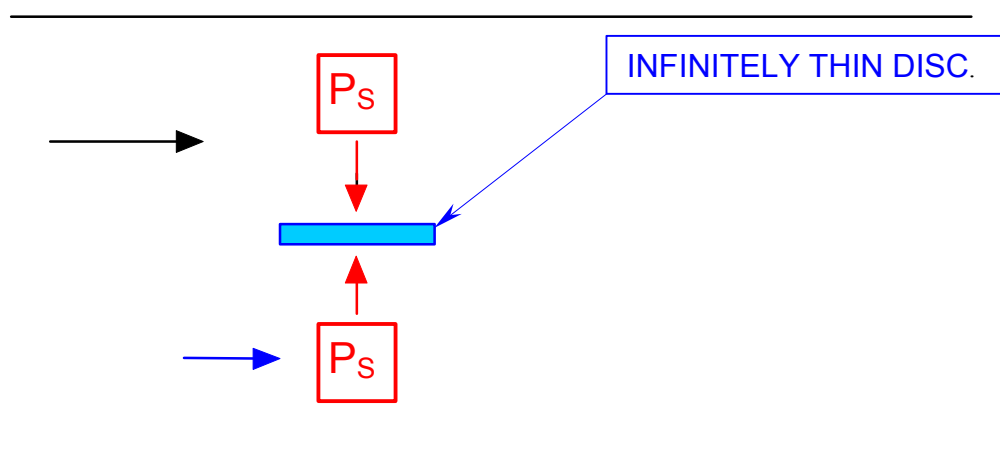
If the disc is stationary the pressure acting on the two surfaces will be the same providing the presence of the disc does not disturb the flow.

P_S

P_S

NO DISTURBANCE
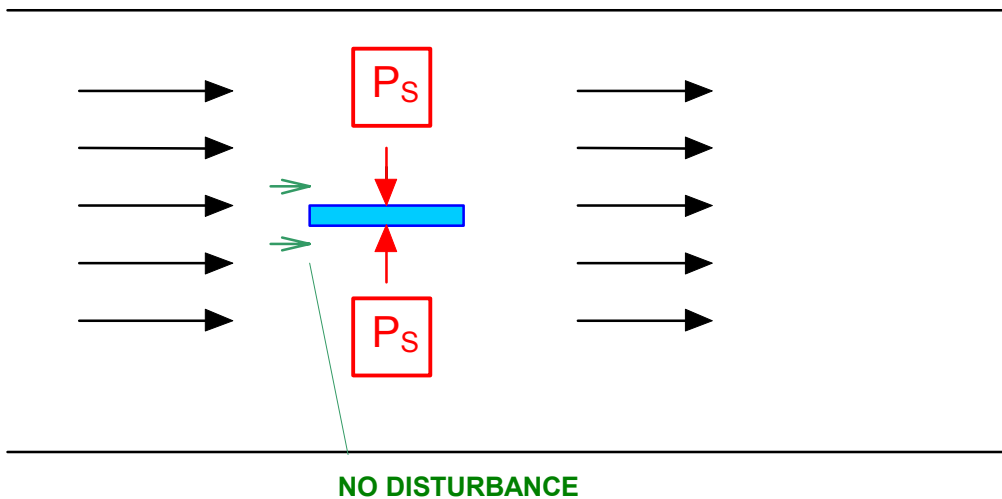
However if the stationary disc is turned through 90° its front face will be subjected to not only static pressure, but also an additional dynamic pressure equal to the velocity pressure in incompressible flow, due to the impact.

P_S

V

P_D

$P_D = \frac{1}{2} \times \rho \times V^2$

ρ = DENSITY OF THE FLUID
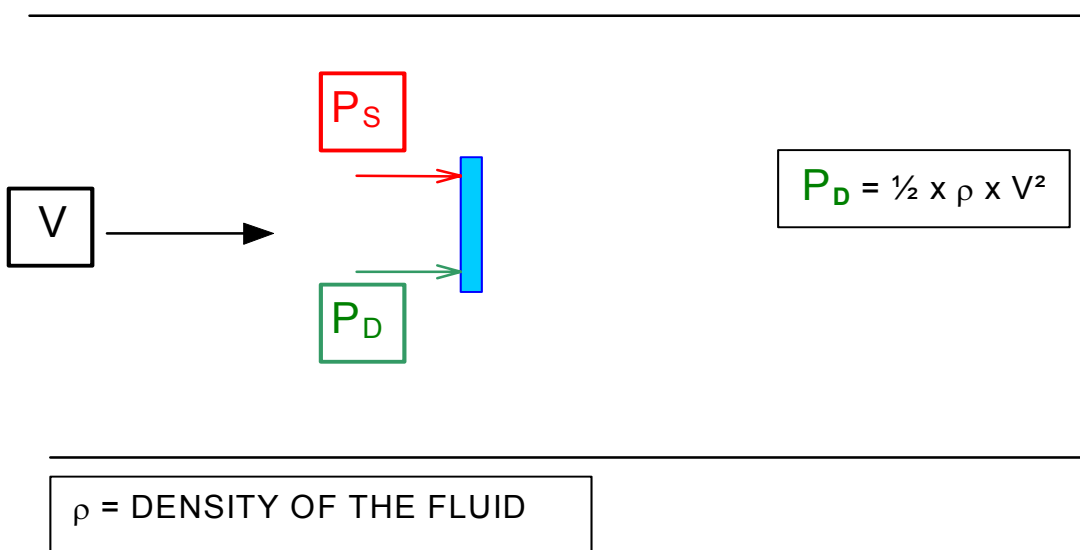
The velocity pressure is due entirely to the motion of the flow and depends upon the velocity and the density of the fluid.
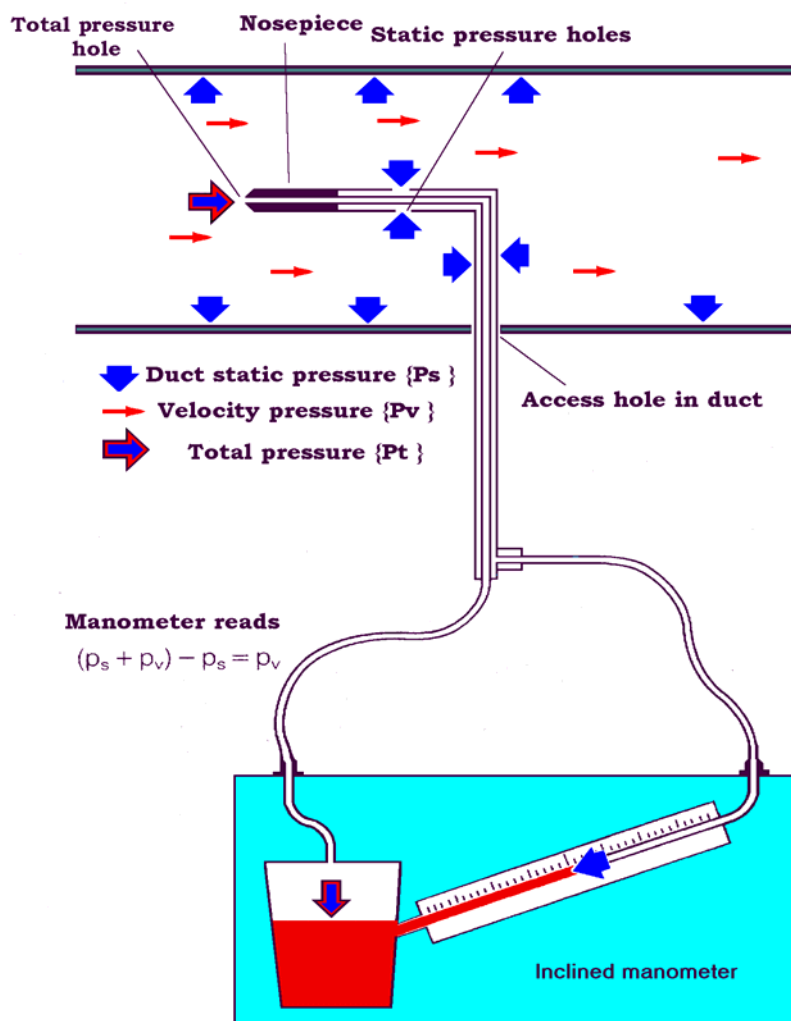
The algebraic sum of the static pressure and the velocity pressure is called the total pressure.

MEASURING TOTAL AND STATIC PRESSURE.

A tube placed in a duct facing into the direction of the flow will measure the total pressure in the duct. If frictional losses are neglected, the mean total pressure at any cross section throughout the duct system is constant.

Static pressure can only be determined accurately by measuring it in a manner such that the velocity pressure has no influence on the measurement at all. This is carried out by measuring it through a small hole at the wall of the duct; or a series of holes positioned at right angles to the flow in a surface lying parallel to the lines of flow. The pitot static tube is an example of this. Figure 1 shows the principle of the pitot static tube.

Figure 1. Principle of the pitot static tube.

Total pressure hole   Nosepiece   Static pressure holes

Duct static pressure {Ps }
Velocity pressure {Pv }
Total pressure {Pt }

Access hole in duct

Manometer reads

$(p_s + p_v) - p_s = p_v$

Inclined manometer

It will be seen that connecting tubes to a manometer makes the measurement of pressure.

INSTRUMENTS FOR MEASURING PRESSURE.

[1]. U TUBE MANOMETER.

Although probably the oldest method of measuring low pressures, the simple U tube has much to commend it.

If a U shaped glass tube is half filled with a liquid, e.g. water, and a pressure is applied to one end of the limb, the other being open to atmosphere, the liquid will move to balance the pressure. The weight of liquid so displaced will be proportional to the pressure applied. As the difference in height of the two columns of liquid and the density are known the pressure can be calculated. Each millimetre height difference of water column represents approximately 10 Pascals.
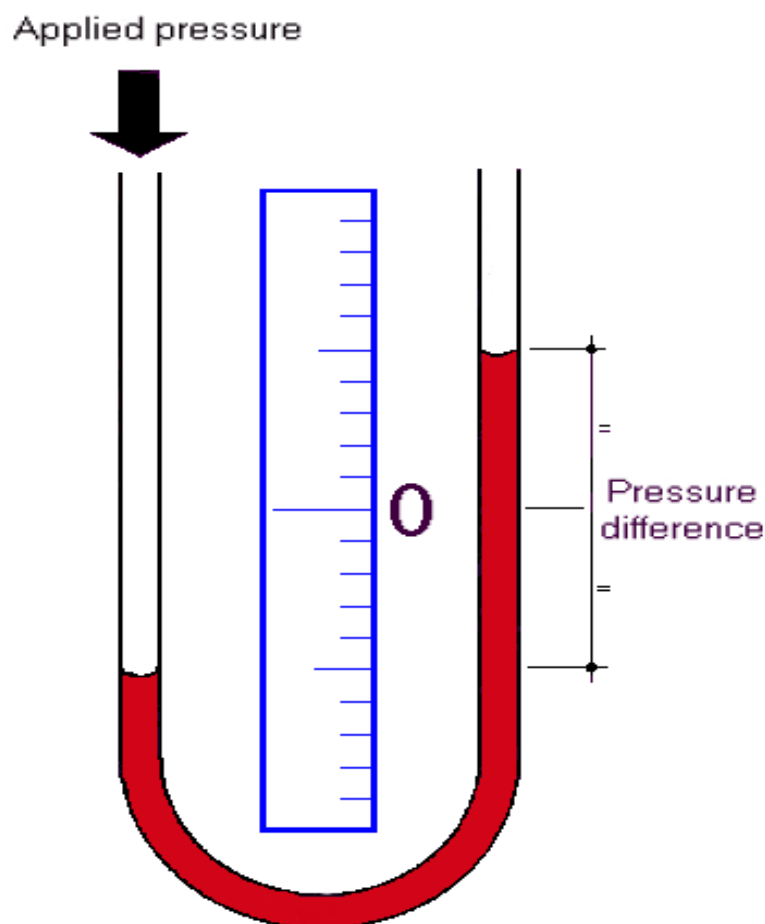

Figure 2. Principle of the U-tube manometer.

A disadvantage of the U tube is that the scale has to be constantly moved to line up with the moving zero

Alternatively with zero taken at the centre point the scale length is halved with subsequent loss of resolution.

[2]. 'LIQUID - IN GLASS' MANOMETERS.

The disadvantages of the simple U tube manometer are overcome and other advantages incorporated in single limb industrial manometers in which it is only necessary to read one liquid level.

In one such design, one of the limbs of the U tube is replaced by a reservoir, thus substantially increasing the surface area. A pressure applied to this reservoir causes the level of fluid to move a small, calculable amount. The same volume of fluid displaced in the glass limb produces a considerable change in the level. This nearly doubles the resolution compared with the U tube manometer for vertical instruments and gives much greater magnification when the limb is inclined.

The manometer fluid may be plain water, but problems can arise from algae growing in the tube causing the density of the fluid to alter. Special blends of paraffin are often used and these have several advantages: a free moving meniscus, no staining of the tube, and expanded scales due to low relative densities. Where higher pressures are required, denser fluids are used, of which mercury is often used. For very low pressures the manometer limb is inclined to improve the resolution further.

More precision can be achieved with adjustable - range limbs and it is possible to achieve from 0 - 125 Pa. to 0 - 5000 Pa. with only two limbs.

Figure 4: Examples of Single Limb Manometers

Figure 3. Precision portable manometer set.

[3]. DIAL GAUGES.

Dial pressure gauges are primarily employed for reading high pressures. At very low pressures they tend to exhibit unacceptable hysteresis errors unless they are very high quality instruments. Due to short scale length, the resolution is not usually very good.

[4]. PRESSURE TRANSDUCERS.

As an alternative to the fundamental liquid - filled portable manometer, electronic pressure transducer based instruments are available for laboratory or site use. They are generally compact as to be hand held, and eliminate the use of fluids, giving an acceptable level of accuracy for normal ventilating and related air movement measurement.
The capacitance transducer employs a precision diaphragm moving between fixed electrodes. This causes capacitance changes proportional to a differential pressure.

The piezo – resistive pressure sensor contains a silicon chip with an integral sensing diaphragm and four piezo-resistors; pressure applied on the diaphragm causes it to flex changing the resistance; this causes a low level output voltage proportional to pressure.

A pressure transducer - based instrument allows continuous monitoring using a recorder, or input to electronic storage or control equipment.

Figure 6. Pocket Manometer DB2.

Microprocessor technology allows for the pressure readings to be converted into velocity readings when using a pitot static tube. In some instances the probe calibration factor may be inputted separately allowing other pressure measuring probes to be used with direct velocity readout.
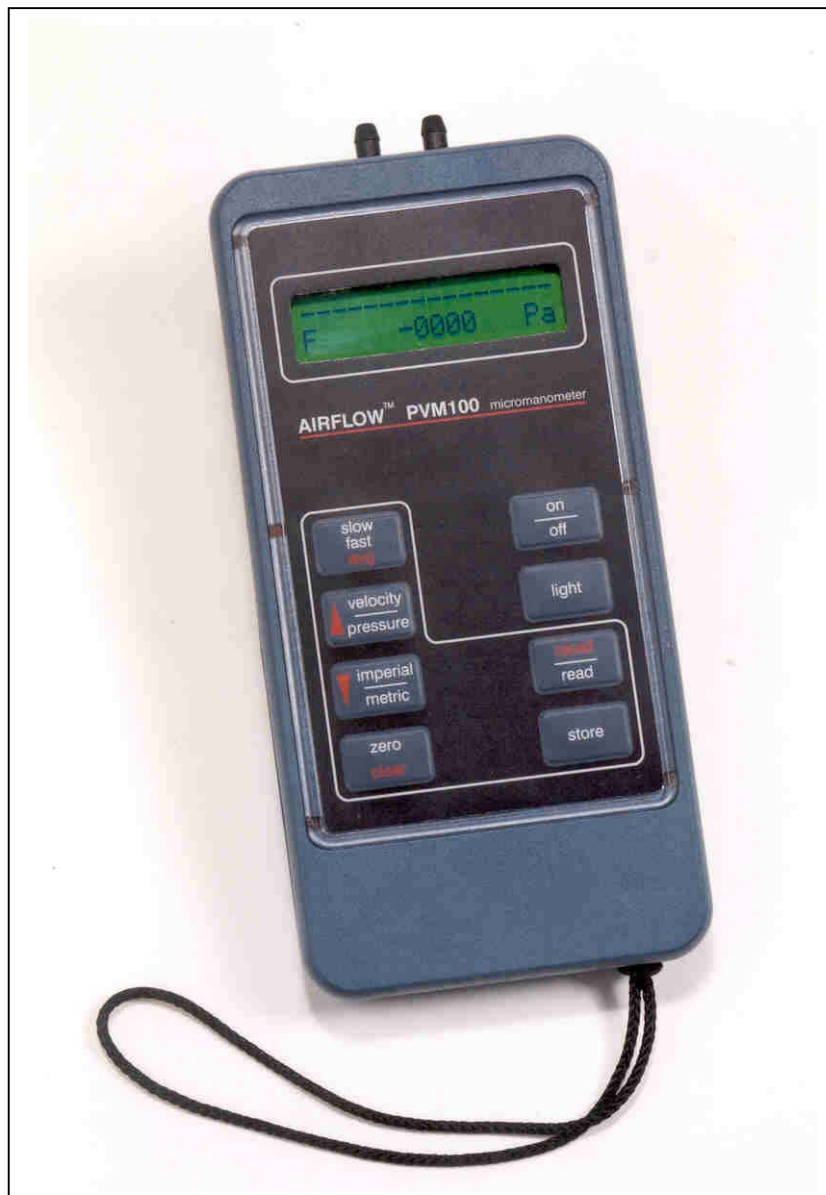
Several readings can be stored, with MIN, MAX and AVE functions. In some instances, duct area can be inputted to allow direct volume flow measurement

Figure 7. Airflow MEDM 5k Micromanometer.

Figure 8. PVM100 Micromanometer.

HOW TO MEASURE VOLUME FLOW RATE.

FORMULAE.

          Volume flow rate   =   Mass flow rate / Density.

or

          Volume flow rate   =   Velocity x duct cross-section area.

The volume flow rate in a system can be measured at the entrance to the system, at the exit from the system, or somewhere within the system itself. This could involve measuring the total flow rate or the flow rate in a portion of the system. Wherever it is measured, it should be a prerequisite that the flow should be swirl - free.

There are several methods with which the flow rate can be measured.

[1]. IN - LINE FLOWMETERS (STANDARD PRIMARY DEVICES)

BS1042 Part 1 : 1990 describes such devices as the venturi nozzle, the orifice plate, and the conical inlet. The venturi nozzle and the orifice plate may be used at the inlet to or the outlet from a system as well as between two sections of an airway. The conical inlet draws air from a 'free' space at the entrance to a system.

With regard to measuring the volume flow rate of general purpose fans, the requirements of BS1042 with regard to the lengths of straight duct upstream of the flow meter is reduced and BS848 Part 1 : 1980 details these changes together with the associated uncertainty of measurement.

The general equation for these differential flowmeters is:

$$q_m \;=\; \alpha \, \varepsilon \left[\pi \, d^2 / 4 \right] \sqrt{2 \, \rho_u \, \Delta P}$$

where

q_m	=	mass flow rate (kg / s)
α	=	flow coefficient
ε	=	expansibility factor
d	=	throat diameter
ρ_u	=	upstream density (kg / m³)
ΔP	=	pressure difference (Pa.)

It is not proposed to go into too much detail with these devices as both BS1042 and BS848 are complete documents and should be referred to.

[2]. PITOT - STATIC TUBE TRAVERSE.

A commonly used method of accurately establishing the air flow rate in a duct is by traversing the duct with a pitot - static tube connected to a precision manometer.

A conveniently accessible part of the duct should be selected; preferably where there is a straight parallel section of duct of at least 5 diameters downstream of any bend, obstruction or abrupt change of section. Velocity readings are required at the prescribed points as shown in figures 6 and 7.

The air velocity at the **point of measurement** can easily be calculated from the velocity pressure reading according to the following formulae:

The standard formula for calculating velocity from velocity pressure is:

$$\mathbf{V} \quad = \quad \mathbf{1.291} \; \sqrt{} \; \mathbf{p_v} \qquad \text{(m/s)}$$

This is only correct for standard air of 1.2 kg/m³

For non - standard air conditions the formula becomes:

$$\mathbf{V = 1.291} \; \sqrt{} \; \mathbf{\{100000/p_a\} \{T/289\} \{100000/(100000+p_s)\} \{p_v\}} \; \text{(m/s)}$$

where

V	=	air velocity (m / s)
p_v	=	velocity pressure (Pa.)
p_a	=	atmospheric pressure (Pa.)
p_s	=	static pressure (Pa.)
T	=	absolute temperature (K) (= t + 273)
t	=	airstream temperature (°C)

The expressions $\{100000/p_a\}$, $\{T/289\}$ and $\{100000/(100000+p_s)\}$ are corrections for atmospheric pressure, air temperature, and duct pressure to bring the measured value of p_v to the equivalent of standard air. If the duct static pressure is less than 2500 Pa. it can normally be ignored. Similarly, the other two expressions can be ignored during site testing if they are not likely to affect the equivalent p_v by 2 or 3%.

When averaging the readings taken on a duct traverse it is strictly correct to average the air velocities (which is equivalent to averaging the square roots

of the velocity pressures). In practice, however, no great error will be introduced by taking a simple average of the velocity pressures when calculating the mean velocity providing the majority of the readings do not
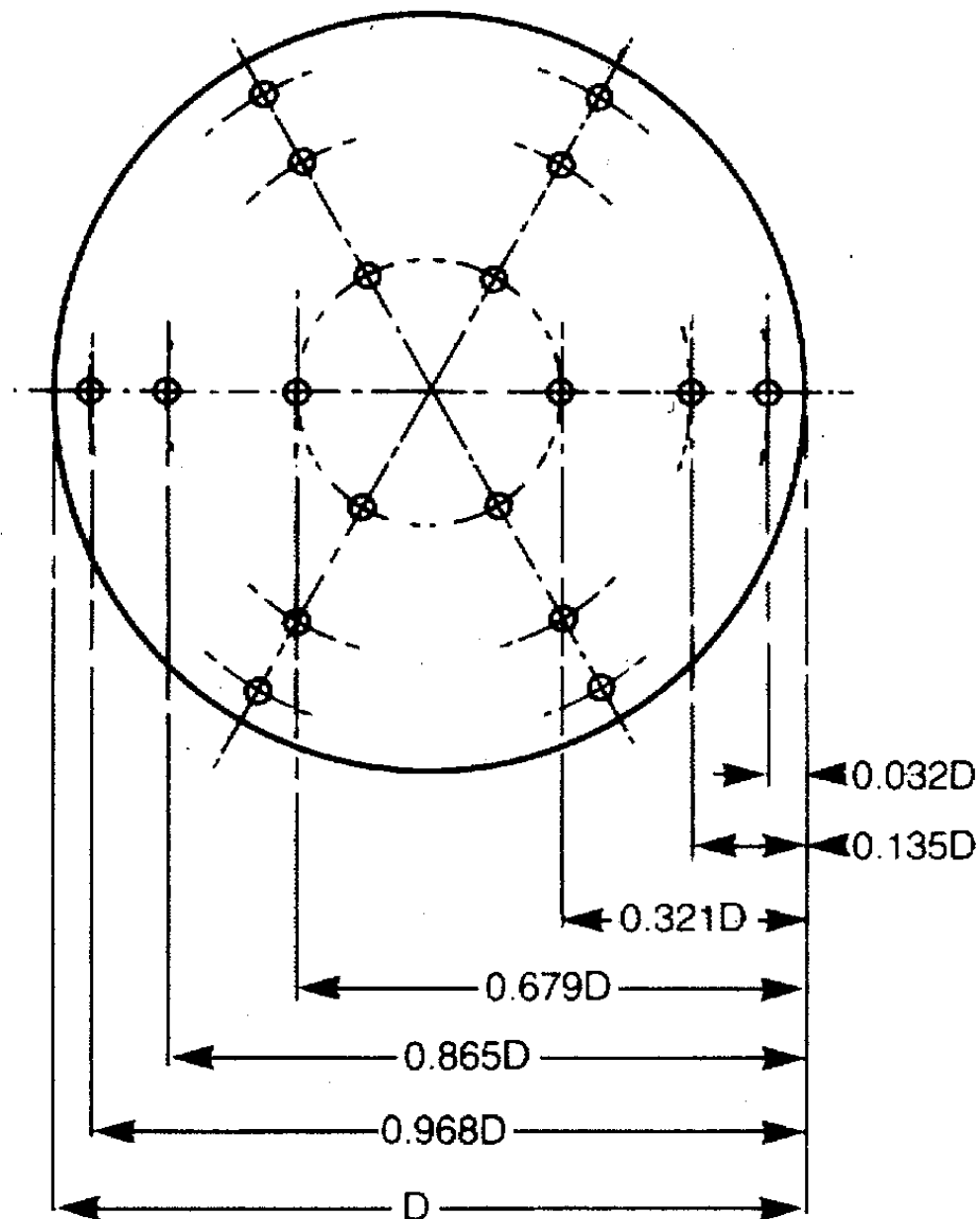
Log Linear rule for traverse points
on 3 diameters in a circular duct

vary by more than about ± 25% from the mean value.

Figure 9. Measuring points for circular ducts. Log linear rule for traverse points on 3 diameters.
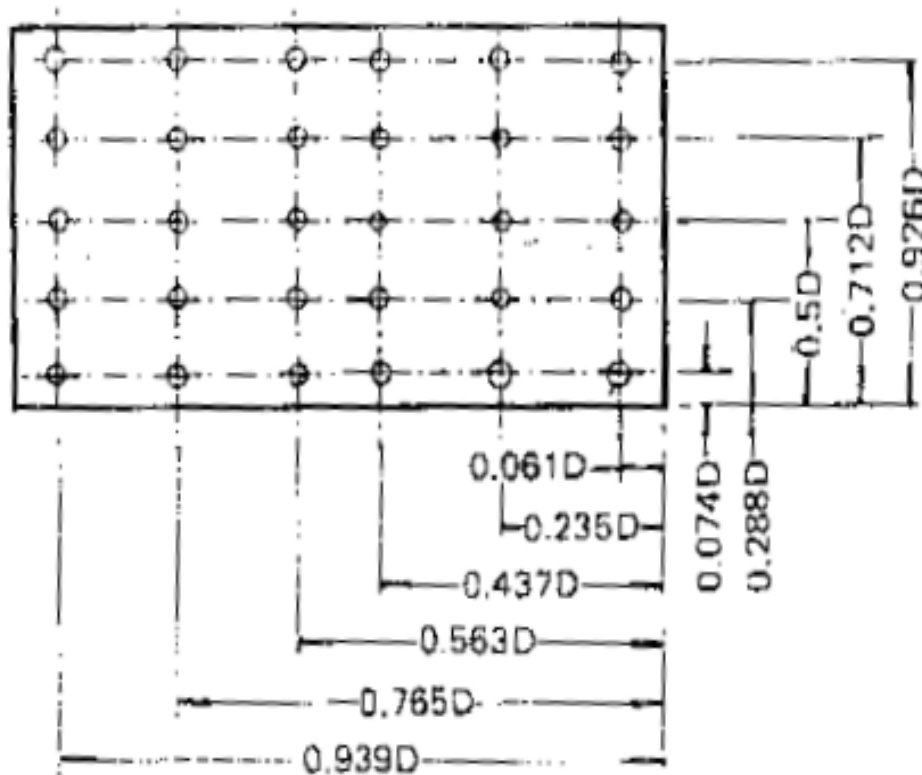
Position of alternative measuring points and traverse lines relative to side lengths for rectangular ducts

No of points or traverse lines.	Position relative to inner wall
5	0.074, 0.288, 0.5, 0.712, 0.926,
6	0.061, 0.235, 0.437, 0.563, 0.765, 0.939.
7	0.053, 0.203, 0.366, 0.5, 0.634, 0.797, 0.947,

Figure 10. Measuring points in rectangular ducts. Log Tchebycheff rule.

[3]. ANEMOMETER DUCT TRAVERSE.

Anemometers are instruments, which measure air velocity. Two popular types are the Rotating vane anemometer and the Thermal anemometer. The rotating vane type is basically a mechanical device where a shrouded rotating vane rotates like a windmill, with delicate clockwork gearing recording the number of revolutions of the vane on a multi - point dial. These anemometers record the linear movement of air past the instrument in metres or feet for as long as it is held in the airstream. By noting the time with a stop watch the velocity in m/s or ft/min can be determined.
In more recent anemometers as each blade of the rotating vane passes a pick up, it is 'counted' electronically, the signal fed into electronic circuitry with its own time base and displays the measured velocity directly and instantaneously without any need for external timing.
The anemometer head is normally 100 mm diameter in size, but heads as small as 16 mm are available.

It can be used in larger ducts to traverse the duct to obtain mean duct velocity as with the pitot - static tube.

Obviously the larger size head (when compared to the pitot - static tube) interferes with the airflow in smaller ducts with the result that it causes the local duct velocity to increase to a significant effect. Figure 11 shows the typical increase in velocity reading when placed in different sized ducts.
It is possible to have one anemometer head centrally located in its own test duct and be independently calibrated for volume flow rate.

The Airflow™ 100mm rotating vane anemometers can be fitted with an Aircone flow hood which allows the volume flow rate through small grilles to be measured easily and accurately.

The volume flow rate can be measured using an ATP600 Airflow Measuring Hood for larger sized grilles.

Alternatively, it is recommended that a 'cardboard skirt' of at least 2 x the length of the shortest side is taped around the grille and an anemometer traverse carried out across the entrance of the 'cardboard skirt' to obtain the mean velocity.
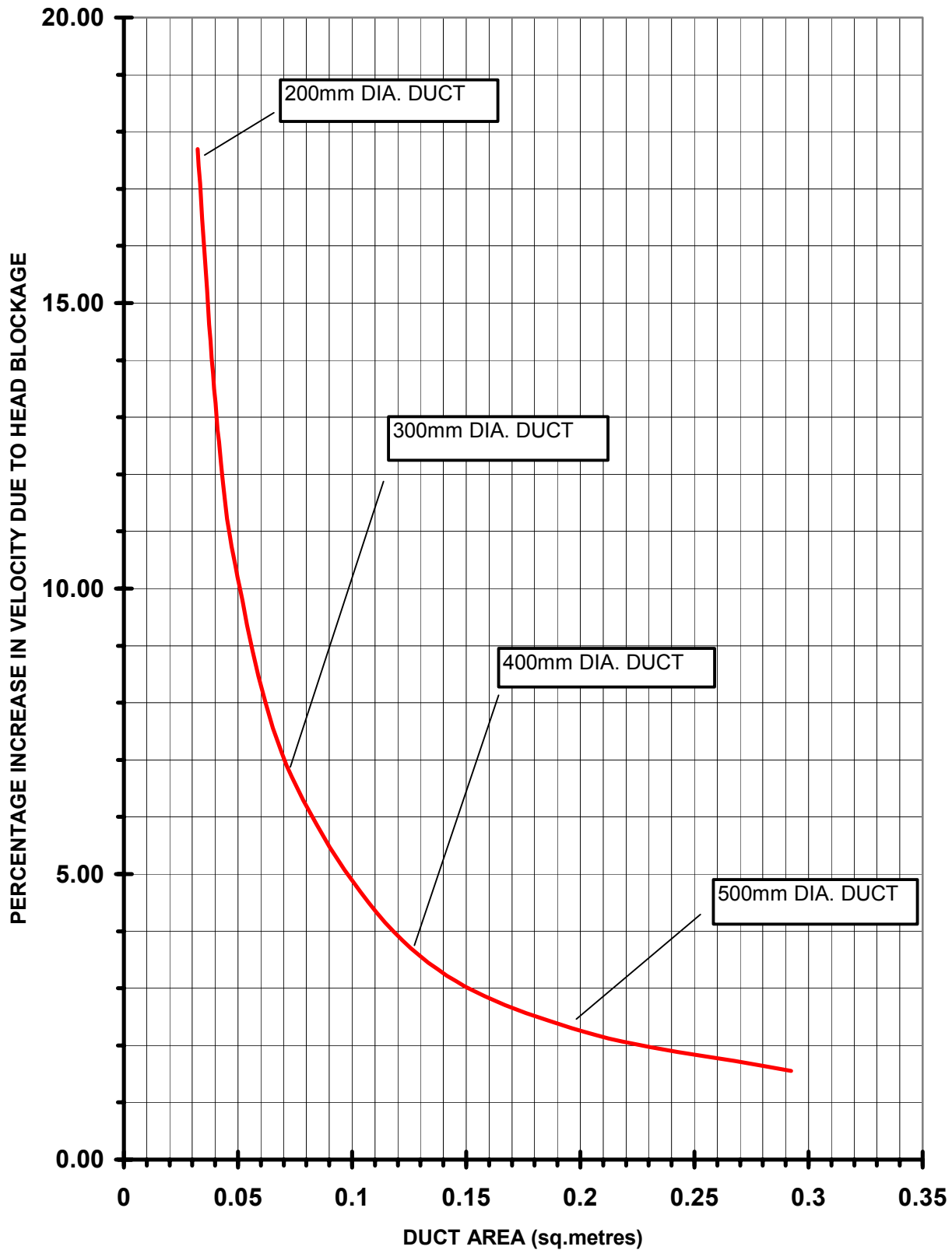
FIGURE 11:-100 mm ANEMOMETER HEAD BLOCKAGE EFFECT.

Figure 12. LCA30iS intrinsically safe vane anemometer.

Figure 15: ProHood Airflow Measuring Hood.

[4]. THERMAL ANEMOMETERS.

A wet finger in the air will detect the direction of the wind because a drop in temperature is felt on the surface facing the wind. Thermal anemometers act in a similar way, in that the passage of air takes heat away from a heated element at a rate dependant upon the velocity. This element is mounted at the end of a probe that can be inserted into the airstream. Velocity readout is direct and instantaneous.

The method of heating the element (which can be a small length of thin wire, a simple thermocouple or a thermister) and the read - out technique determine the quality of the instrument. Because it is a thermal device, it is

important to compensate for variations in ambient temperature, pressure, and the composition of the gas / air being measured.

The probe is normally small similar to that of the pitot - static tube, and is particularly appropriate for use at low velocities where a vane anemometer (due to mechanical friction effects) or pitot - static tube would not be sensitive enough.

Its principal disadvantage is that they take only a point velocity reading and a traverse is needed to obtain an average velocity reading.

Figure 16: TA35 thermal anemometer.

[5]. WILSON FLOW GRID.

The Wilson flow grid consists of a row of parallel tubes with closed ends and forms what can be described as an 'open fence' across the duct at right angles to the axis of flow. Some of the tubes are perforated with small holes facing upstream (sensing total pressure), whilst other tubes have holes on the downstream side to sense throat sub - static pressure. Both sets of tubes are connected to separate manifolds which provide two average pressure signals. The difference between the two signal constitutes an enhanced output signal.
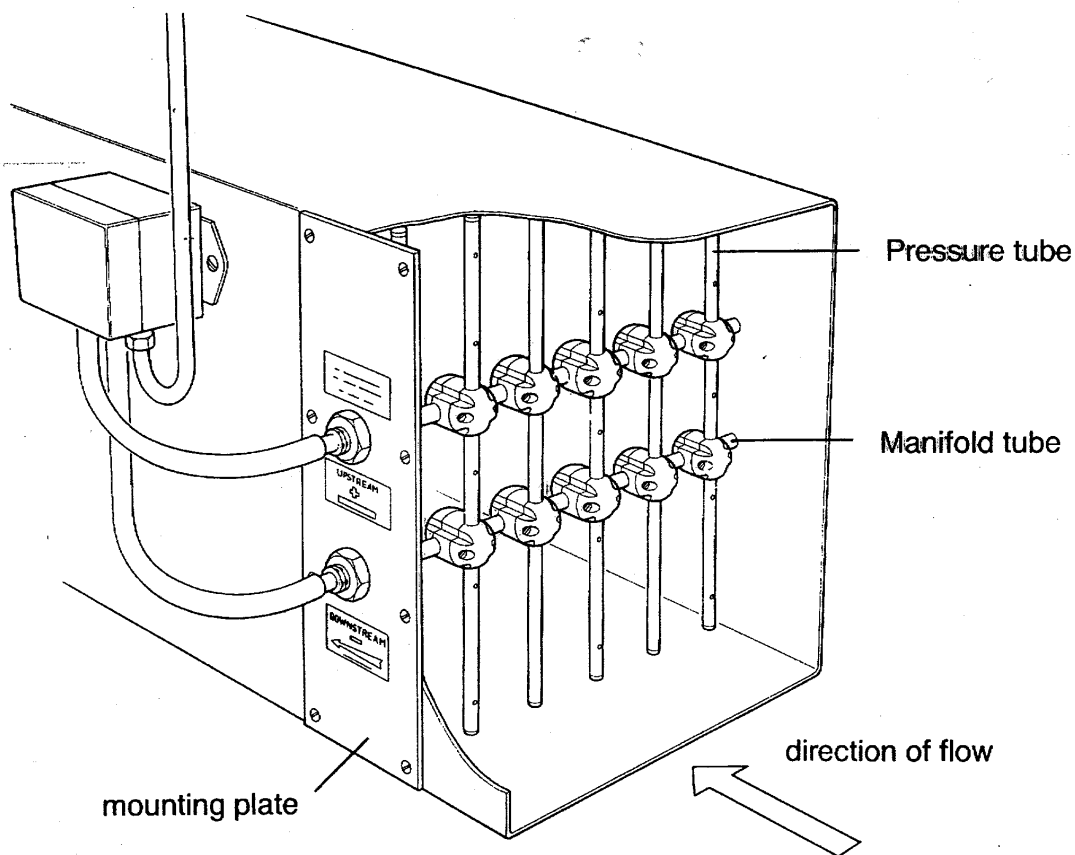

Figure 17. The Wilson flow grid.

The presence of the 'grid' in the duct creates a partial blockage in the cross - sectional area of the duct resulting in an increase in local velocity between the tubes. The positive pressure is derived from the total pressure sampled from the distribution of the forward facing holes. The negative pressure is derived from a combination of the depressed static pressure between the tube and the suction zone immediately behind the tubes.

The holes in the tubes are positioned such that an acceptable sampling system is utilised.

The output signal can be compared to the mean duct velocity pressure that would be present in the duct without the 'grid' being present. This is commonly termed the magnification factor.

The output signal can also be plotted against the volume flow rate in the duct. This is possible because each Wilson flow grid is manufactured to suit a given duct size.

It is possible to use a single 'double' tube in a duct section, but because there is no effective manifold the reading can be slightly erratic. It should also be noted that the single tube type only senses the flow rate in one plane which is not ideal.

TABLE OF CONVERSION FACTORS FOR PRESSURE AND VOLUME FLOW RATE.

In the table below, I have tried to include all of the most popular combinations, with the 'preferred' S.I. unit shown in *blue*

VOLUME FLOW RATE.

1 m³/s	= 999.97 l/s	= 3600 m³/h	= 2118.9 cfm	= 60 m³/min
1 l/s	= 3.60 m³/h	= 2.119 cfm	= 0.06 m³/min	= 0.001 m³/s
1 m³/h	= 0.5886 cfm	= 0.01667 m³/min	= 0.00028 m³/s	= 0.2778 l/s
1 cfm	= 0.0283 m³/min	= 0.000472 m³/s	= 0.4719 l/s	= 1.699 m³/h
1 m³/min	= 0.01667 m³/s	= 16.67 l/s	= 60 m³/h	= 35.315 cfm

VELOCITY.

1 m/s	= 196.85ft/min
1 ft/min	= 0.00508 m/s

PRESSURE.

1 Pa	= 0.01 mbar	= 0.004015 in.wg	= 0.10197 mm.wg	= 0.000145 psi.
1 mbar	= 0.4015 in.wg	= 10.197 mm.wg	= 0.0145 psi.	= 100 Pa.
1 in.wg.	= 25.4 mm.wg	= 0.0361 psi.	= 249.089 Pa.	= 2.49089 mbar.
1 mm.wg	= 0.00142 psi.	= 9.80665 Pa.	= 0.09807 mbar	= 0.03937 in.wg.
1 psi.	= 6894.76 Pa.	= 68.9476 mbar	= 27.68 in.wg.	= 703.07 mm.wg.

It is recommended that the following multiples and sub-multiples of the S.I. units are used in fan technology:

Pressure:	kilopascal	= kPa	=	1000Pa.
Barometric pressure:	millibar	= mbar	=	100 Pa.
Volume flow rate:	litre per second	= l/s	=	10^{-3} m³/s