

**U.S. EPA BASE STUDY
STANDARD OPERATING PROCEDURE
FOR HVAC SYSTEM AND
MOBILE MEASUREMENTS**

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1.0 OBJECTIVE

The objective of the procedures described is to characterize the performance of the HVAC system that supplies air to the indoor area under study. Three air flow streams are of principal interest.

1. Outdoor air -- air supplied to the indoor space from outside the building
2. Return air -- air exiting the indoor space
3. Supply air -- air entering the indoor space (generally a mixture of return air and outdoor air)

The following parameters are measured as part of the HVAC systems' measurements.

- Volumetric flow rates of outdoor air and of supply air
- Instantaneous carbon dioxide (CO₂), relative humidity (RH) and temperature measurements of supply air, return air, and outdoor air
- Local measurements of supply air distribution within the study area
- CO₂, RH and temperature of air supplied to the study area
- Continuous monitoring of CO₂ concentrations in the supply air, return air, and outdoor air for the air handling systems serving the study area

The relative humidity, temperature, and CO₂ content of outdoor air are simultaneously monitored at the outdoor site. These procedures are covered under a separate protocol (see SOP for Continuous Monitoring of Outdoor Air).

The measured parameters, in combination with the simultaneously monitored characteristics of indoor and outdoor air, are used to calculate percent outdoor air intake rate, to check the overall performance of the HVAC system against design criteria, and to evaluate the ventilation efficiency for the indoor space studied.

2.0 GENERAL PROCEDURES

2.1 INSTRUMENTS

The following instruments are used to perform measurements.

2.1.1 Anemometer

The anemometer used for air velocity measurements is a TSI Model 8350 (TSI Inc., Saint Paul, Minnesota), or equivalent, instrument. The nominal instrument accuracy for different flow ranges is summarized in the table below. The instrument readings are temperature compensated in the range of 5°C to 60°C. The TSI 8350 is also equipped with a temperature sensor which permits simultaneous measurement of air temperature at the points where air velocities are measured. The instrument has an adjustable time constant (1s, 2s, 5s, 10s, 15s, or 20s) for smoothing fluctuations of measured velocity in a turbulent flow field. The instrument can store up to 255 individual readings and average them on command from the operator. The meter has an operating range of 40°F to 125°F (5°C to 52°C).

VELOCITY (fpm)*	30 to 500	500 to 2,000	2,000 to 6,000	6,000 to 9,999
RESOLUTION (fpm)	1 fpm	5 fpm	10 fpm	20 fpm
ACCURACY**	2.5% of rdg or ±2.5 fpm	2.5% of rdg or ±2.5 fpm	2.5% of rdg or ±2.5 fpm	
* Velocity Range = 5 to 9,999 fpm (0.08 to 50.00 m/s) ** Temperature compensated over an air temperature range of 40°F to 150°F (5°C to 65°C)				

2.1.2 CO₂ Concentration, Monitor, and Datalogger

The CO₂ concentration inside the supply air and return air ducts are monitored continuously with a TSI Model 8550 Q-Trak Monitor. This is a portable instrument designed for spot readings or continuous logging of CO₂ concentration, relative humidity, and temperature of air.

The CO₂ sensor of the TSI Model 8550 is non-dispersive infrared (NDIR) with a manufacturer quoted accuracy of $\pm 3\%$ of the reading ± 50 ppm (e.g., ± 80 ppm for a concentration of 1,000 ppm) with an additional uncertainty of $\pm 0.11\%/^{\circ}\text{C}$ for changes in temperature away from 25°C. The sensor range is 0 to 5000 ppm and the response time (to 63% of final value) of the instrument is 20 seconds.

The relative humidity sensor of the TSI Model 8550 is thin-film capacitance-based with a manufacturer quoted accuracy of $\pm 3\%$. The sensor range is 0 to 95% RH and its response time (to 63% of final value) is 20 seconds.

The temperature sensor is a thermistor with a range of 0 to 50°C, and an accuracy of 0.6°C. Its response time (to 63% of final value) is 120 seconds.

To continuously sample the supply and return air CO₂ concentrations, the data logger is programmed to sample at a rate of 4 readings per minute with readings averaged over a 5 minute period (20 readings).

2.1.3 Balometer

A factory-calibrated ALNOR digital Balometer (flow hood) (ALNOR Balometer, ALNOR Instrument Co., Skokie, Illinois) is employed for measuring volumetric flow rates of air from diffusers distributing supply air to local areas within the space under study. This instrument may be used for measuring flow rates between approximately 50 cfm and 2,000 cfm (3,400 m³/h). Below 50 cfm the balometer gives no useable data. The nominal accuracy of this instrument is $\pm 3\%$ full scale up to 1,300 cfm (2,200 m³/h), and $\pm 4\%$ full scale for larger flow rates. Two hood sizes (2'x2' and 1'x4') are generally necessary to make measurements on commonly encountered diffuser types, although other hood shapes are available. The response time of the instrument is 4 seconds. The operational temperature range of the instrument is 0 to 50°C. Performance data for the ALNOR digital balometer is detailed in Table 2.2.

Table 2.2 ALNOR Balometer resolution and accuracy				
Flow range (cfm)	0-250	100-500	400-1,000	800-2,000
Resolution (cfm)	5	10	20	50
Accuracy (cfm)	7.5	15	30	60 to 80

2.1.4 Temperature and RH Measurements at Diffusers

Temperature and relative humidity of air supplied through diffusers at the indoor study sites is measured with a portable temperature/RH meter (e.g., Cole Parmer Model AH-37950-10 (Cole-Parmer Instrument Co. Niles, Illinois), Rotronics PA1-SET, TSI 8550, or equivalent). The manufacturer quoted accuracy of temperature sensor of the Cole Parmer Model AH-37950-10 instrument is $\pm 0.5^{\circ}\text{C}$ and its resolution $\pm 0.1^{\circ}\text{C}$.

The manufacturer quoted accuracy of the relative humidity sensor of the Cole-Parmer Model AH-37950-10 instrument is $\pm 3\%$ RH and its operational range is 10 to 95% RH.

2.1.5 CO₂ Concentration Measurements at Diffusers and HVAC System Air Streams

The CO₂ sensor employed for CO₂ concentrations at both the local diffusers as well as within the air handling system supply air, return air, and outdoor air streams, is a FUJI Model ZFP-5 Portable Gas Analyzer (California Analytical Instruments, Inc. Orange, California). The FUJI instrument utilizes non-dispersive infrared absorption for detecting gases present in the sample. The analyzer contains a built-in pump which draws a filtered sample into a measuring cell (“active” sampling). A beam of infrared light is passed through the cell and is attenuated by the CO₂ present in the sample. The degree of attenuation is related to the concentration of CO₂ in the gas sampled. The precision (repeatability) of the instrument is, according to the manufacturer’s specifications, $\pm 5\%$ (approx. ± 20 ppm for outdoor air). For comparison, the BASE Method Performance Requirement for precision is ± 50 ppm and ± 200 ppm for accuracy. The instrument requires a warm-up period of 15 minutes, and its response time (to 90% of the final value) is 10 seconds.

2.2 MEASUREMENTS

The following measurements are performed as part of the HVAC system characterization.

2.2.1 Air Velocity Measurements Across Supply Air, Return Air, and Outdoor Air Duct(s) or “Traverses”

The supply air, return air, and outdoor air flow rates are determined for each air handling unit (AHU) servicing the indoor area under study. Air velocities are measured with a hot wire anemometer inserted into the supply, return, and outdoor air ducts through pre-drilled holes. Air flow rates must be measured twice daily (a.m. and p.m., simultaneously with mobile cart measurements conducted in the study area) on Wednesday and Thursday of the study week. Supply air volume measurements are also performed on the Tuesday afternoon of the study week.

It is critical to select for the traverse measurements a cross-section of the duct that has a regular shape (circular, rectangular) and a reasonably uniform flow velocity (typically $\pm 10\%$) across the section. A location well downstream of fans and more than two duct diameters downstream of constrictions or bends should be selected. For details of how to plan traverse measurements consult the sections from AMCA Publication 203-90 found in Appendix A (*Field Performance Measurement of Fan Systems*. AMCA Publication 203-90. Air Movement and Control Association, Inc.: Arlington Heights, IL).

All traverse measurement locations are selected and marked a day before the measurements are performed. (According to the BASE schedule this requires preparation on Tuesday for measurements on Wednesday and Thursday).

As part of the BASE Protocol, measurements of volumetric air flow rates are performed on the air handling system supply air and outdoor air delivery rates. In most cases, appropriate locations can be found to measure the total supply air delivery rate. However, finding appropriate locations to measure outdoor air delivery rate can be difficult. In cases where this is the case, measurements should be conducted on the return air systems and the outdoor air delivery should be calculated based on the difference in supply air and return air delivery rates.

After selecting test points in accordance with the criteria specified in AMCA 230-90, the corresponding distances from a reference point are marked on the shaft of the anemometer probe, so that its tip can be positioned accurately inside the duct. Care must be taken to position the anemometer (hot wire) orthogonally to the flow direction. This position can be found by turning the anemometer probe until its reading is maximized.

If the TSI Model 8350 instrument is used, the time constant is set to 1 second and the appropriate number of measurements are taken across the duct section in accordance with AMCA 230-90. The average velocity across the duct section is calculated by summing the measurements and dividing the sum by the number of measurements.

NOTE: The instrument must be cleared (“CLEAR” key pressed) before proceeding to the next measurement averaging sequence. **All data must be recorded on a log sheet, even if it is also being entered directly into the computer database.**

2.2.2 Air Handling Unit Temperature and Relative Humidity Measurements

Temperature and relative humidity measurements are conducted on the AHU supply air discharge, return air inlet and the outdoor air intake. To measure temperature, press and hold down the “TEMPERATURE” key until the display reads “TEMP”. The instrument is then ready to measure temperatures in degrees F. Likewise, to measure relative humidity, press and hold down the “relative humidity” key until the display reads “RH”. The instrument is then ready to measure relative humidity in percent.

All measurement data is entered on a log sheet (for double checking of entries) and into the IADCS database. Additional explanatory notes may be entered in a field notebook for later entry into the IADCS database.

2.2.3 Continuous Monitoring of CO₂ Concentrations

The CO₂ concentrations of the supply and return air for each air handling unit serving the study area are continuously monitored employing a TSI Model 8550 Q-Trak CO₂ detector. The datalogger of the instrument is set for recording at a rate of four readings per minute.

The following apparatus is employed for continuous HVAC CO₂ measurements.

- Teflon or latex sampling lines
- Two positive displacement sampling pumps (one used for the AHU supply air, the other used for the AHU return air)
- Air bleed valves located on the discharge side of the sampling pump (used to adjust flow rate to the CO₂ sensor).
- Two TSI Model 8550 Q-Tracks (one used for the AHU supply air, the other used for the AHU return air)
- Calibrated rotameter

Note: If sampling on more than one air handler serving the study area, a duplicate setup of the above listed apparatus will be required.

After selecting the appropriate sites for continuous monitoring, a 3/8" hole is drilled in the duct wall. Sampling lines are inserted into each duct and, using a sampling line of appropriate length, each line is run to a centralized area where the sampling apparatus will be located. An illustration of this setup is detailed in Figure 1 of Appendix B.

The sampling lines, positive displacement pump, bleed off valves and CO₂ sensor are connected as shown in Figure 1. Prior to connecting the sensor line to the CO₂ sensor port, the sample flow rate is adjusted to approximately 1.0 LPM using the calibrated rotameter and bleed off valves. Once the sample flow rate has been adjusted, the sample line is connected to the calibration port on the CO₂ sensor. Logging can now begin.

The set-up must be completed on Monday of the study week and logging of the CO₂ concentrations is started on Tuesday morning. Data from the loggers is downloaded on Tuesday and Wednesday afternoon, and final downloading is done at the end of continuous monitoring on Thursday afternoon.

2.2.4 Flow Rates Through Diffusers and Exhausts

The volumetric flow rates through all supply diffusers and exhausts, including special or dedicated exhausts (bathrooms, kitchens, hoods) located in the study area are measured on Tuesday of the study week. The air flow through the diffusers and exhausts is typically measured with a flow capture hood balometer. However, logistical constraints may require that these measurements be conducted with a hot-wire anemometer.

For Analog Output Balometer Only

*Before conducting the flow rate measurements, check the zero adjustment of the Balometer. This is done by placing the instrument away from any air flow, setting the range selector to the **OFF** position, and verifying that the meter reads zero. If necessary, the zero must be adjusted at its “zero” screw.*

To make the flow rate measurement, the balometer is turned **ON** and its range selector set to the highest reading. Select the flow direction , “SUPPLY” or “RETURN” for measuring flow through supply diffusers and exhausts or return grilles, respectively. Then the Balometer is brought in contact with a perimeter around the diffuser to be measured. To assure maximum accuracy, the foam gasket along the top of the hood frame must be firmly in contact with the surface around the opening and the diffuser must be fully enclosed by the hood frame.

The measured flowrate is recorded on the appropriate log sheets and later entered directly into the IADCS.MTR database. The readings from the balometer are in units of cubic feet per minute.

NOTE: WHEN USING THE BALOMETER TO MEASURE AIR FLOW AT CEILING DIFFUSERS MAKE CERTAIN THAT YOU CAN SAFELY RAISE AND HOLD THE UNIT WHILE MAKING THE MEASUREMENT. THIS IS ESPECIALLY IMPORTANT WHEN WORKING ON A LADDER.

2.2.5 Mobile Cart Measurements

Volumetric flow rates, relative humidities, temperatures and carbon dioxide concentrations of air supplied through diffusers at the indoor sites under study are measured under the "mobile cart" protocol. These measurements must be performed twice daily (a.m. and p.m.) on Wednesday and Thursday of the sampling week, at approximately the same time that the supply duct traverses are being made. A sensory inspection of the area surrounding the mobile monitoring site is also performed as part of the "mobile cart" task.

The "mobile cart" carries a balometer for measuring volumetric flow rates of air at supply diffusers, a probe to measure temperature and pressure of air at the diffuser, an active CO₂ sampler connected via a flexible hose to the air stream discharged from the diffuser. Measurements are made at three "fixed" and two "mobile" sites selected by procedures defined in the BASE protocol. All data collected is recorded on the appropriate log sheets and later entered into the IADCS.MTR database. The following is a breakdown of the measurements conducted as part of the mobile monitoring.

Volumetric Air Flow Rate. In following the BASE Protocol, an air supply diffuser in the immediate vicinity of the indoor sites (three "fixed" and two "mobile") is selected for measurements. The air flow through the diffuser is measured with a flow capture hood balometer. The measurements are conducted by the procedure outlined in Section 2.2.4.

Temperature, Relative Humidity and CO₂ Concentrations. Temperature and relative humidity of air supplied through diffusers is measured by placing the sensor probe of a hand-held RH/temperature meter through a slit in the diffuser grille. After sufficient time is allowed for the readings to stabilize (generally 2 to 5 minutes) the measured

temperature and relative humidity are recorded on the appropriate logsheets. To measure CO₂ concentration of air supplied through the diffuser, the end of a length of flexible tubing connected at the other end to an active CO₂ sampling instrument, is placed at the discharge of the diffuser grille. After the instrument readings have stabilized, they are recorded on the appropriate log sheets.

Flow Rates Through Exhausts and Exhaust Fan Status Checks. The flow rate through dedicated exhausts (bathrooms, kitchens) is measured only once during the study week (typically on Tuesday). Exhaust fan operation is verified throughout the entire study week during the periods when mobile monitoring is conducted. The exhausts are inspected by either observing the flutter of a section of tissue paper placed near the exhaust or by a visual means. This information is recorded on the appropriate logsheet.

3.0 CALIBRATIONS AND QUALITY CONTROL

3.1 TEMPERATURE SENSOR

The temperature sensor is checked against NIST-calibrated thermometers (secondary standards), throughout the study week. Should the sensor deviate by more than $\pm 1^{\circ}\text{C}$ (2) from the secondary standard, the deviation will be recorded and the sensor will be adjusted to correct its reading.

3.2 RELATIVE HUMIDITY SENSOR

The RH sensor is checked against one of several calibrated RH sensors available in the field (see RH Measurements in SOP for Continuous Monitoring at Indoor Sites) throughout the study week. Should the sensor deviate by more than $\pm 6\%$ RH (2) from the laboratory-calibrated standard, the deviation is recorded and the sensor is adjusted to correct its reading.

3.3 FUGI MODEL ZFP-5 CARBON DIOXIDE SENSOR

Prior to each mobile cart measurement and HVAC performance measurement routine, the instrument is zeroed and spanned using calibration gases of zero CO_2 and a known concentration in the 400 to 600 ppm range, respectively.

3.4 TSI MODEL 8550 Q-TRACK CARBON DIOXIDE SENSOR

Each continuous CO_2 sensor will be zeroed and spanned on Tuesday, Wednesday mornings and Thursday afternoon, prior to the take down of the sampling site. The instrument will be zeroed and spanned using calibration gases of zero CO_2 and a known concentration in the range of 600 to 1000 ppm, respectively.

3.5 AIR VELOCITY SENSOR

The TSI Model 8350 hot wire anemometer is factory calibrated yearly to NBS traceability. No field calibrations will be done on this instrument.

3.6 BALOMETER

The Alnor Digital Balometer is factory calibrated yearly to NBS traceability. No field calibrations will be done on this instrument.

4.0 DATA DOWNLOADING

Data collected by the TSI Q-Trak monitors is downloaded to a laptop computer on Tuesday, Wednesday, and Thursday afternoons.

A log book is kept for all sensors and instruments used for HVAC measurements. All procedures and observations conducted with the sensors and instruments, particularly results of comparisons with other instruments and readjustments of output, are recorded in the site logbook.

APPENDIX A

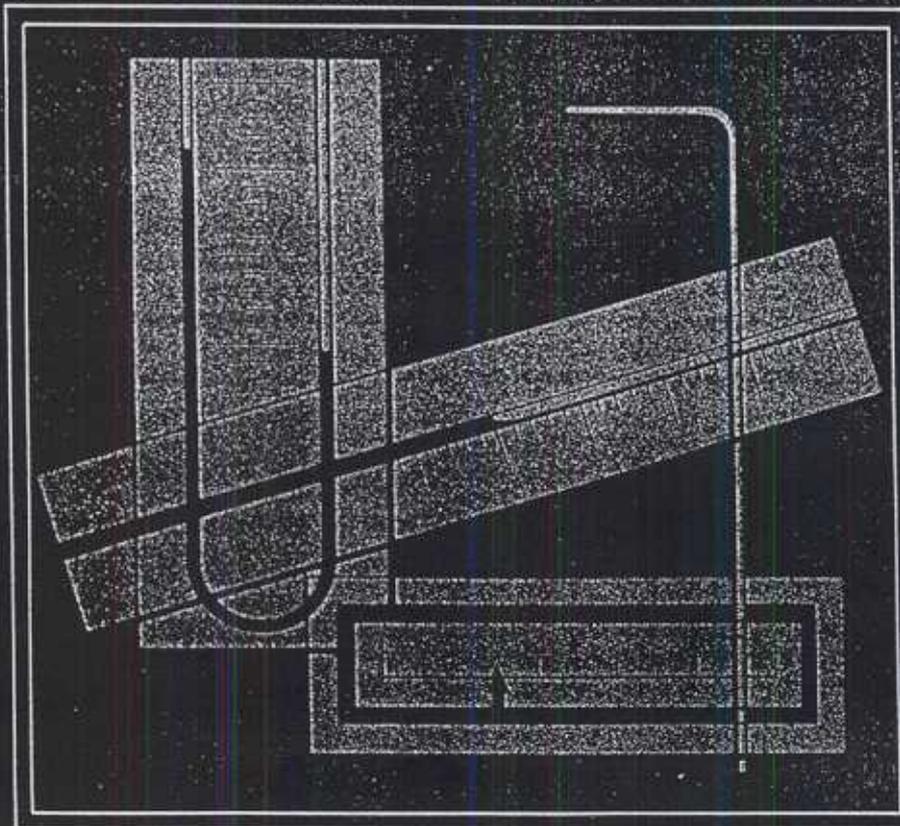
**AMCA PUBLICATION 203-90
PAGES 4 - 8 AND 112-113**



AIR MOVEMENT
AND CONTROL
ASSOCIATION, INC.

FIELD PERFORMANCE MEASUREMENT of Fan Systems

PUBLICATION 203-90



FIELD PERFORMANCE MEASUREMENT OF FAN SYSTEMS

1. INTRODUCTION

Performance ratings of fans are developed from laboratory tests made according to specified procedures on standardized test setups. In North America the standard is ANSI/AMCA Standard 210, ANSI/ASHRAE 51, *Laboratory Methods of Testing Fans for Rating*.

In actual systems in the field very few fans are installed in conditions reproducing those specified in the laboratory standard. This means that, in assessing the performance of the installed fan-system, consideration must be given to the effect on the fan's performance of the system connections including elbows, obstructions in the path of the airflow, sudden changes of area, etc. The effects of system conditions on fan performance is discussed in Section 5 and more completely in AMCA Publication 201, *Fans and Systems*.

A major problem of testing in the field is the difficulty of finding suitable locations for making accurate measurements of flow rate and pressure. Sections 9.3 and 10.3 outline the requirements of suitable measurement sections.

Because these problems and others will require special consideration on each installation it is not practical to write one standard procedure for the measurement of the performance of all fan-systems in the field. This publication offers guidelines to making performance measurements in the field which are practical and flexible enough to be applied to a wide range of fan and system combinations.

Because of the wide variety of fan types and systems encountered in the field Appendix A includes examples of a number of different field tests. In most cases these examples are based on actual tests which have been conducted in the field.

Before performing any field test it is strongly recommended that the following AMCA publications be carefully reviewed:

- AMCA Publication 200 - *Air Systems*
- AMCA Publication 201 - *Fans and Systems*
- AMCA Publication 202 - *Troubleshooting*
- AMCA Standard 210 - *Laboratory Methods of Testing Fans for Rating*

2. SCOPE

The recommendations and examples in this publication may be applied to all types of centrifugal, axial and mixed flow fans in ducted or nonducted installations used for heating, ventilating, air conditioning, mechanical draft, industrial process, exhaust, conveying, drying, air cleaning, dust collection, etc. Although the word air is used when reference is made in the general sense to the medium being handled by the fan, gases other than air are included in the scope of this publication.

Measurement of sound, vibration and stress levels are not within the scope of this publication.

3. TYPES OF FIELD TESTS

There are three general categories of field tests:

- A) **General Fan System Evaluation** - A measurement of the fan-systems' performance to use as the basis of modification or adjustment of the system.
- B) **Acceptance Test** - A test specified in the sales agreement to verify that the fan is achieving the specified performance.
- C) **Proof of Performance Test** - A test in response to a complaint to demonstrate that the fan is meeting the specified performance requirement.

As acceptance and proof of performance tests are related to contract provisions they are usually subject to more stringent requirements and are usually more costly than a general evaluation test. In the case of large fans used in industrial applications and of mechanical draft fans used in the electrical power generation industry the performance of a field test may be part of the purchase agreement between the fan manufacturer and the customer. In addition to Publication 203, AMCA Standard 803, *Site Performance Test Standard-Power Plant and Industrial Fans* defines the conditions which must be met to achieve higher accuracy of measurement. In new installations of this type, it is desirable to include a suitable measuring section in the design. Agreement must be reached on the test method to be used prior to performance of the test.

4. ALTERNATIVES TO FIELD TESTS

In some cases considerations such as cost and problems of making accurate measurements may make alternative methods of testing worth investigation:

- A) Testing the fan before installation in a laboratory equipped to perform tests in accordance with AMCA Standard 210. Limitations in laboratory test facilities may preclude tests on full size fans. In this case the full size fan can be tested at the installation site in accordance with AMCA Standard 210. This will usually require the installation of special ductwork.
- B) Testing a reduced scale model of the fan in accordance with AMCA Standard 210 and determining the performance of the full size fan as described in AMCA Publication 802, *Power Plant Fans - Establishing Performance Using Laboratory Models*.
- C) Testing a reduced scale model of the complete fan and system using the test methods outlined in this publication.

Tests conducted in accordance with AMCA Standard 210 will verify the performance characteristics of the fan but will not take into account the effect of the system connections on the fan's performance (see Section 5).

5. SYSTEM EFFECT FACTORS

AMCA Publication 201, *Fans and Systems*, deals in detail with the effect of system connections on fan performance. It gives *system effect factors* for a wide variety of obstructions and configurations which may affect a fan's performance.

System Effect Factor (SEF) is a pressure loss which recognizes the effect of fan inlet restrictions, fan outlet restrictions, or other conditions influencing fan performance when installed in the system.

SYSTEM EFFECT FACTORS (SEFs) ARE INTENDED TO BE USED IN CONJUNCTION WITH THE SYSTEM RESISTANCE CHARACTERISTICS IN THE FAN SELECTION PROCESS. Where SEFs are not applied in the fan selection process, SEFs must be applied in the calculations of the results of field tests. This is done for the purpose of allowing direct comparison of the test results to the design static pressure calculation. Thus, for a field test, the fan

static pressure is defined as

$$P_s = P_{s2} - P_{s1} - P_{v1} + SEF 1 + SEF 2 + \dots + SEFn.$$

Examples of the application of SEFs in determining the results of field tests are included in Appendix A.

In field tests of fan-system installations in which *system effects* have not been accounted for, it is important that their sources be recognized and their magnitudes established prior to testing.

The alternative to dealing with a large magnitude SEF is to eliminate its source. This requires revisions to the system. This alternative course of action is recommended when swirl exists at the fan inlet (see Publication 201, Figure 9-8). The effect on fan performance as a result of swirl at the inlet is impossible to estimate accurately as the system effect is dependent upon the degree of swirl. The effect can range from a minor amount to an amount that results in the fan-system performance being completely unacceptable.

6. FAN PERFORMANCE

Fan performance is a statement of fan flow rate, fan total or static pressures and fan power input at a stated fan speed and fan air density. Fan total or static efficiencies may be included. The fan air density is the density at the fan inlet. The fan flow rate is the volume flow rate at the fan inlet density.

7. REFERENCED PLANES

Certain locations within a fan-system installation are significant to field tests. These locations are designated as follows:

- Plane 1: Plane of fan inlet
- Plane 2: Plane of fan outlet
- Plane 3: Plane of Pitot-static tube traverse for purposes of determining flow rate
- Plane 4: Plane of static pressure measurement upstream of fan.
- Plane 5: Plane of static pressure measurement downstream of fan.

The use of the numerical designations as subscripts indicate that the values pertain to those locations.

8. SYMBOLS AND SUBSCRIPTS

SYMBOL	DESCRIPTION	UNIT
A	Area of cross-section	ft ²
D	Diameter	ft
D _e	Equivalent diameter	ft
FLA	Full load Amps	amps
H	Fan Power input	hp
H _L	Power transmission loss	hp
H _{mo}	Motor power output	hp
KW	Electrical power	kilowatts
L	Length	ft
N	Speed of rotation	rpm
NLA	No load amps	amps
NPH	Nameplated horsepower	hp
NPV	Nameplated volts	volts
P _s	Fan static pressure	in. wg
P _{sx}	Static pressure at Plane x	in. wg
P _t	Fan total pressure	in. wg
P _{tx}	Total pressure at Plane x	in. wg
P _v	Fan velocity pressure	in. wg
P _{vx}	Velocity pressure at Plane x	in. wg
P _b	Barometric pressure	in. Hg
P _e	Saturated vapor pressure at t _w	in. Hg
p _p	Partial vapor pressure	in. Hg
P _x	Absolute pressure at Plane x	in. Hg
Q	Fan flow rate	cfm
Q _i	Interpolated flow rate	cfm
Q _x	Flow rate at Plane x	cfm
SEF	System effect factor	in. wg
T	Torque	lb-in.
t _d	Dry-bulb temperature	°F
t _w	Wet-bulb temperature	°F
V	Velocity	fpm
ΔP _{x,x'}	Pressure loss between Planes x and x'	in. wg
ΔP _s	Pressure loss across damper	in. wg
ρ	Fan gas density	lbm/ft ³
ρ _x	Gas density at Plane x	lbm/ft ³
Σ	Summation sign	---
◻	Airflow Direction	---

SUBSCRIPT	DESCRIPTION
c	Value converted to specified conditions
r	Reading
x	Plane 1, 2, 3, ..., as appropriate
	Plane 1 (fan inlet)
2	Plane 2 (fan outlet)
3	Plane 3 (plane of Pitot-static traverse for purpose of determining flow rate)
4	Plane 4 (plane of static pressure measurement upstream of fan)
5	Plane 5 (plane of static pressure measurement downstream of fan)

9. FAN FLOW RATE

9.1 GENERAL

Determine fan flow rate using the area, velocity pressure and density at the traverse plane and the density at the fan inlet. The velocity pressure at the traverse plane is the root mean square of the velocity pressure measurements made in a traverse of the plane. The flow rate at the traverse plane is calculated by converting the velocity pressure to its equivalent velocity and multiplying by the area of the traverse plane.

9.2 VELOCITY MEASURING INSTRUMENTS

Use a Pitot-static tube of the proportions shown in Appendix B or a double reverse tube, shown in Appendix C, and an inclined manometer to measure velocity pressure. The velocity pressure at a point in a gas stream is numerically equal to the total pressure diminished by the static pressure. The Pitot-static tube is connected to the inclined manometer as shown in Appendix F. The double reverse tube is connected to the inclined manometer as shown in Appendix C.

9.2.1 Pitot-Static Tube. The Pitot-static tube is considered to be a primary instrument and need not be calibrated if maintained in the specified condition. It is suited for use in relatively clean gases. It may be used in gases that contain moderate levels of particulate matter such as dust, water or dirt, providing certain precautions are employed (see Section 15).

9.2.2 Double Reverse Tube. The double reverse tube is used when the amount of particulate matter in the gas stream impairs the function of the Pitot-static tube. The double reverse tube requires calibration. It is important that the double reverse tube be used in the same orientation as used during calibration. Mark the double reverse tube to indicate the direction of the gas flow used in its calibration.

9.2.3 Inclined Manometers. Inclined manometers are available in both fixed and adjustable range types. Both types require calibration. The adjustable range type is convenient in that it may be adjusted at the test site to the range appropriate to the velocity pressures which are to be measured. It is adjusted by changing the slope to any of the various fixed settings and by changing the range scale accordingly. Each setting provides a different

ratio of the length of the indicating column to its indicated height. Adjustable range type manometers in which the slope may be fixed at 1:1, 20:1 and intermediate ratios are available (see Figure 10 in Appendix G).

The accuracy of the manometer used in the measurement of velocity pressures is of prime importance. Select a manometer that will provide an acceptable degree of accuracy; consider the range, slope, quality, scale graduations, indicating fluid of the instrument and the range of the velocity pressures to be measured. The graph in Appendix G indicates the effect of expected resolution of manometer readings on the accuracy of velocity determinations. The basis for this graph is described in Section 9.6. Determine velocities in the very low range more accurately by using a manometer with a slope of 20:1. Due to practical limitations in length, its use is restricted to measurements where the velocities are very low. Also, errors in velocity determinations made by using a Pitot-static tube and manometer exceed normally acceptable values at velocity pressure readings less than 0.023 in. wg. This corresponds to a velocity of approximately 600 fpm for air of 0.075 lbm/ft³ density.

9.2.4 Low Velocity Instruments. Normally velocities encountered in field test situations are well in excess of 600 fpm. Therefore recommendations regarding alternate test procedures and instrumentation for use for velocities less than 600 fpm are not presented in this publication. Descriptions of various types of instruments used to determine range velocities are presented in Appendix J. Most of the instruments require frequent calibration, and some are not suited for use in high temperature, dirty, wet, corrosive or explosive atmospheres. If it is necessary to use one of these instruments, the procedure for its use, its calibration and the expected accuracy of results should be agreed upon by all interested parties.

9.3 LOCATION OF TRAVERSE PLANE

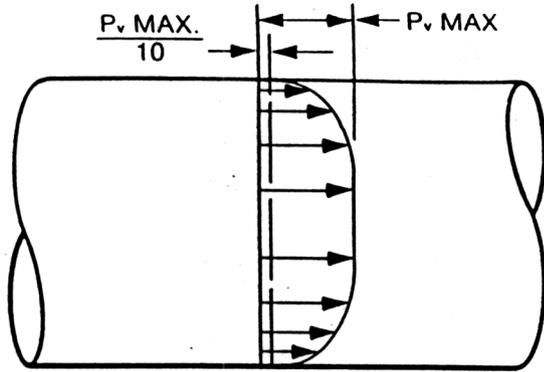
For field tests, suitable test measurement station locations must be provided in the system. When suitable locations are not available, consider making temporary or permanent alterations to the ducting for improved test accuracy.

For free inlet, free outlet fans, convert a free inlet,

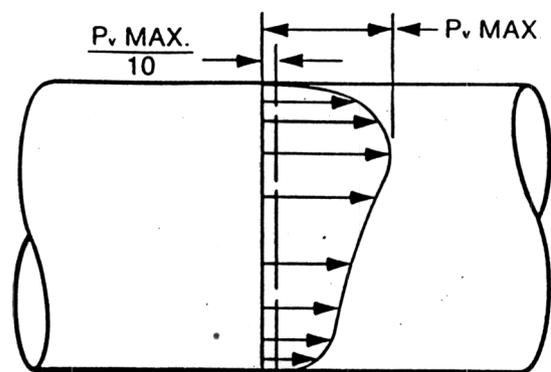
free outlet fan to a ducted inlet, free outlet fan by the addition of a temporary duct. Estimate free inlet, free outlet fan flow rate by measuring other parameters and interpreting certified ratings performance (see Section 17.1).

A Pitot traverse plane suitable for the measurements used to determine flow rate are as follows:

- 1) The velocity distribution should be uniform throughout the traverse plane. The uniformity of distribution is considered acceptable when more than 75% of the velocity pressure measurements are greater than 1/10 of the maximum measurement (see Figure 9-1).
- 2) The flow streams should be at right angles to the traverse plane. Variations from this flow condition as a result of swirl or other mass turbulence are considered acceptable when the angle between the flow stream and the traverse plane is within 10 degrees of a right angle. The angle of the flow stream in any specific location is indicated by the orientation of the nose of the Pitot-static tube that produces the maximum velocity pressure reading at the location.
- 3) The cross-sectional shape of the airway in which the traverse plane is located should not be irregular. Proper distribution of traverse points and accurate determination of the area of the traverse plane are difficult to achieve when the airway does not conform closely to a regular shape.
- 4) The cross-sectional shape and area of the airway should be uniform throughout the length of the airway in the vicinity of the traverse plane. When the divergence or convergence of the airway is irregular or more than moderate in degree, significantly nonuniform flow conditions may exist.
- 5) The traverse plane should be located to minimize the effects of gas leaks between the traverse plane and the fan.
- 6) When it is necessary to locate the traverse plane in a converging or diverging airway (not recommended), note that the traverse plane and area is located at the tip of the Pitot-static tube.

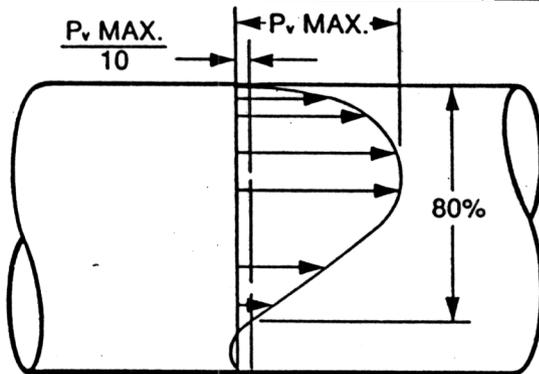


A: IDEAL P_v DISTRIBUTION



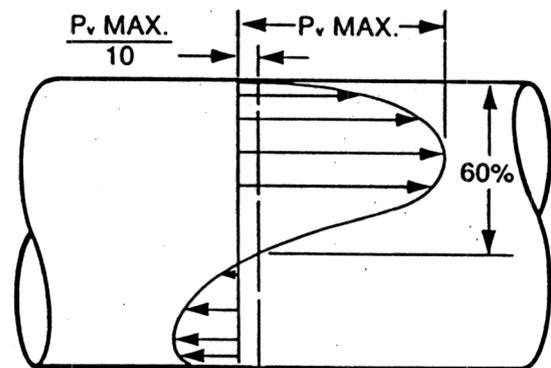
B: GOOD P_v DISTRIBUTION.

(ALSO SATISFACTORY FOR FLOW INTO FAN INLETS, BUT MAY BE UNSATISFACTORY FOR FLOW INTO INLET BOXES — MAY PRODUCE SWIRL IN BOXES)



C: SATISFACTORY P_v DISTRIBUTION — MORE THAN 75% OF P_v READINGS GREATER THAN $\frac{P_v \text{ MAX.}}{10}$

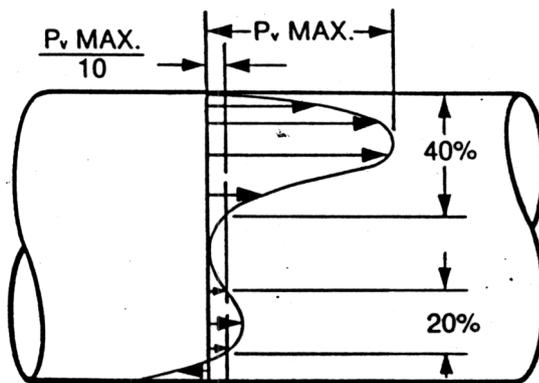
(UNSATISFACTORY FOR FLOW INTO FAN INLETS OR INLET BOXES)



D: DO NOT USE

UNSATISFACTORY P_v DISTRIBUTION — LESS THAN 75% OF P_v READINGS GREATER THAN $\frac{P_v \text{ MAX.}}{10}$

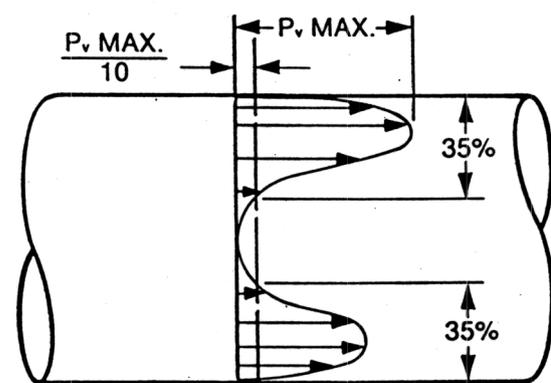
(ALSO UNSATISFACTORY FOR FLOW INTO FAN INLETS OR INLET BOXES)



E: DO NOT USE

UNSATISFACTORY P_v DISTRIBUTION — LESS THAN 75% OF P_v READINGS GREATER THAN $\frac{P_v \text{ MAX.}}{10}$

(ALSO UNSATISFACTORY FOR FLOW INTO FAN INLETS AND INLET BOXES)



F: DO NOT USE

UNSATISFACTORY P_v DISTRIBUTION — LESS THAN 75% OF P_v READINGS GREATER THAN $\frac{P_v \text{ MAX.}}{10}$

(ALSO UNSATISFACTORY FOR FLOW INTO FAN INLETS AND INLET BOXES)

TYPICAL VELOCITY PRESSURE DISTRIBUTIONS ENCOUNTERED IN VELOCITY PRESSURE MEASUREMENT PLANES IN FAN-SYSTEM INSTALLATIONS.

Figure 9-1

A location well downstream in a long, straight run of uniform cross-section duct will usually provide acceptable conditions for the Pitot traverse plane. When locating the traverse plane close to the fan, as is often done in order to minimize the effect of leakage, flow conditions upstream of the fan are usually more suitable. In some installations, more than one traverse plane may be required in order to account for the total flow (Appendix A contains examples).

When a field test is anticipated, particularly when the requirement for a field test is an item in the specifications, the system designer should provide a suitable traverse plane location in the system.

When the fan is ducted outlet and the traverse plane is to be located downstream from the fan, the traverse plane should be situated a sufficient distance downstream from the fan to allow the flow to diffuse to a more uniform velocity distribution and to allow the conversion of velocity pressure to static pressure. Appendix P provides guidance for the location of the traverse plane in these cases. The location of the traverse plane on the inlet side of the fan should not be less than 1/2 equivalent diameter from the fan inlet. Regions immediately downstream from elbows, obstructions and abrupt changes in airway area are not suitable traverse plane locations. Regions where unacceptable levels of swirl are usually present, such as the region downstream from an axial flow fan that is not equipped with straightening vanes, should be avoided. Swirl may form when a fan discharges directly into a stack or similar arrangement, (see Figure 9-2).

9.3.1 Inlet Box Location. When the traverse plane must be located within an inlet box, the plane should be located a minimum of 12 inches downstream from the leaving edges of the damper blades and not less than 1/2 equivalent diameter upstream from the edge of the inlet cone (see Figure 9-3). Do not locate traverse points in the wake of individual damper blades. In the case of double inlet fans, traverses must be conducted in both inlet boxes in order to determine the total flow rate.

9.3.2 Alternative Locations. On occasion, an undesirable traverse plane location is unavoidable, or each of a limited number of prospective locations lacks one or more desirable qualities. In such cases, the alternatives are:

1) Accept the most suitable location and evaluate

the effects of the undesirable aspects of the location on the accuracy of the test results. In some instances, the estimated accuracy may indicate that the results of the test would be meaningless, particularly in acceptance tests and proof of performance tests.

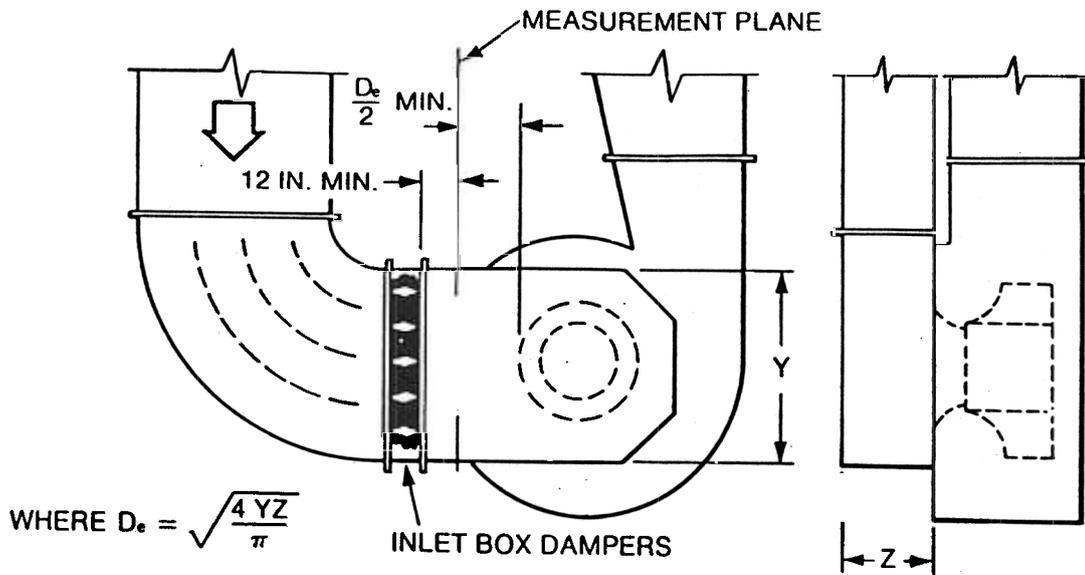
2) Provide a suitable location by modifying the system. This course of action is recommended for acceptance tests and proof of performance tests. The modifications may be temporary, permanent, minor or extensive, depending on the specific conditions encountered. When the inlet side of the fan is not ducted but is designed to accept a duct, consider installing a short length of inlet duct to provide a suitable traverse plane location. This duct should be of a size and shape to fit the fan inlet, a minimum of 2 equivalent diameters long and equipped with a bell shaped or flared fitting at its inlet. The traverse plane should be located a minimum of 1/2 equivalent diameters from the fan inlet and not less than 1-1/2 equivalent diameters from the inlet of the duct. Where the duct is small, its length may necessarily be greater than 2 equivalent diameters in order to ensure that the tip of the Pitot-static tube is a minimum of 1-1/2 equivalent diameters from the duct inlet. This short length of duct should produce no significant addition to the system resistance, but in some cases it may alter the pattern of flow into the fan impeller and thereby affect the performance of the fan slightly.

9.4 THE TRAVERSE

Appendix H contains recommendations for the number and distribution of measurement points in the traverse plane. If the flow conditions at the traverse plane are less than satisfactory, increase the number of measurement points in the traverse plane to improve accuracy.

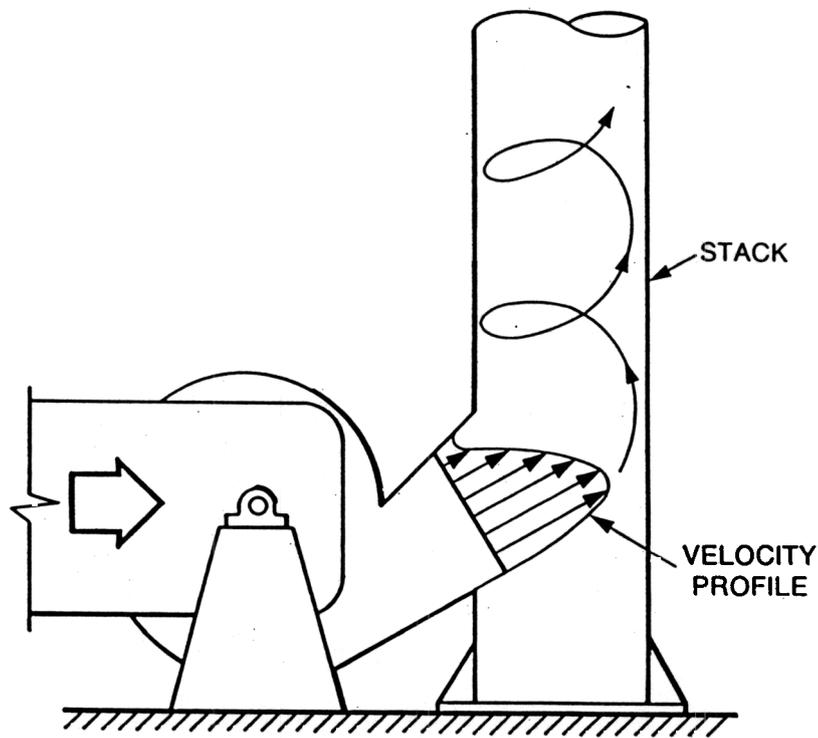
Since the flow at a traverse plane is never strictly steady, the velocity pressure measurements indicated by the manometer will fluctuate. Each velocity pressure measurement should be mentally averaged on a time weighted basis. Any velocity pressure measurement that appears as a negative reading is to be considered a velocity pressure measurement of zero and included as such in the calculation of the average velocity pressure.

When it is necessary to locate the traverse plane in



THE MEASUREMENT PLANE SHOULD BE LOCATED A MINIMUM OF $\frac{1}{2} D_e$ FROM THE INLET CONE BUT NOT LESS THAN 12 IN. FROM THE LEAVING EDGE OF THE DAMPER BLADES

Figure 9-2



SPIRAL VORTEX MAY FORM WHEN FAN DISCHARGES DIRECTLY INTO A STACK OR SIMILAR ARRANGEMENT

Figure 9-3

a converging or diverging airway, orient the nose of the Pitot-static tube such that it coincides with the anticipated line of the flow stream. This is particularly important at measurement points near the walls of the airway (see Appendix A-1A).

No appreciable effect on Pitot-static tube readings occur until the angle of misalignment between the airflow and the tube exceeds 10 degrees.

9.5 FLOW RATE CALCULATIONS

9.5.1 Flow Rate at Traverse Plane. The flow rate at the traverse plane is calculated as follows:

$$Q_3 = V_3 A_3$$

where:

- A_3 = the area of the traverse plane
- V_3 = the average velocity at the traverse plane
= $1096 (P_{v3}/\rho_3)^{0.5}$
- ρ_3 = the density at the traverse plane
- P_{v3} = the root mean square velocity pressure at the traverse plane
= $[\Sigma(P_{v3r})^{0.5}/\text{number of readings}]^2$

P_{v3r} is the velocity pressure reading, corrected for manometer calibration and where applicable, corrected for the calibration of the double reverse tube. It is important that the calibration of the double reverse tube be applied correctly. The use of the calibration of the double reverse tube is described in Appendix C.

9.5.2 Continuity of Mass. The calculations of fan flow rate are based on considerations of continuity of mass, and as such it is assumed that no mass is added or removed from the gas stream between the traverse plane and the fan inlet. In the general application, having determined the flow rate and density at the traverse plane, the flow rate at any location, (x), in the fan-system installation may be calculated, providing the density at this location is known and the assumption noted above is valid, i.e.,

$$Q_x = Q_3 (\rho_3/\rho_x)$$

9.5.3 Fan Flow Rate, Single Traverse Plane. Where a single traverse plane is used, the calculation of the fan flow rate is

$$Q = Q_1 \\ = Q_3 (\rho_3/\rho_1)$$

where:

Q_3 and ρ_3 = as described in Section 9.5.1

ρ_1 = the density at the fan inlet

9.5.4 Fan Flow Rate, Multiple Traverse Planes. When it is necessary to use more than one traverse plane in order to account for the total flow,

$$Q = Q_1 \\ = Q_{3a} (\rho_{3a}/\rho_1) + Q_{3b} (\rho_{3b}/\rho_1) + \\ + Q_{3n} (\rho_{3n}/\rho_1)$$

where:

$Q_{3a}, Q_{3b}, \dots, Q_{3n}$ = the flow rates at traverse planes a, b, ..., n

$\rho_{3a}, \rho_{3b}, \dots, \rho_{3n}$ = the density at traverse planes a, b, ..., n

ρ_1 = the density at the fan inlet

9.6 ACCURACY

The performance item of major concern in most fan-system installations is the flow rate. Every effort should be made to improve the accuracy of the flow rate determination. The uncertainty analysis presented in Appendix T indicates that the uncertainties in flow rate determinations will range from 2% to 10%. This range is based on considerations of the conditions that are encountered in most field test situations. This includes instances in which the conditions at the Pitot traverse plane do not conform to all of the qualifications indicated in Section 9.3.

The graph in Appendix G provides guidance for improving the accuracy of the flow rate determinations. This graph indicates the effect of expected resolution of velocity pressure readings on the accuracy of velocity determinations. This effect is shown for several manometer slope ratios. For all ratios, the expected resolution used as a basis for the graph is the length of indicating column equivalent to 0.05 in. wg in a manometer with slope ratio of 1:1. As indicated in the graph, reading resolution uncertainty can be significant. However, this uncertainty can be controlled by selecting a manometer with a slope suited to the velocity pressures to be measured and by avoiding regions of very low velocity in the selection of the traverse plane location. Reading resolution uncertainties

exceed normally acceptable values at velocity pressures less than 0.023 in. wg. This corresponds to a velocity of approximately 600 fpm for air of 0.075 lbm/ft³ density. Generally ducts are sized for velocities considerably in excess of 600 fpm. Velocities less than 600 fpm may exist in certain sections of the system in some installations, but these sections can usually be avoided. Do not use a Pitot-static tube and manometer to determine velocities in the low ranges associated with filters and cooling coils in air conditioning, heating and ventilating units. In some instances, the uncertainties incurred in the determinations of low velocity flows may be acceptable. For example, an uncertainty of 15% in the determination of the flow rate in a branch duct that accounts for 20% of the total flow rate for the system affects the accuracy of the total flow rate determination by only 3%.

In addition to low range velocities, other conditions may exist at the traverse plane which can significantly affect the accuracy of the flow rate determination. These include nonuniform velocity distribution, swirl and other mass turbulence. Improve the accuracy of the flow rate determination by avoiding these conditions in the selection of the traverse plane location or improve the conditions by modifying the system.

10. FAN STATIC PRESSURE

10.1 GENERAL

Determine fan static pressure by using the static pressures at the fan inlet and outlet, the velocity pressure at the fan inlet and applicable *System Effect Factors*. The use of *System Effect Factors* in the determination of fan static pressure is described in Section 5. The velocity pressure at the fan inlet is the calculated average velocity pressure at this location, and as such, its determination is based on the fan flow rate, the density at the fan inlet and the fan inlet area. The static pressures at the fan inlet and outlet may be obtained directly by making pressure measurements at these locations; or they may be determined by making pressure measurements at other locations, upstream and downstream of the fan. In the latter case, the determinations must account for the effects of velocity pressure conversions and pressure losses, as may occur between the measurement planes and the planes of interest.

10.2 PRESSURE MEASURING INSTRUMENTS

This section describes only the instruments for use in measuring static pressure. Instruments for use in the other measurements involved in the determination of fan static pressure are described in Section 13.

Use a Pitot-static tube of the proportions shown in Appendix B, a double reverse tube as shown in Appendix C, or a side wall pressure tap as shown in Appendix E, and a manometer to measure static pressure.

10.2.1 Pitot-Static Tube. The comments that appear in Section 9.2 regarding the use and calibration of the Pitot-static tube are applicable to its use in the measurement of static pressures.

10.2.2 Double Reverse Tube. The double reverse tube cannot be used to measure static pressure directly. It must be connected to two manometers and the static pressure for each point of measurement must be calculated. Both the manometer connections and the method of calculation are shown in Appendix C.

10.2.3 Pressure Tap. The pressure tap does not require calibration. Use no fewer than four taps located 90 degrees apart. In rectangular ducts, a pressure tap should be installed near the center of each wall. It is important that the inner surfaces of the duct in the vicinities of the pressure taps be smooth and free from irregularities, and that the velocity of the gas stream does not influence the pressure measurements.

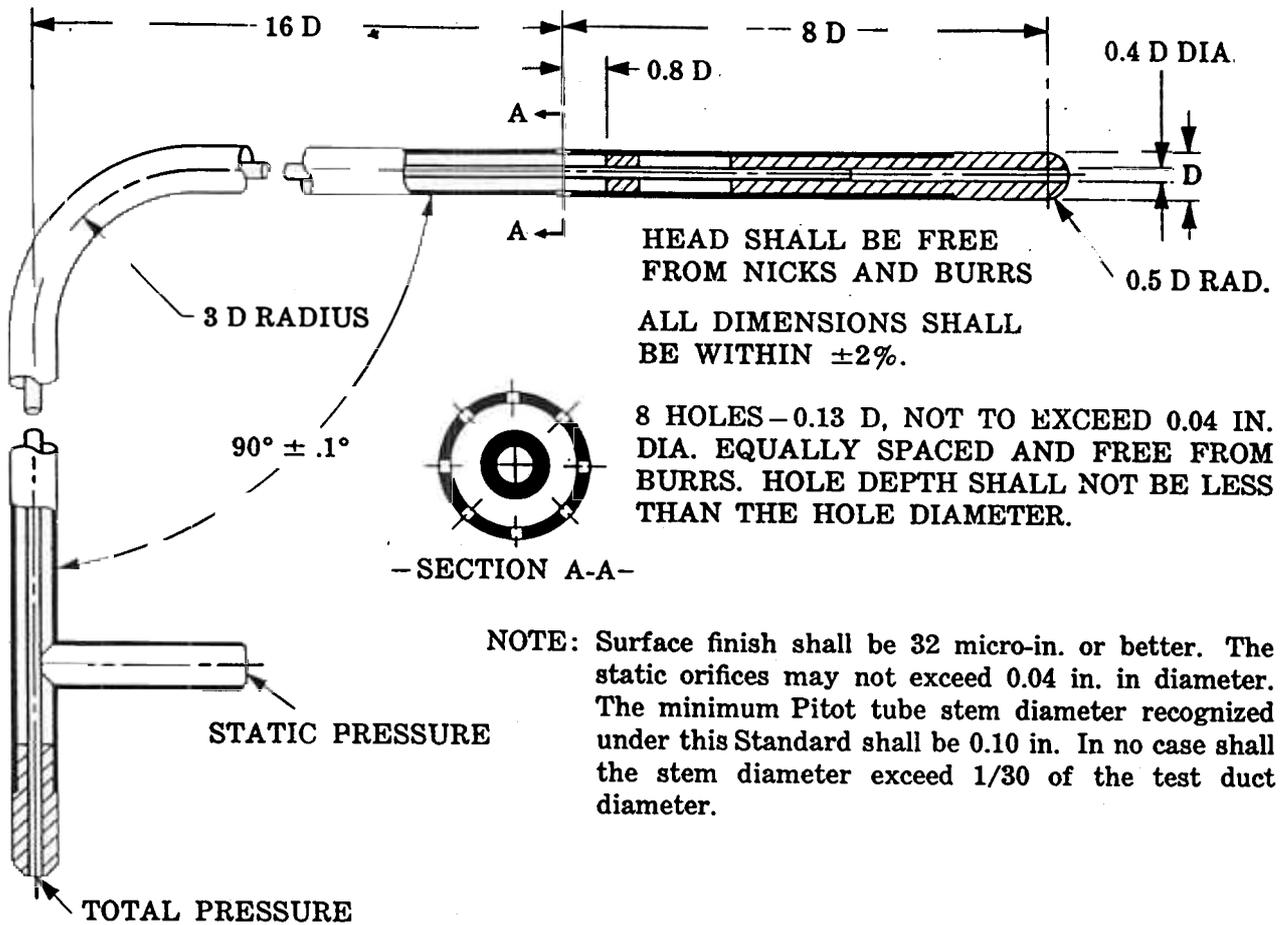
10.2.4 Manometers. A manometer with either vertical or inclined indicating column may be used to measure static pressure. Inclined manometers used to measure static pressures require calibration and should be selected for the quality, range, slope, scale graduations and indicating fluid necessary to minimize reading resolution errors.

10.3 STATIC PRESSURE MEASUREMENTS

It is important that all static pressure measurements be referred to the same atmospheric pressure, and this atmospheric pressure be that for which the barometric pressure is determined.

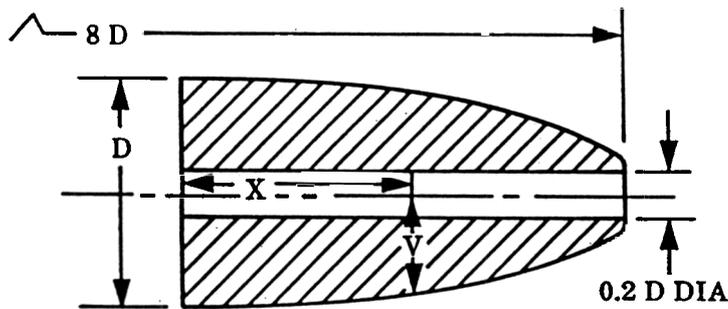
Make static pressure measurements near the fan

APPENDIX B



PITOT-STATIC TUBE WITH SPHERICAL HEAD

ALL OTHER DIMENSIONS ARE THE SAME AS FOR SPHERICAL HEAD PITOT-STATIC TUBES.



$\frac{X}{D}$	$\frac{V}{D}$	$\frac{X}{D}$	$\frac{V}{D}$
0.000	0.500	1.602	0.314
0.237	0.496	1.657	0.295
0.336	0.494	1.698	0.279
0.474	0.487	1.730	0.266
0.622	0.477	1.762	0.250
0.741	0.468	1.796	0.231
0.936	0.449	1.830	0.211
1.025	0.436	1.858	0.192
1.134	0.420	1.875	0.176
1.228	0.404	1.888	0.163
1.313	0.388	1.900	0.147
1.390	0.371	1.910	0.131
1.442	0.357	1.918	0.118
1.506	0.343	1.920	0.109
1.538	0.333	1.921	0.100
1.570	0.323		

ALTERNATE PITOT-STATIC TUBE WITH ELLIPSOIDAL HEAD

Figure B-1

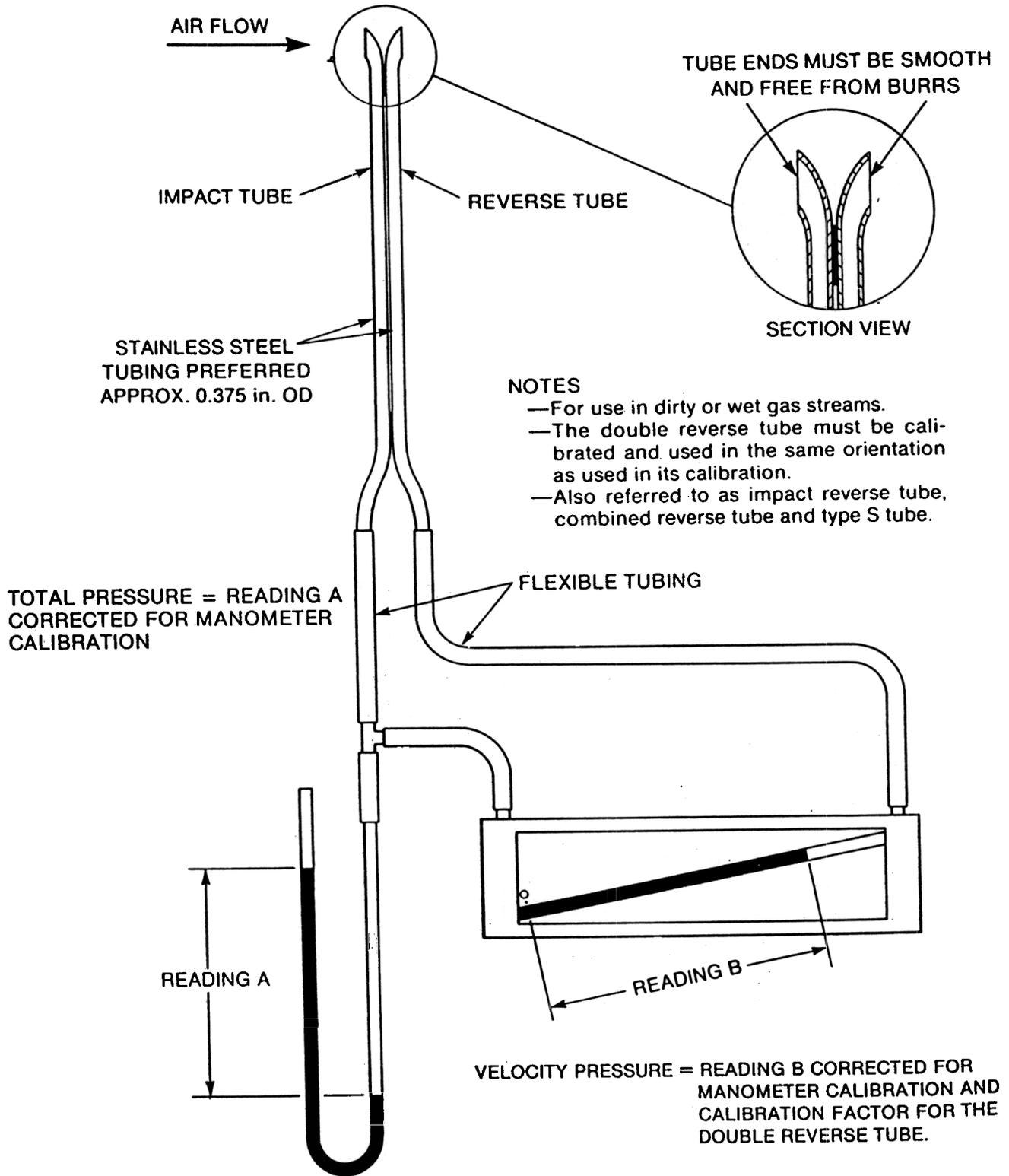


Figure C-1 Double Reverse Tube

APPENDIX D

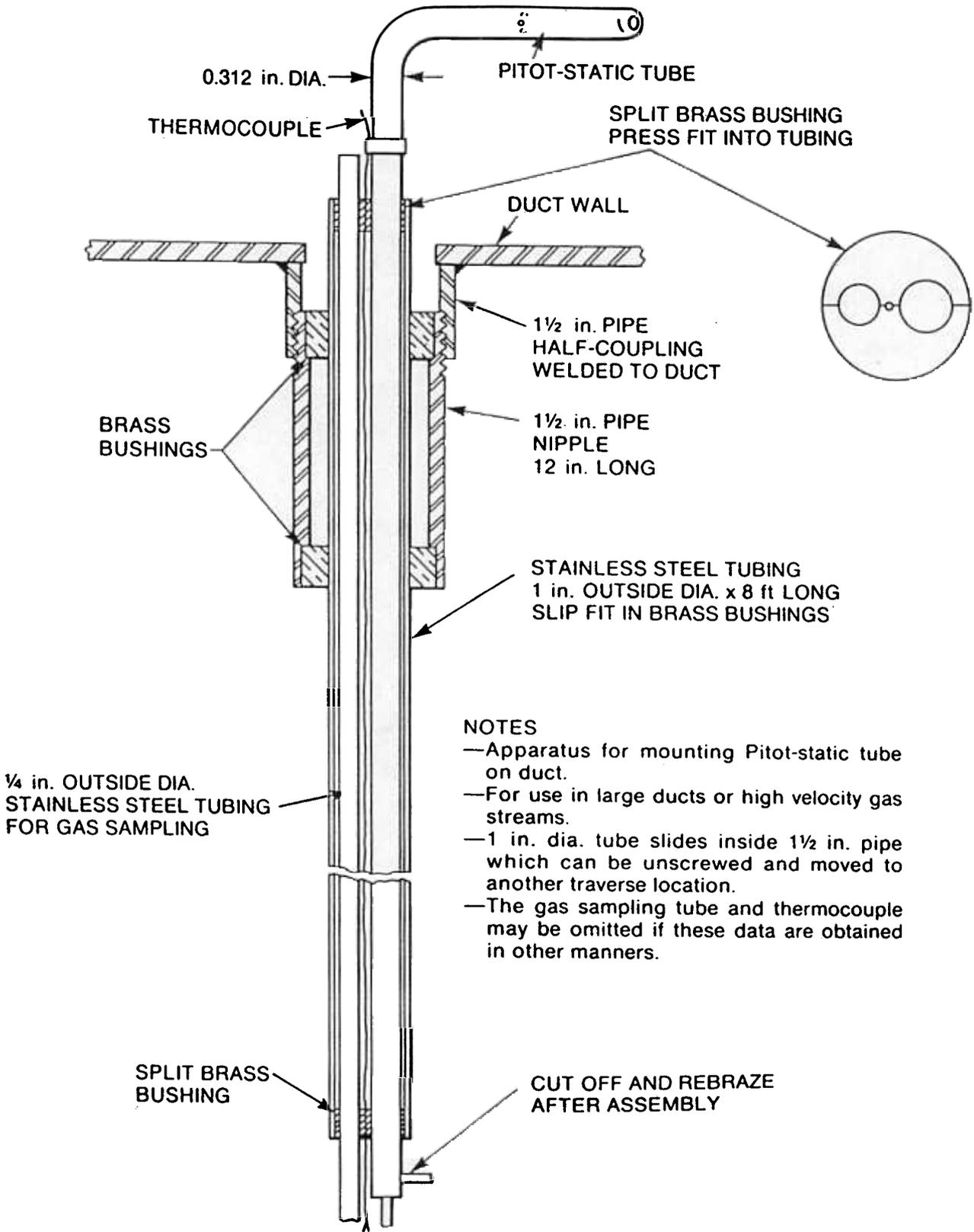
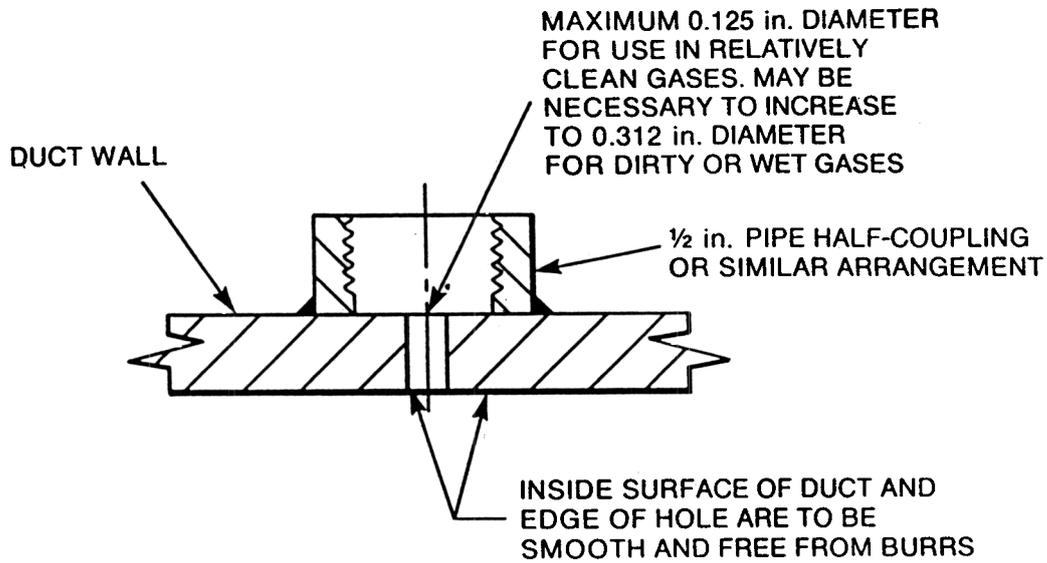


Figure D-1 Pitot-Static Tube Holder (Typical)

APPENDIX E

STATIC PRESSURE TAP



STATIC PRESSURE TAP

Figure E-1

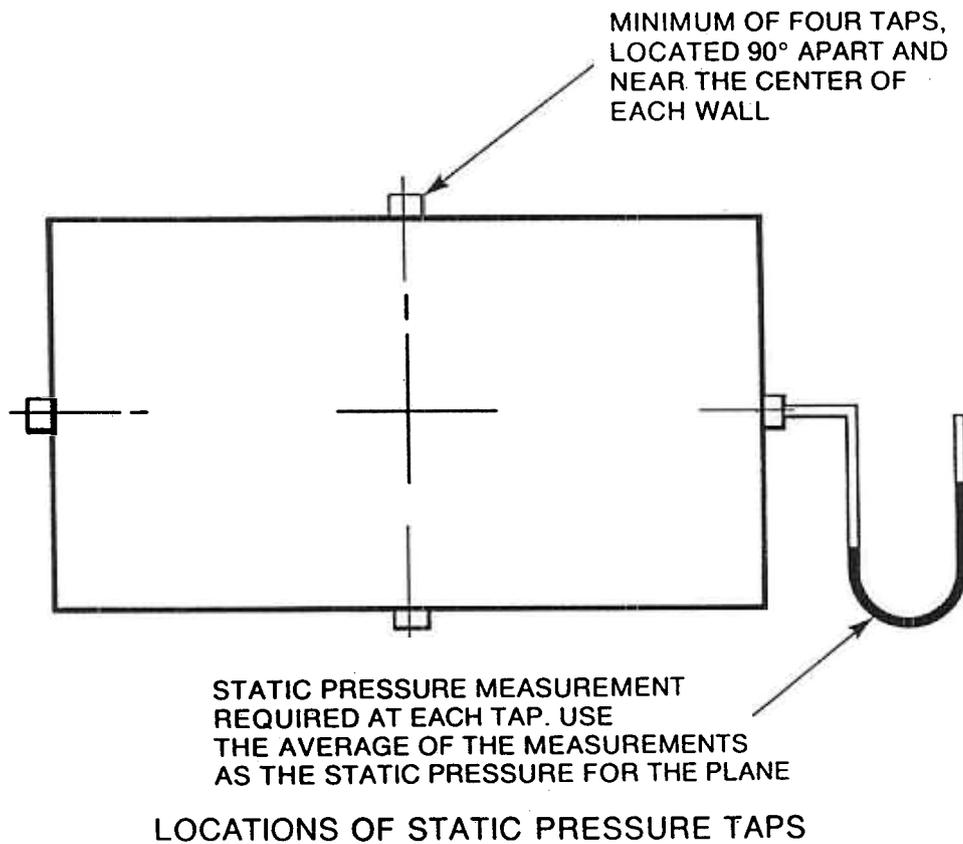
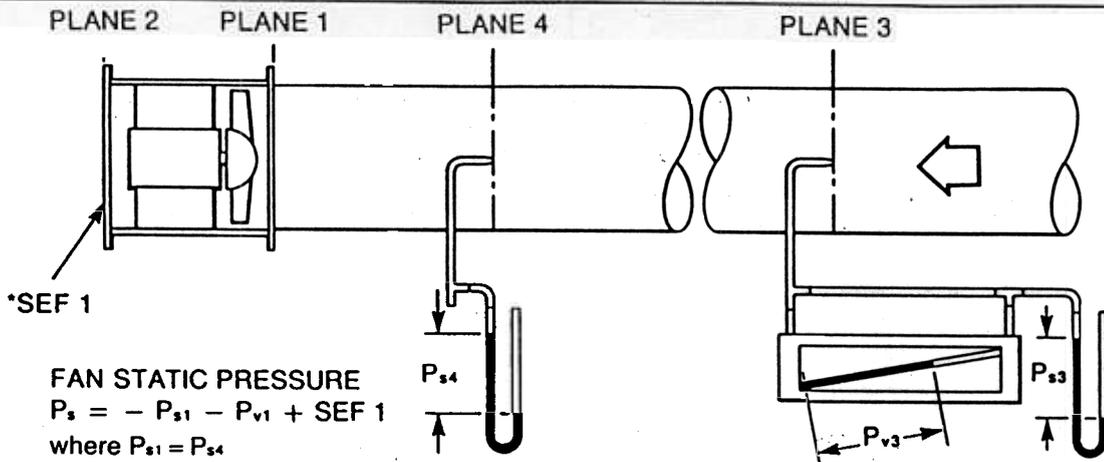


Figure E-2

APPENDIX F

PITOT-STATIC TUBE CONNECTIONS

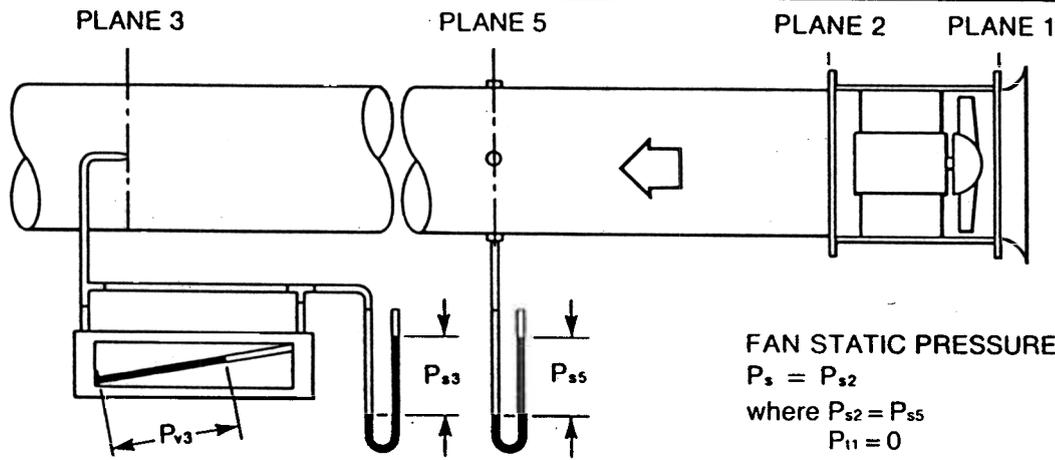


FAN STATIC PRESSURE
 $P_s = - P_{s1} - P_{v1} + SEF 1$
 where $P_{s1} = P_{s4}$
 $P_{v1} = P_{v3}$
 $P_{s2} = 0$

FAN WITH INLET DUCT ONLY

*SEF 1 is due to no duct at fan outlet

Figure F-1

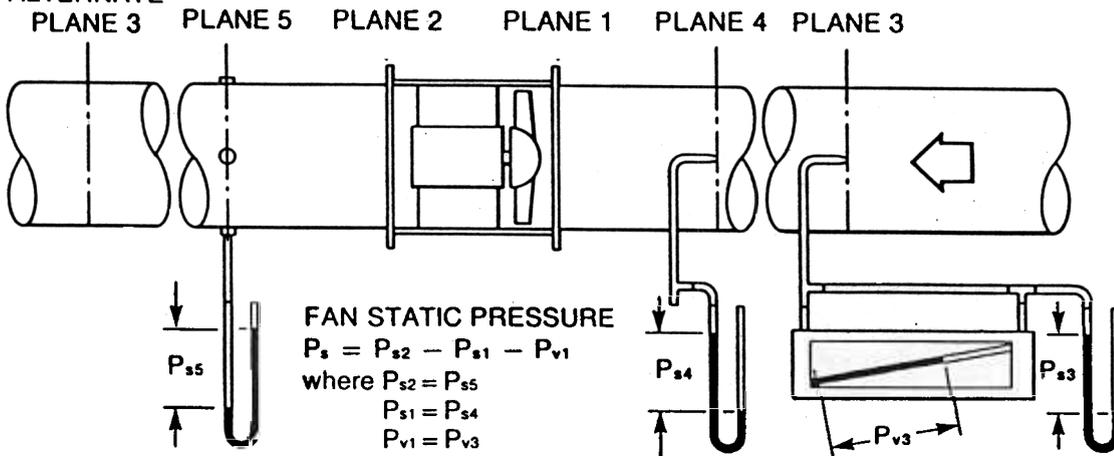


FAN STATIC PRESSURE
 $P_s = P_{s2}$
 where $P_{s2} = P_{s5}$
 $P_{t1} = 0$

FAN WITH OUTLET DUCT ONLY

Figure F-2

ALTERNATE



FAN STATIC PRESSURE
 $P_s = P_{s2} - P_{s1} - P_{v1}$
 where $P_{s2} = P_{s5}$
 $P_{s1} = P_{s4}$
 $P_{v1} = P_{v3}$

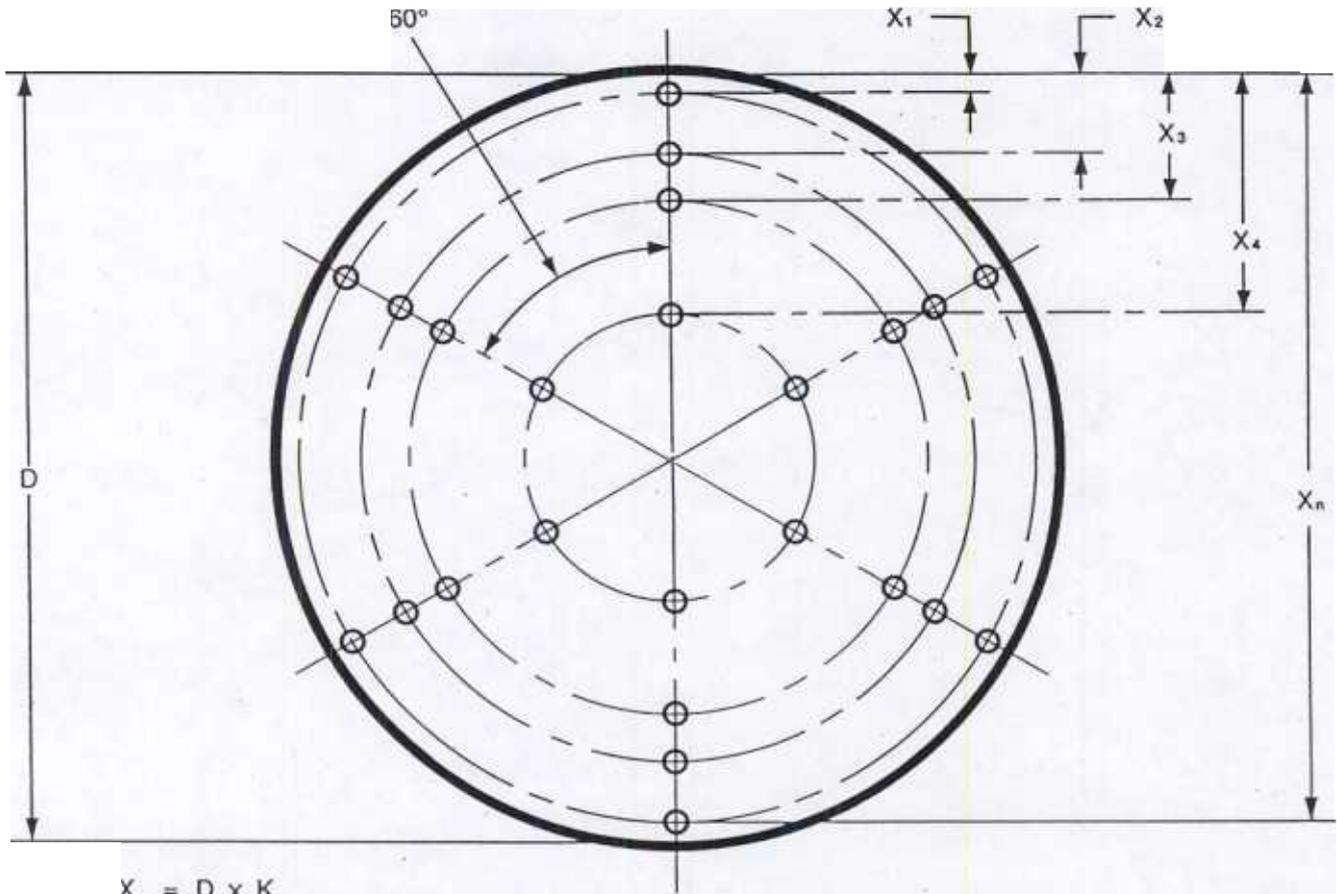
FAN WITH INLET DUCT AND OUTLET DUCT

Figure F-3

APPENDIX H

DISTRIBUTION OF TRAVERSE POINTS

In order to obtain a representative average velocity in a duct, it is necessary to locate each traverse point accurately. It is recommended that the number of traverse points increase with increasing duct size. The distributions of traverse points for circular ducts, as indicated below, are based on log-linear Pitot traverse method.



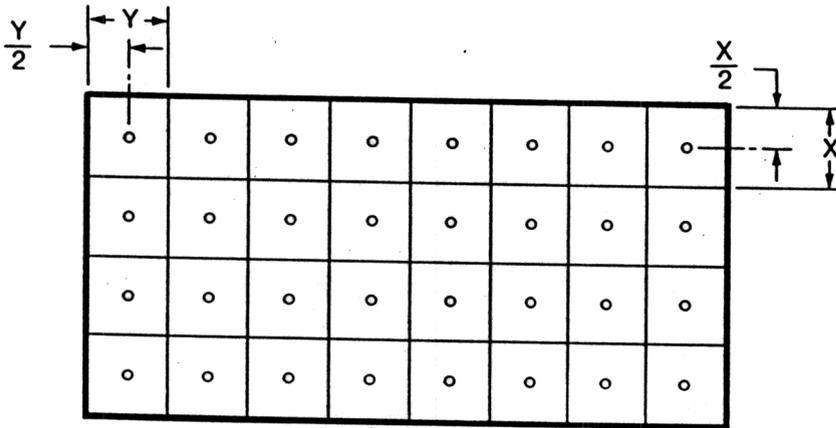
$$X_a = D \times K_a$$

where D is the inside diameter of the duct and K_a is the factor corresponding to the duct size and the traverse point location as indicated in the table below.

INSIDE DIAMETER OF DUCT	NUMBER OF TRAVERSE POINTS IN EACH OF 3 DIAMETERS																
		K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	K_{10}	K_{11}	K_{12}	K_{13}	K_{14}	K_{15}	K_{16}
LESS THAN 8 ft	8	.021	.117	.184	.345	.655	.816	.883	.979	—	—	—	—	—	—	—	—
8 ft THRU 12 ft	12	.014	.075	.114	.183	.241	.374	.626	.759	.817	.886	.925	.986	—	—	—	—
GREATER THAN 12 ft	16	.010	.055	.082	.128	.166	.225	.276	.391	.609	.724	.775	.834	.872	.918	.945	.990

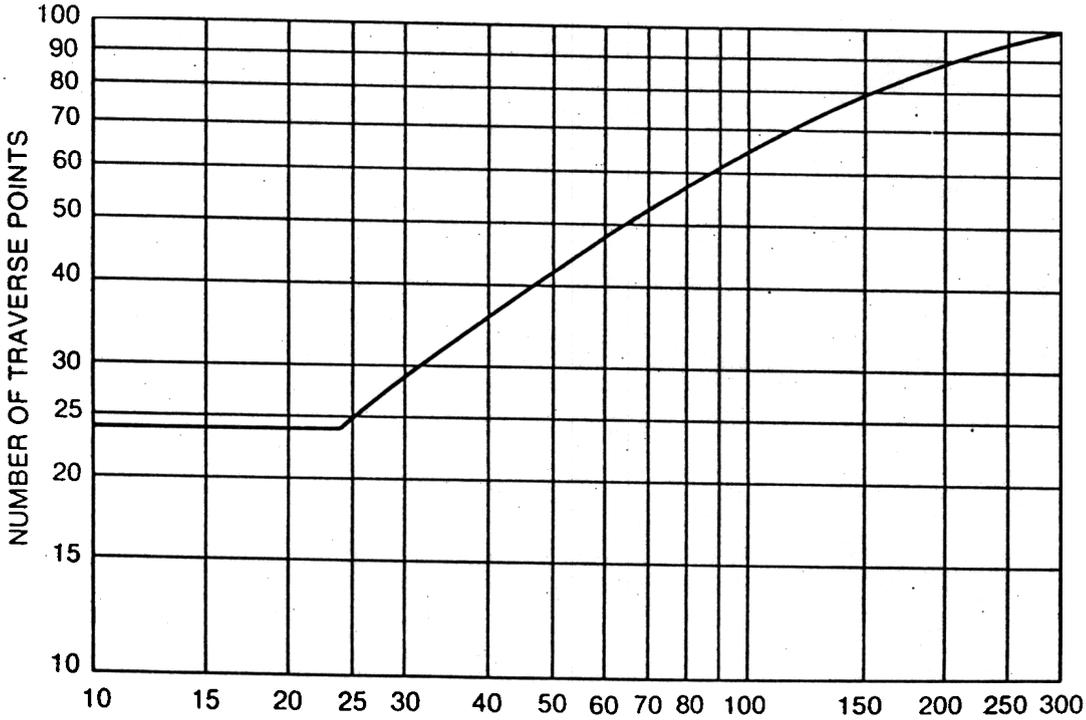
Figure H-1 Distribution of Traverse Points for Circular Ducts

The recommended minimum number of traverse points for rectangular ducts is indicated below in Figure H-3. For rectangular ducts with cross-sectional areas of 24 square feet and less, the recommended minimum number is 24. For cross-sectional areas greater than 24 square feet, the minimum number of points increases as indicated in Figure H-3. The points are to be located in the centers of equal areas with the areas as nearly square as practical (see Figure H-2). If the flow conditions at the traverse plane are less than satisfactory, the accuracy of the determination of flow rate may be improved by using more than the recommended minimum number of points. Fewer points may be used if the flow is very uniform; however, the maximum area covered per point should not exceed 3 square feet.



DISTRIBUTION OF TRAVERSE POINTS FOR RECTANGULAR DUCT

Figure H-2



RECOMMENDED MINIMUM NUMBER OF TRAVERSE POINTS FOR RECTANGULAR DUCTS

Figure H-3

APPENDIX B

SETUP OF HVAC CONTINUOUS MONITORS

FIGURE 1

