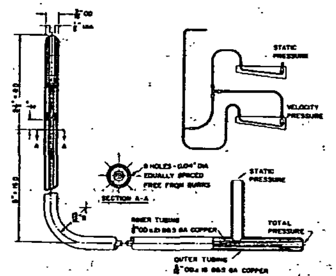

Fig. 3 .... Standard Pitot Tube

Cup Anemometer

The cup-type anemometer is almost universally used for measuring wind speeds. It consists of three or four hemispherical cups mounted radially from a vertical shaft. Wind from any point of the compass will cause the cups and shaft to rotate. The instrument is usually so constructed that wind speeds may be recorded or indicated electrically at some remote point.

Pitot Tube

The Pitot tube, used in conjunction with a suitable manometer, provides a simple method of determining the air velocity in a duct. The construction of a Standard Pitot Tube,[11] and the method of connecting it to a draft gage is shown in Fig. 3. The equation for determining the air velocity from the measured velocity pressure is as follows:

$$V = 1096.5\sqrt{\frac{h_w}{\rho}} \quad (3)$$

where

V = velocity, feet per minute.
h_w = velocity pressure (Pitot tube manometer reading), inches of water.
ρ = density of air, pounds per cubic foot.

Since the velocity in a duct is seldom uniform across any section, and since a Pitot tube reading indicates a velocity at only one location, a *traverse* is usually made to determine the average velocity so that the flow can be computed. In general, the velocity is lowest near the edges or corners, and greatest at or near the center. Suggested Pitot tube locations for traversing round and rectangular ducts are shown in Fig. 4. In round ducts not less than 20 readings should be taken along two diameters at centers of equal areas as shown. In rectangular ducts the readings should be taken in the center of equal areas over the cross-section of the duct. The number of spaces should not be less than 16, and need not be more than 64. When less than 64 are taken, the number of equal spaces should be such that the centers of the areas are not more than 6 in. apart. In determining the average velocity in the duct from the readings given, the calculated individual velocities or the square roots of the velocity heads must be averaged. It is incorrect to use the average velocity head for this purpose.

Since the low peripheral velocities are not measured, the air flow calculated by this method is usually slightly high. Where the velocity profile is unstable or asymmetric, a greater number of readings should be taken. The use of traverses at the inlets and outlets of ducts requires special techniques.[25-28] Those contemplating such measurements should consult the references cited.

Pulsating or disturbed flow will give erroneous results and therefore, if possible, the Pitot tube should be located at least 7½ diameters downstream from a disturbance such as that caused by a turn. Straightening vanes[11] located 1½ duct diameters ahead of the Pitot tube will serve to improve the precision of the measurements.

The type of manometer to be used with a Pitot tube depends upon the magnitude of the velocity pressure being measured and the accuracy desired. At velocities greater than 1500 feet per minute, a draft gage of appropriate range is usually satisfactory. If the Pitot tube is being used to measure low air velocities, a precision manometer of some type is essential.

Many forms of Pitot tubes, other than the one described, have been used and calibrated.[21] A double-ended tube,[22] one end pointing downstream, and one upstream, is sometimes used for low velocities, but it should be carefully calibrated for accurate results. A special form of this tube design consists of two straight ⅛-in. tubes soldered together, closed at the end, and with a 0.04 in. hole in each tube opposite the line of contact. This tube is useful in exploring velocities in exhaust inlets, such as hoods placed around grinding wheels. To meet special conditions, different sized Pitot tubes which are geometrically similar to the standard tube can be used.

Impact Tube

For relatively high velocities and use in small tubes, total pressure readings may be obtained using some form of impact tube. Where the static pressure across the stream is relatively constant, as in turbulent flow in a straight duct, a side-wall tap for static pressure may be used in conjunction with the impact tube to obtain velocity pressure. One form of impact tube is a small tube placed in a position perpendicular to the stream and having a fine hole in its upstream side.

Where a side-wall tap cannot be used because of variable static pressure across the stream a variety of pressure-sensing probes have been used. One of these is a wedge-shaped probe with static holes in the side walls. Another is the Fechheimer tube, a round transverse tube with two holes set at exactly

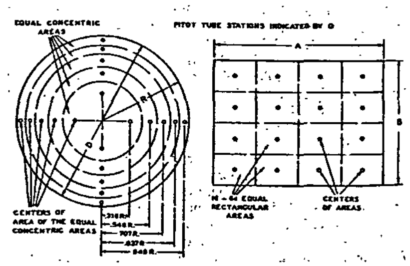

Fig. 4 .... Pitot Tube Traverse for Round and Rectangular Ducts

Table 5 .... Measurement of Volume or Mass Flow Rate

No.	Measurement Means	Application	Range	Precision	Limitations
1	Orifice and manometer	Flow through pipes, ducts and plenums—all fluids	Above Reynolds number of 5,000	1%	Coefficient and accuracy influenced by approach conditions
2	Nozzle and manometer	"	"	1%	"
3	Venturi tube and manometer	Same as 1 and 2 above but used where permissible pressure drop is limited	"	1%	"
4	Rotameters	Normally used for liquids	Any	1%	Must be calibrated for the liquid with which used
5	Timing a given weight flow	Liquids only—used for calibrating other flow means	Any	0.1%	—
6	Displacement meter	Relatively small volume flow at high pressure drop	As high as 1,000 cfm depending on type	0.2–2.0% depending on type	Some types require calibration
7	Gasometer or volume displacement	Short duration tests; used for calibrating other flow means	Total flow limited by available volume of containers	0.5–1.0%	—
8	Element of resistance to flow and manometer	Used for check where there is calibrated resistance element in the system	Lower limit set by readable press drop	1–5%	Secondary reading depends on accuracy of calibration
9	Thomas meter (temperature rise of stream due to electrical heating)	Where elaborate setup is justified by need for good accuracy	Any	1%	Uniform velocity, usually used with gases
10	Heat input and temperature change with steam or water coil	Check value in heater or cooler tests	Any	1–3%	—
11	Instrument for measuring point velocity	Primarily used in installed systems where no special provision for flow measurements have been made	Lower limit set by accuracy of velocity measurement	2–4%	Accuracy depends upon uniformity of flow and completeness of traverse

determined opposite sides of the air direction. Both of these instruments must be carefully made and calibrated. This probe technique should be limited to Mach numbers of 0.3 to 0.5.

VOLUME OR MASS FLOW RATE MEASUREMENT

Means of measuring flow rate are listed in Table 5. Gas and liquid mass or volume flow rates are most often determined by measurement of the pressure difference across an *orifice*, *nozzle*, or *Venturi tube*. The orifice is more easily changed than is the nozzle or Venturi tube and is less affected by change of Reynolds number. The nozzle is often preferred to the orifice because of its relative freedom from the influence of approach conditions and accurate predictability of its coefficient. The Venturi tube is in essence a nozzle followed by an expanding recovery section to reduce the net pressure drop.

Liquid flow may be measured with good precision by *timing a given weight flow*. While this method is commonly used for calibrating other methods, it is particularly useful where the flow rate is low or intermittent and where a high degree of precision is required. A convenient direct-reading flow-meter for liquids and gases is the *variable area meter* (*rotameter*), which comprises a transparent tapered tube in which the rate of flow is indicated by the position assumed by a bob or plug suspended in the upward flow.

For measuring total liquid or gas flow over a period of time, many types of *displacement meters* are available. The two major types for gases are the *gas* meters, which employ leather bellows commonly, and the *wet test* meters, which use a water displacement principle. The *Thomas meter* has been used in the laboratory for measurement of high gas flow rates with a small pressure drop. The gas is heated by electric heaters and the temperature rise measured by two resistance thermometer grids. Knowing the heat input and temperature rise, the flow is calculated as the quantity of gas that will remove the equivalent heat at the same temperature rise.

For field measurement of air flow rates or calibration of large nozzles, a frequently used method is to make a *velocity traverse*, using for the purpose a *Pitot tube* or other velocity-measuring instrument. This method is inapplicable in many cases because of its lack of precision on low velocities or the impracticability of taking traverses where many test runs are in prospect.

Another relatively rough field testing method is to take the *pressure drop* across elements having known pressure-drop characteristics, such as heating and cooling coils, or fans. If the pressure drop-flow rate relationship is calibrated previously, fair precision can be obtained, but if dependence is placed on rating data the method should be used for check purposes only.

Venturi Meter, Nozzle, Orifice

Consideration will first be given to three flow measuring devices: Venturi meter (Fig. 5), flow nozzle (Fig. 6), and orifice plate (Fig. 7). The location of pressure taps used with flow nozzles is shown in Fig. 8.