

AMCA Publication 203-90 (R2007)

Field Performance Measurement of Fan Systems



**AIR MOVEMENT AND CONTROL
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The International Authority on Air System Components



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AMCA PUBLICATION 203-90 (R2007)

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Forward

The original edition of Publication 203 was released in 1976. This, the second edition, updates much of the information that was presented.

Annex K (estimating the power output of three phase motors) and Annex L (estimating belt drive losses) were rewritten and adjusted based on new information received from motor and drive manufacturers. Over four hundred belt drive loss tests were analyzed.

New axial fan *System Effect Factors* were established based on a test project conducted and underwritten by AMCA. These factors were incorporated in their respective, applicable field test examples shown in Annex A.

The intent of this publication is to provide information from which test procedures can be developed to meet the conditions and requirements encountered in specific field test situations. They include the proper procedure for determining various *System Effect Factors*. Numerous examples of actual field tests are presented in detail in Annex A. These examples provide sufficient guidance for the proper field testing of most fan system installations.

Authority

AMCA Publication 203 was approved by the Air Movement Control Association Membership in 1990. It was reaffirmed July, 2007.

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Related AMCA Standards and Publications

Publication 200 ***AIR SYSTEMS***

System Pressure Losses
Fan Performance Characteristics
System Effect
System Design Tolerances

Air Systems is intended to provide basic information needed to design effective and energy efficient air systems. Discussion is limited to systems where there is a clear separation of the fan inlet and outlet and does not cover applications in which fans are used only to circulate air in an open space.

Publication 201 ***FANS AND SYSTEMS***

Fan Testing and Rating
The Fan "Laws"
Air Systems
Fan and System Interaction
System Effect Factors

Fans and Systems is aimed primarily at the designer of the air moving system and discusses the effect on inlet and outlet connections of the fan's performance. System Effect Factors, which must be included in the basic design calculations, are listed for various configurations. AMCA 201-02 and AMCA 203-90 are companion documents.

Publication 202 ***TROUBLESHOOTING***

System Checklist
Fan Manufacturer's Analysis
Master Troubleshooting Appendices

Troubleshooting is intended to help identify and correct problems with the performance and operation of the air moving system after installation.

Publication 203 ***FIELD PERFORMANCE MEASUREMENTS OF FAN SYSTEMS***

Acceptance Tests
Test Methods and Instruments
Precautions
Limitations and Expected Accuracies
Calculations

Field Performance Measurements of Fan Systems reviews the various problems of making field measurements and calculating the actual performance of the fan and system. AMCA 203-90 and AMCA 201-02 are companion documents.

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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, Annex 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-system's 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 the following 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 Methods*.
- 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:

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

Examples of the application of SEFs in determining the results of field tests are included in Annex 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 be 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 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
$\Delta P_{x,x'}$	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	---
$\Rightarrow$	Airflow direction	---

SUBSCRIPT	DESCRIPTION
c	Value converted to specified conditions
r	Reading
x	Plane 1, 2, 3, ..., as appropriate
1	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 Annex B or a double reverse tube, shown in Annex 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 Annex F. The double reverse tube is connected to the inclined manometer as shown in Annex 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, provided 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 other ratios are available (see Figure 10 in Annex 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 Annex 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 the 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 Annex 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 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 (Annex 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

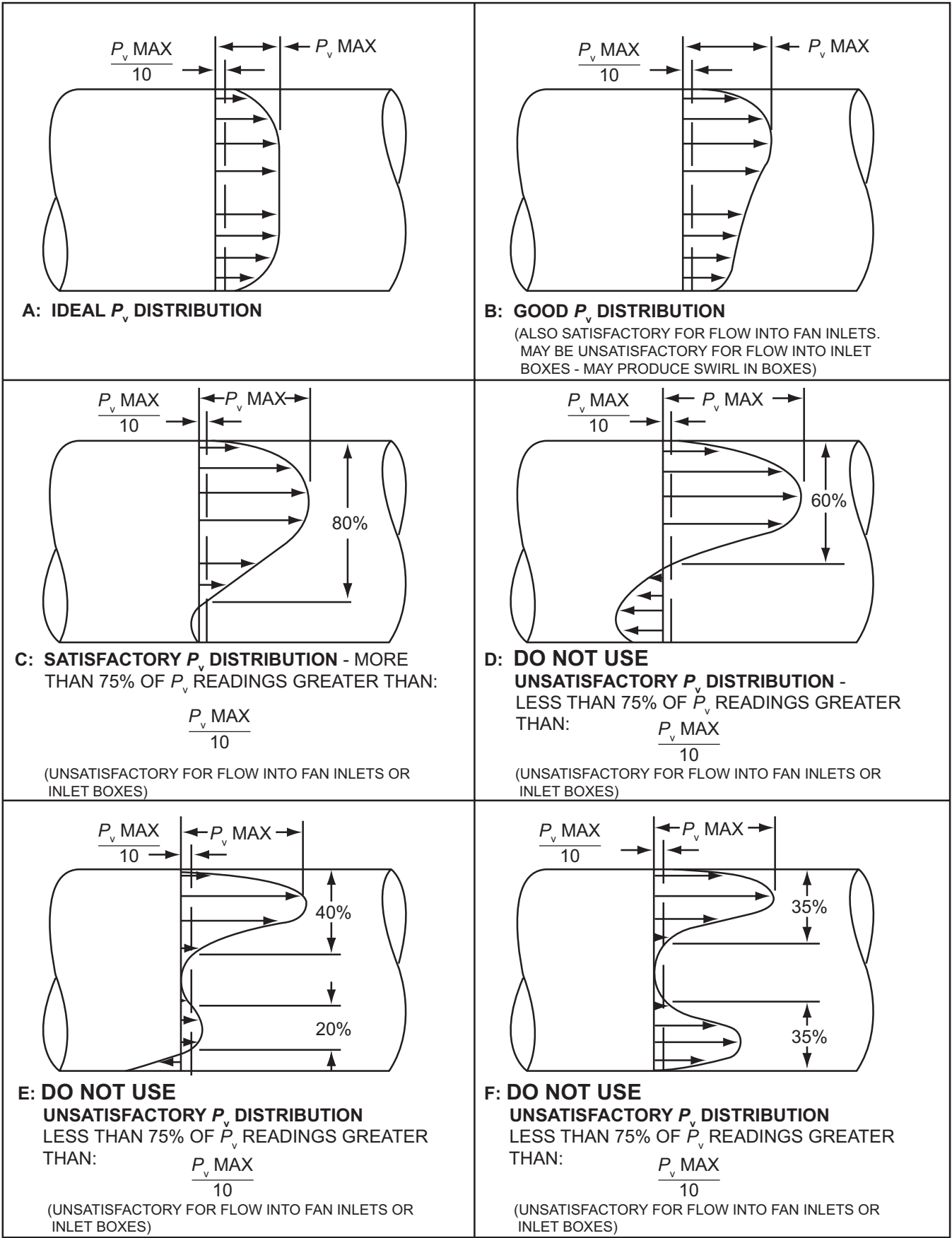
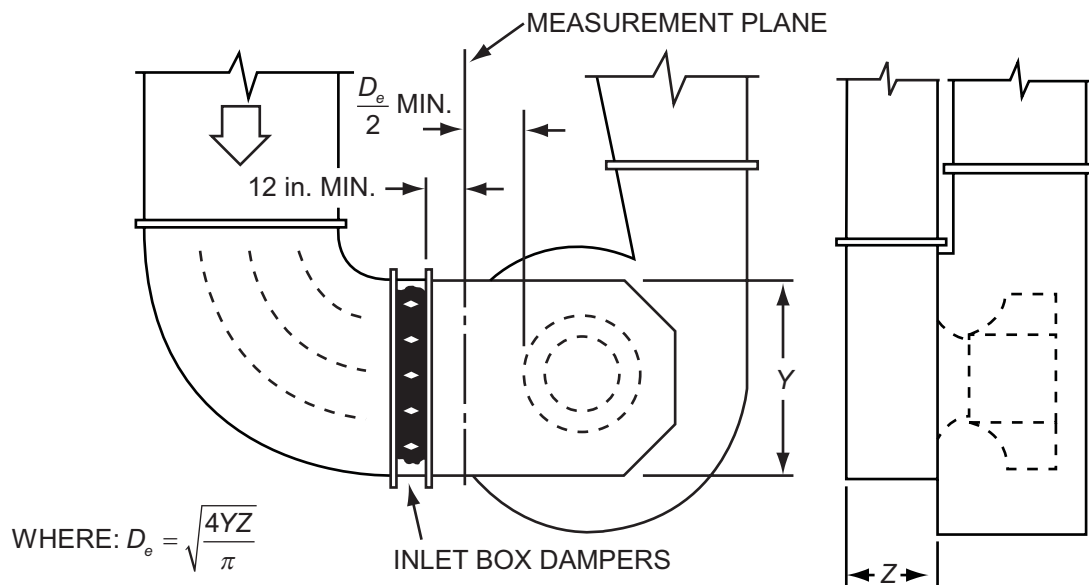
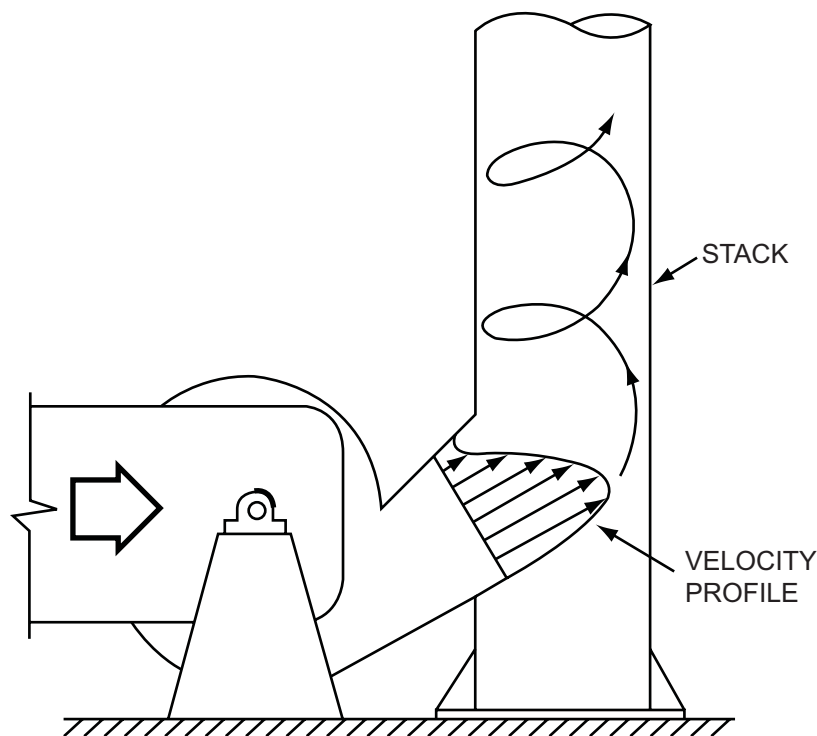


Figure 9.1 - Typical Velocity Pressure Distributions Encountered in Velocity Pressure Measurement Planes in Fan-System Installations



Note: 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



Note: Spiral vortex may form when fan discharges directly into a stack or similar arrangement.

Figure 9.3

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. Annex 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 $\frac{1}{2}$ 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 $\frac{1}{2}$ 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 $\frac{1}{2}$ equivalent diameters from the fan inlet and not less than $1\frac{1}{2}$

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 $1\frac{1}{2}$ 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

Annex 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 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 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 Annex 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
 $= [\sum (P_{v3r})^{0.5} / \text{number of readings}]^2$

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 Annex 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:

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

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 Annex 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 Annex G provides guidance for improving the accuracy of the flow rate

determinations. This graph indicates the effect of expected resolution 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 static 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 Annex B, a double reverse tube as shown in Annex C, or a side wall pressure tap as shown in Annex 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 Annex 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 inlet and the fan outlet, and where the airway

between the measurement plane and the plane of interest is straight and without change in cross-sectional area. Then the duct friction loss between the measurement plane and the plane of interest is usually insignificant, and considerations of velocity pressure conversions and calculations of pressure losses for duct fitting and other system components can be avoided.

When a system component is situated between the measurement plane and the plane of interest, the pressure loss of the component must be calculated and credited to the fan. The calculation of the pressure loss is usually based on the component's performance ratings, which may be obtained from the manufacturer of the item.

If there is a change in area between the measurement plane and the plane of interest, then the calculation of the static pressure at the plane of interest must account for velocity pressure conversion and include any associated pressure loss. When the change in area is moderate and gradual, the conversion of velocity pressure is considered to occur without loss and the static pressure is calculated on the basis of no change in total pressure between the measurement plane and the plane of interest. This assumes that the duct friction loss between the two planes is negligible. When the change in area is an abrupt and sizable enlargement, as in a duct leading into a large plenum, the loss is considered to be equivalent to the velocity pressure in the smaller area, and the static pressure at the plane of interest is considered to be the same as the static pressure at the measurement plane. This assumes that the velocity pressure in the larger area and the duct friction loss are negligible.

10.3.1 Location of the measuring plane. When the fan is ducted outlet, the static pressure measurement plane downstream of the fan should be situated a sufficient distance from the fan outlet to allow the flow to diffuse to a more uniform velocity distribution and to allow the conversion of velocity pressure to static pressure. See Annex P for guidance in locating the measurement plane in these cases. In general, pressure taps should be used if it is necessary to measure static pressure in the immediate vicinity of the fan outlet. The static pressure at this location is difficult to measure accurately with a Pitot-static tube due to the existence of turbulence and localized high velocities. If the surface conditions or the velocities at the duct walls are unsuited for the use of pressure taps, then a Pitot-static tube must be used with extreme care, particularly in aligning the nose of the tube with the lines of the flow streams.

The location of the static pressure measurement

plane upstream of the fan should not be less than $\frac{1}{2}$ equivalent diameter from the fan inlet. In the event that static pressure measurements must be made in an inlet box, the measurement plane should be located as indicated in Figure 9.2. In the case of double inlet fans, static pressure measurements must be made in both inlet boxes in order to determine the average static pressure on the inlet side of the fan.

In general, the qualifications for a plane well suited for the measurement of static pressure are the same as those for the measurement of velocity pressure, as indicated in Section 9.3:

- 1) The velocity distribution should be uniform throughout the traverse plane.
- 2) The flow streams should be at right angles to the plane.
- 3) The cross-sectional shape of the airway in which the plane is located should not be irregular.
- 4) The cross-sectional shape and area of the airway should be uniform throughout the length of the airway in the vicinity of the plane.
- 5) The plane should be located such as to minimize the effects of leaks in the portion of the system that is located between the plane and the fan.

A long, straight run of duct upstream of the measurement plane will usually provide acceptable conditions at the plane. Regions immediately downstream from elbows, obstructions, and abrupt changes in airway area are generally unsuitable locations. Regions where unacceptable levels of turbulence are present should be avoided.

If in any fan-system installation the prospective locations for static pressure measurement planes lack one or more desirable qualities, the alternatives are to accept the best qualified locations and evaluate the effects of the undesirable aspects of the conditions on the accuracy of the test results or provide suitable locations by modifying the system.

10.3.2 When using a Pitot-static tube or a double reverse tube to measure static pressure, a number of measurements must be made throughout the plane. Use Annex H to determine the number and distribution of the measurement points. When using pressure taps, a single measurement at each of the taps located at the plane is sufficient.

10.4 Static pressure calculations

Static pressure measurements may be positive or

negative. By definition, positive values are those measured as being greater than atmospheric pressures; negative values are those measured as being less than atmospheric pressure. In all of the equations in this publication, the values of static pressures must be entered with their proper signs and combined algebraically.

10.4.1 Static pressure at measuring planes. The static pressure at a plane of measurement (x) is calculated as follows:

$$P_{sx} = \frac{\sum P_{sxr}}{\text{number of readings}}$$

Where:

P_{sxr} = the static pressure reading, corrected for manometer calibration

10.4.2 Static pressure at fan inlet or outlet. The static pressure at the fan inlet, P_{s1} , and the static pressure at the fan outlet, P_{s2} , may be measured directly in some cases. In most cases, the static pressure measurements for use in determining fan static pressure will not be made directly at the fan inlet and outlet, but at locations a relatively short distance upstream from the fan inlet and downstream from the fan outlet. These static pressure measurements are designated P_{s4} and P_{s5} , respectively. Static pressure at the fan inlet, P_{s1} , is derived as follows:

$$P_{t4} = P_{t1} + \Delta P_{4,1}$$

Where:

P_{t4} = the total pressure plane of measurement

P_{t1} = the total pressure at the fan inlet

$\Delta P_{4,1}$ = the sum of the pressure losses between the two planes

These losses (ΔP) include those attributable to duct friction, duct fittings, other system components, and changes in airway area. Although ΔP represents a loss in all cases, it is considered a positive value as used in the equations in this publication. By substitution and rearrangement:

$$P_{s1} = P_{s4} + P_{v4} - P_{v1} - \Delta P_{4,1}$$

Similarly, for static pressure at the fan outlet, P_{s2} :

$$P_{t2} = P_{t5} + \Delta P_{2,5}$$

$$P_{s2} = P_{s5} + P_{v5} - P_{v2} + \Delta P_{2,5}$$



Where:

The velocity pressures at the various planes can be determined from the following general equations for the velocity pressure at a plane of measurement (x):

$$P_{vx} = P_{v3} (A_3/A_x)^2 (\rho_3/\rho_x)$$

Or:

$$P_{vx} = (Q_x/1096A_x)^2 \rho_x$$

Locate the static pressure measurement planes such that the pressure losses between the measurement planes and the planes of interest are insignificant. This will eliminate the uncertainties involved in the determination of the pressure losses, and the equations for P_{s1} and P_{s2} reduce to the following:

$$P_{s1} = P_{s4} + P_{v4} - P_{v1}$$

$$P_{s2} = P_{s5} + P_{v5} - P_{v2}$$

These equations may be used when changes in area between the measurement planes and the planes of interest are moderate and gradual, and the pressure losses associated with conversions of velocity pressure to static pressure are negligible.

If, in addition to the losses being negligible there are no changes in the areas between the measurement planes and the respective planes of interest, then the equations are further reduced to:

$$P_{s1} = P_{s4}$$

$$P_{s2} = P_{s5}$$

These equations may also be used when the only losses between the measurement planes and the planes of interest are those associated with changes in area that are abrupt and sizable enlargements in the direction of flow. This assumes that the velocity pressure in the larger area is negligible.

10.4.3 Fan static pressure. The equation for fan static pressure is:

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

Where:

SEF 1, SEF 2, ... SEF n = *System Effect Factors* that account for the various *System Effects* that are uncorrected and exist at the time of the field test.

10.5 Accuracy

The uncertainty analyses in Annex T indicate that the uncertainties in fan static pressure determinations are expected range from 2% to 8%. This range is based on considerations of the conditions expected to be encountered in most field test situations.

Improve the accuracy of the fan static pressure determination by avoiding static pressure measurement plane locations where turbulence or other unsteady flow conditions will produce significant uncertainties in the mental averaging of pressure readings. Other reading resolution uncertainties are not as significant in the fan static pressure determination as in the determination of flow rate. Generally, static pressure measurements are much greater in magnitude than velocity pressure measurements, and the selection of a manometer that will provide reasonably good accuracy is not usually a problem.

The uncertainty analyses in Annex T and the resulting anticipated uncertainty range do not account for uncertainties that may occur in the following:

- Determinations of velocity pressure conversions occurring between the measurement planes and the planes of the fan inlet or fan outlet. The area and density values that are involved in these determinations are usually obtained without significant uncertainties. However, pressure losses associated with velocity pressure conversions are often difficult to determine accurately.
- Determinations of other pressure losses occurring between the measurement planes and the fan inlet or fan outlet. This includes pressure losses in ducts, duct fittings, and other system components. The calculations of these losses are based on the assumption of uniform flow conditions. This assumption may not be valid, and the calculated pressure loss values may be significantly inaccurate.
- Determinations of the values of *System Effect Factors*. These determinations are based on limited information, and as such, are subject to uncertainty.

Avoid situations requiring these determinations, thereby eliminating them as sources for uncertainties. The uncertainties involved in determining the values of *System Effect Factors* can be avoided only by correcting the causes of the *System Effects*. This requires alterations to the system.

11. Fan Power Input

11.1 General

Fan power input data included as part of the fan performance ratings are normally defined and limited to either:

- power input to the fan shaft
- the total of the power input to the fan shaft and the power transmission loss

The losses in fan shaft bearings are included in either case. Since the results of field tests are usually compared to the rated performance characteristics of the fan, field test values of fan power input should be determined on the same basis as that used in the fan ratings. For belt driven fans, the rated fan power input may or may not include belt drive losses. The information regarding the basis of the rated fan power input accompanies the rating data or is otherwise available from the fan manufacturer. In most instances, when a power transmission loss occurs, the loss will have to be determined and subtracted from the motor output in order to obtain the fan power input.

11.2 Power measurement methods

In view of the fact that accuracy requirements for field test determinations of fan power input vary considerably, a number of test methods are recommended. These methods are intended to provide economical and practical alternatives for dealing with various levels of accuracy requirements.

11.2.1 Phase current method. This method for estimating the power output of three phase motors is based on the relationship of motor current and motor power output. The method, described in Annex K, requires measurements of the phase currents and voltages supplied to the motor while driving the fan. Depending on the operating load point of the motor, it may also involve the measurements of the no load phase currents.

The phase current method is convenient and sufficiently accurate for most field tests. In this method, the closer the actual phase current is to the motor nameplate value of full load amps, the greater the accuracy. Since fan motors are normally selected for operation at or near the full load point, this method provides a reasonably accurate estimate of the power output of the fan motor. Determine fan power input by using the motor power output and, where applicable, the power transmission loss.

11.2.2 Typical motor performance data. Typical motor performance data may be used to determine fan power input. These data, which are referred to as typical in that the data and the actual performance of the motor are expected to correspond closely, can usually be obtained from the motor manufacturer. The data provided can be in a variety of forms, but are sufficient to determine motor power output based on electrical input measurements. It is important that the power supplied to the motor during the field test be consistent with that used as the basis for the motor performance data. The phase voltage should be stable and balanced, and the average should be within 2% of the voltage indicated in the performance data.

Depending on the form of the typical motor performance data, motor power output is determined by one of the following methods:

- 1) *Given the typical motor performance chart of watts input versus motor power output at a stated voltage.*

H_{mo} is the value in the typical motor performance data that corresponds to the field test measurement of watts input to the motor.

- 2) *Given the typical motor performance chart of watts input versus torque output and speed at a stated voltage.*

Use the field test measurement of watts input and the corresponding typical motor performance data values of torque output and speed; the motor power output is calculated as:

$$H_{mo} = \frac{T \times N}{63025}$$

- 3) *Given the typical motor performance chart of watts input versus motor efficiency at a stated voltage.*

Use the field test measurement of watts input and the corresponding typical motor performance data value of motor efficiency, the motor power output is calculated as:

$$H_{mo} = \frac{\text{watts input} \times \text{motor efficiency}}{746}$$

- 4) *Given the typical motor performance chart of amps versus power factor and motor efficiency at a stated voltage.*

Use the field test measurements of amps input and volts, and the typical motor performance data values of power factor (pf) and motor efficiency, corresponding to the measured amps input; the motor power output is calculated as:

$$H_{mo} = \frac{\text{amps} \times \text{volts} \times \text{pf} \times \text{motor efficiency}}{746}$$

Or, for three phase motors:

$$H_{mo} = \frac{(3)^{0.5} \times \text{amps} \times \text{volts} \times \text{pf} \times \text{motor efficiency}}{746}$$

In both equations, amps and volts are the field test measurement values and, in the case of three phase motors, are the averages of the measured phase values.

The fan power input is the motor power output minus the power transmission loss, where applicable.

11.2.3 Calibrated motors. A calibrated motor may be used to determine fan power input. When intending to use this method, it is usually necessary to specify in the motor purchase arrangements that the motor be calibrated since an additional cost is normally involved. Calibration data are similar to typical motor performance data with the exception that, instead of being merely typical, the calibration data represent the performance of a specific motor, based on a test of the motor. The motor is calibrated over a range of operation. Electrical input data and other data sufficient for the determination of power output are obtained in the calibration. The calibration normally provides data for operation at nameplate voltage, but may include data for operation at voltages 10% greater and 10% less than nameplate voltage. It is important that the power supplied to the motor during the field test be consistent with that used in its calibration. The phase voltage should be stable and balanced, and the average should be within 2% of the voltage at which the motor was calibrated. The field test measurements and the calculations involved in the determination of motor power output are the same as those described in Section 11.2.2 for use with typical motor performance data. The fan power input is the motor power output minus the power transmission loss, where applicable.

A calibrated motor provides accurate data to determine motor power output. However, the cost of the calibration is a limiting factor in the use of this method in field tests. For low horsepower applications, the fan manufacturer may be able to calibrate a motor.

11.2.4. Torquemeters. Another method to determine fan power input involves the use of a torquemeter installed between the fan and the driver. The use of a torquemeter requires some prearrangement with the purchaser, who would normally have specified such equipment, so that site conditions can be altered to

accommodate its installation. The torquemeter is extremely limited in field test application. This is due mainly to its high cost and the cost of its installation. In addition, the length of the shut down time and the revisions to site conditions required for its installation are usually undesirable. For practical considerations, it is not normally used in cases where the fan is belt driven and where the fan impeller is installed directly on the motor shaft.

11.3 Power measuring instruments

Measurement of current, voltage, watts, and power factor can be obtained by using an industrial type power analyzer of good quality. This type of instrument is available with accuracies of 1% full scale for volts, amps and power factor, and 2% full scale for watts. Normally, the higher levels of accuracy requirements can be met by using this type of instrument, providing the measurements are well up on the scales.

In many cases, accuracy level requirements will permit the use of a clip-on type ammeter-voltmeter. Clip-on instruments with accuracies of 3% full scale are available.

11.4 Power transmission losses

Several types of power transmission equipment are used in driving fans. Those in which power transmission losses should be considered in the determination of fan power input include belt drives, gear boxes, fluid drives, and electromechanical couplings.

Information as to whether the fan power input ratings include power transmission losses is included in the published performance ratings or is otherwise available from the fan manufacturer. It is important that this be established and that the fan power input be determined accordingly in order to provide a valid comparison of field test results to the fan performance ratings. In most cases, fan power input ratings do not include power transmission losses.

11.4.1 Estimating belt drive losses. In view of the lack of published information available for use in calculating belt drive losses, a graph is included in Annex L for this purpose. As indicated in the graph, belt drive loss, expressed as a percentage of motor power output, decreases with increasing motor power output and increases with increasing speed. This graph is based on the results of over 400 drive loss tests provided to AMCA by drive manufacturers. The graph serves as a reasonable guide in evaluating belt drive losses. The calculation of belt drive loss, using this graph, is included in many of the examples in Annex A.

11.4.2 Estimating other transmission losses. For other types of power transmission equipment, consult the fan manufacturer to establish whether transmission losses are included in the fan ratings, and if so, request the magnitudes of the losses allowed in the ratings. Otherwise, it will be necessary to consult the manufacturer of the power transmission equipment for the information regarding transmission losses.

11.5 Accuracy

The uncertainty analyses presented in Annex T indicate that the uncertainties in fan power input determinations are expected to range from 4% to 8%. This range is based on considerations of the conditions encountered in most field test situations, estimated accuracies of the various test methods presented in this publication and allowances for uncertainties in the determinations of power transmission losses.

12. Fan Speed

12.1 Speed measuring instruments

Measure speed with a revolution counter and chronometer, a stroboscopic tachometer, an electronic counter-timer, or any other precision type tachometer which has a demonstrated accuracy of 0.5% of the measured value. Friction driven and magnetic type pickups should not be used in low fan power ranges where they can influence speed and fan power input measurements.

12.2 Speed measurements

Establish the speed by averaging a minimum of three measurements made during the test determination period. The variation in the measurements should not exceed 1% for any single point of operation.

13. Densities

13.1 Locations of density determinations

Determine the densities of the gas stream for Plane 1, the fan inlet; and for Plane 3, the velocity pressure measurement plane. In addition, the density at Plane 2, the fan outlet, must be determined whenever the fan total pressure, the fan velocity pressure, or an SEF at the outlet side of the fan is required.

13.2 Data required at each location

The pressure and temperature of the gas stream must be obtained for each plane at which a density

determination is required. The pressures at Planes 1 and 2 are based on the static pressure measurements made for the purpose of determining the fan static pressure. The pressure at Plane 3 is obtained by averaging static pressure measurements made concurrent with the velocity pressure measurements made in a traverse of Plane 3. The absolute pressure at a plane is calculated by using the static pressure at the plane and the barometric pressure. For this reason, it is important that the barometric pressure be determined for the atmosphere to which static pressure measurements are referred. The temperatures used in density determinations are measured at the planes of interest.

13.3 Additional data

Additional data required in the determination of density depends on the gas stream as indicated below:

- 1) For air, the wet-bulb temperature is required unless it is otherwise known that the air is saturated with water vapor or that the water vapor content of the air is insignificant. It should be noted that incorrect assumptions as to whether the air is dry or saturated can result in substantial errors in density determinations.
- 2) For gases other than air, the normal procedure is to rely on process personnel for the data necessary to determine the density of the gas. The information provided will include density or data sufficient to calculate the density, which should be for stated conditions of temperature and pressure.

13.4 Density values

Gas stream density can be established when the pressure, temperature, and additional data, as indicated in Section 13.3, have been obtained. Procedures for establishing density are described in the examples in Annex M and are further illustrated in the field test examples in Annex A.

Although the pressure and temperature of the gas stream must be obtained for each plane at which a density value is required, it is usually necessary to obtain additional data, such as the wet-bulb temperature, for only one plane in order to establish the densities at all planes. The densities at the planes for which the additional data is not obtained can be calculated, providing the gas stream does not change composition or undergo a change in phase between planes. The calculation is based on density being directly proportional to absolute pressure and

inversely proportional to absolute temperature.

13.4.1 Example calculation - ρ_3 from ρ_1 . Use Figure N.1 of Annex N to establish the density of air at Plane 1 based on the test determinations of barometric pressure, p_b , and the following Plane 1 values:

P_{s1} , static pressure, in. wg
 t_{d1} , dry-bulb temperature, °F
 t_{w1} , wet-bulb temperature, °F

The following data are obtained for Plane 3:

P_{s3} , static pressure, in. wg
 t_{d3} , dry-bulb temperature, °F

Calculate the density at Plane 3 as follows:

$$\rho_3 = \rho_1 \left(\frac{P_{s3} + 13.6p_b}{13.6p_1} \right) \left(\frac{t_{d1} + 460}{t_{d3} + 460} \right)$$

Where:

p_1 = the absolute pressure, in. Hg at Plane 1, calculated as follows:

$$p_1 = p_b + (P_{s1}/13.6)$$

In this manner, ρ_3 can be calculated without having to measure the wet-bulb temperature at Plane 3. These equations can be used for gases other than air and can be adapted for use in calculations involving any two planes, subject to the limitations noted earlier.

In the example calculation of ρ_3 , p_b is determined for the atmosphere to which the measurements of P_{s1} and P_{s3} are referred. **Refer static pressure measurements to a common atmosphere.** When the pressures cannot be referred to a common atmosphere, the absolute pressure for each plane is calculated by using the static pressure measurement at the plane and the barometric pressure for the atmosphere to which the static pressure measurement is referred. However, for the purposes of accuracy, static pressure measurements that are used in the determination of fan static pressure must be referred to a common atmosphere.

13.5 Temperatures

Measure temperatures with mercury-in-glass, dial, or thermocouple type thermometers. For temperatures through 220°F, the thermometer should be accurate within 2°F of the measured value and readable to 1°F or finer. For temperatures above 220°F, the

thermometer should be accurate within 5°F of the measured value and readable to 5°F or finer.

The temperature determination should be representative of the average temperature of the gas stream throughout the plane of interest. When the temperature varies with time or temperature stratification exists at the measurement plane, several temperature measurements may be necessary in order to obtain a representative average. At elevated temperatures, the thermometer may have to be shielded to prevent radiation effects from exposed heat sources.

Locate the wet-bulb thermometer downstream from the dry-bulb thermometer in order to prevent the dry-bulb temperature measurement from being adversely affected. The wet-bulb thermometer wick should be clean, closely fitted, and wetted with fresh water. The velocity of the air over the wick should be between 700 and 2000 fpm. Use a sling psychrometer to obtain dry and wet-bulb air temperature measurements at the fan inlet for free inlet fans.

13.6 Barometric pressure

Use a portable aneroid barometer for field test determinations of barometric pressure when an acceptable site barometer is not available. The barometer should be accurate within 0.05 in. Hg of the measured value. Determine the test value of barometric pressure by averaging measurements made at the beginning and end of the test period.

When the test value of barometric pressure is to be based on data obtained from a nearby airport, it is important that the data include the barometric pressure for the airport site and the elevation for which the pressure was determined (often the barometric pressure is corrected to sea level). This pressure value must then be corrected to the test site elevation. Barometric pressure decreases approximately 0.1 in. Hg for every 100 ft increase in elevation.

13.7 Accuracy

As indicated in Annex T, uncertainties in density determinations are expected to be less than 3%. However, care must be exercised in obtaining representative test measurements in order to prevent the uncertainties from exceeding this value.

14. Conversion Calculations

Generally, the test fan will be operating at a speed and inlet density that are somewhat different from the

fan performance rating values of fan speed and inlet density. In order to provide a common basis for comparing the field test results to the fan performance ratings, each of these two items must be the same in both sets of data. This can be accomplished by converting the results of the field test to the speed and density conditions of the fan performance ratings. The equations for the conversion are as follows.

$$Q_c = Q (N_c / N)$$

$$P_{sc} = P_s (N_c / N)^2 (\rho_c / \rho)$$

$$P_{tc} = P_t (N_c / N)^2 (\rho_c / \rho)$$

$$P_{vc} = P_v (N_c / N)^2 (\rho_c / \rho)$$

$$H_c = H (N_c / N)^3 (\rho_c / \rho)$$

Where the subscript c designates values converted to specified conditions, and items without the subscript c are field test values.

These conversion equations do not account for the effect of the compressibility of the gas stream. However, since the test fan usually operates at conditions of speed and inlet density that are reasonably close to the quoted fan performance, the conversion calculations usually result in small changes from field test values and the effect of the compressibility of the gas stream is considered to be negligible. Where test conditions are considerably different than design conditions, the effect of compressibility may need to be considered.

15. Test Preparation

15.1 The following items should be agreed upon by all interested parties prior to the start of a field performance test:

- 1) AMCA Publication 200, *Air Systems*, AMCA Publication 201, *Fans and Systems*, and AMCA Publication 202, *Troubleshooting*, should be reviewed and implemented before starting the field test.
- 2) Personnel conducting field tests on fans must be technically competent and fully conversant with all four parts of the AMCA Fan Application Manual. The person responsible for conducting the test should be designated and agreed upon by all parties.
- 3) The test instrumentation and locations of test measurement planes should be established.
- 4) *System Effect Factors*, if any, must be established prior to the conduct of the test.
- 5) The expected test uncertainties must be agreed upon prior to the test (see Annex T).
- 6) Responsibility for the cost of the test or any fan-system modifications required as a result of the test should be established.
- 7) Prior to testing, an inspection must be made to ensure that the fan is installed in accordance with the fan manufacturer's recommendations. The duct system should also be inspected for compliance with design specifications, conditions of filters, abnormal duct restrictions, etc.
- 8) The majority of fan field performance tests cover a single point of operation, namely, the design duty. If it is deemed necessary to cover several points of operation, provision must be made in advance for changing the system resistance. The means used to vary the system resistance must not cause adverse flow conditions in the vicinities of the fan and measurement planes. If the fan cannot be tested at the quoted system design point, then it is sufficient for the evaluation of fan field performance to establish the proximity of the field test point to any portion of the fan performance rating curve within the limitations of the uncertainty analysis (see Annex T).
- 9) It must be established that the system remains constant for the duration of the test. Modulating dampers should be set in a fixed position, no process changes shall be undertaken, etc. Variable inlet vane controls or inlet box dampers must be set in the full open position for the duration of the test, except when testing for control characteristics.
- 10) All precautions to ensure the safety of test personnel must be observed.
- 11) The fan-system should be operated for a length of time sufficient to ensure steady state conditions prior to the start of the test.
- 12) It is advisable that representatives of all parties interested in the test results be present at the time of the test to cover their areas of responsibility.

15.2 It is recommended that as a minimum, the following equipment be taken to or be otherwise available at the job site:

- 1) Pitot-static tubes of suitable lengths for the maximum duct size to be traversed. Considerations should be given to the use of a double reverse tube in dirty atmospheres.
- 2) Manometers suitable for measuring static pressures. Manometer fluids other than water are acceptable, provided the specific gravity is known. A spare bottle of manometer fluid is advisable.
- 3) Inclined manometer suitable for measuring velocity pressures.
- 4) Flexible tubing of suitable length to enable manometers to be installed at a convenient location.
- 5) Tubing couplings and "T" type tubing connectors.
- 6) Thermometers to cover the range of anticipated temperatures.
- 7) Sling psychrometer for obtaining dry-bulb and wet-bulb temperatures.
- 8) Clip-on ammeter-voltmeter, power analyzer, or other suitable electrical measurement instruments for the determination of fan power input.
- 9) Fan speed measurement instrument.
- 10) Aneroid barometer.
- 11) Flashlight, tape, measuring rule, hand tools, coveralls, etc.
- 12) Test data sheets, calculator, and necessary drawings.
- 13) Complete AMCA Fan Application Manual containing Publications 200, 201, 202, and 203.
- 2) Static and total pressure manometer tubing must be "pinched off" prior to inserting or removing the Pitot-static tube from the test duct. Release both legs of the tubing simultaneously after the Pitot-static tube is inside the test duct and properly oriented. Failure to release simultaneously may result in manometer fluid being blown from the manometer.
- 3) Loop the manometer tubing well above the manometer so that any fluid which is inadvertently blown from the gauge will drain back into the manometer.
- 4) The Pitot-static tube is intended for measuring pressures in relatively clean gases. When using Pitot-static tubes in dirty, wet, or corrosive atmospheres, both legs of the Pitot-static tube must be cleaned out frequently during the test. **Since fan pressure readings are never strictly steady, absence of fluctuations is an indication of a plugged Pitot-static tube.** Consider using a double reverse tube in these situations.
- 5) When making measurements in wet gas streams, continually check for the presence of moisture in the tubing. Clear plastic tubing is ideal from this standpoint. If moisture collects in the tubing, immediately remove the Pitot-static tube and clean the inside of the tubing and Pitot-static tube before proceeding with the test.
- 6) Before performing any work inside a fan, ductwork, or other system components, make certain that the fan motor starter is "locked out."
- 7) The area at the plane of flow measurement should be measured internally to account for internal insulation or other obstructions.
- 8) Do not rely on damper control indicators to ensure that dampers are fully open. Check visually.
- 9) Measure temperatures on both sides of double inlet fans as temperature differences may exist between each side.

16. Precautions

The following precautions should be observed when conducting a field test:

- 1) Connect the Pitot-static tube to the manometers according to anticipated pressures, i.e., whether the pressures are positive or negative, and the magnitudes of pressures.

17. Typical Fan-System Installations

A fan assembly may include any number of appurtenances: variable inlet vanes, inlet boxes, inlet

box dampers, outlet dampers, inlet screens, belt guards, inlet bells, diffusers (evasés). Alternately, these items may be included in the fan-system installation, but not be a part of the fan assembly. In order to determine the proper field test procedure and to provide a valid basis for comparing field test results to the fan performance ratings, it is important to establish which of these items are considered a part of the fan and which are considered a part of the system. The fan performance ratings may be assumed to include the appurtenances that are established as being a part of the fan assembly.

The locations of the fan inlet and fan outlet depend on whether specific appurtenances are considered to be a part of the fan assembly. If the assembly includes an inlet box, the fan inlet is the inlet to the inlet box. For a fan assembly that includes a diffuser, the fan outlet is the outlet of the diffuser.

In the case of heating, ventilating, and air-conditioning equipment, the field test procedure will depend on whether the equipment is a factory assembled central station unit, a built-up unit, or a packaged unit (see Section 17.4).

The performance ratings for a fan that includes inlet box dampers, variable inlet vanes or outlet dampers cover operation of the fan with these items in the full open positions. In order to be able to compare the field test results to the fan performance ratings, it is essential that these items be fixed in their full open positions for the duration of the test. In addition, when the loss through a damper must be calculated, it is essential that the damper blades be fixed in their full open positions during the test since this is the condition on which the damper pressure loss ratings are based. This consideration arises when a damper, which is not considered a part of the fan is located between a static pressure measurement plane and the fan. In order to determine the fan static pressure, the loss through the damper must be calculated. In these cases, the calculation of the loss is based on the performance ratings for the damper.

17.1 Free inlet, free outlet fans

It is difficult to achieve an accurate field test of a free inlet, free outlet fan. The most obvious problem is the lack of a suitable location for the velocity pressure measurement plane. In addition, in the case of ventilators that supply or exhaust air from a building—the most commonly encountered applications of free inlet, free outlet fans—it is extremely difficult to define, set, and maintain for the duration of the test the “normal” system condition. Items affecting the system include:

- a) The operations of ovens, furnaces, paint booths, air conditioning equipment, other fans, and similar items that may supply or exhaust air from the building in intermittent or modulating fashions.
- b) The use of doors providing access to the building. The effect is most significant when large doors that are normally closed are kept open for extended periods such as in loading operations.
- c) The velocity and direction of the wind outside the building, particularly in conjunction with the item immediately above and as it may affect the flow of air from the outlet of the ventilator.
- d) The use of interior doors that may restrict the flow of air from areas normally expected to be ventilated.

Assuming that these difficulties can be resolved and the desired system is fixed for the duration of the test, determine the fan performance by using one of the following methods:

- 1) Make field test measurements sufficient for determining fan static pressure, fan power input, fan speed, and the density of the air at the fan inlet. In this method for testing a free inlet, free outlet fan, the fan static pressure is calculated as the static pressure on the outlet side of the fan less the static pressure on the inlet side of the fan: $P_s = P_{s2} - P_{s1}$. The static pressure measurements involved must be referred to the same atmospheric pressure and made at locations sufficiently distant from the fan inlet and outlet so as to be unaffected by the velocity of the air entering and leaving the fan. Using the fan manufacturer's certified performance ratings, draw a performance curve for the fan for operation at the test values of fan speed and entering air density. Determine the fan air flow rate by entering this curve at the test values of fan static pressure and fan power input (see Example 5C in Annex A).
- 2) Use the method as described above with the exception that the performance curve is established by a laboratory test of the fan, conducted in accordance with AMCA Standard 210. For the laboratory test, the fan must be set up in a manner that duplicates the field installation conditions. That is, all appurtenances must be in place and any restrictions or obstructions to the free flow of air into the fan inlet and away from the fan outlet must be accurately duplicated in the laboratory test setup.

- 3) Install a duct on the inlet side of the fan for the purpose of providing a location for the velocity pressure measurement plane. All of the test measurements and calculations in this method for testing a free inlet, free outlet fan are the same as those required for a fan with a ducted inlet and a free outlet. The cross-sectional shape and area of the duct, which is temporarily installed for purposes of the test, should be selected on the basis of minimizing its interference with the flow of air into the fan inlet while providing velocity pressure of magnitudes that can be accurately measured. The length of the duct should be a minimum of twice its diameter or equivalent diameter, and the entrance to the duct should be flared in order to reduce the entrance loss. The velocity pressure measurement plane should be located a minimum of 1.5 diameters or equivalent diameters downstream from the duct inlet. The effect of this duct on the system is negligible, but in changing the pattern of the flow of air into the fan inlet, it may affect the performance of the fan slightly. Applications of this method of test are presented in Examples 5A and 5B in Annex A. The equation for calculating fan static pressure for this configuration is:

$$P_s = P_{s2} - (P_{s1} + P_{v1})$$

17.2 Free inlet, ducted outlet fans

In the calculation of fan static pressure for this type of fan-system configuration, the sum of the static pressure at the fan inlet, P_{s1} , and the velocity pressure at the fan inlet, P_{v1} , is considered to be equal to the sum of the static pressure, P_{sx} , and the velocity pressure, P_{vx} , at a point sufficiently distant from the fan inlet as to be in still air. At this point, the static pressure is zero, and the velocity pressure in still air is zero.

$$P_{s1} + P_{v1} = P_{sx} + P_{vx} = 0$$

This consideration, which is the same as that used in the methods for testing fans for performance rating purposes, charges to the fan the losses incurred in accelerating the air into the fan inlet and eliminates inaccuracies which may occur in any attempt to measure velocity pressure and static pressure at the fan inlet. Since $P_{s1} + P_{v1} = 0$, the equation for calculating fan static pressure for this configuration is:

$$P_s = P_{s2} + \text{SEF } 1 + \text{SEF } 2 + \dots + \text{SEF } n$$

17.3 Ducted inlet, ducted outlet fans

In this type of fan-system configuration, there is no special consideration in the calculation of fan static pressure. The equation for this calculation is:

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

In this configuration, the flow conditions on the inlet side of the fan are usually more favorable for the location of the velocity pressure measurement plane.

17.4 Ducted inlet, free outlet fans

In this type of fan-system configuration, the static pressure at the fan outlet, P_{s2} , is zero gauge pressure, referred to the atmospheric pressure in the region of the fan outlet. However, the gas stream may be discharging from the fan into a region in which the atmospheric pressure is somewhat different from that to which all other pressure measurements are referred. When this possibility exists, it is essential that the static pressure measurements in the region of the fan outlet be referred to the same atmospheric pressure as used in all other pressure measurements.

$$P_s = -P_{s1} - P_{v1} + \text{SEF } 1 + \text{SEF } 2 + \dots + \text{SEF } n$$

17.5 Air handling units

This category consists of draw-through and blow-through types of equipment assemblies used in heating, ventilating, and air-conditioning applications. In addition to fans, these equipment assemblies may include any number of combinations of coils, filters, access sections, humidifiers, mixing boxes, dampers, etc. Air handling units include packaged units, factory assembled central station units, and built-up units. The basis used in establishing the air performance ratings for each of these unit types is described below. It is important that the field test method correspond to the rating method in each case.

17.5.1 Packaged units. This type of unit is supplied and rated by the manufacturer as an assembly. The static pressures at the inlet and outlet to the assembly and the velocity pressure at the inlet to the assembly are used in calculating the static pressure generated by this type of air handling unit. See Examples 4C and 4D in Annex A.

17.5.2 Factory assembled central station units.

The air performance ratings for this type of unit are based on the operation of the fan section assembly only, but include the effects of the air flow conditions

entering and leaving the fan section which are created by accessory equipment such as plenums, coils, filters, mixing boxes, etc. The fan section assembly includes the fan and the cabinet in which the fan has been installed. The accessory items are considered to be included in the system in which the fan section operates. The static pressure and the velocity pressure at the inlet of the fan section and the static pressure at the fan section outlet, which coincides with the fan outlet, are used in calculating the static pressure generated by the fan section assembly. See examples 4B and 4E in Annex A.

17.5.3 Built-up units. Built-up units are similar to factory assembled central station units, except that in built-up units, the components are normally obtained from a number of equipment suppliers and the unit is assembled at the installation site. The fans which are used in built-up units are rated as free-standing, unencumbered by the cabinets in which they are installed. In the field test determination of the performance of the fan, the static pressure and velocity pressure at the fan inlet and the static pressure at the fan outlet are used in calculating the fan static pressure. An SEF that accounts for the effect of the cabinet is normally included in this calculation, and it may be necessary to include an SEF to account for the conditions at the fan outlet. See Example 4A in Annex A.

Annex A. Field Test Examples

This annex contains examples of field tests. The examples are presented in detail and cover several types of fan-system combinations. Field test procedures are illustrated in a variety of situations. Portions of the procedures are typical for all fan-system installations. Other portions of the procedures demonstrate methods for dealing with the more difficult features encountered in some installations. Not all of the possible fan-system combinations are included in the examples, but it is expected that the examples will provide sufficient guidance for dealing with those cases not covered.

EXAMPLES OF FANS, INSTALLATION TYPE B: FREE INLET, DUCTED OUTLET

- 1A: Centrifugal Forced Draft Fan
- 1B: Centrifugal Forced Draft Fan with Inlet Silencers
- 1C: Axial Forced Draft Fan with Inlet Silencers
- 1D: Centrifugal Fans in Parallel

EXAMPLE OF FANS, INSTALLATION TYPE D: DUCTED INLET, DUCTED OUTLET

- 2A: Utility Fan in a Ventilating System
- 2B: Centrifugal Fan in a Sawdust Conveying System
- 2C: Axial Fan in a Dryer System
- 2D: Centrifugal Fan in a Scrubber System
- 2E: Centrifugal Fan in a Process System
- 2F: Axial Fan in a Ventilation System
- 2G: High Pressure Centrifugal Fans in Series

EXAMPLES OF FANS, INSTALLATION TYPE C: DUCTED INLET, FREE OUTLET

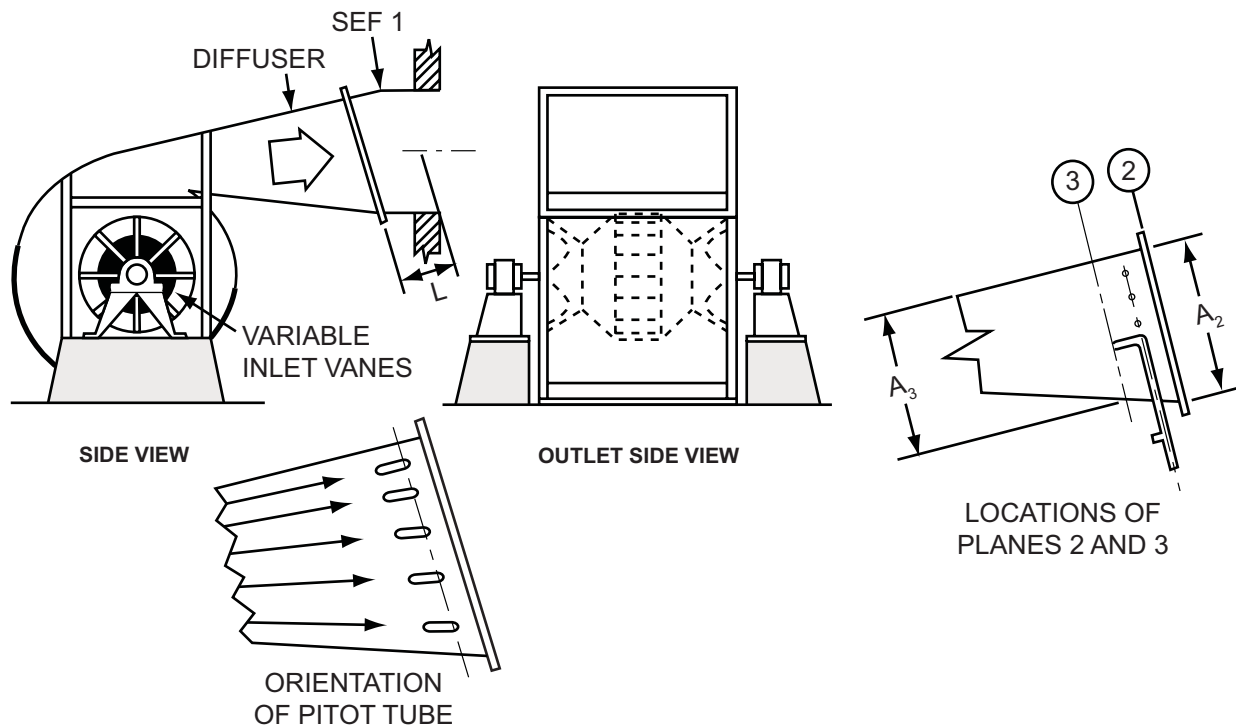
- 3A: Centrifugal Fan in an Exhaust System
- 3B: Axial Fan in an Exhaust System
- 3C: Centrifugal Fan in a Scrubber System
- 3D: Centrifugal Roof Ventilator with Ducted Inlet

EXAMPLES OF AIR HANDLING UNITS

- 4A: Centrifugal Fan in a Built-up Air conditioning Unit
- 4B: Central Station Air Conditioning Unit, Factory Assembled Draw-Through Type
- 4C: Packaged Air Conditioning Unit
- 4D: Packaged Air Conditioning Unit
- 4E: Central Station Air Conditioning Unit, Factory Assembled Blow-Through Type

EXAMPLES OF FANS, INSTALLATION TYPE A: FREE INLET, FREE OUTLET

- 5A: Free Inlet, Free Outlet Roof Ventilator with temporary duct
- 5B: Free Inlet, Free Outlet Propeller Fan with temporary duct
- 5C: Free Inlet, Free Outlet Roof Ventilator as installed

EXAMPLE 1A: CENTRIFUGAL FORCED DRAFT FAN**COMMENTS**

1. The variable inlet vanes are considered part of the fan. Performance ratings for fans with inlet vanes cover operation with the inlet vanes in their full open position. In order to be able to compare the test results to the fan performance ratings, it is essential that the inlet vanes be fixed in their full open positions for the duration of the test.

2. Determine P_{v3} by using the root mean square of the velocity pressure measurements made in a traverse of Plane 3, located near the end of the fan diffuser (evasé). Determine P_{s3} by averaging the static pressure measurements made in the same traverse. Procedures for the traverse are described in Section 9.4. These velocity pressure and static pressure measurements are susceptible to error due to the turbulence existing in the region of the fan outlet. In addition, it is undesirable to have Plane 3 located in a diverging airway. However, no other more suitable location for Plane 3 exists in this example. It is recommended that the Pitot-static tube be oriented so that its nose is aligned with the anticipated flow streams, particularly near the walls of the diffuser, as shown in the diagram. Determine the area of the traverse plane, A_3 , which is located at the tip of the Pitot-static tube, as shown in the diagram, not at the location of the Pitot-static tube access holes in the diffuser.

3. Measure t_{d1} and t_{w1} in the path of the air flowing into the fan inlets. Determine p_b for the general vicinity of the fan. Measure t_{d3} in Plane 3. All of these measurements are used in the determination of densities at the various planes of interest.

4. Measure the fan speed and the motor amps, volts, and, if possible, watts. Record all pertinent motor nameplate data, including volts (NPV) and full load amps (FLA). If the motor power output is to be estimated by using the phase current method described in Annex K, it is not necessary to measure motor watts; however, it may be necessary to disconnect the drive and measure the no load amps (NLA) if the motor is not operating at or near its full load point (refer to Annex K).

5. SEF 1 is due to the effect of insufficient length of duct at the fan outlet. In order to calculate the value of SEF 1, it is necessary to measure the length of the outlet duct, L ; the outlet area of the fan, A_2 ; and the blast area of the fan.

6. The sum of the static pressure, P_{s1} , and velocity pressure, P_{v1} , at the inlets of a fan with unrestricted inlets is considered to be equal to the sum of the static pressure, P_{sx} , and the velocity pressure, P_{vx} , at a point sufficiently distant from the fan inlets, as shown in still air. At this point, the static pressure is zero, and

the velocity pressure in still air is zero.

$$P_{s1} + P_{v1} = P_{sx} + P_{vx} = 0$$

This consideration, which is the same as that used in the methods for testing fans for performance rating purposes, charges to the fan losses incurred in accelerating the air into the fan inlets and eliminates the inaccuracies which arise in any attempt to measure the velocity pressure and static pressure at the fan inlets. To calculate the fan static pressure:

$$\begin{aligned} P_s &= P_{s2} - P_{s1} - P_{v1} + \text{SEF } 1 \\ &= P_{s2} - (P_{s1} + P_{v1}) + \text{SEF } 1 \end{aligned}$$

Since:

$$\begin{aligned} P_{s1} + P_{v1} &= 0 \\ P_s &= P_{s2} + \text{SEF } 1 \end{aligned}$$

7. In order to compare the test results to the quoted fan curve drawn for operation at 1780 rpm and 0.0701 lbm/ft³ density, it is necessary to convert the results to the specified conditions. In this case, the test conditions are identical to the specified conditions and no calculations are required.

OBSERVATIONS

SITE MEASUREMENTS

$p_b = 28.91$ in. Hg
 $t_{d1} = 85^\circ\text{F}$
 $t_{w1} = 63^\circ\text{F}$
 $t_{d3} = 96^\circ\text{F}$
 $P_{s3} = 14.4$ in. wg
 $P_{v3} = 1.52$ in. wg
 $N = 1780$ rpm
 $A_2 = 11.94$ ft²
 $A_3 = 11.3$ ft²
 Blast Area = 7.76 ft²
 $L = 3$ ft.

MEASURED MOTOR DATA

Volts = 570, 560, 572
 = 567 av.
 Amps = 160, 166, 163
 = 163 av.

MOTOR NAMEPLATE DATA

200 hp, 3 phase, 60 hertz
 575 volts, 1800 rpm, 181 FLA

GENERAL

VIVs in full open positions.
 Fan direct connected to motor.

CALCULATIONS

DENSITIES

For fan inlet conditions of:

$$\begin{aligned} t_{d1} &= 85^\circ\text{F} \\ t_{w1} &= 63^\circ\text{F} \\ p_1 &= p_b \\ &= 28.91 \text{ in. Hg} \end{aligned}$$

Use Figure N.1 in Annex N to obtain $\rho_1 = 0.0701$ lbm/ft³

The density at Plane 3:

$$\begin{aligned} \rho_3 &= \rho_1 \left(\frac{P_{s3} + 13.6 p_b}{13.6 p_1} \right) \left(\frac{t_{d1} + 460}{t_{d3} + 460} \right) \\ &= 0.0701 \left(\frac{14.4 + 13.6 \times 28.91}{13.6 \times 28.91} \right) \left(\frac{545}{556} \right) \\ &= 0.0712 \text{ lbm/ft}^3 \end{aligned}$$

In this case, ρ_2 is considered to be equal to ρ_3 .

FLOW RATES

$$\begin{aligned} V_3 &= 1096 (P_{v3}/\rho_3)^{0.5} \\ &= 1096 (1.52/0.0712)^{0.5} \\ &= 5064 \text{ fpm} \end{aligned}$$

$$\begin{aligned} Q_3 &= V_3 A_3 \\ &= 5064 \times 11.3 \\ &= 57223 \text{ cfm} \end{aligned}$$

$$\begin{aligned} Q &= Q_1 \\ &= Q_3 (\rho_3/\rho_1) \\ &= 57223 (0.0712/0.0701) \\ &= 58121 \text{ cfm} \end{aligned}$$

FAN POWER INPUT

$$\begin{aligned} \text{Measured amps/FLA} &= (163/181) \\ &= 0.90 \\ &= 90\% \end{aligned}$$

Annex K indicates that Equation A will provide a reasonably accurate estimate of motor power output for a 200 hp motor operating at 90% FLA.

$$H_{mo} = 200 (163/181) (567/575) \\ = 178 \text{ hp}$$

Since the fan is direct connected to the motor:

$$H = H_{mo} \\ = 178 \text{ hp}$$

SYSTEM EFFECT FACTOR

AMCA Publication 201-90, Figures 7.1 and 8.3 indicate the following calculations:

$$Q_2 = Q_3 (\rho_3/\rho_2) \\ = 57223 (0.0712/0.0712) \\ = 57223 \text{ cfm}$$

$$V_2 = (Q_2/A_2) \\ = (57223/11.94) \\ = 4793 \text{ fpm}$$

Duct diameter equivalent to the diffuser outlet area:

$$D_{e2} = \sqrt{4A_2/\pi} \\ = \sqrt{(4 \times 11.94)/\pi} \\ = 3.9 \text{ ft.}$$

Figure 8.3 shows that for velocities over 2500 fpm, 100% effective duct length is one duct diameter per 1000 fpm,

$$= D_{e2} (V_2/1000) \\ = 3.9 (4793/1000) \\ = 18.7 \text{ ft}$$

$$L \text{ in \% effective duct length} \\ = (L/18.7) 100 \\ = (3/18.7) 100 \\ = 16\%$$

$$\text{Blast area ratio} = \text{Blast Area}/A_2 \\ = 7.76/11.94 \\ = 0.65$$

For blast area ratio of 0.65, and 16% effective duct length, Figure 8.3 shows *System Effect Curve U* applies. For 4793 fpm velocity and curve U, Figure 7.1 shows SEF 1 = 0.6 in. wg at 0.075 lbm/ft³. At 0.0712 lbm/ft³.

$$\text{SEF 1} = 0.6 (0.0712/0.075) \\ = 0.57 \text{ in. wg}$$

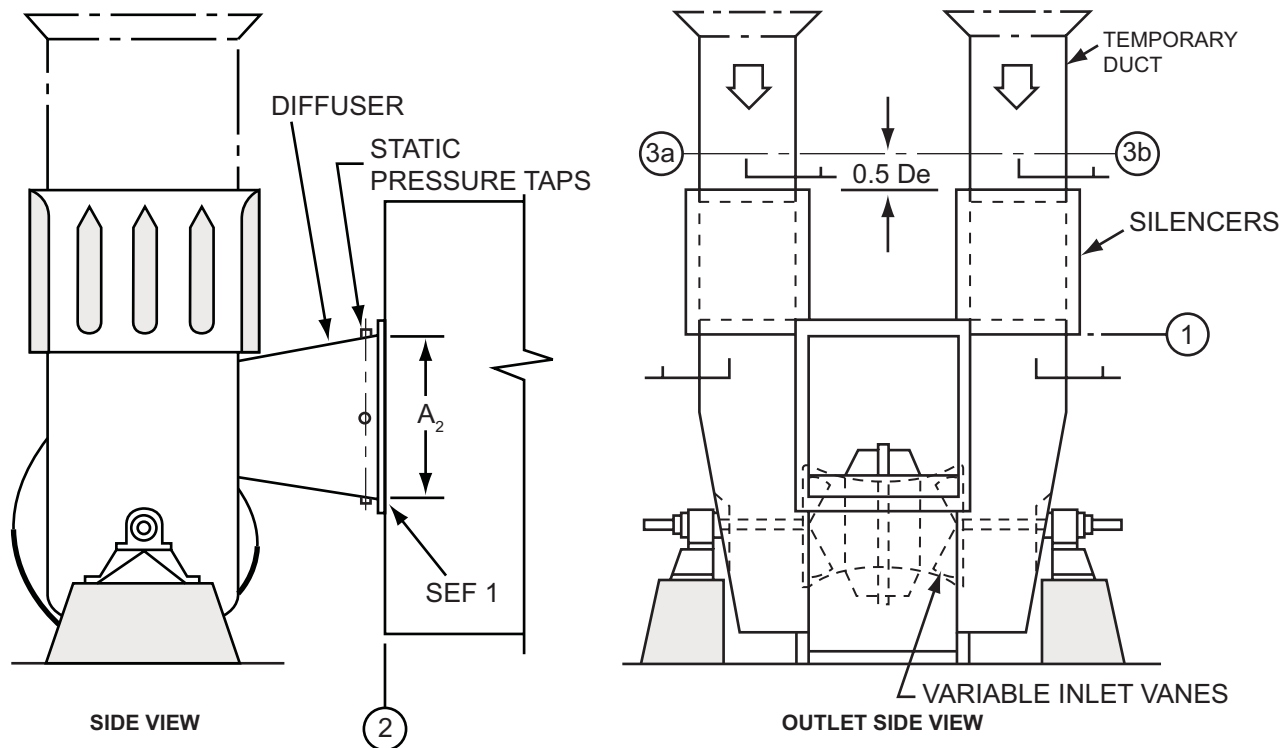
FAN STATIC PRESSURE

Since A_2 is greater than A_3 , there may be some conversion of velocity pressure to static pressure between Planes 3 and 2. However, the amount of conversion will be very small relative to the static pressure measured at Plane 3 and ignoring any change in static pressure from Plane 3 to Plane 2 will have no appreciable effect on the test results. Therefore, P_{s2} is considered equal to P_{s3} .

$$P_s = P_{s2} + \text{SEF 1} \\ = 14.4 + 0.57 \\ = 14.97 \text{ in. wg}$$

CONVERSION TO SPECIFIED CONDITIONS

$$Q_c = Q \\ = 58121 \text{ cfm} \\ P_{sc} = P_s \\ = 14.97 \text{ in. wg} \\ H_c = H \\ = 178 \text{ hp}$$

EXAMPLE 1B: CENTRIFUGAL FORCED DRAFT FAN WITH INLET SILENCERS**COMMENTS**

1. This fan, as supplied and rated by the manufacturer, includes the variable inlet vanes and inlet boxes, but does not include the silencers. Performance ratings for fans with inlet vanes cover operation with the inlet vanes in the full open positions. In order to be able to compare the test results to the fan performance ratings, it is essential that the inlet vanes be fixed in their full open positions for the duration of the test.

2. Determine P_{v3a} and P_{v3b} by using the root mean square of the velocity pressure measurements made in traverses of Planes 3a and 3b. A_{3a} and A_{3b} are the areas traversed. Determine P_{s3a} and P_{s3b} by averaging each of the two sets of static pressure measurements made in the same traverses. Procedures for traverses are described in Section 9.4. P_{s3a} and P_{s3b} are used in determining the density at the traverse plane. A location for Plane 3 measurements may be obtained by installing ducts on each silencer inlet, as shown in the diagram. The ducts should be a minimum of one equivalent diameter in length, and have flared inlets to reduce entrance losses and provide more uniform velocity profiles at the pressure measurement planes.

3. Measure P_{s1a} and P_{s1b} at locations close to the entrances to the inlet boxes and in planes which are substantially equal in area to the planes of the

entrances to the inlet boxes (Plane 1). Determine P_{s2} by averaging the pressure measurements at each of four static pressure taps located near the end of the fan diffuser (evasé). See Annex E for details of static pressure taps.

4. Measure t_{d3} and t_{w3} near the inlet ducts. Determine p_b for the general vicinity of the fan. Measure t_{d2} in Plane 2. All of these measurements are used in the determination of densities at the various planes of interest.

5. Measure the fan speed and the motor amps, volts, and if possible, watts. Record all pertinent motor nameplate data, including volts (NPV) and amps (FLA). If the motor power output is to be estimated by using the phase current method described in Annex K, it is not necessary to measure motor watts; however, it may be necessary to disconnect the drive and measure the no load amps (NLA) if the motor is not operating at or near its full load point. Refer to Annex K.

6. SEF 1 is due to the effect of there being no duct at the fan outlet. In order to calculate the value of SEF 1, it is necessary to measure the fan outlet area, A_2 , and the blast area of the fan.

7. To calculate the fan static pressure:

$$P_s = P_{s2} - P_{s1} - P_{v1} + \text{SEF } 1$$

Where:

$$P_{v1} = (Q/1096A_1)^2 \rho_1$$

8. In order to compare the test results to the quoted fan curve drawn for operation at 1180 rpm and 0.075 lbm/ft³ density, it is necessary to convert the results to the specified conditions. The basis for the calculations is described in Section 14.

OBSERVATIONS

SITE MEASUREMENTS

$$p_b = 29.31 \text{ in. Hg}$$

$$t_{d2} = 93^\circ\text{F}$$

$$t_{d3} = 85^\circ\text{F}$$

$$t_{w3} = 58^\circ\text{F}$$

$$P_{s1a} = -1.20 \text{ in. wg}$$

$$P_{s1b} = -1.30 \text{ in. wg}$$

$$P_{s2} = 10.1 \text{ in. wg}$$

$$P_{s3a} = -0.65 \text{ in. wg}$$

$$P_{s3b} = -0.70 \text{ in. wg}$$

$$P_{v3a} = 0.61 \text{ in. wg}$$

$$P_{v3b} = 0.62 \text{ in. wg}$$

$$N = 1180 \text{ rpm}$$

$$A_{1a} = A_{1b} \\ = 12.5 \text{ ft}^2$$

$$A_2 = 18 \text{ ft}^2$$

$$A_{3a} = A_{3b} \\ = 12.5 \text{ ft}^2$$

$$\text{Blast Area} = 13.5 \text{ ft}^2$$

MEASURED MOTOR DATA

$$\text{Volts} = 460, 455, 465$$

$$= 460 \text{ av}$$

$$\text{Amps} = 257, 256, 258$$

$$= 257 \text{ av}$$

MOTOR NAMEPLATE DATA

200 HP, 3 phase 60 hertz

460 volts, 1180 rpm, 285 FLA

GENERAL

VIVs in full open positions. Fan direct connected to motor. The motor manufacturer advises that this motor type has a peak efficiency of 91% at a power factor of approximately 0.89.

CALCULATIONS

DENSITIES

For Plane 3 conditions of:

$$t_{d3} = 85^\circ\text{F}$$

$$t_{w3} = 58^\circ\text{F}$$

$$P_{s3} = (P_{s3a} + P_{s3b})/2 \\ = (-0.65 - 0.70)/2 \\ = -0.675 \text{ in. wg}$$

$$\rho_3 = p_b + (P_{s3}/13.6) \\ = 29.31 + (-0.675/13.6) \\ = 29.26 \text{ in. Hg}$$

Use Figure N.1 in Annex N to obtain $\rho_3 = 0.0712$ lbm/ft³

It is assumed that the temperature at Plane 1 are the same as those at Plane 3. The density at Plane 1:

$$\rho_1 = \rho_3 \left(\frac{P_{s1} + 13.6p_b}{13.6\rho_3} \right) \left(\frac{t_{d3} + 460}{t_{d1} + 460} \right) \\ = 0.0712 \left(\frac{-1.25 + 13.6 \times 29.31}{13.6 \times 29.26} \right) \left(\frac{545}{545} \right) \\ = 0.0711 \text{ lbm/ft}^3$$

The density at Plane 2:

$$\rho_2 = \rho_3 \left(\frac{P_{s2} + 13.6p_b}{13.6\rho_3} \right) \left(\frac{t_{d3} + 460}{t_{d2} + 460} \right) \\ = 0.0712 \left(\frac{10.1 + 13.6 \times 29.31}{13.6 \times 29.26} \right) \left(\frac{545}{553} \right) \\ = 0.0721 \text{ lbm/ft}^3$$

FLOW RATES

$$V_{3a} = 1096 (P_{v3a}/\rho_3)^{0.5} \\ = 1096 (0.61/0.0712)^{0.5} \\ = 3208 \text{ fpm}$$

$$Q_{3a} = V_{3a} A_{3a} \\ = 3208 \times 12.5 \\ = 40100 \text{ cfm}$$

$$V_{3b} = 1096 (P_{v3b}/\rho_3)^{0.5} \\ = 1096 (0.62/0.0712)^{0.5} \\ = 3234 \text{ cfm}$$

$$Q_{3b} = V_{3b} A_{3b} \\ = 3234 \times 12.5 \\ = 40425 \text{ cfm}$$



$$\begin{aligned}
 Q_3 &= Q_{3a} + Q_{3b} \\
 &= 40100 + 40425 \\
 &= 80525 \text{ cfm}
 \end{aligned}$$

$$\begin{aligned}
 Q &= Q_1 \\
 &= Q_3 (\rho_3/\rho_1) \\
 &= 80525 (0.0712/0.0711) \\
 &= 80638 \text{ cfm}
 \end{aligned}$$

FAN POWER INPUT

$$\begin{aligned}
 \text{Measured amps/FLA} &= (257/285) \\
 &= 0.90 \\
 &= 90\%
 \end{aligned}$$

Annex K indicates that Equation A will provide a reasonably accurate estimate of motor power output for a 250 hp motor operating at 90% FLA.

$$\begin{aligned}
 H_{mo} &= 250 (257/285) (460/460) \\
 &= 225 \text{ hp}
 \end{aligned}$$

As a check of this value, using the motor efficiency data and the appropriate equation in Section 11.2.2:

$$\begin{aligned}
 H_{mo} &= \frac{\sqrt{3} \times 257 \times 460 \times 0.89 \times 0.91}{746} \\
 &= 222 \text{ hp}
 \end{aligned}$$

Since the motor is not fully loaded, the power factor and efficiency may be less, which would reduce H_{mo} as calculated using the second method. However, this is a reasonable check. The value of H_{mo} is selected to be the average of the two results:

$$H_{mo} = 224 \text{ hp}$$

Since the fan is direct-connected to the motor, there is no drive loss, and:

$$\begin{aligned}
 H &= H_{mo} \\
 &= 224 \text{ hp}
 \end{aligned}$$

SYSTEM EFFECT FACTOR

AMCA Publication 201-90, Figures 7.1 and 8.3 indicate the following calculations:

$$\begin{aligned}
 Q_3 (\rho_3/\rho_2) &= 80525 (0.0712/0.0721) \\
 &= 79520 \text{ cfm}
 \end{aligned}$$

$$\begin{aligned}
 (Q_2/A_2) &= (79520/18) \\
 &= 4418 \text{ fpm}
 \end{aligned}$$

$$\begin{aligned}
 \text{Blast area ratio} &= \text{Blast Area}/A_2 \\
 &= 13.5/18 \\
 &= 0.75
 \end{aligned}$$

For a blast area ratio of 0.75, and no duct, Figure 8.3 shows *System Effect Curve T* applies. For 4418 fpm velocity and curve T, Figure 7.1 shows SEF 1 = 0.65 in. wg at 0.075 lbf/ft³. At 0.0720 lbf/ft³:

$$\begin{aligned}
 \text{SEF 1} &= 0.65 (0.0721/0.075) \\
 &= 0.62 \text{ in. wg}
 \end{aligned}$$

FAN STATIC PRESSURE

$$\begin{aligned}
 P_{v1} &= (Q_1/1096 A_1)^2 \\
 &= (80638/1096 \times 25)^2 0.0711 \\
 &= 0.62 \text{ in. wg}
 \end{aligned}$$

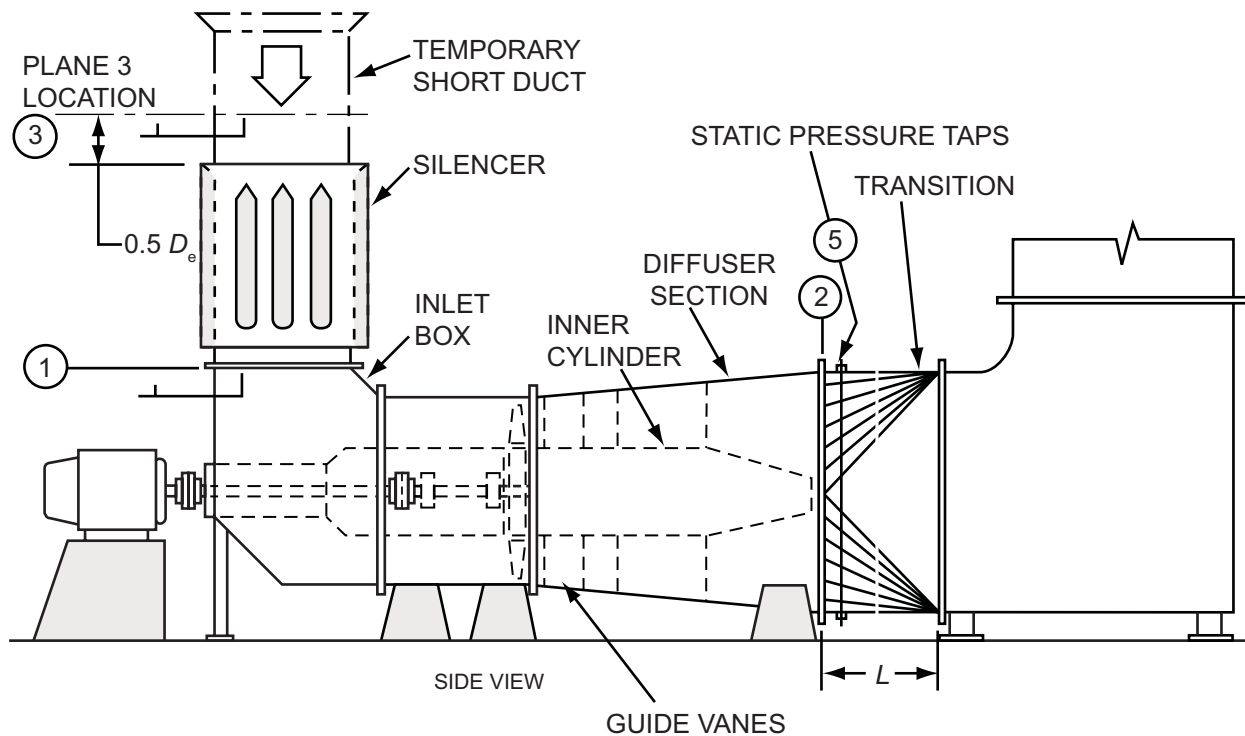
$$\begin{aligned}
 P_s &= P_{s2} - P_{s1} - P_{v1} + \text{SEF 1} \\
 &= 10.1 - (-1.25) - 0.62 + 0.62 \\
 &= 11.33 \text{ in. wg}
 \end{aligned}$$

CONVERSION TO SPECIFIED CONDITIONS

$$\begin{aligned}
 Q_c &= Q \\
 &= 80638 \text{ cfm}
 \end{aligned}$$

$$\begin{aligned}
 P_{sc} &= 11.33 (0.075/0.0711) \\
 &= 11.95 \text{ in. wg}
 \end{aligned}$$

$$\begin{aligned}
 H_c &= 224 (0.075/0.0711) \\
 &= 236 \text{ hp}
 \end{aligned}$$

EXAMPLE 1C: AXIAL FORCED DRAFT FAN WITH INLET SILENCER**COMMENTS**

1. This is a variable pitch axial flow fan. The fan assembly, as supplied and rated by the manufacturer, includes the inlet box and diffuser section, but does not include the silencer. It is essential that the blade pitch angle be fixed for the duration of the test. This blade angle should be agreed upon by all interested parties.

2. A temporary short duct is installed upstream of the silencer to establish Plane 3 in which more uniform pressures can be obtained. The duct should be a minimum of one equivalent diameter in length, and have a flared inlet to reduce entrance losses and provide a more uniform velocity profile at the pressure measurement plane. Determine P_{v3} by using the root mean square of the velocity pressure measurements made in a traverse of Plane 3. P_{s3} is determined by averaging the static pressure measurements made in the same traverse. Procedures for traverses are described in Section 9.4. P_{s3} is used in determining the density at the traverse plane.

3. Measure P_{s1} at a location close to the entrance to the inlet box and in a plane which is substantially equal in area to the plane of the entrance to the inlet box (Plane 1). Determine P_{s5} by averaging the pressure measurements at each of four static pressure taps located near the end of the fan diffuser.

See Annex E for details of static pressure taps. In this example, P_{s2} is considered to be equal to P_{s5} .

4. Measure t_{d3} and t_{w3} near the entrance to the short inlet duct. Determine p_b for the general vicinity of the fan. Measure t_{d5} in Plane 5. All of these measurements are used in the determination of densities at the various planes of interest.

5. Measure the fan speed and the motor amps, volts, and if possible, watts. Record all pertinent motor nameplate data, including volts (NPV) and full load amps (FLA). If the motor power output is to be estimated by using the phase current method described in Annex K, it is not necessary to measure motor watts; however, it may be necessary to disconnect the drive and measure the no load amps (NLA) if the motor is not operating at or near its full load point. Motor performance data, supplied by the motor manufacturer, are used in the determination of motor power output for this example.

6. SEF 1 is due to the effect of insufficient length of duct between the diffuser outlet and the elbow downstream of the diffuser. In order to calculate the value of SEF 1, it is necessary to measure the length of the transition, L , and the outlet area of the diffuser, A_2 .

7. To calculate the Fan Static Pressure:

$$P_s = P_{s2} - P_{s1} - P_{v1} + \text{SEF } 1$$

Where:

$$P_{v1} = P_{v3} (A_3/A_1)^2 (\rho_3/\rho_1)$$

8. Axial fans are often rated in Fan Total Pressure. Computation of Fan Total Pressure is illustrated in the **CALCULATIONS** section of this example.

9. In order to compare the test results to the quoted fan curve drawn for operation at 880 rpm and 0.0740 lbm/ft³ density, it is necessary to convert the results to the specified conditions. In this case, the test conditions are identical to the specified conditions and no calculations are required.

OBSERVATIONS

SITE MEASUREMENTS

$\rho_b = 29.8 \text{ in. Hg}$
 $t_{d3} = 68^\circ\text{F}$
 $t_{w3} = 62^\circ\text{F}$
 $t_{d5} = 88^\circ\text{F}$
 $P_{s1} = -1.80 \text{ in. wg}$
 $P_{s3} = -1.40 \text{ in. wg}$
 $P_{s5} = 20.8 \text{ in. wg}$
 $P_{v3} = 1.30 \text{ in. wg}$
 $N = 880 \text{ rpm}$
 $A_1 = 170.3 \text{ ft}^2$
 $A_2 = 176 \text{ ft}^2$
 $A_3 = 170.3 \text{ ft}^2$
 $A_5 = A_2$
 $L = 15 \text{ ft}$

MEASURED MOTOR DATA

Volts = 4000, 4000, 4100
 = 4033 av
 Amps = 450, 445, 448
 = 448 av

MOTOR NAMEPLATE DATA

4000 hp, 3 phase 60 hertz
 4000 volts, 900 rpm, 520 FLA

GENERAL

Fan direct connected to motor. Motor performance data at operating load, as supplied by motor manufacturer: 0.88 power factor, 95% efficiency.

CALCULATIONS

DENSITIES

For Plane 3 conditions of:

$$t_{d3} = 68^\circ\text{F}$$

$$t_{w3} = 62^\circ\text{F}$$

$$\begin{aligned}
 \rho_3 &= \rho_b + (P_{s3}/13.6) \\
 &= 29.8 + (-1.40/13.6) \\
 &= 29.70 \text{ in. Hg}
 \end{aligned}$$

Use Figure 20 in Annex N to obtain $\rho_3 = 0.0744 \text{ lbm/ft}^3$

It is assumed that $t_{d1} = t_{d3}$. The density at Plane 1:

$$\begin{aligned}
 \rho_1 &= \rho_3 \left(\frac{P_{s1} + 13.6\rho_b}{13.6\rho_3} \right) \left(\frac{t_{d3} + 460}{t_{d1} + 460} \right) \\
 &= 0.0744 \left(\frac{-1.8 + 13.6 \times 29.8}{13.6 \times 29.70} \right) \left(\frac{528}{528} \right) \\
 &= 0.0743 \text{ lbm/ft}^3
 \end{aligned}$$

The density at Plane 2:

$$\begin{aligned}
 \rho_2 &= \rho_5 \\
 &= \rho_3 \left(\frac{P_{s5} + 13.6\rho_b}{13.6\rho_3} \right) \left(\frac{t_{d3} + 460}{t_{d5} + 460} \right) \\
 &= 0.0744 \left(\frac{20.8 + 13.6 \times 29.8}{13.6 \times 29.70} \right) \left(\frac{528}{548} \right) \\
 &= 0.0756 \text{ lbm/ft}^3
 \end{aligned}$$

FLOW RATE

$$\begin{aligned}
 V_3 &= 1096 (P_{v3}/\rho_3)^{0.5} \\
 &= 1096 (1.3/0.0744)^{0.5} \\
 &= 4581 \text{ fpm}
 \end{aligned}$$

$$\begin{aligned}
 Q_3 &= V_3 A_3 \\
 &= 4581 \times 170.3 \\
 &= 780144 \text{ cfm}
 \end{aligned}$$

$$\begin{aligned}
 Q &= Q_1 \\
 &= Q_3 (\rho_3/\rho_1) \\
 &= 780144 (0.0744/0.0743) \\
 &= 781194 \text{ cfm}
 \end{aligned}$$

FAN POWER INPUT

$$\begin{aligned}
 H_{mo} &= \frac{\sqrt{3} \times \text{volts} \times \text{amps} \times \text{power factor} \times \text{efficiency}}{746} \\
 &= \frac{\sqrt{3} \times 4033 \times 448 \times 0.88 \times 0.95}{746} \\
 &= 3507 \text{ hp}
 \end{aligned}$$

Since the fan is direct connected to the motor, there is no drive loss, and:

$$\begin{aligned}
 H &= H_{mo} \\
 &= 3507 \text{ hp}
 \end{aligned}$$

SYSTEM EFFECT FACTOR

AMCA Publication 201-90, Figures 7.1, 8.1, and 8.4 indicate the following calculations:

$$\begin{aligned}
 Q_2 &= Q_3 (\rho_3/\rho_2) \\
 &= 780144 (0.0744/0.0756) \\
 &= 767761 \text{ cfm}
 \end{aligned}$$

$$\begin{aligned}
 V_2 &= (Q_2/A_2) \\
 &= (767761/176) \\
 &= 4362
 \end{aligned}$$

Duct diameter equivalent to the diffuser outlet area:

$$\begin{aligned}
 D_{e2} &= \sqrt{4A_2/\pi} \\
 &= \sqrt{(4 \times 176)/\pi} \\
 &= 15 \text{ ft.}
 \end{aligned}$$

Figure 8.1 shows that for velocities over 2500 fpm, 100% effective duct length is one duct diameter for every 1000 fpm:

$$\begin{aligned}
 &= D_{e2} (V_2/1000) \\
 &= 15 (4362/1000) \\
 &= 65.43 \text{ ft.}
 \end{aligned}$$

L in % effective duct length

$$\begin{aligned}
 &= (L/65.43) 100 \\
 &= (15/65.43) 100 \\
 &= 23\%
 \end{aligned}$$

For 23% effective duct length and a vaneaxial fan with a 2 piece elbow, Figure 8.4 shows *System Effect Curve V* applies. For 4362 fpm velocity and curve V, Figure 7.1 shows SEF 1 = 0.32 in. wg at 0.075 lbm/ft³. At 0.0756 lbm/ft³.

$$\begin{aligned}
 \text{SEF 1} &= 0.32 (0.0756/0.075) \\
 &= 0.32 \text{ in. wg}
 \end{aligned}$$

FAN STATIC PRESSURE

$$\begin{aligned}
 P_{v1} &= P_{v3} (A_3/A_1)^2 (\rho_3/\rho_1) \\
 &= 1.3 (170.3/170.3)^2 (0.0744/0.0743) \\
 &= 1.30 \text{ in. wg}
 \end{aligned}$$

$$\begin{aligned}
 P_{s2} &= P_{s5} \\
 &= 20.8 \text{ in. wg}
 \end{aligned}$$

$$\begin{aligned}
 P_s &= P_{s2} - P_{s1} - P_{v1} + \text{SEF 1} \\
 &= 20.8 - (-1.80) - 1.30 + 0.32 \\
 &= 21.62 \text{ in. wg}
 \end{aligned}$$

FAN TOTAL PRESSURE

$$\begin{aligned}
 P_{t1} &= P_{s1} + P_{v1} \\
 &= -1.8 + 1.30 \\
 &= -0.50 \text{ in. wg}
 \end{aligned}$$

$$\begin{aligned}
 P_{v2} &= P_{v3} (A_3/A_2)^2 (\rho_3/\rho_2) \\
 &= 1.3 (170.3/176)^2 (0.0744/0.0756) \\
 &= 1.20 \text{ in. wg}
 \end{aligned}$$

$$\begin{aligned}
 P_{t2} &= P_{s2} + P_{v2} \\
 &= 20.8 + 1.20 \\
 &= 22.00 \text{ in. wg}
 \end{aligned}$$

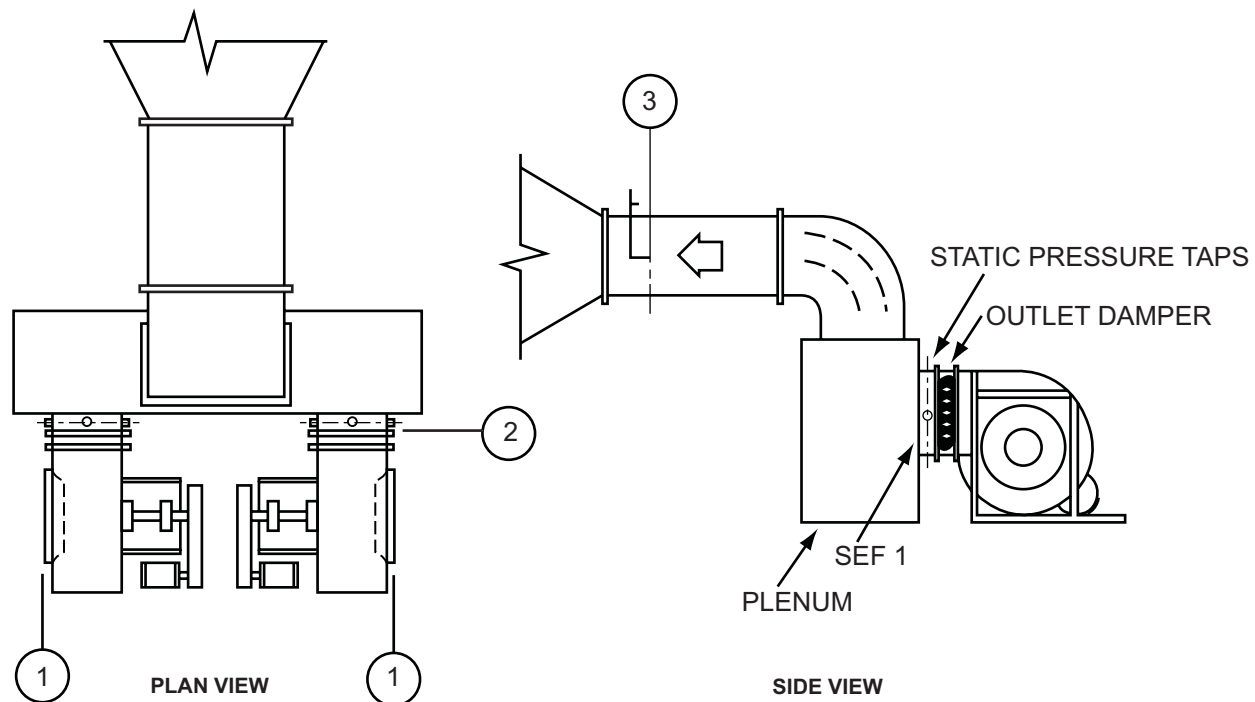
$$\begin{aligned}
 P_t &= P_{t2} - P_{t1} + \text{SEF 1} \\
 &= 22.00 - (-0.50) + 0.32 \\
 &= 22.82 \text{ in. wg}
 \end{aligned}$$

Also:

$$\begin{aligned}
 P_t &= P_s + P_v \\
 P_v &= P_{v2} \\
 &= 1.20 \text{ in. wg} \\
 P_t &= 21.62 + 1.20 \\
 &= 22.82 \text{ in. wg}
 \end{aligned}$$

CONVERSION TO SPECIFIED CONDITIONS

$$\begin{aligned}
 Q_c &= Q \\
 &= 781194 \text{ cfm} \\
 P_{sc} &= P_s \\
 &= 21.62 \text{ in. wg} \\
 P_{tc} &= P_t \\
 &= 22.82 \text{ in. wg} \\
 H_c &= H \\
 &= 3507 \text{ hp}
 \end{aligned}$$

EXAMPLE 1D: CENTRIFUGAL FANS IN PARALLEL**COMMENTS**

1. Each of the fans, as supplied and rated by the manufacturer, includes an outlet damper. Performance ratings for fans with outlet dampers cover operation with the outlet damper in the full open position. In order to be able to compare the test results to the fan performance ratings it is essential that the outlet dampers be fixed in the full open positions for the duration of the test.

2. In this example, there are no suitable locations for traverse planes for use in determining directly the flow rate for each fan. The alternative is to determine the total flow rate and since the fans and their operating speeds are alike, assume that each fan delivers a flow rate proportional to its actual speed. Determine P_{v3} by using the root mean square of the velocity pressure measurements made in a traverse of Plane 3, located near the end of a straight run of duct, such as shown in the diagram. Determine P_{s3} by averaging the static pressure measurements made in the same traverse. Procedures for traverses are described in Section 9.4. P_{s3} is used in determining the density at the traverse plane. Measure the area of traverse plane, A_3 , which is located at the tip of the Pitot-static tube.

3. Determine P_{s2} for each fan by averaging the pressure measurements at each of four static pressure taps located in the short length of duct

between the outlet damper and the plenum. See Annex E for details of static pressure taps. Measure t_{d2} in Plane 2 for each fan.

4. For each fan, measure t_{d1} and t_{w1} in the path of the air flowing into the fan inlet. Determine p_b for the general vicinity of the fans. Measure t_{d3} in Plane 3. All of these measurements are used in the determination of densities at the various planes of interest.

5. Measure the fan speed and the motor amps, volts, and if possible, watts for each fan. Record all pertinent motor nameplate data, including volts (NPV) and full load amps (FLA). If the motor power outputs are to be estimated by using the phase current method described in Annex K, it is not necessary to measure motor watts; however, it may be necessary to disconnect the drives and measure the no load amps (NLA) if the motors are not operating at or near their full load points. Refer to Annex K.

6. SEF 1 is due to the effect of insufficient length of duct between the outlet of each fan and the plenum. In this case, the duct length is so short as to be judged equivalent to there being no duct at all. In order to calculate the value of SEF 1, it is necessary to measure the outlet areas of the fans, A_2 , and their blast areas.

7. The sum of the static pressure, P_{s1} , and the velocity pressure, P_{v1} , at the inlet of a fan with an unrestricted inlet is considered to be equal to the sum of the static pressure, P_{sx} , and the velocity pressure, P_{vx} , at a point sufficiently distant from the inlet as to be in still air. At this point, the static pressure is zero, and the velocity pressure in still air is zero.

$$P_{s1} + P_{v1} = P_{sx} + P_{vx} \\ = 0$$

This consideration, which is the same as that used in the methods for testing fans for performance rating purposes, charges to the fan losses incurred in accelerating the air into the fan inlet and eliminates the inaccuracies which arise in any attempt to measure the velocity pressure and static pressure at the fan inlet. To calculate the Fan Static Pressure:

$$P_s = P_{s2} - P_{s1} - P_{v1} + \text{SEF } 1 \\ = P_{s2} - (P_{s1} + P_{v1}) + \text{SEF } 1$$

Since $P_{s1} + P_{v1} = 0$:

$$P_s = P_{s2} + \text{SEF } 1$$

8. In order to compare the test results to the quoted fan curve drawn for operation at 1900 rpm and 0.075 lbm/ft³ density, it is necessary to convert the results to the specified conditions. The basis for the calculations is described in Section 14.

OBSERVATIONS

SITE MEASUREMENTS

$$p_b = 29.05 \text{ in. Hg}$$

$$t_{d3} = 78^\circ\text{F}$$

$$P_{s3} = 5.6 \text{ in. wg}$$

$$P_{v3} = 0.47 \text{ in. wg}$$

$$A_3 = 7.4 \text{ ft}^2$$

LH Fan

$$t_{d1} = 75^\circ\text{F}$$

$$t_{w1} = 57^\circ\text{F}$$

$$t_{d2} = 79^\circ\text{F}$$

$$P_{s2} = 6.4 \text{ in. wg}$$

$$N = 1910 \text{ rpm, LH fan speed}$$

$$A_2 = 3.2 \text{ ft}^2$$

$$\text{Blast Area} = 2.25 \text{ ft}^2$$

RH Fan

$$t_{d1} = 75^\circ\text{F}$$

$$t_{w1} = 57^\circ\text{F}$$

$$t_{d2} = 79^\circ\text{F}$$

$$P_{s2} = 6.4 \text{ in. wg}$$

$$N = 1890 \text{ rpm, RH fan speed}$$

$$A_2 = 3.2 \text{ ft}^2$$

$$\text{Blast Area} = 2.25 \text{ ft}^2$$

MEASURED MOTOR DATA

LH Fan

$$\text{Volts} = 575, 572, 578$$

$$= 575 \text{ av}$$

$$\text{Amps} = 16, 17, 17$$

$$= 16.7 \text{ av}$$

$$\text{NLA} = 7.0$$

RH Fan

$$\text{Volts} = 575, 574, 573$$

$$= 574 \text{ av}$$

$$\text{Amps} = 15, 16, 16$$

$$= 15.7 \text{ av}$$

$$\text{NLA} = 7.0$$

MOTOR NAMEPLATE DATA

LH Fan

$$25 \text{ hp, 3 phase, 60 hertz}$$

$$575 \text{ volts, 1780 rpm, 23 FLA}$$

RH Fan

$$25 \text{ hp, 3 phase, 60 hertz}$$

$$575 \text{ volts, 1780 rpm, 23 FLA}$$

GENERAL

Outlet dampers in full open positions. Fans connected to motors through belt drives.

CALCULATIONS

DENSITIES

For inlet conditions for both fans of:

$$t_{d1} = 75^\circ\text{F}$$

$$t_{w1} = 57^\circ\text{F}$$

$$p_1 = p_b$$

$$= 29.05 \text{ in. Hg}$$

Use Figure N.1 in Annex N to obtain $\rho_1 = 0.0718 \text{ lbm/ft}^3$

The density at Plane 2:

$$\begin{aligned}\rho_2 &= \rho_1 \left(\frac{P_{s2} + 13.6 p_b}{13.6 p_1} \right) \left(\frac{t_{d1} + 460}{t_{d2} + 460} \right) \\ &= 0.0718 \left(\frac{6.4 + 13.6 \times 29.05}{13.6 \times 29.05} \right) \left(\frac{535}{539} \right) \\ &= 0.0724 \text{ lbm/ft}^3\end{aligned}$$

The density at Plane 3:

$$\begin{aligned}\rho_3 &= \rho_1 \left(\frac{P_{s3} + 13.6 p_b}{13.6 p_1} \right) \left(\frac{t_{d1} + 460}{t_{d3} + 460} \right) \\ &= 0.0718 \left(\frac{5.6 + 13.6 \times 29.05}{13.6 \times 29.05} \right) \left(\frac{535}{538} \right) \\ &= 0.0724 \text{ lbm/ft}^3\end{aligned}$$

FLOW RATES

$$\begin{aligned}V_3 &= 1096 (P_{v3}/\rho_3)^{0.5} \\ &= 1096 (0.47/0.0724)^{0.5} \\ &= 2792 \text{ fpm}\end{aligned}$$

$$\begin{aligned}Q_3 &= V_3 A_3 \\ &= 2792 \times 7.4 \\ &= 20661 \text{ cfm}\end{aligned}$$

$$\begin{aligned}Q &= Q_1 \\ &= Q_3 (\rho_3/\rho_1) \\ &= 20661 (0.0724/0.0718) \\ &= 20834 \text{ cfm}\end{aligned}$$

Assume that the air flow rate for each fan is proportional to its speed.

$$\begin{aligned}\text{LH Fan} \\ Q &= Q_1 \\ &= 20834 [1910/(1910 + 1890)] \\ &= 10472 \text{ cfm}\end{aligned}$$

$$\begin{aligned}\text{RH Fan} \\ Q &= Q_1 \\ &= 20834 [1890/(1910 + 1890)] \\ &= 10362 \text{ cfm}\end{aligned}$$

FAN POWER INPUT

$$\begin{aligned}\text{LH Fan} \\ \text{Measured amps/FLA} &= (16.7/23) \\ &= 0.73 \\ &= 73\%\end{aligned}$$

$$\begin{aligned}\text{RH Fan} \\ \text{Measured amps/FLA} &= (15.7/23) \\ &= 0.68 \\ &= 68\%\end{aligned}$$

Annex K indicates that the average of the results of Equation A and Equation B will provide a reasonably accurate estimate of motor power output for a 25 hp motor operating at approximately 70% FLA.

LH Fan

$$\begin{aligned}\text{Eqn A} &= 25 (16.7/23) (575/575) \\ &= 18.15 \text{ hp}\end{aligned}$$

$$\begin{aligned}\text{Eqn B} &= 25 [(16.7 - 7)/(23 - 7)] (575/575) \\ &= 15.16 \text{ hp}\end{aligned}$$

$$\begin{aligned}H_{mo} &= (18.15 + 15.16)/2 \\ &= 16.66 \text{ hp}\end{aligned}$$

RH Fan

$$\begin{aligned}\text{Eqn A} &= 25 (15.7/23) (574/575) \\ &= 17.04 \text{ hp}\end{aligned}$$

$$\begin{aligned}\text{Eqn B} &= 25 [(15.7 - 7)/(23 - 7)] (574/575) \\ &= 13.57 \text{ hp}\end{aligned}$$

$$\begin{aligned}H_{mo} &= (17.04 + 13.57)/2 \\ &= 15.31 \text{ hp}\end{aligned}$$

Figure L.1 in Annex L indicates estimated belt drive loss of 5% for each fan.

LH Motor

$$\begin{aligned}H_L &= 0.05 H_{mo} \\ &= 0.05 \times 16.66 \\ &= 0.83 \text{ hp} \\ H &= H_{mo} - H_L \\ &= 16.66 - 0.83 \\ &= 15.83 \text{ hp}\end{aligned}$$

RH Motor

$$\begin{aligned}H_L &= 0.05 H_{mo} \\ &= 0.05 \times 15.31 \\ &= 0.77 \text{ hp} \\ H &= H_{mo} - H_L \\ &= 15.31 - 0.77 \\ &= 14.54 \text{ hp}\end{aligned}$$

SYSTEM EFFECT FACTOR

AMCA Publication 201-90, Figures 7.1 and 8.3 indicate the following calculations:

LH Fan

$$\begin{aligned}Q_2 &= Q_1 (\rho_1/\rho_2) \\ &= 10472 (0.0718/0.0724) \\ &= 10385 \text{ cfm}\end{aligned}$$

$$\begin{aligned}V_2 &= (Q_2/A_2) \\ &= (10385/3.2) \\ &= 3245 \text{ fpm}\end{aligned}$$



$$\begin{aligned}\text{Blast area ratio} &= \text{Blast Area}/A_2 \\ &= 2.25/3.2 \\ &= 0.70\end{aligned}$$

RH Fan

$$\begin{aligned}Q_2 &= Q_1 (\rho_1/\rho_2) \\ &= 10362 (0.0718/0.0724) \\ &= 10276 \text{ cfm}\end{aligned}$$

$$\begin{aligned}V_2 &= (Q_2/A_2) \\ &= (10276/3.2) \\ &= 3211 \text{ fpm}\end{aligned}$$

$$\begin{aligned}\text{Blast area ratio} &= \text{Blast Area}/A_2 \\ &= 2.25/3.2 \\ &= 0.70\end{aligned}$$

For a blast area ratio of 0.7 and no duct, Figure 8.3 shows *System Effect Curve S* applies. For each fan with velocities of 3245 fpm and 3211 fpm and curve S, Figure 7.1 shows SEF 1 = 0.5 in. wg at 0.075 lbm/ft³. At 0.0724 lbm/ft³:

$$\begin{aligned}\text{SEF 1} &= 0.5 (0.0724/0.075) \\ &= 0.48 \text{ in. wg}\end{aligned}$$

FAN STATIC PRESSURE

$$P_s = P_{s2} + \text{SEF 1}$$

LH Fan

$$\begin{aligned}P_s &= 6.4 + 0.48 \\ &= 6.88 \text{ in. wg}\end{aligned}$$

RH Fan

$$\begin{aligned}P_s &= 6.4 + 0.48 \\ &= 6.88 \text{ in. wg}\end{aligned}$$

CONVERSION TO SPECIFIED CONDITIONS

LH Fan

$$\begin{aligned}Q_c &= 10472 (1900/1910) \\ &= 10417 \text{ cfm}\end{aligned}$$

$$\begin{aligned}P_{sc} &= 6.88 (1900/1910)^2 (0.075/0.0718) \\ &= 7.11 \text{ in. wg}\end{aligned}$$

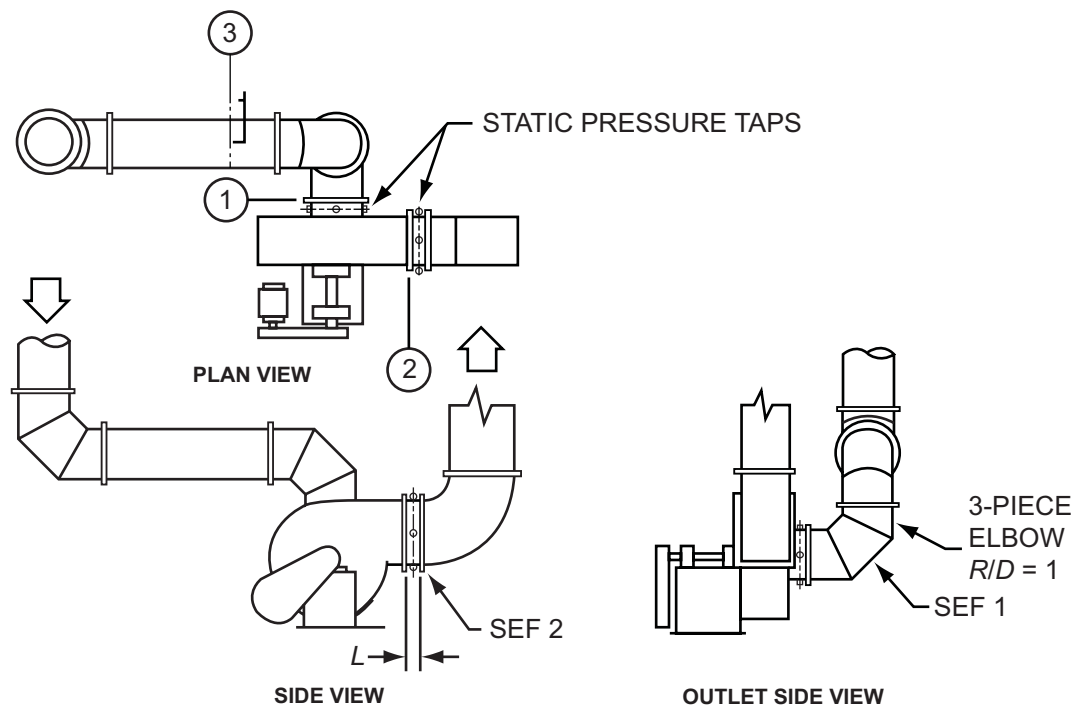
$$\begin{aligned}H_c &= 15.83 (1900/1910)^3 (0.075/0.0718) \\ &= 16.28 \text{ hp}\end{aligned}$$

RH Fan

$$\begin{aligned}Q_c &= 10362 (1900/1890) \\ &= 10417 \text{ cfm}\end{aligned}$$

$$\begin{aligned}P_{sc} &= 6.88 (1900/1890)^2 (0.075/0.0718) \\ &= 7.26 \text{ in. wg}\end{aligned}$$

$$\begin{aligned}H_c &= 14.54 (1900/1890)^3 (0.075/0.0718) \\ &= 15.43 \text{ hp}\end{aligned}$$

EXAMPLE 2A: UTILITY FAN IN A VENTILATION SYSTEM**COMMENTS**

1. Determine P_{v3} by using the root mean square of the velocity pressure measurements made in a traverse of Plane 3, located near the end of a straight run of duct, such as shown in the diagram. Determine P_{s3} by averaging the static pressure measurements made in the same traverse. Procedures for traverses are described in Section 9.4. P_{s3} is used in determining the density at the traverse plane. Measure the area of the traverse plane, A_3 , which is located at the tip of the Pitot-static tube.

2. Determine P_{s1} by averaging the pressure measurements at each of four static pressure taps in the collar connection at the fan inlet. Determine P_{s2} by averaging the pressure measurements at each of four static pressure taps located near the fan outlet.

3. Measure t_{d3} and t_{w3} in the traverse plane. Assume t_{d1} is equal to t_{d3} . Determine p_b for the general vicinity of the fan. Measure t_{d2} in Plane 2. All of these measurements are used in determining densities at the various planes of interest.

4. Measure the fan speed and the motor amps, volts, and if possible, watts. Record all pertinent motor nameplate data, including volts (NPV) and full load amps (FLA). If the motor power output is to be estimated by using the phase current method

described in Annex K, it is not necessary to measure motor watts; however, it may be necessary to disconnect the drive and measure the no load amps (NLA) if the motor is not operating at or near its full load point. Refer to Annex K.

5. SEF 1 is due to the effect of the elbow located at the fan inlet. SEF 2 is due to the effect of insufficient length of duct between the fan outlet and the elbow downstream of the fan. In order to calculate the values of the SEFs, it is necessary to measure the inlet area and the outlet area of the fan, A_1 and A_2 ; the length of the outlet duct, L ; and the blast area of the fan.

6. To calculate the Fan Static Pressure:

$$P_s = P_{s2} - P_{s1} - P_{v1} + \text{SEF 1} + \text{SEF 2}$$

Where:

$$P_{v1} = P_{v3} (A_3/A_1)^2 (\rho_3/\rho_1)$$

7. In order to compare the test results to the quoted fan curve drawn for operation at 1880 rpm and 0.075 lbm/ft³ density, it is necessary to convert the results to the specified conditions. The basis for the calculations is described in Section

OBSERVATIONS**SITE MEASUREMENTS**

$p_b = 29.20$ in. Hg
 $t_{d2} = 72^\circ\text{F}$
 $t_{d3} = 72^\circ\text{F}$
 $t_{w3} = 66^\circ\text{F}$
 $P_{s1} = -2.18$ in. wg
 $P_{s2} = 0.35$ in. wg
 $P_{s3} = -1.95$ in. wg
 $P_{v3} = 0.45$ in. wg
 $N = 1730$ rpm
 $A_1 = 1.07$ ft²
 $A_2 = 1.17$ ft²
 $A_3 = 1.07$ ft²
 Blast Area = 0.7 ft²
 $L = 0.83$ ft

MEASURED MOTOR DATA

Volts = 227, 229, 228
 = 228 av
 Amps = 10.2, 10.3, 10.4
 = 10.3 av
 NLA = 7.1

MOTOR NAMEPLATE DATA

5 hp, 3 phase, 60 hertz
 230 volts, 1750 rpm, 14 FLA

GENERAL

Fan connected to motor through belt drive.

CALCULATIONS**DENSITIES**

For Plane 3 conditions of:

$t_{d3} = 72^\circ\text{F}$
 $t_{w3} = 66^\circ\text{F}$

$$\begin{aligned}
 p_3 &= p_b + (P_{s3}/13.6) \\
 &= 29.20 + (-1.95/13.6) \\
 &= 29.06 \text{ in. Hg}
 \end{aligned}$$

Use Figure N.1 in Annex N to obtain $\rho_3 = 0.0719$ lbm/ft³

It is assumed that $t_{d1} = t_{d3}$

The density at Plane 1:

$$\begin{aligned}
 \rho_1 &= \rho_3 \left(\frac{P_{s1} + 13.6 p_b}{13.6 p_3} \right) \left(\frac{t_{d3} + 460}{t_{d1} + 460} \right) \\
 &= 0.0719 \left(\frac{-2.18 + 13.6 \times 29.20}{13.6 \times 29.06} \right) \left(\frac{532}{532} \right) \\
 &= 0.0718 \text{ lbm/ft}^3
 \end{aligned}$$

The density at Plane 2:

$$\begin{aligned}
 \rho_2 &= \rho_3 \left(\frac{P_{s2} + 13.6 p_b}{13.6 p_3} \right) \left(\frac{t_{d3} + 460}{t_{d2} + 460} \right) \\
 &= 0.0719 \left(\frac{0.35 + 13.6 \times 29.20}{13.6 \times 29.06} \right) \left(\frac{532}{532} \right) \\
 &= 0.0723 \text{ lbm/ft}^3
 \end{aligned}$$

FLOW RATES

$$\begin{aligned}
 V_3 &= 1096 (P_{v3}/\rho_3)^{0.5} \\
 &= 1096 (0.45/0.0719)^{0.5} \\
 &= 2742 \text{ fpm}
 \end{aligned}$$

$$\begin{aligned}
 Q_3 &= V_3 A_3 \\
 &= 2742 \times 1.07 \\
 &= 2934 \text{ cfm}
 \end{aligned}$$

$$\begin{aligned}
 Q &= Q_1 \\
 &= Q_3 (\rho_3/\rho_1) \\
 &= 2934 (0.0719/0.0718) \\
 &= 2938 \text{ cfm}
 \end{aligned}$$

FAN POWER INPUT

$$\begin{aligned}
 \text{Measured amps/FLA} &= 10.3/14 \\
 &= 0.74 \\
 &= 74\%
 \end{aligned}$$

Annex K indicates that the average of the results of Equation A and Equation B will provide a reasonably accurate estimate of motor power output for a 5 hp motor operating at 74% FLA.

$$\begin{aligned}
 \text{Eqn A} &= 5 (10.3/14) (228/230) \\
 &= 3.65 \text{ hp}
 \end{aligned}$$

$$\begin{aligned}
 \text{Eqn B} &= 5 [(10.3 - 7.1)/(14 - 7.1)] (228/230) \\
 &= 2.30 \text{ hp}
 \end{aligned}$$

$$\begin{aligned}
 H_{mo} &= (3.65 + 2.30)/2 \\
 &= 2.98 \text{ hp}
 \end{aligned}$$