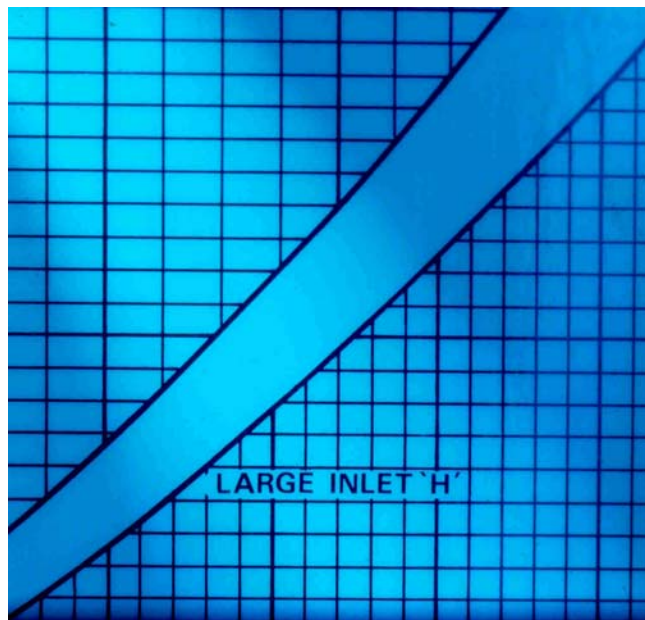


HOW TO DETERMINE AIR FLOW



by
G.J. Matthews



Laboratory test methods.

BS848: Part 1 is the Standard that fan manufacturers' use to determine the air performance of all types of fans with the exception of those fans designed solely for air circulation. e.g. ceiling fans and table fans.

The 1963 version offered 9 test methods, and consisted of 77 pages of A5 size.

The 1980 version introduced standardised airways, recognised 4 installation types with at least 4 test methods for each installation. The publication had increased by just 2 pages in length, but was now doubled to A4 size.

The 1997 version is better known as ISO5801. It represents basic agreement internationally for air performance test methods, and is the result of almost thirty years of discussion, comparative testing and detailed analyses by leading specialists from research organisations and the fan industry throughout the world. The publication now extends to 232 A4 pages.

Clearly AIR is not conducive to being measured. We cannot see it. Its motion is three dimensional and turbulent, and it would need a great many measurements of velocity and direction to integrate a total volume flow, unless the air were first collected and then straightened in a suitable test airway.

What we do have are test procedures for determining a fan's performance that will produce repeatable results under laboratory conditions.

[When ducting is attached to the inlet, outlet, or both inlet and outlet, of a fan, its performance is changed]

Fans are classified according to the four types of installation:

Type A - Free inlet, Free outlet,

Type B - Free inlet, Ducted outlet,

Type C - Ducted inlet, Free outlet,

Type D - Ducted inlet, Ducted outlet.

It is also recognised that to achieve a repeatable and consistent determination of fan pressure, it is necessary to fit standardised duct sections to the inlet or outlet of the fan.

To illustrate the four classification types and show the standardised inlet and outlet ducts, Figure 1 shows the determination of flow rate by use of inlet or outlet orifice.

Figure 1/. Illustration of the four classification types of installation.

Site testing.

It has been stated that fan manufacturers' are able to give a fan's performance tested under laboratory conditions.

In practice, however, a fan is rarely installed in a system identical to such conditions.

Normally there are obstructions within the system that cause resistance to flow. Most component manufacturers produce resistance to flow data and system designers are able to estimate an overall resistance to flow and size a fan accordingly.

However, there will always be instances where the system does not operate to the design specification and it is not uncommon to suggest that the fan is not doing what it ought. Some designers will over specify the fan in order to overcome such deficiencies. This, whilst solving any foreseeable problems, is very energy inefficient, and does not correct the problem at source. Discrepancies may be due to any of the following:

- Leakage, recirculation, or other faults within the system;
- Inaccurate estimation of flow resistance;
- Erroneous application of the 'standardised' fan data;
- Excessive loss in a system component located too close to the fan inlet, outlet, or elsewhere;
- Disturbance of the fan performance caused by a bend or other system component located too close to the fan inlet.

It should be appreciated that the accuracy achieved on site will be substantially inferior than that achieved under laboratory conditions, and where a site test forms the basis of a fan acceptance test, the manufacturer should have the opportunity to inspect the system design in order to:

- (1). Agree the best locations for measurement,
- (2). Have the opportunity to advise any changes to the system that will affect the overall performance of the fan.

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.

This could involve measuring the total volume flow rate or the flow rate in a portion of the system.

It is always possible to install a permanent measuring device within the system. This could be integrated as part of a management system and can be relatively inexpensive when compared to the total cost of the system.

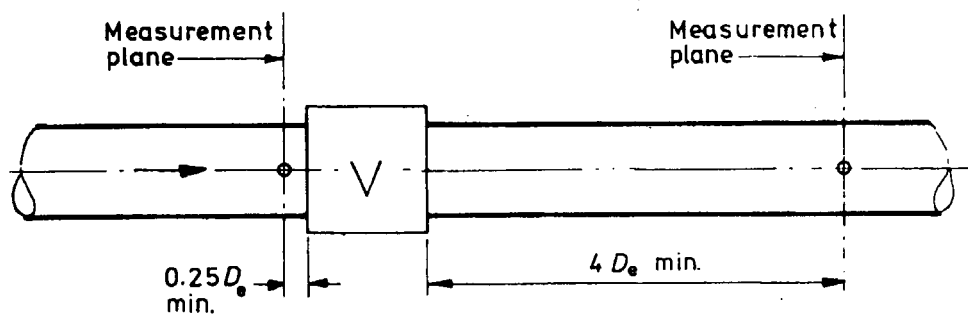
Wherever it is measured, it should be a prerequisite that the flow should be swirl-free; checks should also be made to ensure that the fan and any associated components are functioning properly; and that the fan operating speed is stable. i.e. The system is operating at steady conditions (temperature).

BS848: Part 1: 1980 gives instructions for site testing and location of measurement planes. The flow measurement plane should preferably be sited at the inlet to the fan. Bends, contractions and other obstructions should be situated as far away from the measuring plane as is practicable. It is allowed to introduce guide vanes in order to improve the flow conditions.

For the purposes of measuring the pressure rise across the fan, the static pressure should be measured close to the fan inlet and outlet. Where it is not possible to measure close to the fan, allowances have to be made for duct friction effects between the fan and the measuring plane.

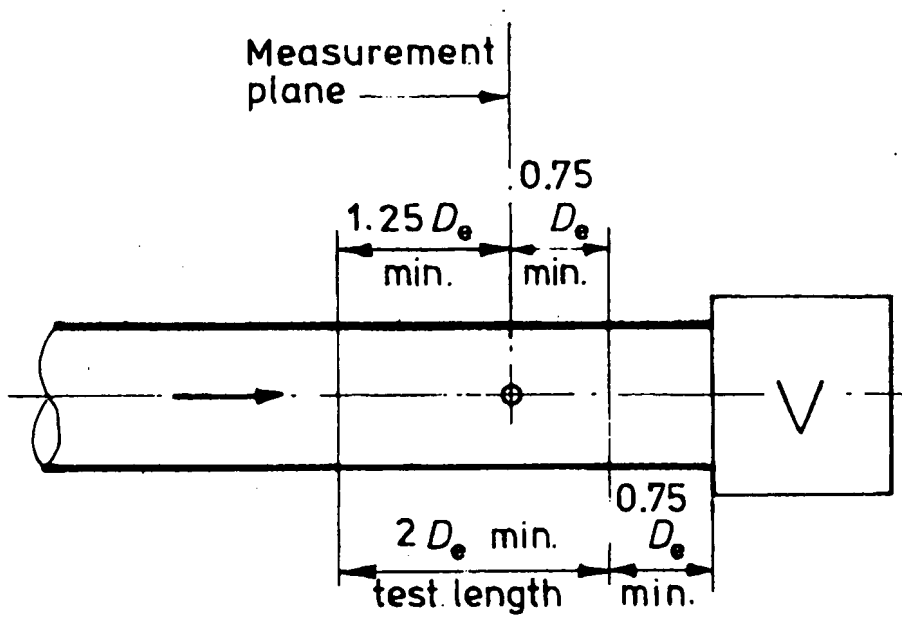
What has to be appreciated is that where irregular flow conditions are present, there will be a component of velocity pressure present and may be recorded as well as the static pressure and this will lead to erroneous readings.

The measuring planes for recording flow and pressure as laid out in BS848: Part 1: 1980 are shown below.

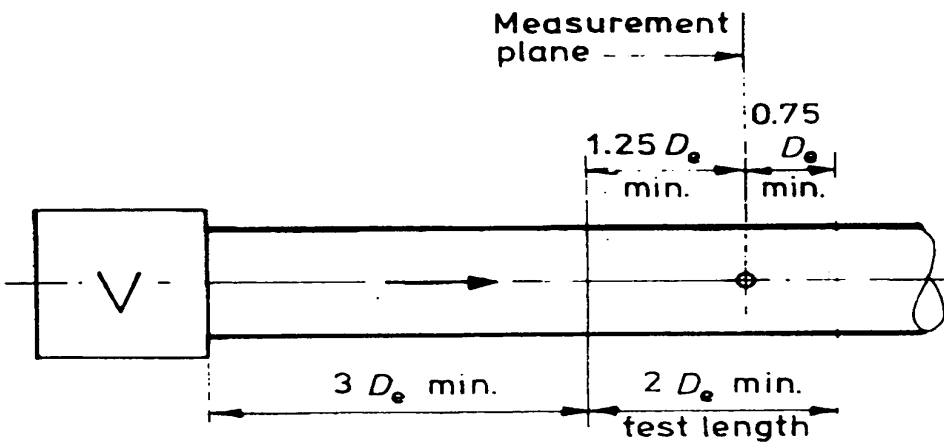


NOTE. For installation type D it is essential that pressure is measured on both inlet and outlet of the fan.

Figure 2 - Location of pressure measuring plane for site testing.



Test length on inlet side of fan



Test length on outlet side of fan

Figure 3 - Location of the flow measuring planes for site testing.

There is at present, waiting in the wings, a draft ISO/DIS 5802 standard entitled 'Industrial fans - Methods of performance testing in situ' and will be compulsive reading for those testing on site.

How to measure pressure.

It is not proposed to venture to fully into the fundamental principles as this has been covered in previous seminars, except to say that the only pressure acting a point in a stationary fluid is hydrostatic pressure which acts equally in all directions.

When the fluid is set in motion, there is an additional dynamic pressure due entirely to the motion of the flow and the density of the fluid.

The algebraic sum of the static pressure and the velocity pressure is called the total pressure.

Pressure measurements are usually made relative to atmospheric pressure and are corrected to 'Standard Conditions' such that comparisons between readings are possible.

The internationally agreed 'Standard Conditions' for air having a density of 1.2 kg/m^3 .

Practical methods of measuring volume flow rate.

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 4 shows the principle of the pitot static tube. It will be seen that connecting tubes to a manometer makes the measurement of pressure.

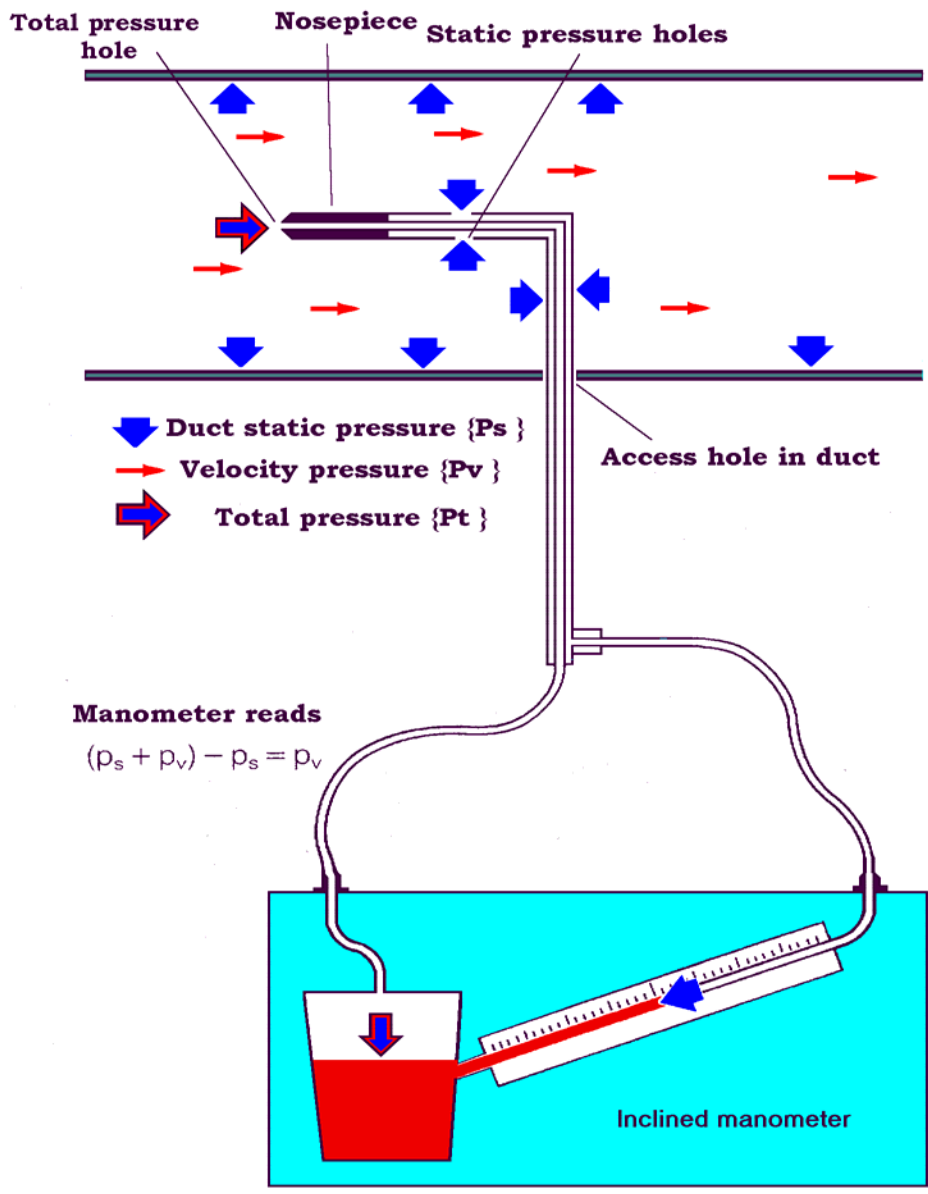


Figure 4. Principle of the pitot static tube.

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.

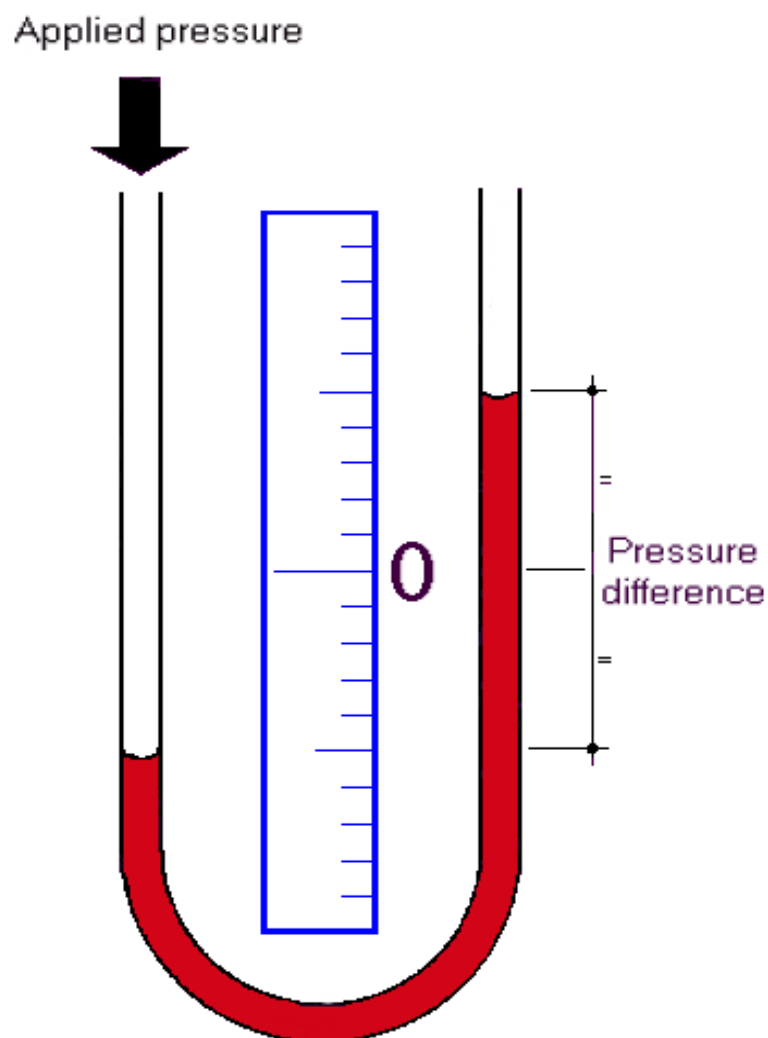


Figure 5. Principle of the U-tube manometer.

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.

[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.

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 6: Airflow Developments Ltd PVM100 Micromanometer.

How to measure volume flow rate.

FORMULAE.

$$\text{Volume flow rate} = \text{Mass flow rate} / \text{Density.}$$

or

$$\text{Volume flow rate} = \text{Velocity} \times \text{duct cross-section area.}$$

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 : 1997 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 volume 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 7 and 8.

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:

$$V = 1.291 \sqrt{p_v} \text{ (m/s)}$$

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

For non - standard air conditions the formula becomes:

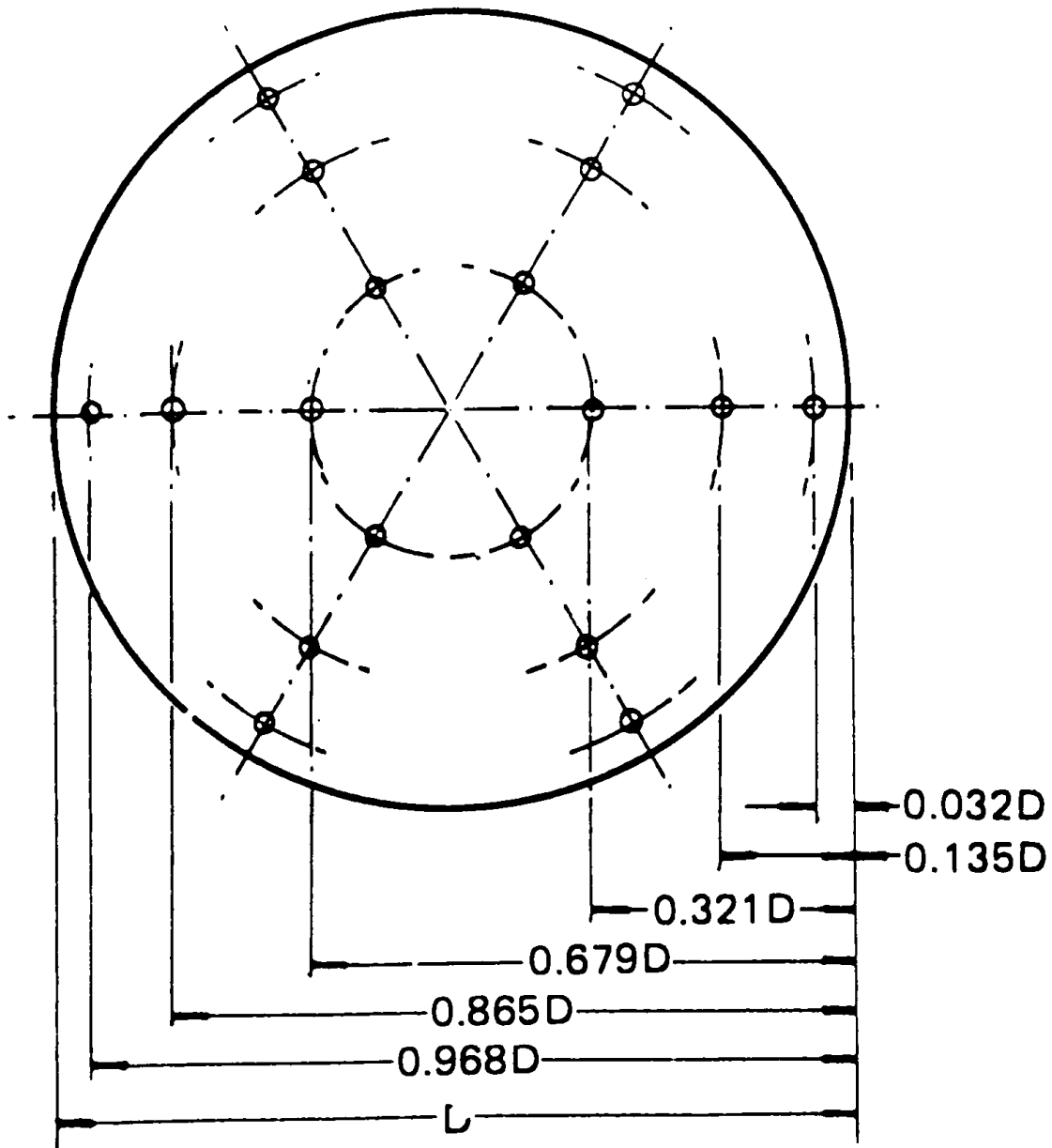
$$V = 1.291 \sqrt{\{100000/p_a\} \{T/289\} \{100000/(100000+p_s)\} \{p_v\}} \text{ (m/s)}$$

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)

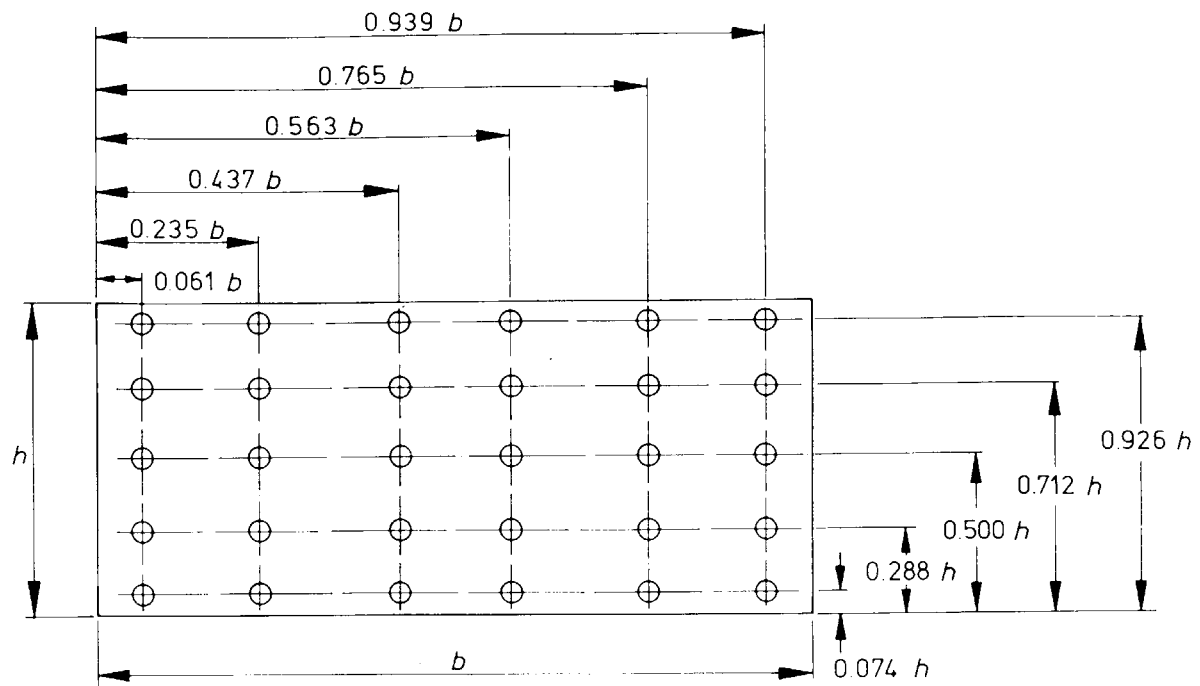
The expressions {100000/p_a} , {T/289} and {100000/(100000+p_s)} are corrections for atmospheric pressure, air temperature, and duct pressure to bring the measured value of p_v to the equivalent of standard air. If the duct static pressure is less than 2500 Pa. it can normally be ignored. Similarly, 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 vary by more than about ± 25% from the mean value.



Log Linear rule for traverse points on 3 diameters in a circular duct

Figure 7. Measuring points for circular ducts. Log linear rule for traverse points on 3 diameters.



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 8. 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 air stream. 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 9 shows the typical increase in velocity reading when placed in different sized ducts.

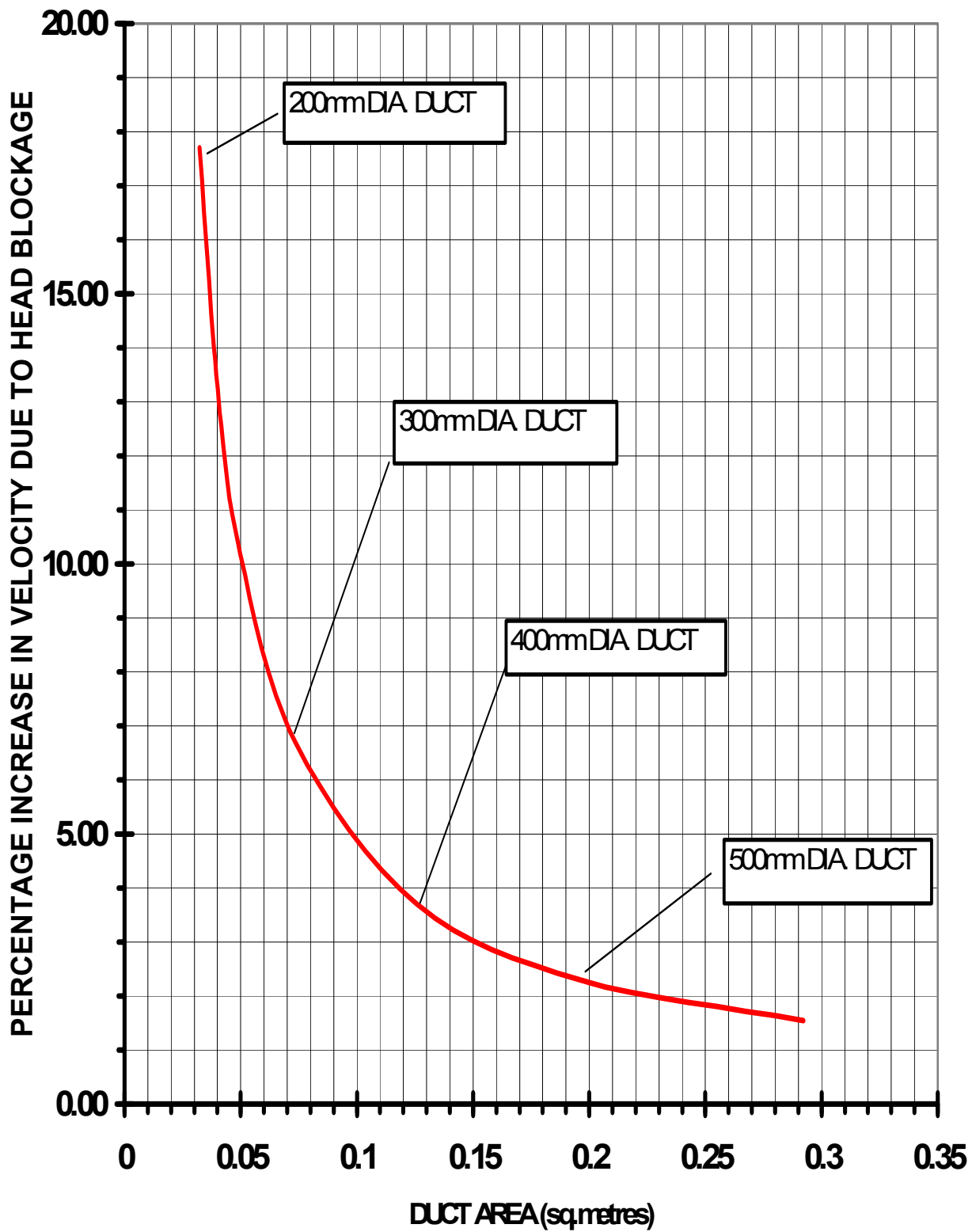
It is possible to have one anemometer head centrally located in its own test duct and be independently calibrated for volume flow rate.

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 9:-100 mm ANEMOMETER HEAD BLOCKAGE EFFECT.



[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.

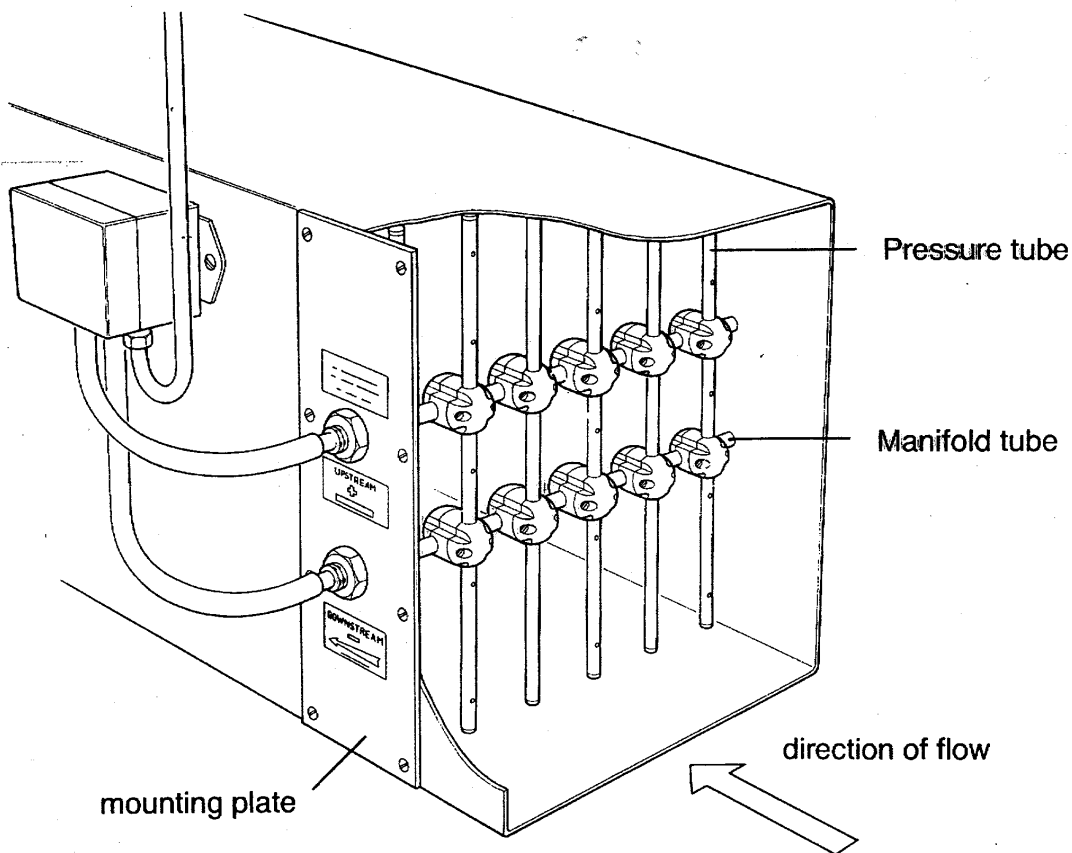


Figure 10: AIRFLOW™ TA3 thermal anemometer.

[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 signals constitutes an enhanced output signal.

Figure 11. 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.

Accuracy of readings.

Single point and multi-point measuring devices have been considered for the measurement of volume flow rate.

Where there are obstructions upstream of the measuring section, typical lengths of straight ducting between the obstruction and the measuring section in order to maintain a given accuracy with repeatability of measurement are given below:

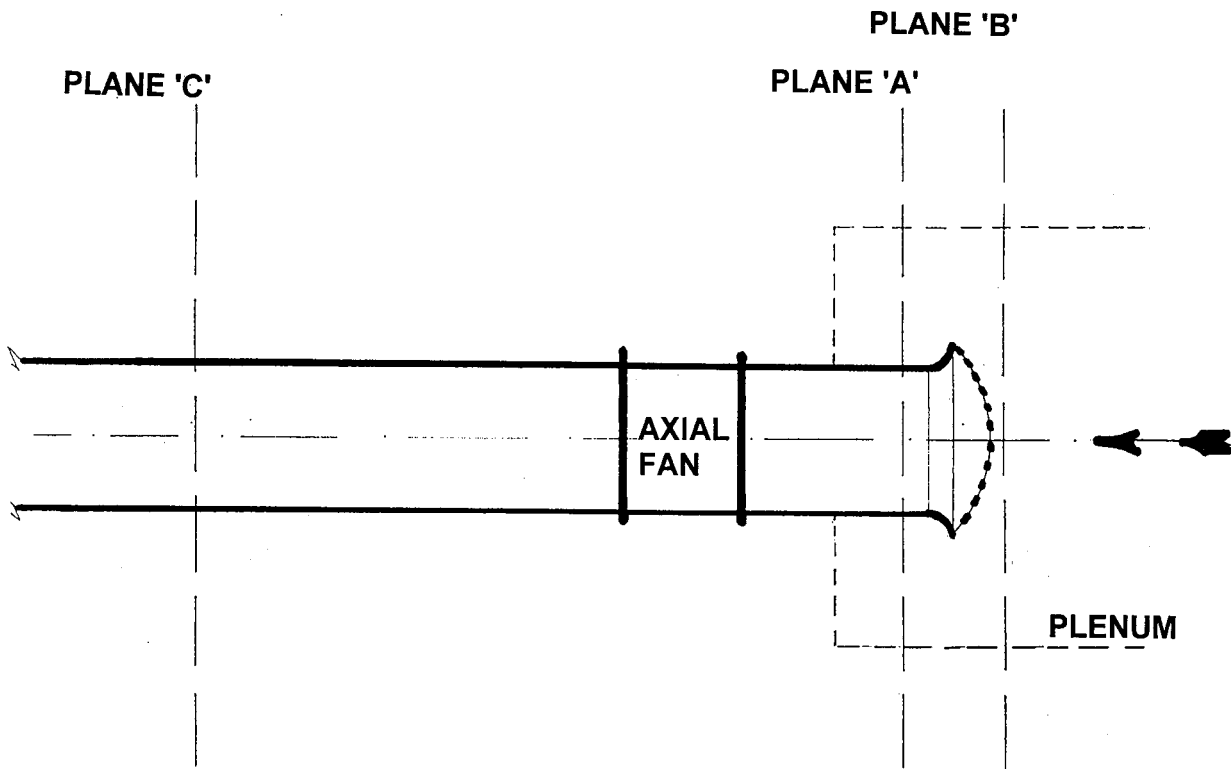
	Multi-point	Multi-point	Single-point	Single-point.
OBSTRUCTION	Straight length req. for $\pm 5\%$	Straight length req. for $\pm 10\%$	Straight length req. for $\pm 10\%$	Straight length req. for $\pm 15\%$
Right angled bend	5D	3D	10D	3.5D
Radius bend R=1D	5D	2D	10D	3.5D
Opposed blade damper	5D	2D	10D	3.5D
30° bend	3D	1D	3.5D	2D
Tapered contraction	2D	1D	3.5D	2D
Sudden contraction	2D	1D	3.5D	2D

Note: For circular ducts D = Diameter of the duct
 For rectangular ducts D = (width + height of the duct) / 2.

Practical example of measuring the volume flow rate on site.

I recently received a telephone call from an engineer in India. He had purchased a vane anemometer and was querying what figure he should use for the 'area' in order for him to calculate the inlet volume flow rate of a fan.

It transpired that he was taking velocity measurements at a plane somewhere close to a bellmouth inlet which was not of conventional shape. Additionally, in the interests of safety, there was a wire mesh attached to the inlet.



The fan and associated ducting was 710 mm diameter.

- [1]/. Should he mount the anemometer within the duct section at plane 'A' and make an allowance for any blockage caused by its presence?
Answer: Yes you should, but look you have an axial fan very close and the flow pattern is inevitably going to have a swirl condition.
This could enhance the reading from the anemometer, or even reduce the reading, as the flow pattern will be influential.
Thus, this is not an ideal situation.
- [2]. How about a velocity traverse at the intake (at plane 'B')?

Answer: Again the positioning is not ideal. You will get a velocity reading, but you must take due account of the direction of the velocity.

Solution:

Using the anemometer:

[3]. Create a plenum chamber that will not interfere with the air pattern at the intake. Carry out a traverse across the inlet to the plenum; compute an average velocity and multiply it by the plenum face area.

[4]. There is a long length of straight ducting attached to the fan outlet. Carry out a velocity traverse at plane 'C'.

Alternatively, you could:

[5]. Carry out a pitot traverse at plane 'C'.

[6]. Utilise the inlet cone, by adding static pressure tapping points at plane 'A', measure the static pressure and compute the volume flow rate using the following formula:

$$Q_v = 1.291 A \alpha \sqrt{p_s}$$

where

Q_v	=	volume flow rate in m^3/s .
A	=	cross sectional area in m^2
p_s	=	static pressure in Pa.
α	=	entry coefficient. (0.85).

This method adopts Bernoulli's theorem that the drop in static pressure which takes place when air accelerates in an air stream is equal to the rise in dynamic pressure which takes place. This assumes no friction effect, (which in practice increases the numerical value of the static pressure. There has been a lot of tests carried out on different types of entry and reliable data exists for the entry coefficient.

The entry coefficient is defined as the factor which the square root of the static pressure has to be multiplied by in order to obtain the equivalent square root of the velocity pressure.

Don't forget. You are carrying this operation out in India and you must take due allowance of the site temperature where necessary.

[I know that this is a very simple case, but it does demonstrate where problems can occur. If you are in any doubt, refer the problem to the fan manufacturer. Most are affiliated to FMA and have BSI registration. They can be useful and trustworthy.]