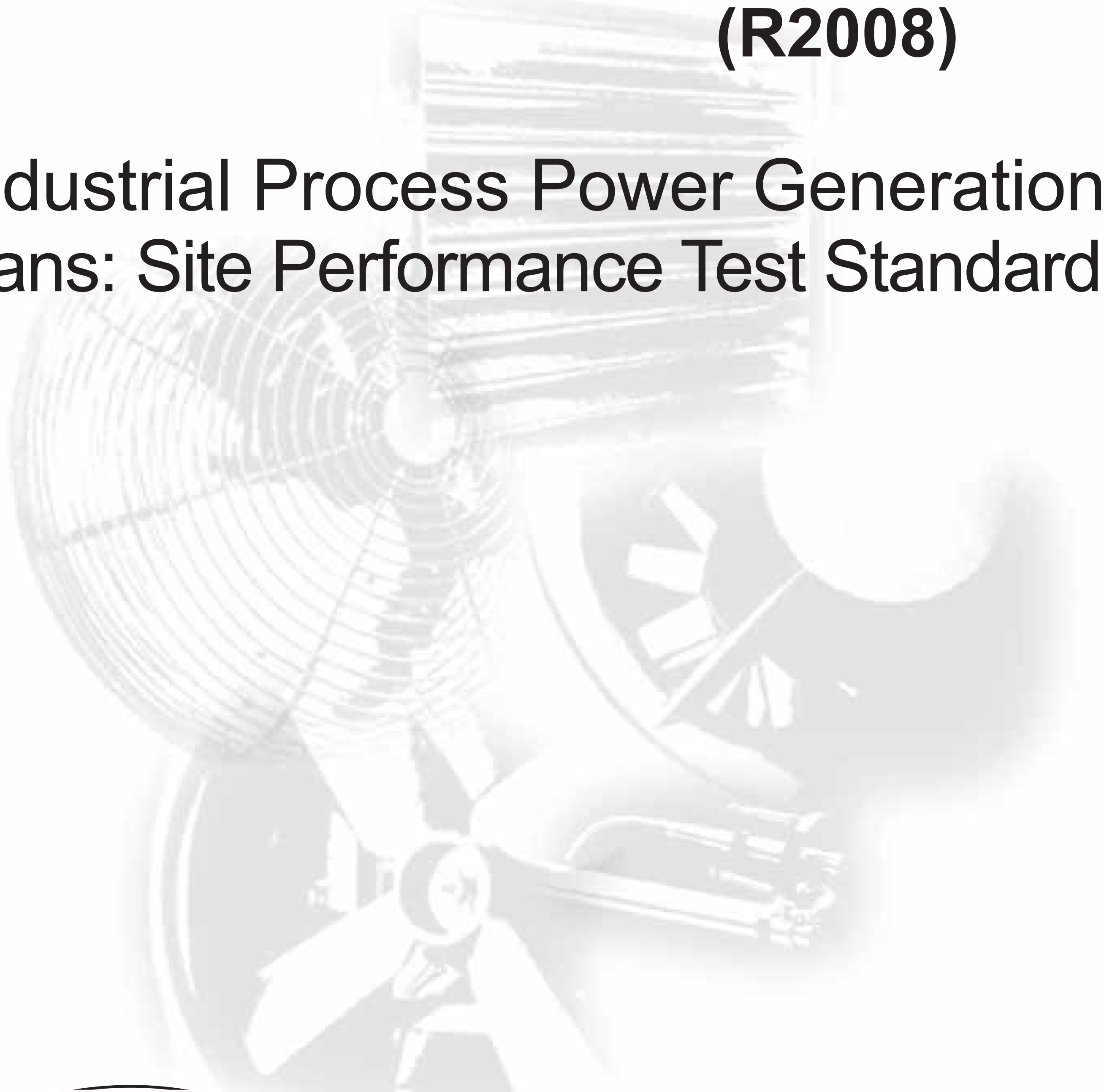
AMCA
Standard 803-02
(R2008)

Industrial Process Power Generation Fans: Site Performance Test Standard



AIR MOVEMENT AND CONTROL ASSOCIATION INTERNATIONAL, INC.

The International Authority on Air System Components

AMCA STANDARD 803-02 (R2008)

Industrial Process / Power Generation Fans: Site Performance Test Standard

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Authority

AMCA Standard 803-02 was adopted by the membership of the Air Movement and Control Association International, Inc. It was reaffirmed by the membersip on May 4, 2008. The 2008 edition incorporated an errata which fixed the numbering of equations and both clarified and added a Figure to Annex A.

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RELATED AMCA STANDARDS

For Air Performance:

ANSI/AMCA Standard 210	*Laboratory Method of Testing Fans for Aerodynamic Performance Rating*

For Sound:

AMCA Standard 300	*Reverberant Room Method for Sound Testing of Fans*
AMCA Standard 301	*Methods for Calculating Fan Sound Ratings from Laboratory Test Data*
AMCA Standard 320	*Laboratory Methods of Sound Testing of Fans Using Sound Intensity*

For Balance and Vibration:

ANSI/AMCA Standard 204	*Balance Quality and Vibration Levels for Fans*

Industrial Process / Power Generation Series:

AMCA Publication 801	*Industrial Process/Power Generation Fans: Specification Guidelines*
AMCA Publication 802	*Industrial Process/Power Generation Fans: Establishing Performance Using Laboratory Models*
AMCA Standard 803	*Industrial Process/Power Generation Fans: Site Performance Test Standard*

Fan Application Manual:

AMCA Publication 200	*Air Systems*
AMCA Publication 201	*Fans and Systems*
AMCA Publication 202	*Troubleshooting*
AMCA Publication 203	*Field Performance Measurement of Fan Systems*

TABLE OF CONTENTS

Industrial Process / Power Generation Fans: Site Performance Test Standard

1. Purpose

This standard establishes uniform methods to be used in measuring the aerodynamic performance of industrial process or power generation fans under actual operating conditions on the site. The standard also defines rules for converting the measured performance to other specified operating conditions.

This standard is also intended to produce results comparable to those obtained in a laboratory test of a fan in accordance with ANSI/AMCA 210 *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*. Fans in systems which have unstable operating characteristics or have distorted flow profiles at the inlet of the fan may not be suitable for testing in accordance with this standard.

The object of a performance test on a fan installed in its system generally falls into one of the following categories:

a) General Fan and System Evaluation
The purpose for conducting this type of an on-site test is to evaluate the performance of the fan in its system as a basis for future modifications to the fan or system.

b) Acceptance Tests
An on-site test specified as part of the sales agreement for the purpose of verifying the quoted fan performance.

c) Proof of Performance Test
This type of on-site test is conducted as a result of a complaint that the fan or system is not performing as intended.

This standard defines the quantities which need to be measured to establish fan performance, the personnel, the location of the measurement points, the calculation of results, the degree of uncertainty, the measurement methods and instrumentation which are to be used. Limits on the types of fans and systems which may be regarded as meeting the requirements of this test standard are also defined.

2. Scope

The term **on-site test**, as used in this standard, is a test conducted for the purpose of determining the aerodynamic performance of a fan when operating in the system for which it was intended.

2.1 Acceptable fans

This standard may be used as the basis for testing all types of centrifugal, axial, and mixed flow fans in ducted installations. The ducting may be on either the inlet side of the fan, the outlet side of the fan, or both.

The term **fan** encompasses all types of air or gas moving devices including blowers and exhausters, having one or more stages, but without interstage cooling. Circulating fans such as ceiling fans and desk fans, and positive displacement machines are not within the scope of this standard.

Sound tests, vibration tests, and mechanical tests of all types are not within the scope of this standard.

2.2 Acceptable installations

The performance of a fan when installed in a system is dependent not only on the fan, but also on the system, and on the interaction of one with the other. The effect of the system of the fan performance is known as “System Effect.”

Assuming that the fan is rated and manufactured correctly, the three most common causes of deficient performance of the fan and system combination are:

- Improper inlet and/or outlet connections
- Non-uniform inlet flow
- Swirl at the fan inlet

These conditions alter the aerodynamic characteristics of the fan so that its flow potential is not fully realized. The conditions will occur when the connections to the fan inlet and/or outlet are poorly designed or installed. One bad connection can reduce the fan’s actual performance to a point far below its rated performance.

This standard defines minimum requirements for flow velocity profiles at the measurement stations and duct geometry requirements which will result in insignificant system effects. Any installation which does not fall within the defined limitations is regarded as unacceptable for the purposes of on-site testing to this standard.

Full size fan performance is generally calculated by manufacturers based on laboratory model tests in accordance with ANSI/AMCA 210 [1]. Scaling rules are defined in AMCA Publication 802 [2]. Calculated fan performance is therefore based on ideal laboratory flow conditions designed to facilitate accurate measurement.

On site, the magnitude of the System Effect may vary from zero for a well designed system to an amount that makes fan performance appear totally unacceptable. Significant System Effects may render an on-site performance test meaningless.

An unacceptable installation must be altered to bring it within the requirements stated in this standard if an on-site test to this standard is mandatory. In the event that suitable installation modifications cannot be achieved, then a test according to Standard 803 is not possible. In this case, various alternatives to an on-site test according to this standard are outlined in Annex F.

3. Units of Measurement

3.1 System of units. SI units (The International System of Units - Le Systéme International d'Unités) [3] are the primary units employed in this standard, with I-P units given as the secondary reference. SI units are based on the fundamental values of the International Bureau of Weights and Measures [4], and I-P values are based on the values of the National Institute of Standards and Technology which are, in turn, based on the values of the International Bureau.

3.2 Basic units. The unit of length is the meter (m) or millimeter (mm); I-P units are the foot (ft) or inch (in.). The unit of mass is the kilogram (kg); the I-P unit is the pound-mass (lbm). The unit of time is either the minute (min) or the second (s). The unit of temperature is either the kelvin (K) or the degree Celsius (°C); I-P units are the degree Rankine (°R) or the degree Fahrenheit (°F). The unit of force is the newton (N); the I-P unit is the pound (lb).

3.3 Flow rate and velocity. The unit of flow rate is the cubic meter per second (m^3/s); the I-P unit is the cubic foot per minute (cfm). The unit of velocity is the meter per second (m/s); the I-P unit is the foot per minute (fpm).

3.4 Pressure. The unit of pressure is either the pascal (Pa); the I-P unit is either the inch water gauge (in. wg), or the inch mercury column (in. Hg). Values of in. Hg shall be used only for barometric pressure measurements. The in. wg shall be based on a one inch column of distilled water at 68°F under standard gravity and a gas column balancing effect based on standard air. The in. Hg shall be based on a one inch column of mercury at 32°F under standard gravity *in vacuo*.

3.5 Power, energy, and torque. The unit of power is the watt (W); the I-P unit is the horsepower (hp). The unit of energy is the joule (J); the I-P unit is the foot pound (ft-lb). The unit of torque is the Newton-meter (N•m); the I-P unit is the pound inch (lb-in.).

3.6 Efficiency. Efficiencies are expressed on a per unit basis. Percentage values can be obtained by multiplying by 100.

3.7 Speed. There is no unit of rotational speed as such in the SI system of units. The commonly used unit in both systems is the revolution per minute (rpm).

3.8 Gas properties. The unit of density is the kilogram per cubic meter; the I-P unit is the pound-mass per cubic foot. The unit of viscosity is the pascal second (Pa•s); the I-P unit is the pound-mass per foot-second (lbm/ft•s). The unit of gas constant is the joule per kilogram kelvin (J/kg•K); the I-P unit is the foot pound per pound mass degree Rankine (ft-lb/lbm-°R).

3.9 Dimensionless groups. Various dimensionless quantities appear in the text. Any consistent system of units may be employed to evaluate these quantities unless a numerical factor is included, in which case units must be as specified.

3.10 Physical constants. The value of standard gravitational acceleration shall be taken as 9.80665 m/s^2 at mean sea level at 45° latitude; the I-P value is 32.1740 ft/s^2 at mean sea level at 45° latitude [4]. The density of distilled water at saturation pressure shall be taken as 998.278 kg/m^3 at 20°C; the I-P value is 62.3205 lbm/ft^3 at 68°F [5]. The density of mercury at saturation pressure shall be taken as 13595.1 kg/m^3 at 0°C; the I-P value is 848.714 lbm/ft^3 at 32°F [5]. The specific weights in kg/m^3 (lbm/ft^3) of these fluids in vacuum under standard gravity are numerically equal to their densities at corresponding temperatures.

4. Symbols and Subscripts

4.1 Symbols and subscripted symbols

Symbol	Description	SI Units	I-P Units
A	Area of cross-section	m^2	ft^2
C_p	Specific heat at constant pressure	J/kg K	BTU/lbm°F
C_v	Specific heat at constant volume	J/kg K	BTU/lbm°F
D	Diameter and equivalent diameter	m	ft
D_h	Hydraulic diameter	m	ft
e	Base of natural logarithm (2.718...)	Dimensionless	
E	Energy factor	Dimensionless	
f	Coefficient of friction	Dimensionless	
H	Fan power input	kW	hp
H_o	Fan power output	kW	hp
K_p	Compressibility coefficient	Dimensionless	
$L_{x,x'}$	Length of duct between planes x and x’	m	ft
ln	Natural logarithm	--	--
N	Speed of rotation	rpm	rpm
n	Number of readings	Dimensionless	
P_s	Fan static pressure	Pa	in. wg
P_{sx}	Static pressure at plane x	Pa	in. wg
P_t	Fan total pressure	Pa	in. wg
P_{tx}	Total pressure at plane x	Pa	in. wg
P_v	Fan velocity pressure	Pa	in. wg
P_{vx}	Velocity pressure at plane x	Pa	in. wg
p_b	Corrected barometric pressure	kPa	in. Hg
p_e	Saturated vapor pressure at t_w	kPa	in. Hg
p_p	Partial vapor pressure	kPa	in. Hg
Q	Fan flow rate	m^3/s	cfm
Q_x	Flow rate at plane x	m^3/s	cfm
R	Gas constant	j/kg K	ft-lb/lbm-°R
Re	Reynolds number	Dimensionless	
S	Aspect parameter	Dimensionless	
t_d	Dry-bulb temperature	°C	°F
t_t	Total temperature	°C	°F
t_w	Wet-bulb temperature	°C	°F
u_x	Uncertainty for Parameter x	Per Unit	
V	Velocity	m/s	fpm
$\overline{V}$	Mean velocity at Plane 1	m/s	fpm
$\hat{V}_a$	Velocity distortion parameter (axial):	%	%
$\hat{V}_t$	Velocity distortion parameter (transverse):	%	%
$\hat{V}_r$	Velocity distortion parameter (radial):	%	%
$\hat{V}_\theta$	Velocity distortion parameter (circumferential):	%	%

Square or Rectangular Flow Passage, re: Velocity Distortion

T	Number of traverse grid velocity measurements in transverse direction	--	--
U	Number of transverse grid velocity measurements in axial direction	--	--
i	Index in transverse direction for velocity matrix	--	--
j	Index in axial direction for velocity matrix	--	--
$\overline{V}_i$	Mean velocity for each of the T traverses	m/s	fpm
$\overline{V}_j$	Mean velocity along each of the U grid stations	m/s	fpm

Circular Flow Passage, re: Velocity Distortion

r	Index in the radial direction in the measuring plane	--	--
θ	Index in the circumferential direction in the measuring plane	--	--
t	Number of velocity measurements at a given radius, r, taken in circumferential increments	--	--
u	Number of velocity measurements at a given angle, θ, taken at radial increments	--	--
$\overline{V}_\theta$	Mean velocity at a given angle, θ, in the measuring plane	m/s	fpm
$\overline{V}_r$	Mean velocity at a given radius, r, from duct center	m/s	fpm
W	Power input to motor	kW	W
x	Function used to determine K_p	Dimensionless	
y	Thickness of straightener element	m	ft
z	Function used to determine K_p	Dimensionless	
γ	Ratio of specific heats	Dimensionless	
ΔP	Pressure differential	Pa	in. wg
η	Motor efficiency	Per unit	
η_s	Fan static efficiency	Per unit	
η_t	Fan total efficiency	Per unit	
μ	Gas viscosity	Pa•s	lbm/ft-s
ρ	Fan gas density	kg/m^3	lbm/ft^3
ρ_x	Gas density at plane x	kg/m^3	lbm/ft^3
Σ	Summation sign	--	--

4.2 Additional subscripts

Subscript	Description
c	Converted value
r	Reading
x	Plane 0, 1, 2, ... as appropriate
0	Plane 0 (general test area)
1	Plane 1 (fan inlet)
2	Plane 2 (fan outlet)
3	Plane 3 (Pitot traverse station)
4	Plane 4 (downstream static pressure)

5. Definitions

This section is excerpted from the AMCA Standards handbook [6].

5.1 Shall and should

The word **shall** is to be understood as mandatory, the word **should** as advisory.

5.2 Fan

(1) A device which utilizes a power-driven rotating impeller for moving air or gases and which has at least one inlet opening and one outlet opening. The openings may or may not have elements for connection to ductwork. The internal energy (enthalpy) increase imparted by a fan to a gas does not exceed 25 kJ/kg (10.75 BTU/lbm). (2) A device having a power-driven rotating impeller without a housing for circulating air in a room. (AMCA 99)

In many instances, a customer lists the system requirements and requests that the fan manufacturer supply additional accessories such as silencers or dampers. The pressure losses for accessories must be accounted for if the system is to operate properly.

If the fan manufacturer supplies these items, then the appropriate accessory losses are added to the system requirements and a fan is selected for the sum of the overall pressure losses.

5.3 Equivalent diameter

The equivalent diameter, D, of a rectangular cross-section duct with inside traverse dimensions a and b is:

$$D = \sqrt{\frac{4ab}{\pi}}$$

5.4 Fan inlet

The fan inlet is defined as the plane perpendicular to the airstream where it first meets the inlet cone or the inlet box furnished by the fan manufacturer. In this publication, the fan inlet is indicated by **Plane 1** (see Figure 5.1).

5.5 Inlet flow profile

The shape of the flow field just upstream of the fan inlet. It is an indicator of the varying flow in a plane extending across the flow passage.

5.6 Velocity distortion parameter - inlet flow

An indicator of the variation of the flow field at the inlet plane of a fan. It is calculated by applying the principle of standard deviation using velocity measurements taken in a matrix form in a transverse plane across the flow field and is expressed as percent distortion.

5.6.1 Velocity distortion parameter, axial, ($\hat{V}_a$). The distortion of the inlet flow which is parallel to the fan shaft centerline in a rectangular inlet plane (see Figure 7.1)

5.6.2 Velocity distortion parameter, transverse, ($\hat{V}_t$). The distortion of the inlet airflow perpendicular to the fan shaft. It is expressed as a percentage of the mean velocity (see Figure 7.1). (AMCA 99)

5.6.3 Velocity distortion parameter, radial ($\hat{V}_r$). The distortion of the inlet flow relative to the radial position of a circular inlet plane (see Figure 7.1).

5.6.4 Velocity distortion parameter, circumferential ($\hat{V}_\theta$). The distortion of the inlet flow relative to the circumferential position in a circular inlet plane (see Figure 7.1).

5.7 Fan outlet

The fan outlet is defined as the plane perpendicular to the gas stream at the outlet opening of the fan or the outlet opening of the evasé or diffuser. In this publication, the fan outlet is indicated by **Plane 2** (see Figure 5.1).

5.8 Flow

5.8.1 Flow rate. The flow rate is the volumetric flow rate at a specific gas density.

5.8.2 Mass flow rate. Mass flow rate is the volumetric flow rate multiplied by the gas density.

5.8.3 Fan flow rate. Fan flow rate is the volumetric flow rate at fan gas density at the fan inlet.

5.9 Pressure

5.9.1 Absolute pressure. Pressure above a perfect vacuum; the sum of gauge pressure and atmospheric pressure. The value is always positive. (AMCA 99)

5.9.2 Barometric pressure. The absolute pressure exerted by atmosphere at a location of measurement. (AMCA 99)

5.9.3 Gauge pressure. Gauge pressure is the value of a pressure when the reference pressure is the barometric pressure at the point of measurement. It may be negative or positive.

5.9.4 Total pressure. The air pressure which exists by virtue of the degree of compression and the rate of motion. It is the algebraic sum of the velocity pressure and the static pressure at a point. Thus, if the air is at rest, the total pressure will equal the static pressure. (AMCA 99)

5.9.5 Velocity pressure. Velocity pressure is that portion of the pressure that exists by virtue of the rate of motion only. It is always positive.

5.9.6 Static pressure. Static pressure is that portion of the pressure that exists by virtue of the degree of compression only. It may be positive or negative relative to the ambient atmospheric pressure.

5.9.7 Fan total pressure (P_t). Fan total pressure is the difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

$$P_t = P_{t2} - P_{t1}$$

5.9.8 Fan velocity pressure (P_v). Fan velocity pressure is the pressure corresponding to the average velocity at the specified fan outlet area.

$$P_v = P_{v2}$$

5.9.9 Fan static pressure (P_s). Fan static pressure is the difference between the fan total pressure and the fan velocity pressure. Therefore, the fan static pressure is the difference between the static pressure at the fan outlet and the total pressure at the fan inlet (See Figure 5.2).

$$P_s = P_t - P_v = P_{t2} - P_{t1} - P_{v2}$$
$$P_s = (P_{s2} + P_{v2}) - P_{t1} - P_{v2}$$
$$P_s = P_{s2} - P_{t1}$$

5.9.10 Fan static pressure rise (ΔP_s). The increase in static pressure between fan outlet and fan inlet. (AMCA 99)

Fan static pressure rise is often mistaken for fan static pressure. The value of fan static pressure rise is the static pressure at the fan outlet minus the static pressure at the fan inlet (See Figure 5.2).

$$\Delta P_s = P_{s2} - P_{s1}$$

It can be shown that the difference between fan static pressure and fan static pressure rise is the inlet velocity pressure.

$$\begin{aligned}\Delta P_s - P_s &= (P_{s2} - P_{s1}) - (P_{s2} - P_{t1}) \\ &= P_{s2} - P_{s1} - P_{s2} + P_{s1} + P_{v1} \\ &= P_{v1}\end{aligned}$$

5.10 Compressibility

Compressibility is the characteristic of a gas to change its density as a function of pressure.

5.10.1 Compressibility coefficient. A thermodynamic coefficient used to correct the perfect gas equation when applied to real gases, in determining fan total efficiency (AMCA 99). It is the ratio of the mean flow rate through the fan to the flow rate at the fan gas density. It is also the ratio of the fan total pressure that would be developed with an incompressible fluid to the fan total pressure that is developed with a compressible fluid.

5.11 Density

5.11.1 Gas density. Gas density is the mass per unit volume of the gas.

5.11.2 Fan gas density. Fan gas density is the density of the gas corresponding to the total pressure and total temperature at the fan inlet.

5.11.3 Duct gas density. Duct gas density is the density of the gas corresponding to the total pressure and total temperature at a specific plane in the duct.

5.12 Viscosity

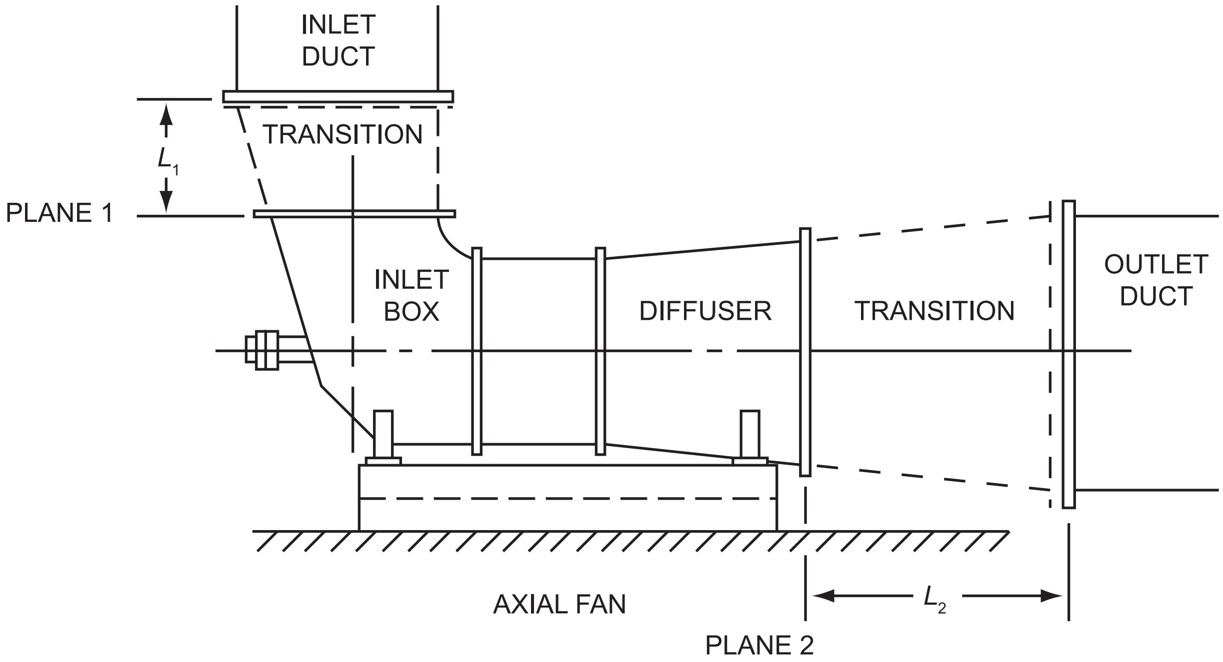
5.12.1 Fluid viscosity. Viscosity is the characteristic of all fluids to resist flow.

5.12.2 Absolute viscosity. Absolute viscosity is the proportionality factor relating shearing stress (force per unit area) and rate of shear (incremental velocity per incremental distance).

5.12.3 Kinematic viscosity. The kinematic viscosity is the absolute viscosity divided by mass density.

5.13 Reynolds number

The Reynolds number is a dimensionless number representing the ratio of inertial forces to viscous forces at a particular point of a fluid in motion. Its value is calculated as the flow velocity at the point of interest multiplied by a characteristic linear dimension and divided by the fluid’s kinematic viscosity.



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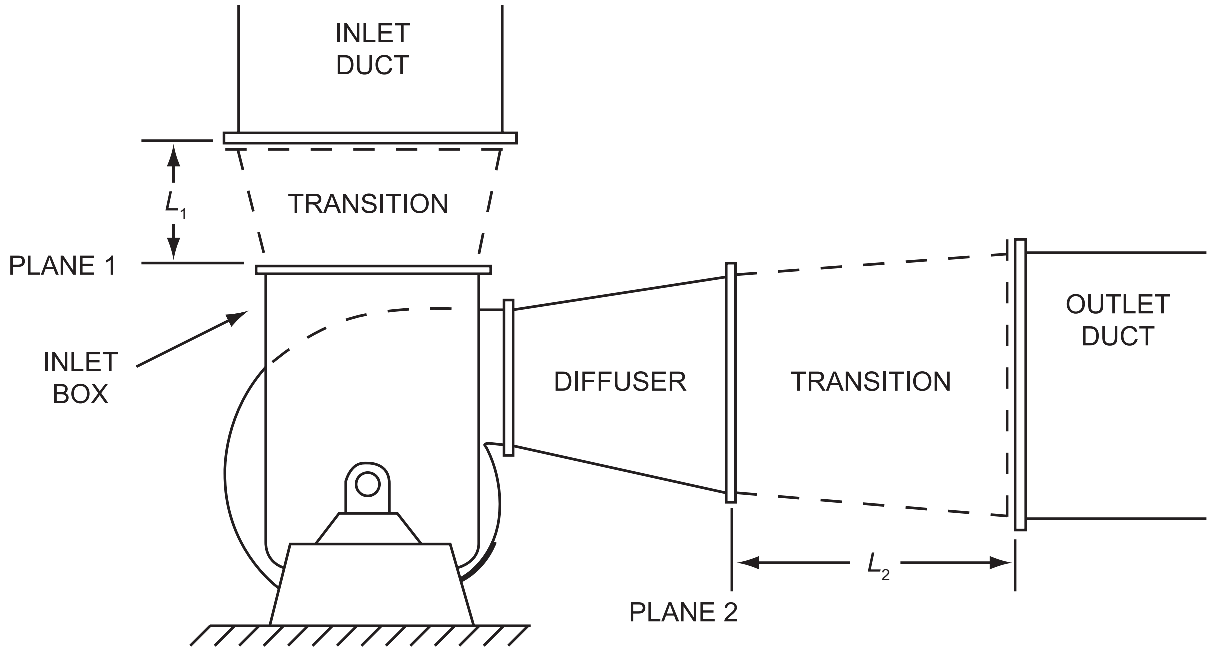

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Figure 5.1

5.14 Temperature

5.14.1 Total temperature. Total temperature is the temperature which exists by virtue of the internal and kinetic energy of the gas. If the gas is at rest, the total temperature will equal the static temperature.

5.14.2 Static temperature. Static temperature is the temperature which exists by virtue of the internal energy of the gas only.

5.15 Specific heat

5.15.1 Specific heat at constant pressure. Specific heat at constant pressure is the quantity of heat required to increase the temperature of a unit mass of substance one degree at constant pressure.

5.15.2 Specific heat at constant volume. Specific heat at constant volume is the quantity of heat required to increase the temperature of a unit mass of substance one degree at constant volume.

5.15.3 Specific heat ratio. Specific heat ratio is the numerical ratio of the specific heat of a gas at constant pressure to that of the same gas at constant volume.

5.16 Standard air

Standard air is air with a density of 1.2 kg/m^3, a ratio of specific heats of 1.4, a viscosity of 1.819 × 10^{-5} Pa•s, and an absolute pressure of 101.325 kPa. Air at 20°C, 50% relative humidity, and 101.325 kPa has these properties, approximately.

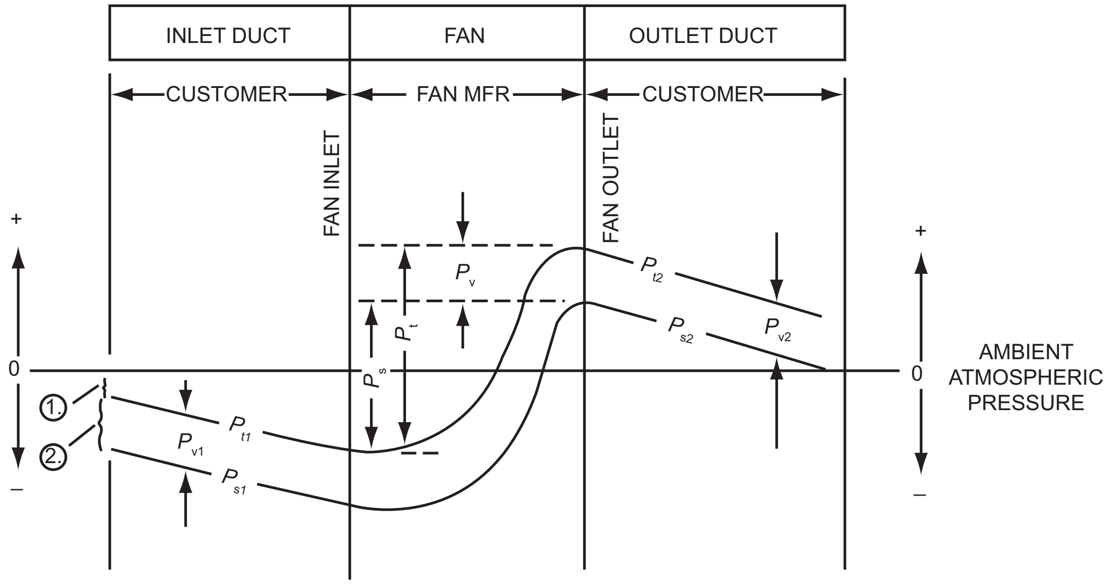
In the I-P system, standard air is air with a density of 0.075 lbm/ft^3, a ratio of specific heats of 1.4, a viscosity of 1.2 × 10^{-5} lbm/ft-s. Air at 68°F, 50% humidity, and 29.92 in. Hg has these properties, approximately.

5.17 Power

5.17.1 Motor power. Motor power is the power delivered from the output shaft of the motor.

5.17.2 Fan shaft power (fan power input). The fan shaft power is the power delivered to the input end of the fan shaft and does not include any drive losses (e.g. belts and sheaves, etc.) other than the fan bearings, fan shaft seal and fan shaft cooler (heat flinger).

5.17.3 Fan impeller power. This is the power delivered to the fan impeller, specifically, the fan shaft power minus the fan shaft losses.



1. ENTRANCE LOSS
2. ACCELERATION ENERGY

There is a distinct difference between an entrance loss and the acceleration energy when using static pressure nomenclature. Total pressure nomenclature should be used when discussing fan performance, however, from past practice, static pressure terminology is still used. It is most important to recognize the interdependence between total and static pressure in a typical system.

Figure 5.2 - Fan Pressure Interpretation

5.17.4 Fan shaft losses. Fan shaft losses are the power losses resulting from friction in the main bearings of the fan, the shaft seal, and/or the aerodynamic losses from the shaft cooler (heat flinger).

5.17.5 Fan power output. The fan power output is the useful power delivered to the fluid being handled. This output is proportional to the product of the fan flow rate, the fan total pressure, and the compressibility coefficient (K_p).

5.18 Efficiency

5.18.1 Efficiency-total. Ratio of fan output power divided by the fan input power.

5.18.2 Efficiency-static. Total efficiency times fan static pressure divided by fan total pressure.

5.19 Performance points

5.19.1 Maximum continuous rating (MCR). The maximum continuous rating point at which the fan is expected to operate.

5.19.2 Test block (TB). That point above and beyond the MCR demonstrating the fan margin to the customer.

5.19.3 Design point. That rating point which establishes the size and speed of the fan. In power generation, this would normally be the Test Block condition.

5.19.4 Point of rating. Point of rating is a specified operating point on the fan characteristic curve.

5.19.5 Point of operation. Point of operation is the relative position on the fan characteristic curve corresponding to a particular flow rate.

5.19.6 Determination. A determination is a complete set of measurements for a particular point of operation of a fan. The measurements must be sufficient to determine all fan performance variables as defined in Section 8.

6. Instruments and Methods of Measurement

6.1 General

Fan performance shall be defined by the accurate determination of flow rate, fan static or total pressure, speed, input power, and inlet density of the gas being handled. This section describes the minimum requirements for determining each of these parameters.

Instruments used in making measurements shall be in good condition and possess the capability of performing their intended function for the complete duration of the test. Portable instruments shall not require changes in batteries, and fragile, sensitive instrumentation shall not be located where it can be subjected to the influences of inclement weather, temperature, or vibration. This may require special protective enclosures such as vans, tents, etc. The instruments shall be calibrated for the environment in which they will be used, and shall be used in accordance with the manufacturer’s recommendations.

Personnel operating instruments shall be familiar with the instruments and shall possess enough experience to detect a possible malfunction or degradation of instrument performance. When instruments require corrective measures, personnel shall make an immediate evaluation as to the impact of the corrective action upon the parameter being measured and determine whether to void the test data or substitute alternate replacement equipment. Suspect instruments shall be removed from service until calibrated.

6.2 Instrument calibration

All instrumentation used in the test shall have a calibration against a known standard. The complexity of the calibration may vary from a minimum of a physical inspection, such as for a Pitot tube to ensure it does not leak and dimensionally agrees with appropriate standards, to a complete calibration which can be traced to the National Institute of Standards and Technology (NIST) if necessary. Specific calibration requirements are defined for each instrument in the appropriate sections which follow, however, the following calibration requirements apply to all instrumentation used in the test:

a) All parties shall agree with the method of calibration, the calibration results, and the interval between the test and the last calibration

b) Any calibration shall cover the range of readings to be encountered during the test

c) The instrument shall not be used in any environment which violates its calibration

d) Each instrument shall have a current calibration tag. The calibration period should be that recommended by the instrument manufacturer. If operational data can demonstrate that a longer period can be maintained between calibrations, the interval can be increased. Portable equipment should have a maximum calibration period of six months. Self-calibrating equipment is exempt from the above requirements, but shall be identified on the report document by make and serial number. A calibration which is not in general agreement with historical data for the same instrument may indicate a malfunction, or indicates physical damage may have occurred.

e) Each instrument shall be verified as operational prior to and after the test. If there are any irregularities such as a meter not returning to zero in the operational verification after the test, the test data may be inaccurate and unusable.

f) Instrumentation used as individual components shall have individual calibrations. If the instrument is used as part of a measurement system or data acquisition system, the entire system shall be calibrated.

g) Instruments which have a discontinuity or readability (resolution) not commensurate with the accuracy required for the test shall not be used.

h) Calibration data may be curve-fit for use in computerized data acquisition systems, however, the curve fit must accurately represent the data so that no errors are introduced into the final results. All parties shall agree to the method of curve fit, and to the verification that it indeed does accurately reflect the data.

6.3 Instrument accuracy

Instrument accuracy forms a very important part of the overall consideration involved in test error analysis. Individual instrument accuracies or measured system accuracies listed in the appropriate sections represent maximum levels consistent with obtaining accurate results. All parties to the test shall agree prior to the test on the allowable measurement errors.

6.4 Measurement concepts

This standard utilizes the traverse method for determining average values of test data in which a duct cross-sectional area is divided into many smaller elemental areas dimensionally proportional to the original duct dimensions. A measurement of the desired parameter is then obtained at the center of each elemental area. These measurements are then combined to yield an average value of that test data parameter.

The measurement may be made using four general approaches as follows:

6.4.1 Manual recording of data. Using a grid pattern as defined in Section 7.7, an estimate of each parameter is obtained by observing and hand recording data from manometers or other instruments for several seconds while a sensor is located at the center of each elemental area. Once an average is obtained at one location, the sensor is sequentially moved to the centers of other areas where other average values are obtained.

6.4.2 Automatic recording of data. This technique is similar to the manual method, however, the sensor is connected to a transducer which is then connected to an automatic recording instrument such as a strip chart recorder. While holding the sensor steady at the center of each elemental area, the output is recorded for a specified time interval on the recording instrument. This provides a time history of the data at each location which is then analyzed at a later time to obtain the average value along with maximum and minimum values and any trends which were present. The strip chart recorder provides a copy of the data which is independent of mental averaging.

6.4.3 Continuous trace with automatic recording of data (See Figure 6.5A). This method uses the previously defined grid pattern, but instead of obtaining individual mental estimates (manual method) or time histories (automatic recording method), the sensor is moved very slowly and at a constant rate as agreed to by the participants (See Figure 6.5A) across the grid pattern while recording the output from the transducers on a strip chart recorder or other recording instrument. After the test, the area under the data on the strip chart can be integrated using many hundreds of readings to provide an average value of the parameter. This method has the advantage or providing not only a hard copy of the data and its fluctuations, but also a profile of the data across the duct as the sensor is moved. It can provide an evaluation of possible system effects and may become a criterion for acceptability of the test itself.

6.4.4 Automatic data acquisition systems with multiple point recording (See Figure 6.5B). This method uses multiple stationary sensors instead of one sensor that is systematically moved from one location to another. As an example, the sensors may be a Pitot tube array within a duct such that a Pitot tube is located at the center of each previously defined elemental area of the grid pattern. The output from each sensor is either manually or electronically sampled usually under a controlled data acquisition system. The data can be automatically stored and analyzed with the results being immediately available.

Use of this approach requires detailed considerations of sampling rates, durations, and numbers of samples in order to achieve representative test results. The entire data acquisition system shall be calibrated and if a computer is employed, the computer program and calibration corrections verified as being correct.

6.5 Determination of measured parameters

6.5.1 Flow rate. Flow rate is based upon the measurement of velocity pressure and gas density at Plane 1 or 3. The instrumentation used to measure velocity pressure is discussed in Section 6.5.2. The velocity pressure at Plane 1 or 3 is defined as the squared mean root of all of the individual velocity pressure measurements at the center of the elemental areas. The flow rate at Plane 1 or 3 is calculated by converting the velocity pressure to its equivalent velocity and multiplying by the area of the traverse plane.

6.5.2 Pressure measurements. This section applies to the measurement of velocity pressure and static pressure at any of the measurement planes. Instruments used for pressure measurement include a sensor and an output device, or indicator, and may or may not include a recording instrument. Sensors include Pitot-static tubes and double reverse tubes. Output or indicating devices include manometers, slack tubes, water filled U-tubes, or pressure transducers and digital readout. Recording devices include strip chart or magnetic tape recorders.

The accuracy of the pressure measuring system shall be ± 1% of the reading. Corrections shall be made for differences between calibration conditions and actual usage, such as manometer fluid specific weight, gas column balancing effect, or the expansion/contraction of scales due to differences in temperature.

Calibration of the system shall be against a water filled hook gauge, micro manometer, or other commercially available pressure standard device. The number of calibration points shall include the extremes of the anticipated pressures for the test and about nine essentially equally spaced intermediate points.

6.5.2.1 Instrumentation

Pitot-static tube. The Pitot-static tube of the proportions shown in Figure 6.1 is the primary sensing instrument for this standard. It is connected as shown in Figure 6.2 to an inclined manometer or pressure transducer for measurements of static pressure and velocity pressure.

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

Pitot-static tubes shall be used subject to the following conditions:

a) The Pitot-static tube shall be manufactured in conformity with the dimensional specifications stipulated in Figure 6.1 and shall be in good condition.

b) The axis of the head of the Pitot-static tube shall be parallel to the axis of the duct within ±7.5°. Appropriate devices shall be provided for this purpose (see Figure 6.3). [7]

c) The Pitot-static tube shall be kept firmly in place during the measurements.

d) The distance between the axis of the Pitot-static tube and the wall shall be greater than the diameter of the head of the tube.

e) The local Reynolds number, related to the diameter of the head of the tube, shall be greater than 500. Where a Pitot-static tube is used to determine the Reynolds number, Reynolds number shall be determined by:

$$\mathrm{Re} = \frac{\rho d_t V}{\mu}$$

Where:

ρ = density of gas, kg/m^3 (lbm/ft^3)
μ = absolute viscosity of gas, Pa•s (lbm/ft-s)
d_t = as given below

For tests with atmospheric air, the velocity shall not be less than:

$$v = \frac{B}{d_t}$$

Where:	SI Units	I-P Units
v is the minimum velocity in:	m/s	fpm
d_t is the diameter of the head of the tube in:	mm	in.
B is equal to:	7.5	58

For additional information on Reynolds number calculations, see ANSI/AMCA 210.

Double reverse (Stauscheibe or S-Tube). The double reverse tube is intended for use in those instances in which the amount of particulate matter in the gas stream impairs the function of the Pitot-static tube. The double reverse tube shall be calibrated in a laboratory immediately before and after the test. It is important that the tube be used in the same orientation as used during calibration. The tube shall be marked to indicate the direction of the gas flow used in its calibration. The double reverse tube is connected to the inclined manometer as shown in Figure 6.4.

The tube upstream senses a true total pressure and the downstream tube a pseudo static pressure. A calibration factor is applied to each individual velocity pressure reading in order to determine true values of velocity pressure. The true static pressure is calculated by subtracting the true velocity pressure from the true total pressure.

Static Pressure Wall Taps. A tap can be used to sense static pressure at the surface of a duct. The tap needs no calibration. It shall conform to certain minimum requirements as illustrated in Figure 6.6. No fewer than four taps shall be used at a single measurement plane, and the tap shall be located near the center of each wall. The inner surfaces of the duct in the vicinity of the taps shall be smooth and free from irregularities. The tap shall be perpendicular to the direction of flow so that the velocity of the gas stream does not influence the pressure measurements by impinging upon the hole.

Whereas in an ideal flow situation the static pressure at a duct surface is usually identical to that obtained in a Pitot tube traverse taken across a duct, this is not always true when changes in duct area, or elbows or bends are present. Care should be exercised in this regard.

Before the commencement of any series of observations, the pressure at the four side taps should be individually measured at a flow rate towards the maximum of the series. If any one of the four readings lies outside a range equal to 5% of the rated fan pressure, the taps and manometer connections should be examined for defects, and if none are found, the flow shall be examined for uniformity. In the event that the flow is found to be non-uniform, pressure measurement should be performed by Pitot traverse.

The individual static pressure readings may be arithmetically averaged or the wall taps may be manifolded as shown in Figure 6.6C. Care shall be taken to ensure that all tubing and connections are free from blockage and leakage.

Manometers. 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 pressures which are to be measured. It is adjusted by changing the slope to any of the various fixed settings and by changing the range scale accordingly. Each setting provides a different ratio of the length of the indicating column to its indicated height. Adjustable range type manometers in which the slope may be fixed at 1:1, 20:1, and intermediate ratios are available.

The accuracy of the manometer used in the measurement of velocity pressures is of prime importance. The considerations involved in selecting a manometer that will provide an acceptable degree of accuracy include the range, slope, quality, scale graduations and indicating fluid of the instrument and the range of the pressures to be measured. Due to practical limitations in length, the manometer use is restricted to instances where the measured velocity pressures are very low. Recommended minimum value is 10 Pa (0.023 in. wg) at standard gas density.

Slack-Tubes. A slack-tube or water filled U-tube may be used for pressures above 2.5 kPa (10 in. wg) without calibration. This instrument shall not be used for velocity pressure measurement.

Pressure Transducers. A pressure transducer is a pressure sensing device whose voltage output is proportional to the pressure applied. A typical system is shown in Figure 6.5. The pressure measurement system shall be calibrated by a hook gauge, a micro manometer, or another pressure standard. The transducer shall be sized such that the pressures measured are within its linear range so that no over range condition can occur. The transducer shall not be subjected to vibration or heat beyond vendor specifications, and shall have a sufficient warm-up period prior to its use to eliminate the possibility of drift.

Readout Devices. Devices such as strip chart recorders, digital readouts, and magnetic tape recorder shall be calibrated as part of the system or have a reference calibration signal applied as in the case of magnetic tape. The resolution of the instrument shall be consistent with the overall system accuracy requirements.

6.5.3 Barometric pressure measurements. A Fortin type or a portable aneroid barometer is recommended for determinations of barometric pressure. The barometer shall be accurate within 0.05 in. Hg (170 Pa) of the measured value and readable to (35 Pa) 0.01 in. Hg. The test value of barometric pressure shall be determined by averaging measurements made at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test.

Barometers shall be calibrated against a mercury column barometer with a calibration that is traceable to the National Institute of Standards and Technology or other national physical measures recognized as equivalent by NIST. A convenient method of doing this is to use an aneroid barometer as a transfer instrument and carry it back and forth to the Weather Bureau Station for comparison [8]. A permanently mounted mercury column barometer should hold its calibration well enough so that comparisons every three months should be sufficient. Transducer type barometers shall be calibrated for each test. Barometers shall be maintained in good condition.

6.5.4 Temperature measurements. Temperature measurements are necessary in order to calculate the gas density in the duct as well as at ambient conditions. A duct temperature measurement must be obtained for each pressure measurement obtained in the center of each elemental area. A wet bulb duct gas temperature may be required to calculate the duct gas density. Duct gas temperatures are normally obtained using thermocouples or thermistors in conjunction with a readout device. A continuous temperature trace may be obtained providing the system reaction time is commensurate with the rate of temperature change across the duct. Temperatures shall be accurate within 1°C (2°F) of the measured value using instruments with a resolution of 0.5°C (1°F). The instruments must be calibrated as a system, taking care to correct for reference junctions or other conditions which might influence the reading.

Ambient temperatures should be obtained using a thermometer or other calibrated instrument. Obtain readings at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test. Wet-bulb temperature should be obtained with a psychrometer or thermometer with a wick. The wet-bulb thermometer wick should be clean, closely fitted, and wetted with fresh water. The velocity of the air over the wick shall be between 3.5 and 10.2 m/s (700 and 2000 fpm).

A sling psychrometer is recommended for use in obtaining dry and wet-bulb air temperature measurements at the fan inlet for fans with nonducted inlets.

6.5.5 Gas stream composition measurements. Gas stream density can be established when the pressure, temperature, and composition of the gas (including moisture) is known. Pressure and temperature measurements are discussed in Sections 6.5.2 and 6.5.4 respectively.

If the gas being handled has a composition other than air, each constituent must be identified whether by weight or volume. Gas analysis by electronic means, by chemical composition analysis, or other analysis system should be used. The system used must have a demonstrated accuracy of 1.0% by volume. This should be verified using commercial gas samples.

Gas composition measurements need to be obtained at only one measurement plane providing the gas stream does not change composition or undergo a change of state between planes. Calculations of density between planes is based on the density being directly proportional to the absolute pressure and inversely proportional to the absolute temperature. Measurements necessary to determine gas composition need to be obtained at the center of every other elemental area of every other traverse. The number of measurements can be reduced if all parties to the test agree that no stratification is present and that the composition does not change with time.

Moisture in the gas stream at elevated temperatures is sometimes very difficult to determine accurately. It is possible to withdraw a sample of gas into a desiccation sampling system or other measuring system. A system using condensation or desiccant method which has a demonstrated accuracy of 0.001 mass units of water vapor per mass unit of dry gas is required. Calibration of the system should be in accordance with the appropriate sections of ASME PTC 19 [9].

6.5.6 Speed measurements. Fan performance is a function of speed. This relationship is expressed by the compressible fan laws. It is important that during a test the fan speed be held constant. If a fan is direct connected to a motor, this may not be a problem. However, if the fan has a variable speed drive in the driveline, this is a very important consideration.

Speed shall be recorded at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test. Readings should not vary by more than 1% for the total duration of the test. Acceptable instruments include a tachometer-generator system, an electronic counter timer initiated by a positive trigger such as a 60 tooth gear or shaft key, and a photoelectric triggered counter. A stroboscopic device triggered by the line frequency of a public utility is considered a primary instrument and need not be calibrated if it is maintained in good condition. Speed measurement systems shall have a demonstrated accuracy of 0.5% of the measured value and shall be calibrated against a line-frequency oscillator which has previously been calibrated, or other frequency standard.

6.5.7 Input power measurement. Fan input power shall be determined through the use of torque meters or calibrated electric motors in conjunction with electric line measurements. 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 that 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.

Only with prior agreement between all parties can typical motor performance data be used in the determination of 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.

If the fan is supplied with bearings, it is assumed that any quoted fan power includes bearing friction losses, fan shaft seal friction losses, etc. It is only necessary to establish the motor output power to determine the fan power input since the coupling losses are assumed to be negligible for direct driven fans.

In the case of belt driven fans, the fan shaft power has to be established by deducting any drive loss from the calculated motor output power. The value of the drive losses must be determined by agreement between the parties if not included in the original performance quoted.

The data provided can be in a variety of forms, but must be sufficient to determine motor power output based on electrical input measurements. It is important that the power supplied to the motor during an on-site 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.

Measurements 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% of full scale for volts, amps, and power factor and 2% of full scale for watts.

On motors controlled by variable frequency AC controllers, electric line measurements cannot be used to determine fan input power. The data would be erroneous due to voltage variations and the nonsinusoidal wave shape of the current.

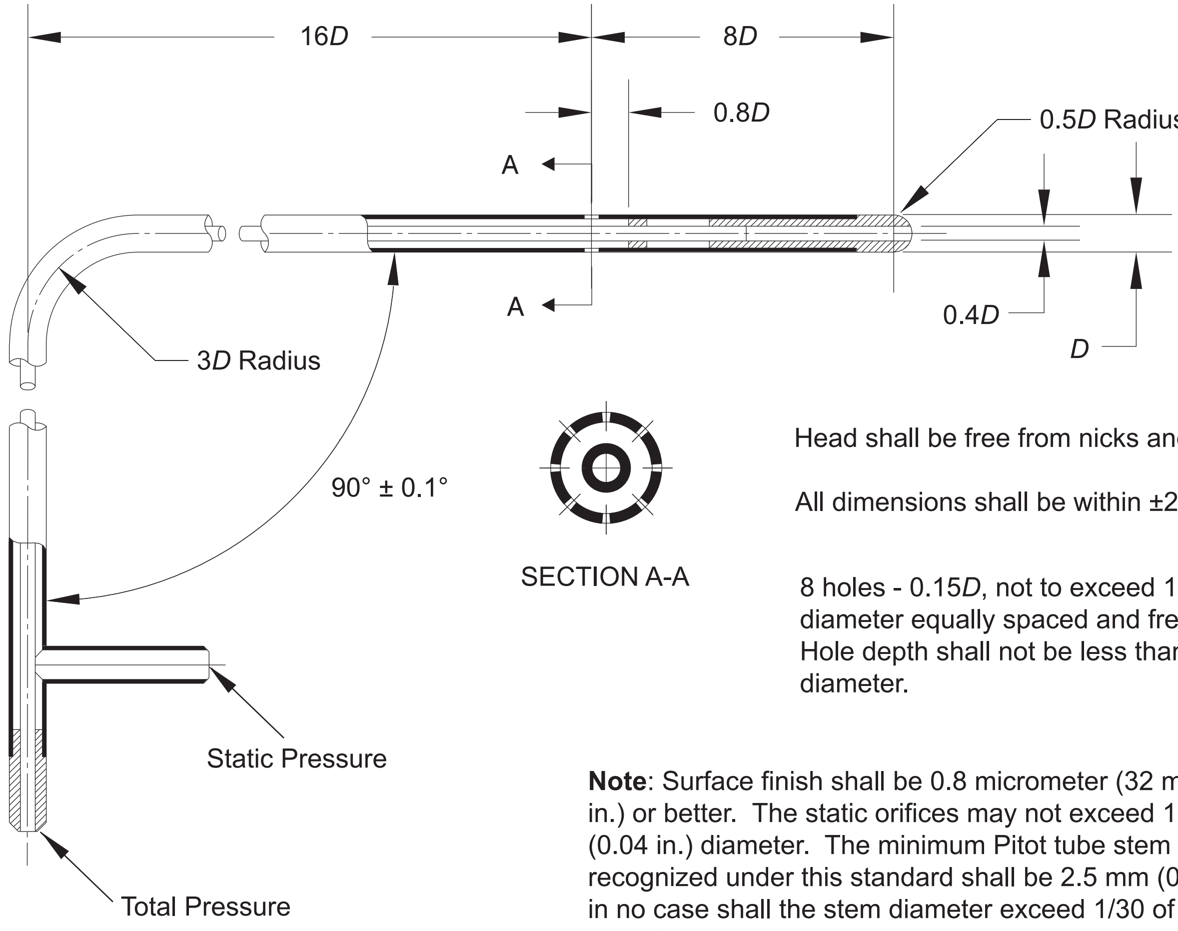
Calibration of power using instrumentation shall be based upon appropriate documents as follows:

Direct current machines	IEEE 113-1999 [10]
Gas turbines	ASME PTC 22 1997 [11]
Hydraulic prime movers	ASME PTC 18 1992 [12]
Induction Motors/Generators	IEEE 112 1996 [13]
Measurement of shaft power	ASME PTC 19.2 1987 R1998 [9]
Steam turbines	ASME PTC 6S 1988 R1995 [13]
Synchronous machines	IEEE 115 1995 [14]
Torque meters	ASME PTC 19.2 1987 R1998 [9]

For other types of power transmission equipment it is suggested that the fan manufacturer be consulted to establish whether transmission losses are included in the fan ratings, and, if so, 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.

Measurement of power shall be obtained at the beginning of the test and at specified time intervals not to exceed 20 minutes for the duration of the test.



Head shall be free from nicks and burrs.

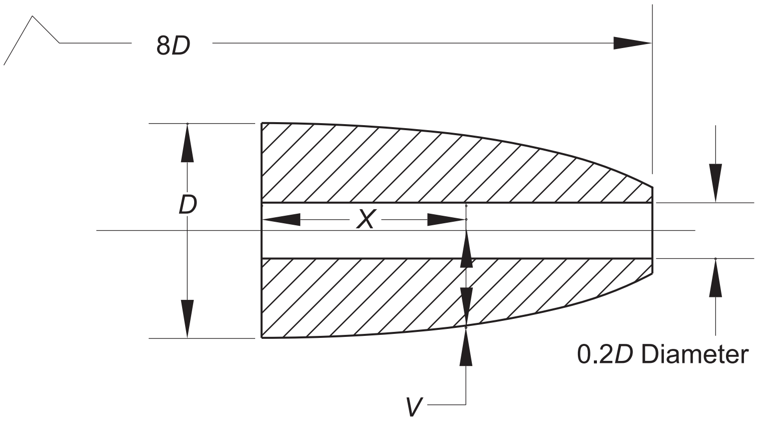
All dimensions shall be within ±2%.

8 holes - 0.15*D*, not to exceed 1mm (0.04 in.), diameter equally spaced and free from burrs. Hole depth shall not be less than the hole diameter.

Note: Surface finish shall be 0.8 micrometer (32 micro-in.) or better. The static orifices may not exceed 1 mm (0.04 in.) diameter. The minimum Pitot tube stem diameter recognized under this standard shall be 2.5 mm (0.10 in.) in no case shall the stem diameter exceed 1/30 of the test duct diameter.

PITOT-STATIC TUBE WITH SPHERICAL HEAD

All other dimensions are the same as for spherical head pitot-static tubes.



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

ALTERNATE PITOT-STATIC TUBE WITH ELLIPSOIDAL HEAD

Figure 6.1 - Pitot-Static Tubes (From ANSI/AMCA 210-99)

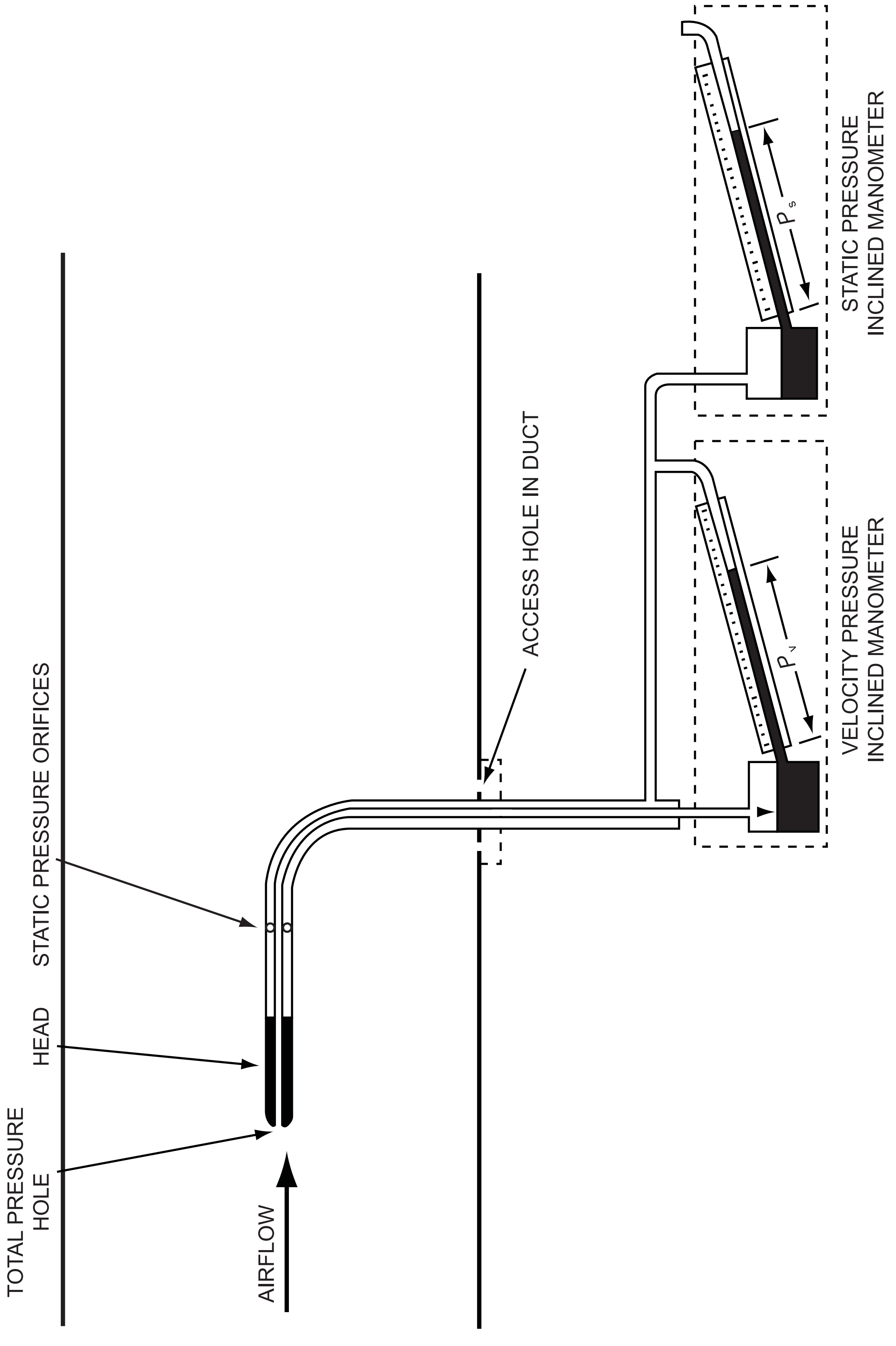
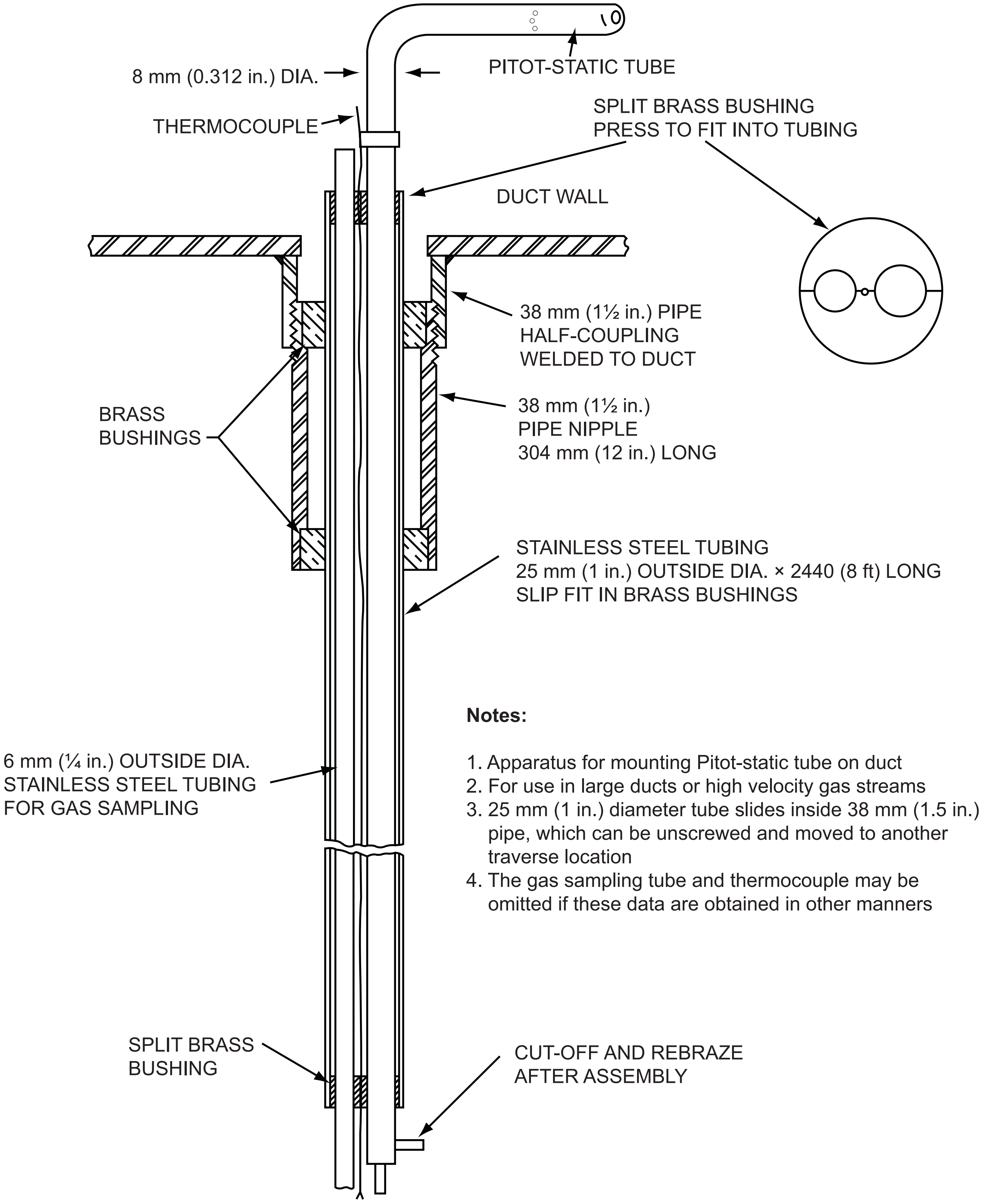


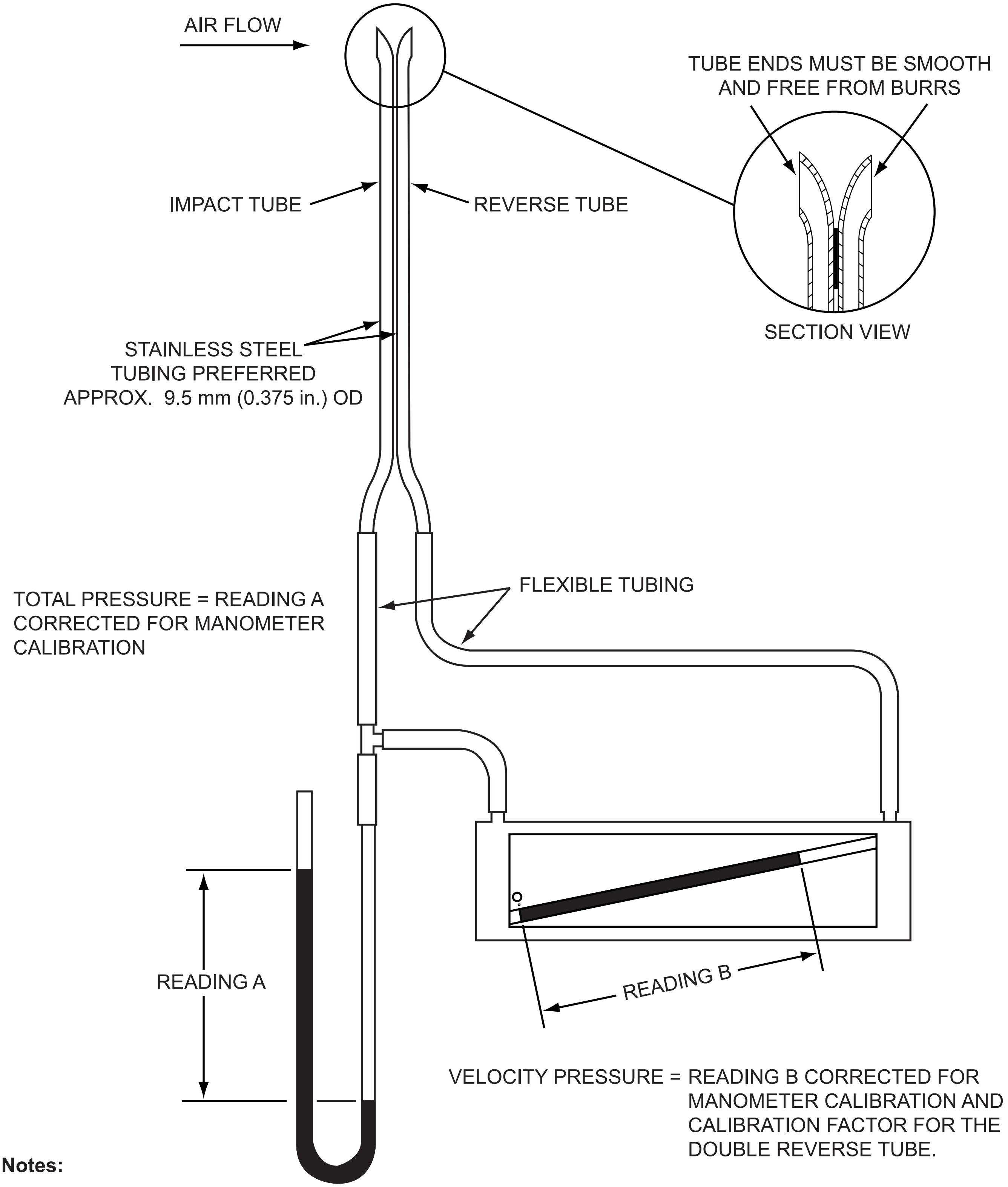
Figure 6.2 - The Pitot-Static Tube Connection



Notes:

1. Apparatus for mounting Pitot-static tube on duct
2. For use in large ducts or high velocity gas streams
3. 25 mm (1 in.) diameter tube slides inside 38 mm (1.5 in.) pipe, which can be unscrewed and moved to another traverse location
4. The gas sampling tube and thermocouple may be omitted if these data are obtained in other manners

Figure 6.3 - Example Pitot-Static Tube Holder



Notes:

1. For use in dirty or wet gas streams.
2. The double reverse tube must be calibrated and used in the same orientation as used in its calibration
3. Also referred to as impact reverse tube, combined reverse tube, and type S tube.

Figure 6.4 - Double Reverse Tube (Stauschiebe or S-Tube)

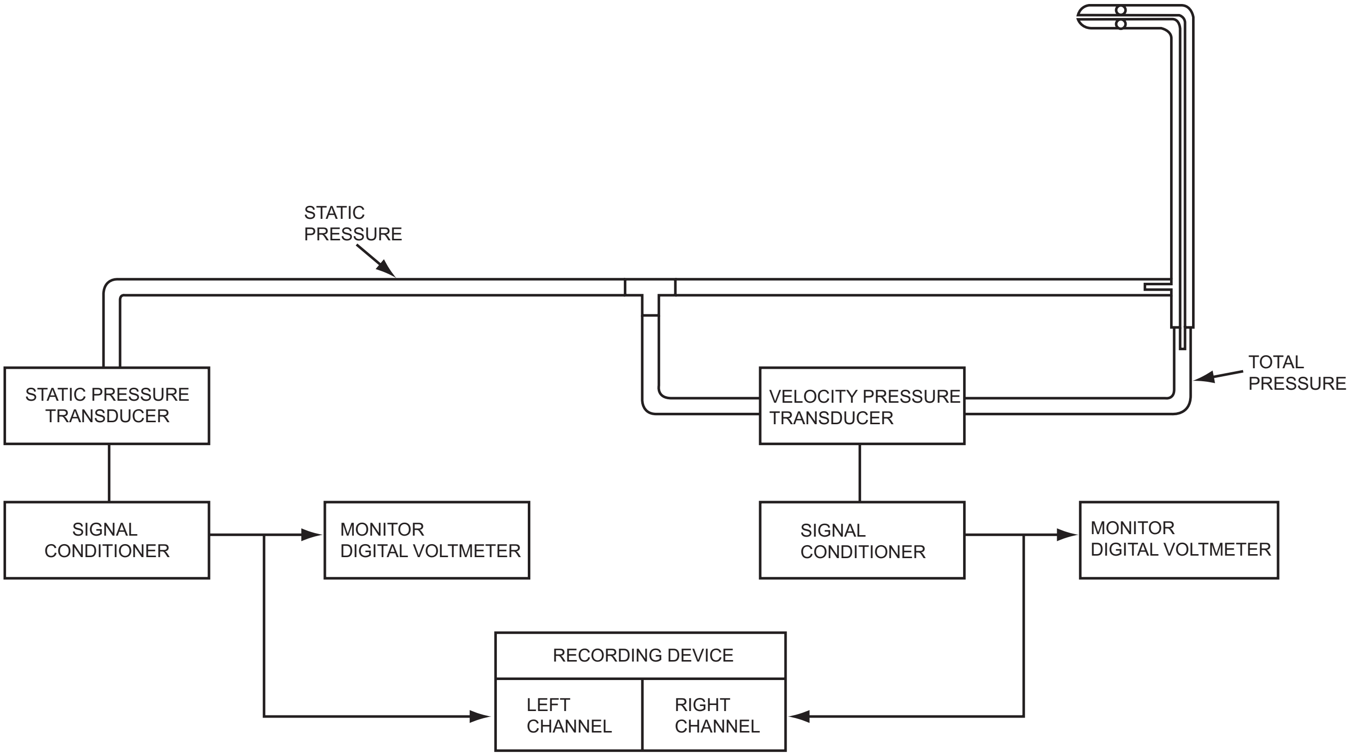


Figure 6.5A - Typical Continuous Trace System Instrumentation Schematic

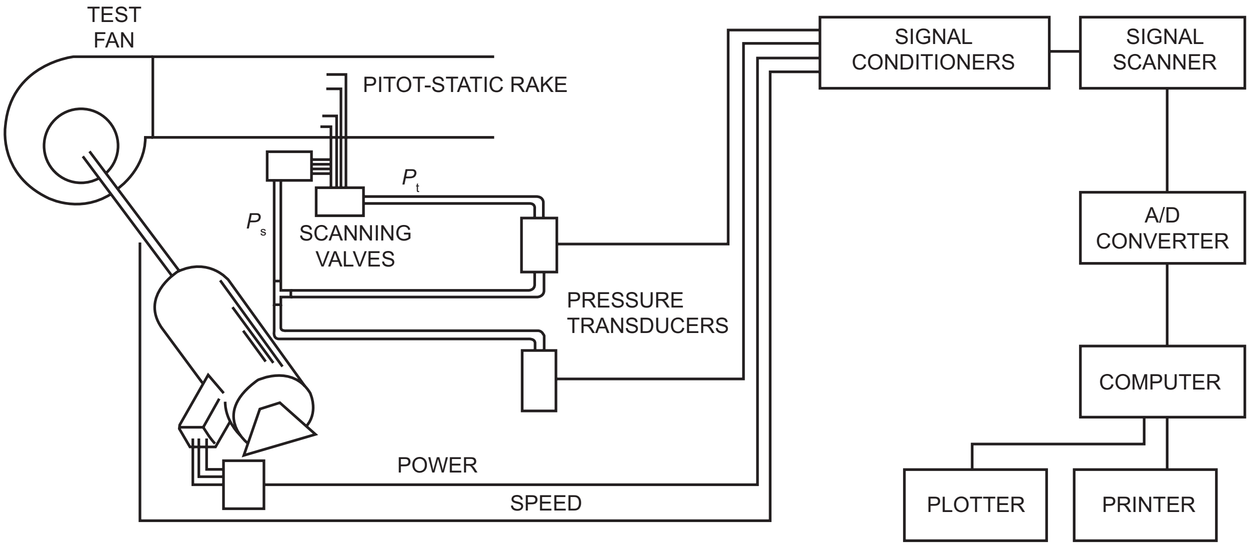


Figure 6.5B - Typical Automatic Data Acquisition System Instrumentation Schematic

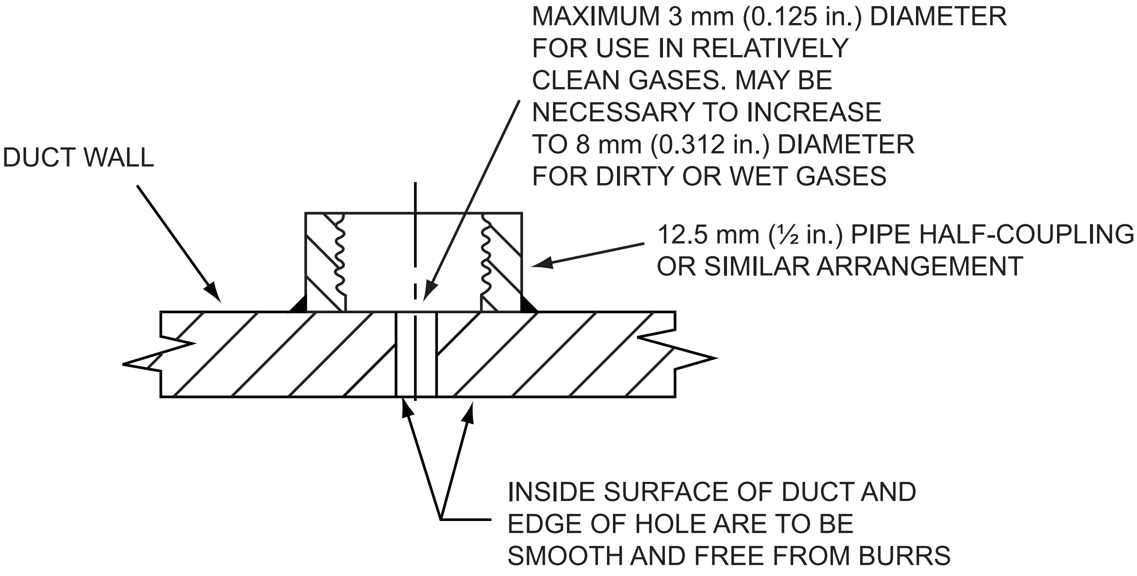


Figure 6.6A - Static Pressure Tap

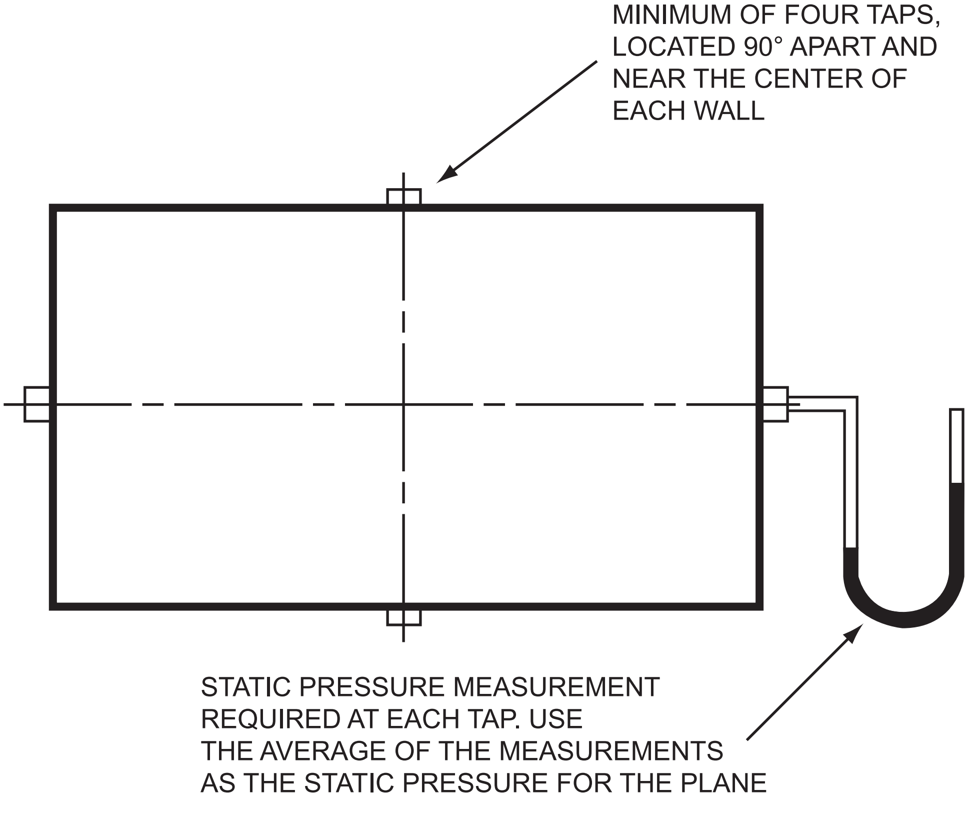
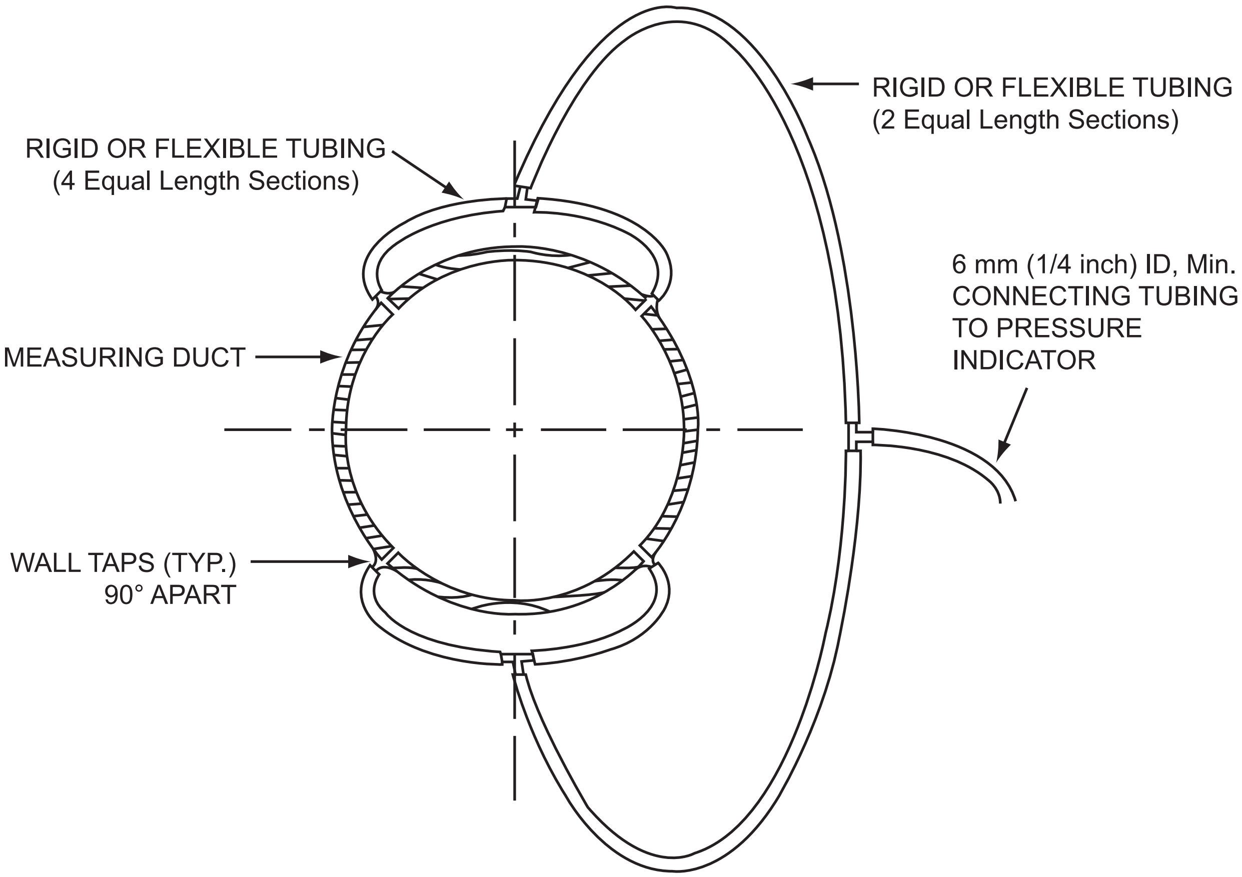


Figure 6.6B - Locations of Static Pressure Taps

Figure 6.6 - Static Pressure Wall Taps



Notes:

1. Manifold tubing internal area shall be at least 4 times that of a wall tap.
2. Connecting tubing to pressure indicator shall be 6 mm (1/4 in.) or larger in ID.
3. Taps shall be within ±13 mm (1/2 in.) in the longitudinal direction.

Figure 6.6C - Piezometer Ring Manifolding

7. Measurement Plane Configuration

7.1 General

Fan performance is determined from measurements upstream and downstream of the fan. The location of such measurements is critical to the quality of the test since uncertainty will increase if the measurements are taken in regions where the flow is unsteady, or if the flow profile is highly skewed or distorted.

7.2 Requirements for measurement planes

The final selection of measurement planes can be made only after careful review of the fan and duct installation drawings, and, if necessary, an on-site inspection. All measurement planes shall be chosen to meet the following requirements:

a) The cross-section of the duct at the measurement plane shall be circular or rectangular, with no irregularities

b) The measurement plane shall be free from any accumulation of dust or debris.

c) The measurement plane shall not intersect any internal stiffeners, supports, splitters, vanes, etc., and shall clear such internal obstructions by at least 0.5 *D*.

d) Any measurement plane shall be at least 0.5 *D* upstream and 1.0 *D* downstream of any bend or change in cross-sectional area. Specific recommendation on a case by case basis are shown elsewhere in this standard.

e) The measurement plane should not coincide with any external duct flanges or stiffeners.

f) The dimensions of the measurement plane should be such that a typical Pitot-static tube or double reverse tube can be inserted and maneuvered. See Section 6.5.2 for probe descriptions. The depth of insertion should be limited to 3 m (10 ft). If the width of the duct is greater than 3 m (10 ft), then the probe should be inserted from both sides of the duct in order to complete the traverse.

g) If it is not possible to choose a measurement plane which fulfills all the above conditions, a measurement plane can be chosen by common agreement between the parties and in such a case it may be necessary to increase the number of traverse points to increase the accuracy of the test. In this case, the validity of the results should be established by mutual agreement.

7.2.1 Definitions of measurement planes. A measurement plane is defined as the location of any duct cross-section in which data are obtained for the purposes of determining fan performance. For the purposes of this standard four measurement planes have been defined which shall be used to determine flow rate, pressure rise, and inlet flow profile. The following nomenclature is used:

Plane 1 - Plane of fan inlet and flow profile
Plane 2 - Plane of fan outlet
Plane 3 - Plane for determining flow rate
Plane 4 - Plane of static pressure measurement downstream of the fan

7.3 Plane 1, fan inlet plane

The purpose of establishing Plane 1 is to specify the location just upstream of the fan inlet at which a Pitot tube traverse is to be conducted, as defined in Section 7.7, in order to measure the inlet flow profile and upstream static pressure. The static pressure shall be measured as the arithmetic average of each traverse point measurement.

For fans with ducted inlet, Plane 1 shall be established immediately adjacent to the fan inlet flange on the upstream side. For fans with inlet boxes installed, Plane 1 shall be considered at the entrance to the inlet box. For open inlet fans, Plane 1 shall be an imaginary plane at the inlet flange. No measurements are required at Plane 1 for open inlet fans not in a plenum. For double inlet fans, an identical Plane 1 shall be established for each inlet.

The performance of a fan is very dependent upon entry flow conditions and therefore is very sensitive to the shape of the inlet flow profile.

Any significant departure from an ideal flow profile will prevent the fan from developing the full performance of which it is capable.

In order to quantify the effects of the inlet flow profile on fan performance, velocity distortion parameters must be calculated. For this standard, the velocity distortion parameters are V_a and V_t as described in Section 5, and as outlined in Sections 7.3.1 and 7.3.2 below.

7.3.1 Velocity profile for rectangular duct. For fan inlet ducts with rectangular cross-sections, the minimum number of Pitot-tube traverse points required to obtain a well defined inlet flow profile is given in Figure 7.4.

Letting $V_{i,j}$ denote the elements in the velocity profile matrix, then:

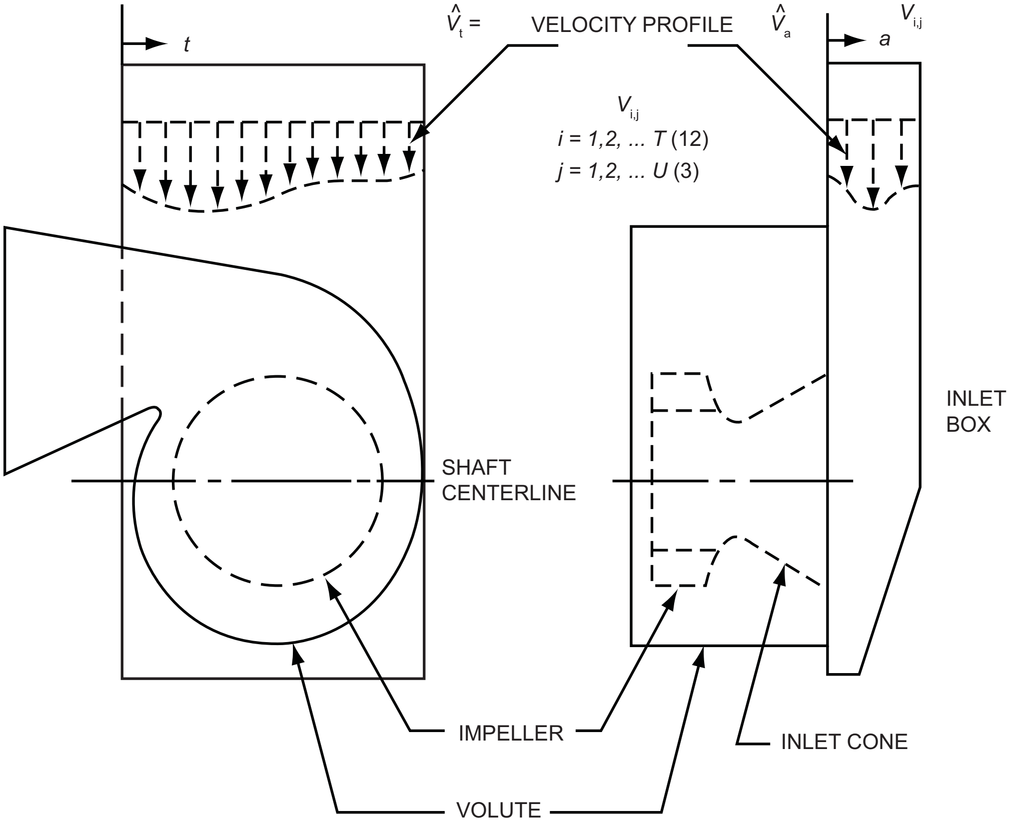


Figure 7.1A - Centrifugal Fan

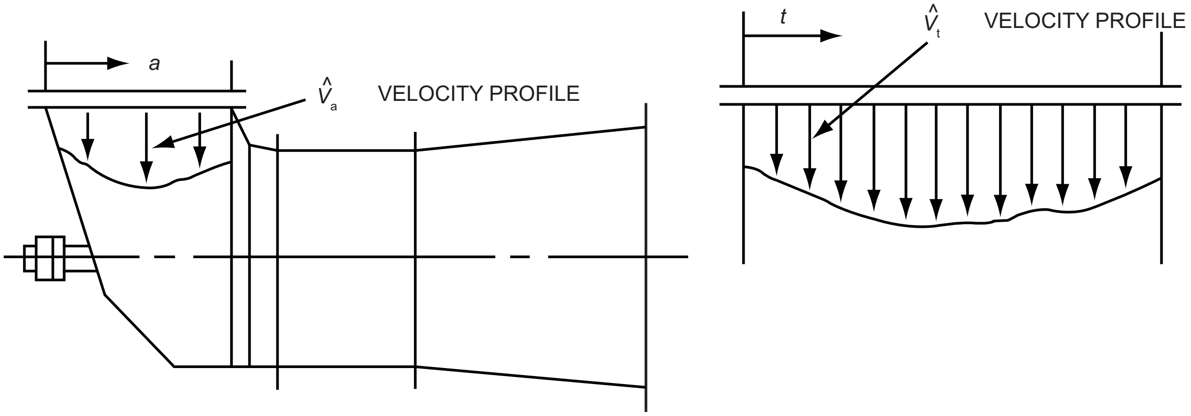


Figure 7.1B - Axial Fan

AIRFOIL FAN - SWSI

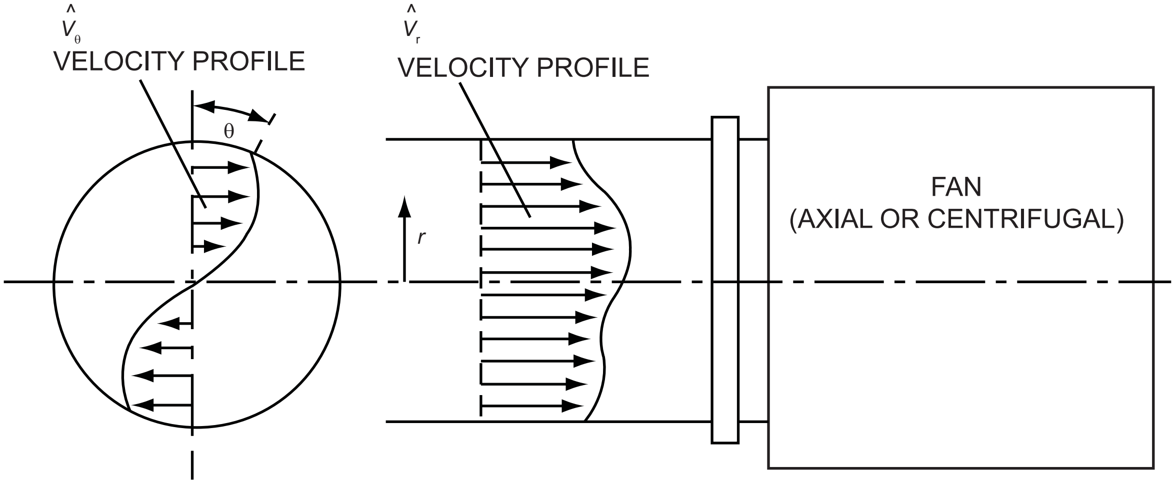


Figure 7.1C - Circular Inlet Duct

Figure 7.1 - Fans with Inflow Distortion

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1) The mean of all velocity readings taken in Plane 1 is:

$$\overline{V} = \frac{\left(\sum_{j=1}^{U}\sum_{i=1}^{T} V_{\mathrm{i,j}}\right)}{UT} \qquad \text{Eqn 7.1}$$

2) The mean velocity along each of the *T* grid traverses is:

$$\overline{V}_{\mathrm{j}} = \frac{\left(\sum_{j=1}^{U} V_{\mathrm{i,j}}\right)}{U} \qquad \text{Eqn 7.2}$$

3) The mean velocity along each of the *U* grid traverses is:

$$\overline{V}_{\mathrm{i}} = \frac{\left(\sum_{i=1}^{T} V_{\mathrm{i,j}}\right)}{T} \qquad \text{Eqn 7.3}$$

4) The traverse distortion parameter:

$$\hat{V}_{\mathrm{t}} = \frac{\sqrt{\dfrac{\sum_{i=1}^{T}\left(\overline{V}_{\mathrm{i}} - \overline{V}\right)^2}{T}} \times 100}{\overline{V}} \qquad \text{Eqn 7.4}$$

5) The axial distortion parameter:

$$\hat{V}_{\mathrm{a}} = \frac{\sqrt{\dfrac{\sum_{j=1}^{U}\left(\overline{V}_{\mathrm{j}} - \overline{V}\right)^2}{U}} \times 100}{\overline{V}} \qquad \text{Eqn 7.5}$$

7.3.2 Velocity profile for circular duct. For a fan having a circular inlet duct connected to the fan inlet flange the inlet velocity profile shall be obtained by taking six traverses in the measurement plane, 60 degrees apart (see Figure 7.2) using log linear distribution for radial velocity reading locations as specified in Figure 7.3. See Annex A.2 for an example calculation.

Formulae for determining velocity profile distortion in circular inlet ducts are given below.

1) The mean of all velocity readings taken in Plane 1:

$$\overline{V} = \frac{\left(\sum_{\theta=1}^{T}\sum_{r=1}^{U} V_{\mathrm{r},\theta}\right)}{UT} \qquad \text{Eqn 7.6}$$

2) The circumferential distortion parameter:

$$\hat{V} = \frac{\sqrt{\frac{\sum_{\theta=1}^{T}\left(\bar{V}_\theta - \bar{V}\right)^2}{0.5T}} \times 100}{\bar{V}} \qquad \text{Eqn 7.7}$$

Where:

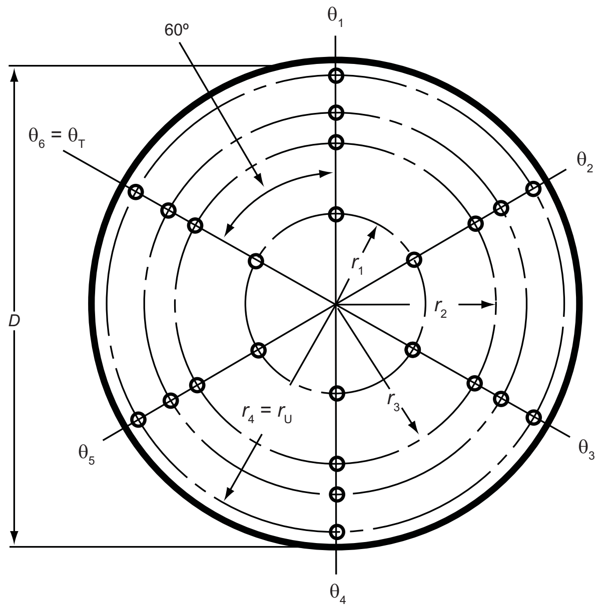
$$\bar{V}_\theta = \frac{\left[\sum_{r=1}^{U} V_{r,\theta}\right]}{U} \qquad \text{Eqn 7.8}$$

3) The radial distortion parameter:

$$\hat{V} = \frac{\sqrt{\frac{\sum_{r=1}^{U}\left(\bar{V}_r - \bar{V}\right)^2}{U}} \times 100}{\bar{V}} \qquad \text{Eqn 7.9}$$

Where:

$$\bar{V}_r = \frac{\left[\sum_{\theta=1}^{T} V_{r,\theta}\right]}{T} \qquad \text{Eqn 7.10}$$



T = 1, 2, ... 6
D = Inside diameter of the duct

Figure 7.2 - Velocity Profile Locations for Circular Inlet Duct

7.3.3 Distortion limits. Any installation in which the fan has an inlet flow profile measured in Plane 1 in which any distortion parameter V_a, V_t, V_θ, or V_r exceeds 10% of the *mean* of all velocities taken in that plane shall be considered to be an unacceptable candidate for testing per AMCA Standard 803.

For any installation with a double inlet fan, each inlet plane shall meet the inlet profile distortion parameter requirement separately and in addition, the *mean* inlet velocity at each of the two inlets shall not differ by more than 5%. Double inlet installations which do not meet these requirements shall be considered to be an unacceptable candidate for testing per AMCA Standard 803. Installations which do not meet the requirements for inlet flow profile may be modified by the addition of turning vanes, splitters, etc., upstream of Plane 1 and retested. As an alternative, the test may be performed with unacceptable inlet flow profiles; however, such a test would no longer be regarded as an AMCA Standard 803 test for the purposes of judging fan performance acceptability, and will be considered only as the measure of the performance of a fan installed in a system unacceptable to this standard.

7.4 Plane 2, fan outlet plane

Plane 2 shall be established immediately adjacent to the fan outlet flange on the downstream side. It is a reference plane for the purposes of establishing theoretical fan performance from inlet flange to outlet flange, and as such may not require that measurements actually be taken at Plane 2. However, it is possible that the location of Plane 2 may also meet the requirements of Plane 3 or Plane 4, in which case measurements would be required.

7.5 Plane 3, flow rate determination plane

Plane 3 shall be located in any suitable straight length where the airflow conditions are substantially axial, symmetrical, and free from swirl or flow reversal.

A traverse shall be conducted in accordance with Section 7.7 to establish the flow rate and profile. The flow profile shall be considered acceptable if the standard deviation, *s*, of the velocity variation is less than 10% of the mean velocity. If unstable flow patterns due to unstable pressure readings are suspected, a survey should be conducted to determine the angle of flow at each traverse point. Measurements should be made using a Fecheimer probe, Wedge probe, three-hole cylindrical probe, or other suitable angle-sensitive measuring device. The angle formed by the direction of flow at each point and the axis of the duct shall not exceed 15°. The number of points which may exceed 10° is limited to

10% of the total number of traverse points [15].

Tests conducted where the flow at Plane 3 does not meet the above requirements shall be considered invalid. If no plane meeting the above requirements for Plane 3 can be found, the installation should be altered by using turning vanes, splitters, straighteners, etc., so that the requirements can be met.

Alternatively, the parties to the test may mutually agree to use a plane which does not meet the requirements, but shall agree in advance to the additional uncertainty to be applied. In such case, the test cannot be regarded as an AMCA Standard 803 test.

It is possible that the fan inlet plane (Plane 1) will also meet the requirements for Plane 3. In this case, one set of measurements will suffice for both planes.

In the event that Plane 3 is on the discharge side of the fan, it is possible, particularly for an axial fan, that Plane 2 may meet the requirements for Plane 3 in which case Planes 2 and 3 will be coincident. For a centrifugal fan, it is unlikely that Plane 3 will be closer than 2 *D* to the discharge flange due to the highly distorted nature of the flow at the discharge flange of a centrifugal fan.

If Plane 3 is not coincident with Planes 1 or 2, then there must be no leakage or source of flow between Plane 3 and the fan.

7.6 Plane 4, downstream static pressure measurement plane

Plane 4 shall be located in a suitable straight length of duct where the flow conditions are substantially axial, symmetrical, and free from swirl or flow reversal. Static pressure at Plane 4 may be measured by Pitot traverse in accordance with Section 7.6 or by static pressure taps in accordance with Figure 6.6.

Plane 4 may be coincident with Plane 3 (flow rate determination). Plane 4 should not be coincident with Plane 2 (fan discharge plane) unless Plane 2 meets the requirements for Plane 3.

The allowance for pressure drop between Plane 4 and Plane 2 must be mutually agreed upon between the parties prior to the test [16].

7.7 Traverse grid definition

In order to obtain representative measurements in a duct, it is necessary to divide the duct into elemental areas and take measurements at the centroid of each elemental area. The number and position of the elemental areas is important to the quality of the test and they are defined in Figure 7.3 for circular ducts.

For rectangular ducts, the minimum number of traverse points is 24 and this minimum requirement increases with increasing duct size, as defined in Figure 7.4.

The points are to be located in the centroids of equal elemental areas with the elemental areas chosen to be similar in geometric shape to the duct cross-section, such that:

1) The aspect parameter, *S*, shall be between 2/3 and 4/3.

   Where:

$$S = \frac{\textit{aspect of elemental area}}{\textit{aspect of duct cross-section}}$$

2) The long dimension of the elemental area shall align with the long dimension of the duct cross-section

8. Conduct of Test

8.1 General requirements

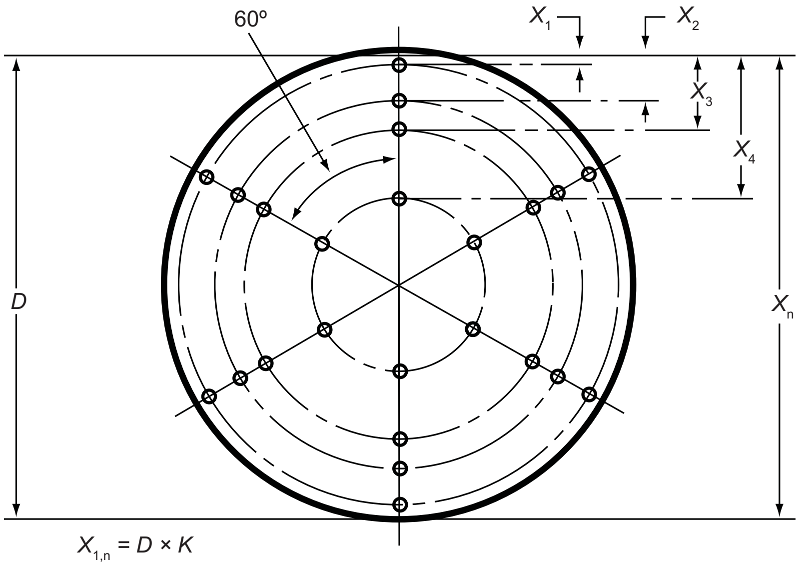
Any test shall be performed only after the fan has been found by inspection to be in satisfactory condition to undergo the test. The owner and the vendor shall mutually decide when the test is to be performed.

The parties to the test shall be entitled to have present such members of their staffs as are required for them to be assured that the test is conducted in accordance with this standard, and with any written agreements made prior to the test.

An internal inspection of the ductwork at planes where velocity or pressure measurements are to be made shall be conducted by the parties to the test to ensure that no obstructions will affect the measurements. Areas where there is an accumulation of dust such that the duct area is significantly reduced must be avoided. This may cause the duct cross-sectional area to change during the test.

8.2 Agreements

Prior to conducting a standard test, written agreement shall be reached by the parties to the test



$X_{1,n} = D \times K$

TABLE OF *K* VALUES			
POINT	DIAMETER Up to 8 ft. (2.4 m) 8 POINTS	DIAMETER 8 to 12 ft. (2.4 to 3.6 m) 12 POINTS	DIAMETER over 12 ft. (3.6 m) 16 POINTS
X_1	.021	.014	.010
X_2	.117	.075	.055
X_3	.184	.114	.082
X_4	.345	.183	.128
X_5	.655	.241	.166
X_6	.816	.374	.225
X_7	.883	.626	.276
X_8	.979	.759	.391
X_9		.817	.609
X_{10}		.886	.724
X_{11}		.925	.775
X_{12}		.986	.834
X_{13}			.872
X_{14}			.918
X_{15}			.945
X_{16}			.990

Where:

D = Duct inside diameter
K = Value in the table corresponding to traverse point location

Figure 7.3 - Log Linear Distribution of Traverse Points for Circular Ducts

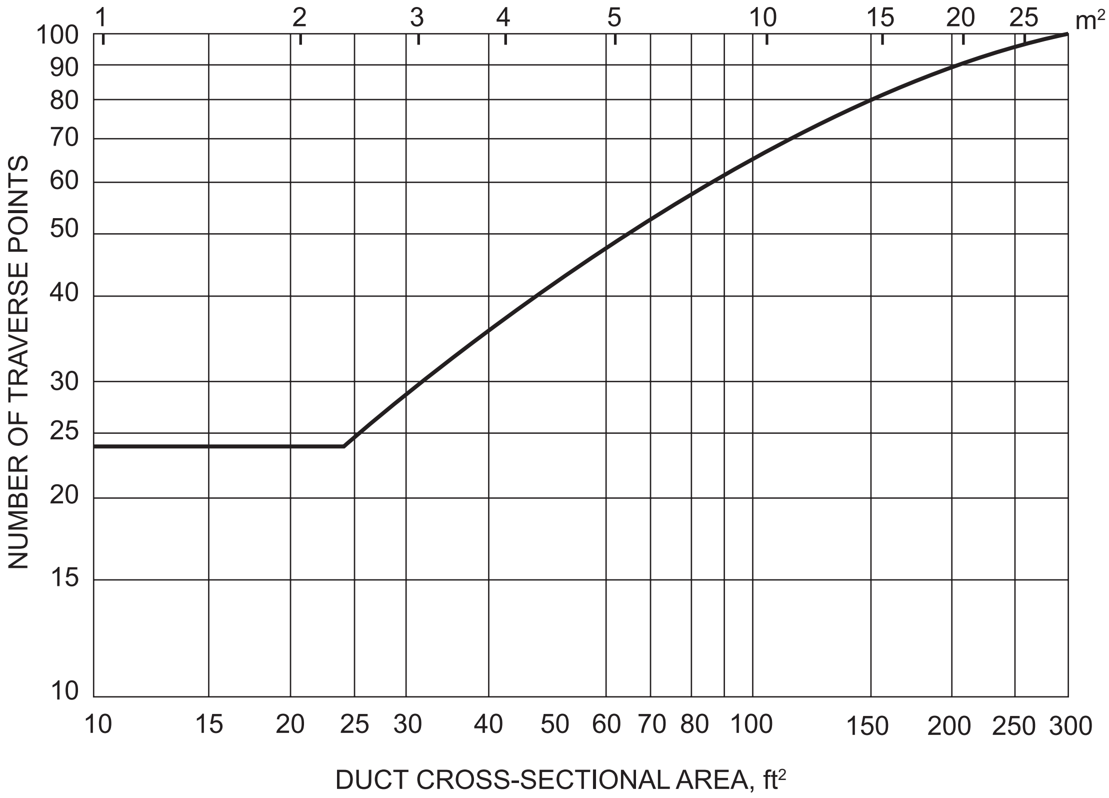


Figure 7.4 - Distribution or Traverse Points for Rectangular Ducts

on the following items:

a) Object of test

b) Duration of operation under test conditions

c) Test personnel and assignments

d) Person in charge of test

e) Test methods to be used

f) Test instrumentation, methods of calibration and calibration results

g) Locations at which measurements are to be taken

h) Number and frequency of measurements

i) Method of computing results

j) A pre-test uncertainty analysis shall be performed

k) Arbitrator to be used if one becomes desirable

l) Application contract performance curves and/or the specified performance and operating conditions

m) Tolerances on performance

n) Number of test runs

Prior to the test, the manufacturer or supplier shall have reasonable opportunity to inspect the fan and accessories for correction of noted defects, for normal adjustments to meet specifications and contract agreements, and to otherwise place the equipment in condition to undergo further operating and testing. The manufacturer or supplier shall not alter or change the equipment or accessories in such a manner as to modify or void specifications or contract agreements, or to prevent continuous and reliable operation of the equipment at all capacities and outputs under all specified operating conditions.

Adjustments to the fan which may affect test results are not permitted once the test has started. Should such adjustments be deemed necessary, prior test runs shall be voided and the test restarted. Any readjustments and reruns shall be agreed to by the parties to the test.

8.3 Personnel

A test team shall be selected that includes a sufficient number of test personnel to record the various readings in the allotted time. Test personnel shall have the experience and training necessary to obtain accurate and reliable records. All data sheets shall be signed by the observers.

The person in charge of the test shall direct the test, exercise authority over the conduct of the test, and shall certify that the test is conducted in accordance with this standard and with all written agreements made prior to the test. If more than one point of operation is required, a test must be made for each point of operation. The parties to the test must agree prior to the tests on the method of varying the system resistance to obtain the various points of operation.

8.4 System conditions

When a system contains fans operating in parallel, the fan to be tested shall be operated in the manual mode during the test and the remaining fans in the system used to follow load variants. The fan to be tested shall be operated at a constant speed with constant damper, or constant blade vane position.

The system shall be operated to maintain constant system load conditions for the duration of the test. If inconsistencies in the measurements are observed during the conduct of the test, the person in charge of the test shall be permitted to take steps to remedy the inconsistency and to continue the test. Any actions in this regard must be noted and are subject to approval by the parties to the test. Any such action shall be fully documented in the test report.

For the purposes of determining that the system has reached steady state, for verifying the constancy of operating conditions and for verifying that the fan performs at a constant point of operation during the test, the following reference measurements shall be made:

a) Speed

b) Drive current or power

c) Static pressure near Plane 1

d) Static pressure near Plane 2

e) Temperature near Plane 1

f) Temperature near Plane 2

g) Velocity pressure (single point) in either Plane 1 or Plane 2

h) Barometric pressure

8.5 Measurements

The reference measurements shall be averaged and recorded over a one (1) minute window of time, every twenty (20) minutes.

If any one of the reference measurements departs from steady conditions by more than the predetermined uncertainty for that parameter, the test shall be invalidated.

The person in charge of the test shall be solely responsible for deciding when operating conditions are sufficiently constant to begin the test and to continue the test.

Any bi-stable performance points (airflow rates at which two different pressure values can be measured) shall be so reported. The points shall be identified as that for decreasing airflow rate and that for increasing airflow rate.

The cross-sectional duct area shall be confirmed by at least four equally spaced measurements across each nominal duct dimension. If the uncertainty in area exceeds 0.5%, more than four measurements must be performed. Suitable expansion or contraction corrections shall be made for temperature and pressure where applicable.

9. Calculations

9.1 Calibration correction

Calibration corrections, when required, shall be applied to individual readings before averaging or other calculations.

Calibration corrections need not be made if the correction is smaller than one half the maximum allowable error as specified in Section 6.5.

9.2 Density and viscosity of gas

9.2.1.1 For atmospheric air, the density shall be calculated as follows: the density of atmospheric air (ρ_0) shall be determined from measurements, taken in the general test area, of dry-bulb temperature (t_{d0}), wet-bulb temperature (t_{w0}), and barometric pressure (p_b) using the following formulae:

$$p_e = 0.00325\, t_{w0}^2 - 0.0186\, t_{w0} + 0.692 \qquad \text{Eqn 9.1 SI}$$

$$p_e = 0.000296\, t_{w0}^2 - 0.0159\, t_{w0} + 0.41 \qquad \text{Eqn 9.1 I-P}$$

$$p_p = p_e - p_b\left(\frac{t_{d0} - t_{w0}}{1500}\right) \qquad \text{Eqn 9.2 SI}$$

$$p_p = p_e - p_b\left(\frac{t_{d0} - t_{w0}}{2700}\right) \qquad \text{Eqn 9.2 I-P}$$

$$\rho_0 = \frac{\left(p_b - 0.378 p_p\right) \times 10^3}{R\left(t_{d0} + 273.15\right)} \qquad \text{Eqn 9.3 SI}$$

$$\rho_0 = \frac{70.73\left(p_b - 0.378 p_p\right)}{R\left(t_{d0} + 459.67\right)} \qquad \text{Eqn 9.3 I-P}$$

The first equation is approximately correct for p_e for a range of t_{w0} between 4.4°C and 32.2°C (40°F and 90°F). More precise values of p_e can be obtained from the ASHRAE Handbook of Fundamentals [15]. The gas constant (R) may be taken as 287 J/kg°K (53.35 ft-lb/lbm°R) for air.

9.2.1.2 For atmospheric air, the absolute viscosity shall be calculated as follows:

$$\mu = (17.23 + 0.0482 t_d) \times 10^{-6} \qquad \text{Eqn 9.4 SI}$$

$$\mu = (11.00 + 0.018 t_d) \times 10^{-6} \qquad \text{Eqn 9.4 I-P}$$

9.2.2 Other gases. For gases other than atmospheric air, the density and viscosity must be determined based on a gas sample analysis (Section 6.5.5) or other means.

9.2.3 Fan gas density, ρ. The fan gas density, ρ, shall be calculated from the density of gas at a known reference condition, ρ_0, from Sections 9.2.1 or 9.2.2, the total pressure at the fan inlet, P_{t1}, and the total temperature at the fan inlet, t_{t1}, using:

$$\rho = \rho_0\left(\frac{P_{t1} + 1000 p_b}{1000 p_b}\right)\left(\frac{t_{d0} + 273.15}{t_{t1} + 273.15}\right) \qquad \text{Eqn 9.5 SI}$$

$$\rho = \rho_0\left(\frac{P_{t1} + 13.63 p_b}{13.63 p_b}\right)\left(\frac{t_{d0} + 459.67}{t_{t1} + 459.67}\right) \qquad \text{Eqn 9.5 I-P}$$

9.2.4 Duct gas density. The duct gas density at Plane x, ρ_x, shall be calculated from the density of gas at a known reference condition, ρ_0, from Sections 9.2.1 or 9.2.2, the total pressure, P_{tx}, and total temperature, t_{tx}, at Plane x using:

$$\rho_x = \rho_0\left(\frac{P_{tx}+1000p_b}{1000p_b}\right)\left(\frac{t_{d0}+273.15}{t_x+273.15}\right) \quad \text{Eqn 9.6 SI}$$

$$\rho_x = \rho_0\left(\frac{P_{tx}+13.63p_b}{13.63p_b}\right)\left(\frac{t_{d0}+459.67}{t_{tx}+459.67}\right) \quad \text{Eqn 9.6 IP}$$

9.3 Fan flow rate at test conditions, *Q*

$$P_v = \left(\frac{\Sigma\sqrt{P_{v3r}}}{n}\right)^2 \quad \text{Eqn 9.7}$$

Where:

P_{v3r} = the velocity pressure at each traverse plane location

n = the number of traverse points

$$V_3 = 1.414\sqrt{\frac{P_{v3}}{\rho_3}} \quad \text{Eqn 9.8 SI}$$

$$V_3 = 1097\sqrt{\frac{P_{v3}}{\rho_3}} \quad \text{Eqn 9.8 I-P}$$

Where:

$$\rho_3 = \rho_0\left(\frac{P_{t3}+1000p_b}{P_{t1}+1000p_b}\right)\left(\frac{t_{t1}+273.15}{t_{t3}+273.15}\right) \quad \text{Eqn 9.9 SI}$$

$$\rho_3 = \rho_0\left(\frac{P_{t3}+13.63p_b}{P_{t1}+13.63p_b}\right)\left(\frac{t_{t1}+459.67}{t_{t3}+459.67}\right) \quad \text{Eqn 9.9 I-P}$$

$Q_3 = V_3A_3$ Eqn 9.10

Where:

A_3 = the cross-sectional area of Plane 3

$$Q = Q_1 = Q_3\left(\frac{\rho_3}{\rho}\right) \quad \text{Eqn 9.11}$$

9.4 Fan velocity pressure at test condition, P_v

$$P_v = P_{v3}\left(\frac{\rho_3}{\rho_2}\right)\left(\frac{A_3}{A_2}\right)^2 \quad \text{Eqn 9.12}$$

9.5 Fan total pressure at test conditions, P_t

9.5.1 Flow measurement plane on outlet side of fan. When Plane 3 is on the outlet side of the fan and Plane 4 is coincident with Plane 3.

$$P_{t2} = P_{s3} + P_{v3} + f\left(\frac{L_{2,3}}{D_{h3}}\right)P_{v3} \quad \text{Eqn 9.13}$$

Where:

$$P_{s3} = \frac{\sum P_{s3r}}{n} \quad \text{Eqn 9.14}$$

$$f = \frac{0.14}{\text{Re}^{0.17}} \quad \text{Eqn 9.15}$$

$$\text{Re} = \frac{D_{h3}V_3\rho_3}{\mu} \quad \text{Eqn 9.16 SI}$$

$$\text{Re} = \frac{D_{h3}V_3\rho_3}{60\mu} \quad \text{Eqn 9.16 I-P}$$

Where:

D_{h3} = Hydraulic diameter of the duct at Plane 3. For round ducts it is the actual diameter. For rectangular ducts it shall be calculated from the inside duct dimensions *a* and *b* using:

$$D_{h3} = \frac{2ab}{a+b} \quad \text{Eqn 9.17}$$

$L_{2,3}$ = length of duct between Planes 2 and 3.

$P_{t1} = P_{v1} + P_{s1}$ Eqn 9.18

$$P_{v1} = P_{v3}\left(\frac{\rho_3}{\rho_1}\right)\left(\frac{A_3}{A_1}\right)^2 \quad \text{Eqn 9.19}$$

$$P_{s1} = \frac{\sum P_{s1r}}{n} \quad \text{Eqn 9.20}$$

$P_t = P_{t2} - P_{t1}$ Eqn 9.21

9.5.2 Flow measurement plane on inlet side of the fan

$P_{t1} = P_{s1} + P_{v1}$ Eqn 9.22

$$P_{\mathrm{v1}} = \left(\frac{\sum\sqrt{P_{\mathrm{v1r}}}}{n}\right)^2$$ Eqn 9.23

When Plane 1 is the flow measurement plane, the duct friction loss is considered to be negligible.

$$P_{\mathrm{v2}} = P_{\mathrm{v1}}\left(\frac{\rho_1}{\rho_2}\right)\left(\frac{A_1}{A_2}\right)^2$$ Eqn 9.24

$$P_{\mathrm{s2}} = \frac{\sum P_{\mathrm{s2r}}}{n}$$ Eqn 9.25

$P_{\mathrm{t2}} = P_{\mathrm{v2}} + P_{\mathrm{s2}}$ Eqn 9.26

$P_{\mathrm{t}} = P_{\mathrm{t2}} - P_{\mathrm{t1}}$ Eqn 9.27

9.6 Fan static pressure at test conditions, *P*$_{\mathrm{s}}$

$P_{\mathrm{s}} = P_{\mathrm{t}} - P_{\mathrm{v}}$ Eqn 9.28

9.7 Fan power input at test conditions, *H*

9.7.1 If a torquemeter is used:

$H = 1.047 \times 10^{-4} NT$ Eqn 9.29 SI

$H = 1.587 \times 10^{-5} NT$ Eqn 9.29 I-P

Where:

$$T = \frac{\sum T_{\mathrm{r}}}{n}$$ Eqn 9.30

$$T = \frac{\sum N_{\mathrm{r}}}{n}$$ Eqn 9.31

9.7.2 If a calibrated motor is used:

$H = W\eta$ Eqn 9.32 SI

$$H = \frac{W\eta}{746}$$ Eqn 9.32 I-P

Where:

$$W = \frac{\sum W_{\mathrm{r}}}{n}$$

η = motor efficiency as a decimal

9.7.2.1 Non-calibrated motor. A generic motor curve may be used with a non-calibrated motor provided the greater degree of uncertainty is agreed upon by both parties.

9.8 Fan efficiency

9.8.1 Fan total efficiency, η_{t}

$$\eta_{\mathrm{t}} = \frac{QP_{\mathrm{t}}K_{\mathrm{p}}}{1000H}$$ Eqn 9.33 SI

$$\eta_{\mathrm{t}} = \frac{QP_{\mathrm{t}}K_{\mathrm{p}}}{6362H}$$ Eqn 9.33 I-P

Where:

K_{p} = the compressibility coefficient. See Annex B for calculation.

9.8.2 Fan static efficiency, η_{s}

$$\eta_{\mathrm{s}} = \eta_{\mathrm{t}}\left(\frac{P_{\mathrm{s}}}{P_{\mathrm{t}}}\right)$$ Eqn 9.34

9.9 Conversions to nominal constant values of density and speed

During a test, the air density and speed of rotation may vary slightly from one test point to another. It will be necessary to convert the results calculated for test conditions to those that would prevail at nominal constant density, nominal constant speed, or both. This may be done provided the nominal constant density, ρ_{c}, is within 10% of the actual density, ρ, and the nominal constant speed, N_{c}, is within 5% of the actual speed, N.

9.9.1 Compressibility factor ratio. In order to make the density and speed conversions it is necessary to determine the ratio of the compressibility coefficient for actual conditions to that for nominal conditions ($K_{\mathrm{p}}/K_{\mathrm{pc}}$). This can be accomplished using previously calculated values of *x* and *z* for actual conditions as follows:

$$\frac{z}{z_{\mathrm{c}}} = \left(\frac{P_{\mathrm{t1c}} + 1000p_{\mathrm{bc}}}{P_{\mathrm{t1}} + 1000p_{\mathrm{b}}}\right)\left(\frac{\rho}{\rho_{\mathrm{c}}}\right)\left(\frac{N}{N_{\mathrm{c}}}\right)^2\left(\frac{\gamma_{\mathrm{c}}}{\gamma_{\mathrm{c1}}}\right)\left(\frac{\gamma - 1}{\gamma}\right)$$

Eqn 9.35 SI

$$\frac{z}{z_{\mathrm{c}}} = \left(\frac{P_{\mathrm{t1c}} + 13.63p_{\mathrm{bc}}}{P_{\mathrm{t1}} + 13.63p_{\mathrm{b}}}\right)\left(\frac{\rho}{\rho_{\mathrm{c}}}\right)\left(\frac{N}{N_{\mathrm{c}}}\right)^2\left(\frac{\gamma_{\mathrm{c}}}{\gamma_{\mathrm{c1}}}\right)\left(\frac{\gamma - 1}{\gamma}\right)$$

Eqn 9.35 I-P

$$z_c = \frac{z}{(z/z_c)}$$ Eqn 9.36

$$\ln(1+x_c) = \ln(1+x)\left(\frac{\ln(1+z_c)}{\ln(1+z)}\right)\left(\frac{\gamma-1}{\gamma}\right)\left(\frac{\gamma_c}{\gamma_c-1}\right)$$ Eqn 9.37

$x_c = e^{\ln(1+x_c)} - 1$ Eqn 9.38

And:

$$\frac{k_p}{k_{pc}} = \left(\frac{z}{z_c}\right)\left(\frac{x_c}{x}\right)\left(\frac{\gamma}{\gamma-1}\right)\left(\frac{\gamma_c-1}{\gamma_c}\right)$$ Eqn 9.39

9.9.1 Conversion formulae. Actual test results may be converted to nominal test results using the following [2]:

$$Q_c = Q\left(\frac{N_c}{N}\right)\left(\frac{K_p}{K_{pc}}\right)$$ Eqn 9.40

$$P_{tc} = P_t\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right)$$ Eqn 9.41

$$P_{vc} = P_v\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right)$$ Eqn 9.42

$P_{sc} = P_{tc} - P_{vc}$ Eqn 9.43

$$H_c = H\left(\frac{N_c}{N}\right)^3\left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right)$$ Eqn 9.44

$\eta_{sc} = \eta_t$ Eqn 9.45

And:

$$\eta_{sc} = \eta_{tc}\left(\frac{P_{sc}}{P_{tc}}\right)$$ Eqn 9.46

10. Uncertainties

Any test, whether a laboratory test or a site test, may result in uncertainties due to uncertainty in measuring devices and to uncertainty in measured values.

Before a site test is undertaken, it is necessary to make an estimate of the uncertainty to avoid subsequent discussion of the validity of the test results. This estimate shall be followed by a detailed calculation of the uncertainty which would form part of the final report.

10.1 Definitions

The following definitions are used:
X = Measured quantity
ΔX = Absolute uncertainty in X
u_x = $\Delta X/X$ per unit uncertainty in X

The **per unit uncertainty** used in this standard is based on a 95% confidence limit, which implies that out of a large number of measurements having a normal statistical distribution, 95% may be expected to be within the limits specified, 2.5% being above the top, and 2.5% below the bottom limit.

$X \pm \Delta X$

The symbol u, with the appropriate subscript, will be used for the **per unit uncertainty**.

Example:

u_Q = Per unit uncertainty of fan flow rate.

For special use in this section, it is necessary to add subscripted symbols as follows:

Symbol	**Uncertainty of**	**I-P Units or SI Units**
u_A	Duct Area	per unit
u_b	Barometric Pressure	per unit
u_C	Pitot-Static Tube Coefficient	per unit
u_d	Dry-bulb Temperature	per unit
u_η	Fan Efficiency	per unit
u_f	Friction Loss Coefficient	per unit
u_H	Fan Shaft Power	per unit
u_N	Speed	per unit
u_{Kp}	Compressibility	per unit
u_m	Gas Composition	per unit
u_K	Pressure Losses	per unit
u_L	Power Losses	per unit
u_p	Pressure	per unit
u_{Pv}	Calculated Velocity Pressure	per unit
u_ρ	Gas Density	per unit
u_{Ps}	Static Pressure	per unit
u_{Pt}	Total Pressure	per unit
u_{Pv}	Measured Velocity Pressure	per unit
u_Q	Fan Flow Rate	per unit
u_T	Torque Meter	per unit
u_{TR}	Pitot-Static Tube Location	per unit
u_v	Wet-Bulb Temperature	per unit
u_w	Electrical Power Input	per unit

Symbol	Uncertainty of	I-P Units or SI Units
Δi	Absolute Reading Error Value	Varies w/ Instrument
ΔK	Pressure Loss	Absolute

Quantity	Affected or Influenced By	Subscripted Symbol
Gas Density		u_ρ
	Barometric Pressure	u_b
	Dry-Bulb Temperature	u_d
	Wet-Bulb Temperature	u_v
	Gas Composition	u_m
Measured Velocity Pressure		u_{Pvf}
	Instrumentation	Δi
	Pressure Readings	u_P
Fan Flow Rate		u_Q
	Gas Density	u_ρ
	Duct Area	u_A
	Calculated Velocity Pressure	u_{Pv}
	Pitot-Static Tube Location	u_{TR}
	Pitot-Static Coefficient	u_C
	Speed	u_N
	Compressibility	u_{Kp}
Calculated Velocity Pressure		u_{Pv}
	Fan Flow Rate	u_Q
	Duct Area	u_A
	Gas Density	u_ρ
Static Pressure		u_{Ps}
	Pressure Losses	ΔK
	Friction Loss Coefficient	u_f
	Instrumentation	Δi
	Pressure Readings	u_P
	Measured Velocity Pressure	u_{Pv}
	Speed	u_N
	Gas Density	u_ρ
	Compressibility	u_{Kp}
Total Pressure		u_{Pt}
	Static Pressure	u_{Ps}
	Velocity Pressure	u_{Pv}
	Pressure Losses	ΔK
	Friction Loss Coefficient	u_f
	Compressibility	u_{Kp}
	Speed	u_N
	Gas Density	u_ρ
Fan Shaft Power		u_H
	Electrical Power Input	u_W
	Speed	u_N
	Power Losses	u_L
	Torque Meter	u_T
	Compressibility	u_{Kp}
	Gas Density	u_ρ
Fan Efficiency		u_η
	Fan Flow Rate	u_Q
	Static Pressure, or	u_{Ps}
	Total Pressure	u_{Pt}
	Compressibility	u_{Kp}
	Fan Shaft Power	u_H

10.2 Formulae

In this section the necessary formulae for the uncertainty calculation are given without any values.

Examples of values for most of the **per unit uncertainties** are given in Annex D, but it is imperative that the test personnel involved use experience and common sense.

10.2.1 Density of gas handled by the fan

Air $$u_\rho = \sqrt{u_b^2 + u_d^2 + u_v^2} \qquad \text{Eqn 10.1}$$

Flue Gas $$u_\rho = \sqrt{u_b^2 + u_d^2 + u_m^2} \qquad \text{Eqn 10.2}$$

10.2.2 Flow (mass flow or volume flow)

In a section x:

$$u_{Qx} = \sqrt{u_A^2 + \left(\frac{u_{\rho x}}{2}\right)^2 + \left(\frac{u_{Pvf}}{2}\right)^2 + u_{TR}^2 + u_c^2}$$

Eqn 10.3

Converted to inlet volume flow:

$$u_{Q1} = \sqrt{u_{Qx}^2 + u_\rho^2} \qquad \text{Eqn 10.4}$$

Converted to another rpm, *N*:

$$u_{\mathrm{QNKp}} = \sqrt{u_{\mathrm{Q1}}{}^2 + u_{\mathrm{N}}{}^2 + u_{\mathrm{Kp}}{}^2} \qquad \text{Eqn 10.5}$$

10.2.3 Velocity pressure

$$u_{\mathrm{Pvx}} = \sqrt{4u_{\mathrm{Qx}}{}^2 + u_{\rho}{}^2 + 4u_{\mathrm{A}}{}^2} \qquad \text{Eqn 10.6}$$

10.2.4 Fan total pressure. The following calculation will be followed in the site test to establish per unit uncertainty for the fan total pressure where the plane of traverse measurement and the plane of static pressure measurement are the same.

$$\Delta P_{\mathrm{t2}} = \sqrt{\Delta P_{\mathrm{s3}}{}^2 + \Delta P_{\mathrm{v3}}{}^2 + \Delta K^2} \qquad \text{Eqn 10.7}$$

Otherwise:

$$\Delta P_{\mathrm{t2}} = \sqrt{\Delta P_{\mathrm{s4}}{}^2 + \Delta P_{\mathrm{v4}}{}^2 + \Delta K^2} \qquad \text{Eqn 10.8}$$

$$\Delta P_{\mathrm{t1}} = \sqrt{\Delta P_{\mathrm{s1}}{}^2 + \Delta P_{\mathrm{v1}}{}^2} \qquad \text{Eqn 10.9}$$

$$\Delta P_{\mathrm{t}} = \sqrt{\Delta P_{\mathrm{t1}}{}^2 + \Delta P_{\mathrm{t2}}{}^2} \qquad \text{Eqn 10.10}$$

$$u_{\mathrm{Pt}} = \frac{\Delta P_{\mathrm{t}}}{P_{\mathrm{t}}} \qquad \text{Eqn 10.11}$$

Converted to another rpm and density:

$$u_{\mathrm{PtN\rho Kp}} = \sqrt{u_{\mathrm{Pt}}{}^2 + 4u_{\mathrm{N}}{}^2 + u_{\rho}{}^2 + u_{\mathrm{Kp}}{}^2} \qquad \text{Eqn 10.12}$$

10.2.5 Fan static pressure. The following calculation will be followed in the site test to establish the per unit uncertainty for fan static pressure where the plane of traverse measurement and the plane of static pressure are the same.

$$\Delta P_{\mathrm{s2}} = \sqrt{\Delta P_{\mathrm{s3}}{}^2 + \Delta K^2} \qquad \text{Eqn 10.13}$$

Otherwise:

$$\Delta P_{\mathrm{s2}} = \sqrt{\Delta P_{\mathrm{s4}}{}^2 + \Delta K^2} \qquad \text{Eqn 10.14}$$

$$\Delta P_{\mathrm{t1}} = \sqrt{\Delta P_{\mathrm{s1}}{}^2 + \Delta P_{\mathrm{v1}}{}^2} \qquad \text{Eqn 10.15}$$

$$\Delta P_{\mathrm{s}} = \sqrt{\Delta P_{\mathrm{s2}}{}^2 + \Delta P_{\mathrm{t1}}{}^2} \qquad \text{Eqn 10.16}$$

$$u_{\mathrm{Ps}} = \frac{\Delta P_{\mathrm{s}}}{P_{\mathrm{s}}} \qquad \text{Eqn 10.17}$$

Converted to another rpm and density:

$$u_{\mathrm{PsN\rho Kp}} = \sqrt{u_{\mathrm{Ps}}{}^2 + 4u_{\mathrm{N}}{}^2 + u_{\rho}{}^2 + u_{\mathrm{Kp}}{}^2} \qquad \text{Eqn 10.18}$$

10.2.6 Power

10.2.6.1 Calibrated motor

$$u_{\mathrm{H}} = \frac{\sqrt{\Delta W^2 + \Delta L^2}}{H}$$

$$= \frac{\sqrt{\left(u_{\mathrm{w}}W\right)^2 + \left(u_{\mathrm{L}}L\right)^2}}{H} \qquad \text{Eqn 10.19}$$

Where:

L = losses

Converted to another rpm and density:

$$u_{\mathrm{HN\rho Kp}} = \sqrt{u_{\mathrm{H}}{}^2 + 9u_{\mathrm{N}}{}^2 + u_{\rho}{}^2 + u_{\mathrm{Kp}}{}^2} \qquad \text{Eqn 10.20}$$

10.2.6.2 Torquemeter

Power if Torquemeter is used:

$$u_{\mathrm{H}} = \sqrt{u_{\mathrm{T}}{}^2 + u_{\mathrm{N}}{}^2} \qquad \text{Eqn 10.21}$$

Converted to another rpm and density:

$$u_{\mathrm{Hn\rho}} = \sqrt{u_{\mathrm{H}}{}^2 + 4u_{\mathrm{N}}{}^2 + u_{\rho}{}^2} \qquad \text{Eqn 10.22}$$

10.2.7 Efficiency

$$u_{\eta\mathrm{s}} = \sqrt{u_{\mathrm{Q1}}{}^2 + u_{\mathrm{Ps}}{}^2 + u_{\mathrm{H}}{}^2 + u_{\mathrm{Kp}}{}^2} \qquad \text{Eqn 10.23}$$

$$u_{\eta\mathrm{t}} = \sqrt{u_{\mathrm{Q1}}{}^2 + u_{\mathrm{Pt}}{}^2 + u_{\mathrm{H}}{}^2 + u_{\mathrm{Kp}}{}^2} \qquad \text{Eqn 10.24}$$

Notice that u_{Q1}, u_{Pt}, u_{Ps}, and u_{H} are used as measured and not the values corrected to any other nominal condition. If the corrected values are used inadvertently, then an increase in the total efficiency uncertainty would occur from u_{t} to $((u_{\mathrm{t}})^2 + 18(u_{\mathrm{N}})^2)^{0.5}$. A similar increase would occur for the static efficiency uncertainty.

The following derivation illustrates that the uncertainty of η_t will not be altered by a change of N (applies to η_s also):

$$\eta_t = \frac{Q_N P_{tN} K_{pN}}{H_N}$$

$$= \frac{Q_1\left(\frac{N}{N_1}\right)\left(\frac{K_{p1}}{K_{pN}}\right)P_t\left(\frac{N}{N_1}\right)^2\left(\frac{K_{p1}}{K_{pN}}\right)K_{pN}}{N\left(\frac{N}{N_1}\right)^3\left(\frac{K_{p1}}{K_{pN}}\right)} \qquad \text{Eqn 10.25}$$

$$\eta_t = \frac{Q_1 P_t K_{p1}}{H_1}\,\frac{\left(\frac{K_{p1}}{K_{pN}}\right)\left(\frac{N}{N_1}\right)^3}{\left(\frac{K_{p1}}{K_{pN}}\right)\left(\frac{N}{N_1}\right)^3} \qquad \text{Eqn 10.26}$$

11. Presentation of Results

The results of the fan site performance test, and the procedure followed in obtaining them, shall be presented in the form of a written report which shall include all necessary explanatory drawings, graphs, etc. The report shall be certified as correct by the person in charge of the test. The report shall include sections as described in Sections 11.1 through 11.9, plus any other information necessary for a complete understanding of all aspects of the test.

11.1 Introduction

The introduction shall define the objectives of the test, and shall list the various relevant contractual agreements and performance guarantees, if any, which are to be met. It shall also list the following information:

a) Fan size, type, manufacturer, and serial number
b) Fan owner, location and application
c) Specified fan performance and operating conditions
d) Names of those involved in the test, identifying the name of the person in charge
e) Date and time of test

A description of the system in which the fan is operating shall be included. This requirement may best be achieved by including a sketch or drawing of the system with the position of the fan being tested clearly marked. The description should refer in particular to any parts of the system which may influence the fan performance or the test results, and should indicate any features which deviate from any earlier contractual agreements or understandings.

11.2 Test procedure

This section shall describe the procedure followed during the test, including any preliminary or abortive tests. The operating conditions of the system during these tests shall be defined, and the magnitude of variations in the operating conditions noted. Where more than one test point is being obtained, the means of altering the operating point shall be described.

11.3 Instruments and methods of measurement

Full details of all instrumentation used in the test shall be given. The information given must include, when possible: the instrument manufacturer, model type, serial number, date and method of calibration, and the location in which the instrument was situated. Again, a sketch or drawing of the system with the instrument locations marked on it may be used.

Any measurement methods or instruments which are not in accordance with the recommendations of this standard must be defined, and the justification for such methods or instruments clearly shown.

11.4 Measurement readings

All measurements recorded manually during the site test shall be recorded on data sheets such as those shown in Annex H. Copies of all such data sheets shall be included in this section, or if preferred, they may be included as an appendix to the report. If data acquisition equipment has been used, then measurement readings may not be available. In this case, the requirements of Section 11.5 regarding detailed description of computer calculations will apply to the complete process from initial data gathering to presentation results. Any observations concerning test conditions, environment, system variations, measurement fluctuations, etc. should be recorded in this section.

11.5 Calculation methods

The methods used to calculate the results of the test from the measurements taken shall be clearly defined. If hand calculation methods are used, a sample calculation of at least one test point shall be shown in detail. If a computer or data acquisition system is used, then a description of the calculations performed shall be documented.

The uncertainty analysis described in Section 10 is a mandatory requirement of this standard and must be included in the calculations. Where necessary, justification of the uncertainty values used shall be shown.

11.6 Results

The results of the calculations and uncertainties shall be clearly presented in tabular or graphical form. The presentation must include the calculated fan performance under the operating conditions of the test, and the calculated fan performance under the specified operating conditions, together with the calculated uncertainties in the performance variables. Graphical presentations should be used in comparing measured test results with specified (or guaranteed) points. Typical graphical presentations are shown in Annex E.

11.7 Discussion

Any comments or observations on the test may be recorded in this section. When applicable, a comparison of measured and specified fan performance should be made, and any possible sources or error in the test data should be discussed.

11.8 Conclusions

The conclusions drawn from the test results shall be stated along with any recommendations for further action.

11.9 Appendices

Any documentation which will expand or clarify preceding sections of the report may be included in this section.

Annex A. Example Inlet Flow Distortion Calculations

(For a typical industrial process fan, see Annexes H and J)

A.1 Example: Flow distortion calculation, rectangular duct

Test data sheet and velocity calculations

Inlet Box (Plane 1) Outboard Side						
Traverse Number	Position Number					
	$j = 1$		$j = 2$		$j = 3$	
	P_{v1c}	V_1	P_{v1c}	V_1	P_{v1c}	V_1
	Pa (in. wg)	m/s (fpm)	Pa (in. wg)	m/s (fpm)	Pa (in. wg)	m/s (fpm)
$i = 1$	113 (0.456)	14.464 (2851)	123 (0.496)	15.090 (2973)	111 (0.446)	14.335 (2819)
$i = 2$	126 (0.506)	15.273 (3003)	141 (0.568)	16.156 (3182)	118 (0.476)	14.780 (2913)
$i = 3$	136 (0.547)	15.867 (3122)	144 (0.578)	16.327 (3210)	129 (0.517)	15.454 (3044)
$i = 4$	151 (0.608)	16.720 (3292)	159 (0.639)	17.157 (3375)	141 (0.568)	16.156 (3182)
$i = 5$	167 (0.670)	17.583 (3456)	172 (0.690)	17.844 (3507)	146 (0.588)	16.440 (3237)
$i = 6$	172 (0.690)	17.844 (3507)	179 (0.721)	18.204 (3585)	144 (0.578)	16.327 (3210)
$i = 7$	172 (0.690)	17.844 (3507)	169 (0.680)	17.688 (3481)	146 (0.588)	16.440 (3237)
$i = 8$	167 (0.670)	17.583 (3456)	161 (0.649)	17.264 (3401)	154 (0.619)	16.885 (3321)
$i = 9$	164 (0.659)	17.424 (3427)	167 (0.670)	17.583 (3456)	141 (0.568)	16.156 (3182)
$i = 10$	151 (0.608)	16.720 (3292)	151 (0.608)	16.720 (3292)	133 (0.537)	15.691 (3094)
$i = 11$	141 (0.568)	16.156 (3182)	141 (0.568)	16.156 (3182)	131 (0.527)	15.573 (3065)
$i = 12$	123 (0.496)	15.090 (2973)	136 (0.547)	15.867 (3122)	121 (0.486)	14.967 (2943)
Average	148 (0.5947)*	16.547 (3256)	153 (0.6161)*	16.838 (3314)	134 (0.5404)*	15.767 (3104)

Note: Velocity pressures (P_{v1c}) were corrected for manometer calibration.

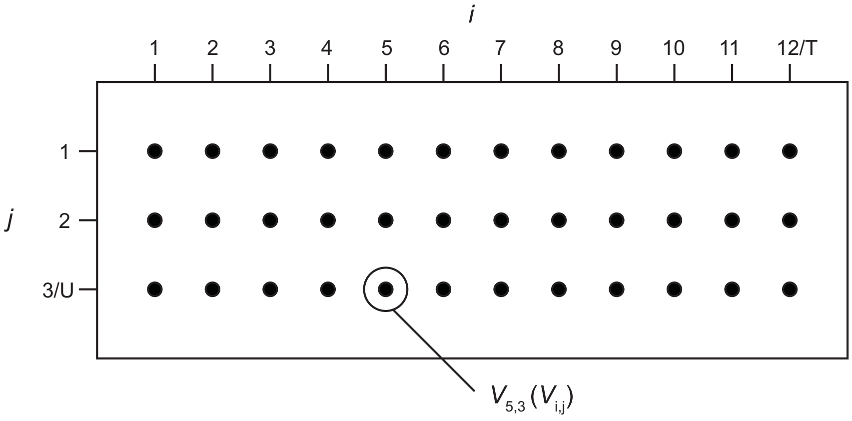
$$*RMS\ Average\ P_{v1c} = \left(\frac{\Sigma \sqrt{P_{v1c}}}{12} \right)^2$$

INLET DUCT - PLANE 1

Width	1.399 m (55.1 in.)
Length	4.064 m (160 in.)
Duct Cross-Section Area, A	5.686 m^2 (61.2 ft^2)
Gas Density, ρ	1.08 kg/m^3 (0.0674 lbm/ft^3)
Inlet Velocity (SI) $V_1 = 1.414 (P_{v1c}/\rho)^{0.5}$	15.75 m/s
Inlet Velocity (I-P) $V_1 = 1097 (P_{v1c}/\rho)^{0.5}$	3103 fpm

Note: Using inlet duct velocities from the table above, as determined from Pitot tube traverses, the flow distortion at Plane 1 is calculated as shown in Annex A.1.1.

A.1.1 Example: Rectangular flow distortion calculation



Plane 1

(SI)

$$\bar{V} = \frac{\left(\sum_{j=1}^{U}\sum_{i=1}^{T} V_{i,j}\right)}{UT}$$

= (198.568 + 202.056 + 189.204)/36
= 16.384 m/s

(I-P)

$$\bar{V} = \frac{\left(\sum_{j=1}^{U}\sum_{i=1}^{T} V_{i,j}\right)}{UT}$$

= (39068 + 39766 +37247)/36
= 3224 fpm

Eqn 7.1

Inlet Box (Plane 1) Outboard Side					
Traverse No.	j = 1	j = 2	j = 3 = U	$\bar{V}_{\mathrm{i}}$	$\left(\bar{V}_{\mathrm{i}} - \bar{V}\right)^2$
	m/s (fpm)	m/s (fpm)	m/s (fpm)	m/s (fpm)	(m/s)^2 (fpm^2)
i = 1	14.464 (2851)	15.090 (2973)	14.335 (2819)	14.690 (2881)	3.168 (117649)
i = 2	15.273 (3003)	16.156 (3182)	14.780 (2913)	15.403 (3033)	0.972 (36481)
i = 3	15.867 (3122)	16.327 (3210)	15.454 (3044)	15.883 (3125)	0.256 (9801)
i = 4	16.720 (3292)	17.157 (3375)	16.156 (3182)	16.678 (3283)	0.084 (3481)
i = 5	17.583 (3456)	17.844 (3507)	16.440 (3237)	17.289 (3400)	0.810 (30976)
i = 6	17.844 (3507)	18.204 (3585)	16.327 (3210)	17.458 (3434)	1.143 (44100)
i = 7	17.844 (3507)	17.688 (3481)	16.440 (3237)	17.324 (3408)	0.874 (33856)
i = 8	17.583 (3456)	17.264 (3401)	16.885 (3321)	17.244 (3393)	0.731 (38561)
i = 9	17.424 (3427)	17.583 (3456)	16.156 (3182)	17.054 (3355)	0.442 (17161)
i = 10	16.720 (3292)	16.720 (3292)	15.691 (3094)	16.377 (3226)	0.000 (4)
i = 11	16.156 (3182)	16.156 (3182)	15.573 (3065)	15.962 (3143)	0.182 (6561)
i = 12 = T	15.090 (2973)	15.867 (3122)	14.967 (2943)	15.308 (3013)	1.169 (44521)
TOTAL	198.568 (39068)	202.056 (39766)	189.204 (37247)		9.831 (373152)
$\bar{V}_{\mathrm{j}}$	16.547 (3256)	16.838 (3314)	15.767 (3104)		
	(m/s)^2 (fpm^2)	(m/s)^2 (fpm^2)	(m/s)^2 (fpm^2)	Total = 0.614 (23524)	
$\left(\bar{V}_{\mathrm{i}} - \bar{V}\right)^2$	0.027 (1024)	0.206 (8100)	0.381 (14400)		

Traverse distortion parameter

(SI)

$$\hat{V}_{t} = \frac{\sqrt{\frac{\sum_{i=1}^{T}\left(\overline{V}_{i} - \overline{V}\right)^{2}}{T}} \times 100}{\overline{V}}$$

$$= \frac{\left(\sqrt{\frac{9.831}{12}} \times 100\right)}{16.384} = 5.52\%$$

(I-P)

$$\hat{V}_{t} = \frac{\sqrt{\frac{\sum_{i=1}^{T}\left(\overline{V}_{i} - \overline{V}\right)^{2}}{T}} \times 100}{\overline{V}} \qquad \text{Eqn 7.4}$$

$$= \frac{\left(\sqrt{\frac{373152}{12}} \times 100\right)}{3224} = 5.47\%$$

Axial distortion parameter

(SI)

$$\hat{V}_{a} = \frac{\sqrt{\frac{\sum_{j=1}^{U}\left(\overline{V}_{j} - \overline{V}\right)^{2}}{U}} \times 100}{\overline{V}}$$

$$= \frac{\left(\sqrt{\frac{0.614}{3}} \times 100\right)}{16.384} = 2.76\%$$

(I-P)

$$\hat{V}_{a} = \frac{\sqrt{\frac{\sum_{j=1}^{U}\left(\overline{V}_{j} - \overline{V}\right)^{2}}{U}} \times 100}{\overline{V}} \qquad \text{Eqn 7.5}$$

$$= \frac{\left(\sqrt{\frac{23524}{3}} \times 100\right)}{3224} = 2.75\%$$

Note: This inlet flow profile meets the requirements of this test standard since V_a and V_t are each under 10%. This example covers a typical inlet velocity profile qualification test and calculation of the inlet flow distortion at the entrance of one inlet box of the typical double-inlet double-width industrial process fan described in Annex H. Since this fan has two inlet boxes, each inlet box must meet the flow distortion requirements using this procedure. In addition, the mean gas velocity at the entrance to each inlet box shall not differ by more than 5% (see Section 7.3.3).

A.2 Example: Flow distortion calculation, circular duct

(For a typical large axial flow fan example, see Annex J)

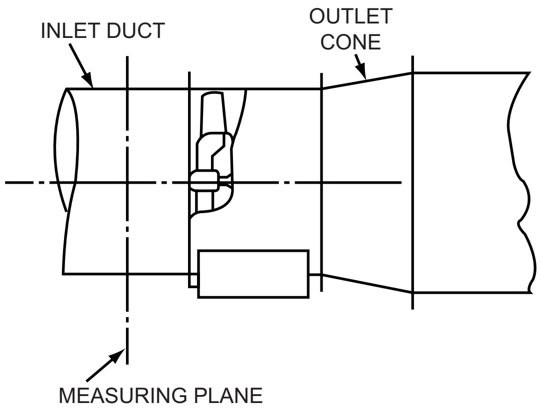


Figure A.2

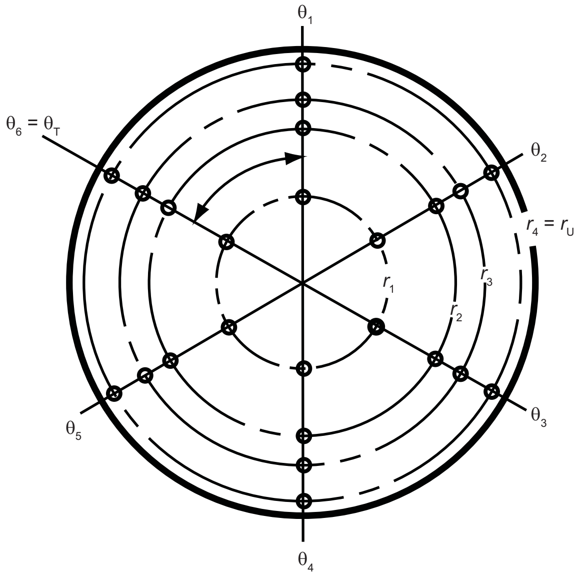


Figure A.3

Traverse No.	r_1	r_2	r_3	$r_1 = r_U$	$\overline{V}_\theta$	$\left(\overline{V}_\theta - \overline{V}\right)^2$
	m/s (fpm)	m/s (fpm)	m/s (fpm)	m/s (fpm)	m/s (fpm)	(m/s)^2 (fpm^2)
θ_1	21.590 (4250)	23.368 (4600)	22.860 (4500)	20.447 (4025)	22.066 (4344)	6.037 (226576)
θ_2	22.860 (4500)	24.994 (4920)	25.908 (5100)	23.749 (4675)	24.378 (4799)	0.021 (441)
θ_3	26.797 (5275)	27.940 (5500)	26.924 (5300)	25.146 (4950)	26.702 (5256)	4.748 (190096)
θ_4	24.638 (4850)	26.035 (5125)	25.908 (5100)	24.130 (4750)	25.178 (4956)	0.429 (18496)
θ_5	25.654 (5050)	26.670 (5250)	24.892 (4900)	24.384 (4800)	25.400 (5000)	0.769 (32400)
$\theta_6 = \theta_T$	22.479 (4425)	24.130 (4750)	23.876 (4700)	23.180 (4375)	23.416 (4563)	1.225 (66049)
Total	144.018 (28350)	153.137 (30145)	150.368 (29600)	141.036 (27575)		13.229 (534058)
$\overline{V}_r$	24.003 (4725)	25.523 (5024)	25.061 (4933)	23.506 (4596)		
	(m/s)^2 (fpm^2)	(m/s)^2 (fpm^2)	(m/s)^2 (fpm^2)	(m/s)^2 (fpm^2)	Total = 2.593 (113586)	
$\left(\overline{V}_r - \overline{V}\right)^2$	0.270 (9025)	1.000 (41616)	0.289 (12769)	1.034 (50176)		

Average velocity

(SI)

$$\overline{V} = \frac{\left(\sum_{\theta=1}^{T}\sum_{r=1}^{U} V_{\mathrm{r},\theta}\right)}{TU}$$

$$= \left(144.018 + 153.137 + 150.368 + 141.036\right)/24$$

$$= 24.523 \text{ m/s}$$

(I-P)

$$\overline{V} = \frac{\left(\sum_{\theta=1}^{T}\sum_{r=1}^{U} V_{\mathrm{r},\theta}\right)}{TU}$$

Eqn 7.6

$$= \left(28350 + 30145 + 29600 + 27575\right)/24$$

$$= 4820 \text{ fpm}$$

Circumferential distortion parameter

(SI)

$$\hat{V}_{\theta} = \frac{\sqrt{\frac{\sum_{\theta=1}^{T}\left(\overline{V}_{\theta} - \overline{V}\right)^2}{0.5T}} \times 100}{\overline{V}}$$

$$= \frac{\left(\sqrt{\frac{13.229}{3}} \times 100\right)}{24.523} = 8.56\%$$

(I-P)

$$\hat{V}_{\theta} = \frac{\sqrt{\frac{\sum_{\theta=1}^{T}\left(\overline{V}_{\theta} - \overline{V}\right)^2}{0.5T}} \times 100}{\overline{V}}$$

Eqn 7.7

$$= \frac{\left(\sqrt{\frac{534058}{3}} \times 100\right)}{4820} = 8.75\%$$

Radial Distortion parameter

(SI)

$$\hat{V}_{a} = \frac{\sqrt{\frac{\sum_{r=1}^{U}\left(\overline{V}_{\mathrm{r}} - \overline{V}\right)^2}{U}} \times 100}{\overline{V}}$$

$$= \frac{\left(\sqrt{\frac{2.593}{4}} \times 100\right)}{24.523} = 3.28\%$$

(I-P)

$$\hat{V}_{a} = \frac{\sqrt{\frac{\sum_{r=1}^{U}\left(\overline{V}_{\mathrm{r}} - \overline{V}\right)^2}{U}} \times 100}{\overline{V}}$$

Eqn 7.8

$$= \frac{\left(\sqrt{\frac{113586}{4}} \times 100\right)}{4820} = 3.5\%$$

Note: Velocity profile is acceptable to this standard since $\hat{V}_{\mathrm{a}}$ and $\hat{V}_{\mathrm{t}}$ are each under 10%.

Annex B. Compressibility Coefficient (K_p) Calculation

Compressibility is a term that defines the volumetric change in a gas due to changes in pressure, temperature, and composition. The compressibility coefficient, K_p, is used to mathematically express the difference between compressible and incompressible conditions. This coefficient may be determined using the following equations or Figure B.1.

$$x = \frac{P_t}{P_{t1} + 1000p_b} \quad \text{and} \quad z = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{1000\left(\frac{H}{Q}\right)}{P_{t1} + 1000p_b}\right) \qquad \text{Eqn B.1 SI}$$

$$K_p = \left(\frac{\ln(1+x)}{x}\right)\left(\frac{z}{\ln(1+z)}\right) \qquad \text{Eqn B.2 SI}$$

$$x = \frac{P_t}{P_{t1} + 13.63p_b} \quad \text{and} \quad z = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{6362\left(\frac{H}{Q}\right)}{P_{t1} + 13.63p_b}\right) \qquad \text{Eqn B.1 I-P}$$

$$K_p = \left(\frac{\ln(1+x)}{x}\right)\left(\frac{z}{\ln(1+z)}\right) \qquad \text{Eqn B.2 I-P}$$

γ = Specific heat ratio. See Annex C for calculation.

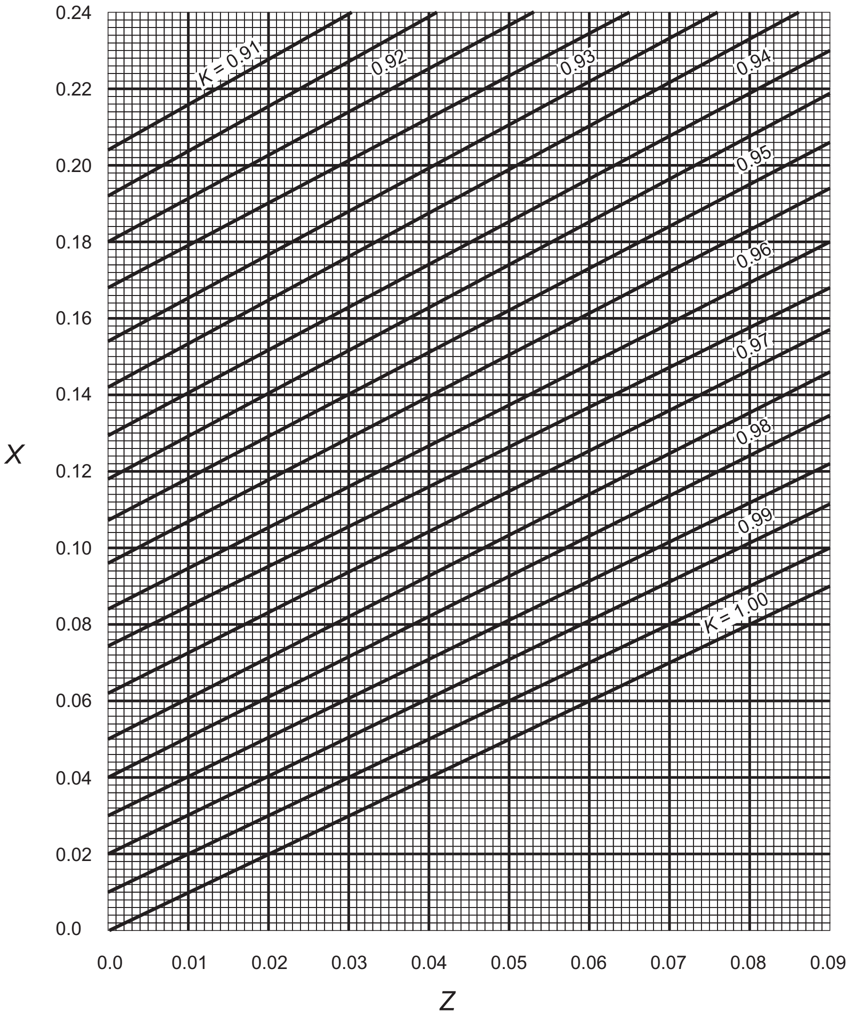

X
Z
0.0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
K = 0.91
0.92
0.93
0.94
0.95
0.96
0.97
0.98
0.99
K = 1.00

Figure B.1

Annex C. Specific Heat Ratio Calculation

The specific heat ratio (γ) of a gas is the ratio of the specific heat of the gas at constant pressure (C_p) to that of the same gas at constant volume (C_v). The specific heat ratio of a gas must be determined in order to properly calculate the compressibility coefficient (K_p) used in the fan laws. This annex outlines the procedures to be used in determining the specific heat ratio of any gas.

Avogadro's Law and Dalton's Law are used to determine the properties of various gases. Avogadro's Law states that equal volumes at the same temperature and pressure contain equal number of molecules. Dalton's Law states that each constituent in the gas acts as if the other constituents were not present. These are expressed mathematically as follows:

$MV = m_1v_1 + m_2v_2 + \ldots m_iv_i$
$G/M = g_1/m_1 + g_2/m_2 + \ldots g_im_i$
$CG = c_1g_1 + c_2g_2 + \ldots c_ig_i$

Where:
M = molecular weight of the mixture
m = molecular weight of the constituent
G = weight of the mixture
g = weight of the constituent
V = total volume of the mixture
v = volume of constituent
C = specific heat of the mixture
c = specific heat of the constituent

Using this concept, it is possible to calculate the molecular weight and specific heat of any mixture of gases at a specified temperature provided the percentage volume or weight of the mixture for each constituent is known.

EXAMPLE 1

Determine the molecular weight and ratio of specific heats (γ) for a gas with a volumetric analysis of 15% CO_2, 4% O_2, and 81% N_2.

Gas	m	$\%V$	$\%Vm$	$\%G = \%Vm/M$	C_p	$\%GC_p$
CO_2	44	0.15	6.60	0.216	850 (0.203)	183.6 (0.0438)
O_2	32	0.04	1.28	0.042	909 (0.217)	38.21 (0.0091)
N_2	28	0.81	22.68	0.742	1022 (0.244)	758.3 (0.181)
		1.0	M = 30.56	1.00		C_p = 980.1 (0.2340)

$$R = \frac{8315}{M} = \frac{8315}{30.56} = 272.1$$

$$R = \frac{1544}{M} = \frac{1544}{30.56} = 50.52$$

$$C_v = C_p - R = 980.1 - 272.1 = 708$$

$$C_v = C_p - \frac{R}{778} = 0.234 - \frac{50.52}{778} = 0.234 - 0.065 = 0.169$$

$$\gamma = \frac{C_p}{C_v} = \frac{980.1}{708} = 1.38$$

$$\gamma = \frac{C_p}{C_v} = \frac{0.234}{0.169} = 1.38$$

Where:

M = molecular weight
R = gas constant
C_v = specific heat at constant volume
C_p = specific heat at constant pressure
γ = ratio of specific heats
Vm = present volume of constituent

EXAMPLE 2

Determine the molecular weight and ratio of specific heats (γ) for a gas with weight percentages of 32.2% CO_2, 53.5% N_2, 16.3% O_2.

Gas	$\%G$	C_p	C_v	$\%GC_p$	$\%GC_v$
CO_2	0.322	1968 (0.470)	1507 (0.360)	633.7 (0.142)	485.3 (0.109)
O_2	0.535	1022 (0.244)	724 (0.173)	546.8 (0.131)	387.3 (0.093)
N_2	0.163	909 (0.217)	649 (0.155)	148.2 (0.035)	105.8 (0.025)
				C_p = 1328.7 (0.308)	C_v = 978.4 (0.227)

$$\gamma = \frac{C_p}{C_v} = \frac{1328.7}{978.4} = 1.35 \qquad \gamma = \frac{C_p}{C_v} = \frac{0.308}{0.227} = 1.35$$

Figure C.1 illustrates ranges in γ for dry air and flue gas over a wide range in temperature with unknown constituents but with an overall molecular weight of 30.

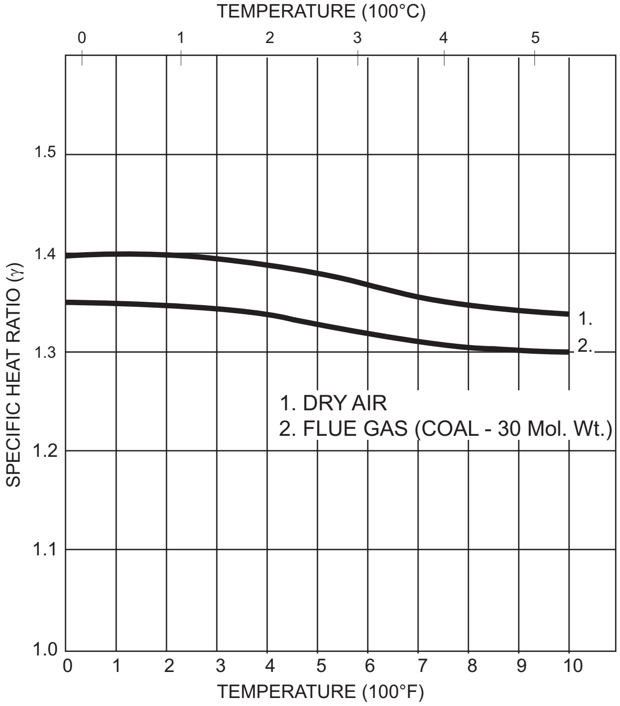


Figure C.1 - Specific Heat Ratio Versus Temperature for Calculating Compressibility Coefficient (K_p)

Annex D. Per Unit Uncertaintes

List of per unit uncertainties.

D.1 Barometric pressure

D.1.1 Barometric pressure measured on mercury barometer.

p_b = Hg ± 0.05 in. Hg

$u_b = 0.0018$

If p_b is to be established in a duct, P_{sx} has to be added, which may result in $u_b = 0.002$.

D.1.2 Barometric pressure measured with aneroid barometer $u_b = 0.003$.

D.2 Temperature

D.2.1 Dry-bulb temperature. Δt_d can have values from 1-2°C (2 to 4°F) for air and in flue gas from 2-8°C (4 to 15°F).

$$u_d = \frac{\Delta t_d {}^\circ\mathrm{C}}{273.15 + t_d} \quad \text{Eqn D.1 SI}$$

$$u_d = \frac{\Delta t_d {}^\circ\mathrm{F}}{459.67 + t_d} \quad \text{Eqn D.1 I-P}$$

D.2.2 Wet-bulb temperature. Per unit uncertainty in u_ρ resulting from uncertainty in t_w.

$u_v = 0.002$

D.3 Gas composition

The gas consists mainly of gases such as N_2, O_2, CO_2, CO, H_2O and some flue ash as dust.

It is characterisitic that most of the gases in the composition (N_2, O_2, CO) have a molecular weight between 28 and 32. Minor variations in the composition of those gases have negligible influence on the uncertainty of the density. H_2O and CO_2 have molecular weights of 18 and 44, respectively, which differ very much from the mean molecular weight, and an estimate of the uncertainty (e_m) resulting from the uncertainty in the gas composition of those gases gives uncertainty as stated below.

Uncertainty in the Content of CO_2 and H_2O in the Gas Content	Uncertainty in Density
An absolute uncertainty of 0.5%	$u_m = 0.002$
An absolute uncertainty of 1%	$u_m = 0.004$
An absolute uncertainty of 1.5%	$u_m = 0.006$

The effect of normal amounts of flue ash or other particulates can be considered negligible or included in u_m.

D.4 Duct Area

D.4.1 Area if well defined. $u_A = 0.005$. An area is well defined if:

a) **Round Ducts**. Actual measurements at four diameters equally spaced can be made with an uncertainty of 0.002, and the difference between the biggest and the smallest does not exceed 0.005*D*.

b) **Rectangular Ducts**. Actual measurements at four equally spaced stations at each side can be made with an uncertainty of 0.002, and the difference between the biggest and the smallest at each side does not exceed 0.003 of the measured values.

D.4.2 Area normally defined. $u_A = 0.01$. An area is normally defined if:

a) **Round Ducts**. Actual measurements at two diameters can be made with an uncertainty of 0.003, and the difference between the measured values does not exceed 0.01*D*.

b) **Rectangular Ducts**. Actual measurements at four equally spaced stations at each side can be measured with an uncertainty of 0.003, and the difference between the biggest and the smallest at each side does not exceed 0.01 of the measured value.

D.4.3 Area if poorly defined. $u_A = 0.02$. An area is poorly defined if it cannot be measured within the uncertainty described above.

D.4.4 No measurements possible. If no measurements can be made, it is up to the test engineer to judge whether or not to use the drawing. In such a case the area may be poorly defined and the uncertainty could very well exceed 0.02.

D.5 Pitot-static tubes

Per unit uncertainty resulting from deviation in locating the Pitot-static tubes.

If rigid and fixed at each point: $u_{\mathrm{TR}} = 0.005$

If normal procedure: $u_{\mathrm{TR}} = 0.010$

The exact formula for the velocity:

$$V = C\sqrt{\frac{P_v}{\rho}} \qquad \text{Eqn D.2}$$

This formula includes a constant, C, which is a function of compressibility correction, calibration, gradient velocity, blockage effect, and Pitot-static tube inclination. If all these effects are neglected and C is set to unity, then $u_c = 0.01$.

D.6 RPM

D.6.1 One measurement covering the whole test at a steady speed.

Electronic measuring: $u_{\mathrm{N}} = 0.002$

Other measuring system; however: $u_{\mathrm{N}} = 0.005$ max

D.6.2 More than one measurement during the test:

$$u_{\mathrm{N}} = \sqrt{u_{\mathrm{NM}}{}^2 + \left(\frac{N_{\max} - N_{\min}}{2N_{\mathrm{mean}}}\right)^2} \qquad \text{Eqn D.3}$$

Where:

u_{NM} = the measuring uncertainty (e_{N}) specified in Section D.6.1
$N_{\max}$ = maximum measured speed
$N_{\min}$ = minimum measured speed
N_{mean} = mean value of all measured speeds

D.7 Power electrical input

D.7.1 Precision instrument for 3-phase measurement

0.2% of range uncertainty instrument: $u_w = 0.005$

0.5% of range uncertainty instrument: $u_w = 0.010$

D.7.2 Two wattmeter method

0.2% of full range uncertainty instruments:
$u_w = 0.008$
0.5% of full range uncertainty instruments:
$u_w = 0.020$

Motor losses are difficult to measure, but a rough estimate gives: $u_{\mathrm{L}} = 0.1$. Because of these motor losses, u_{H} is dependant on the motor efficiency.

D.7.3 For a calibrated motor, u_{H} will be dependant upon the calibration. It is necessary to maintain voltage and frequency in accordance with calibration values and the motor run a period of time so that its temperature can be considered constant. Under these circumstances and by using 0.2% of full range uncertainty instruments:

For low voltage motors smaller than 500 kW,
u_{H} can be 0.020
For low voltage motors bigger than 500 kW,
u_{H} can be 0.015
For high voltage motors smaller than 500 kW,
u_{H} can be 0.015
For high voltage motors bigger than 500 kW,
u_{H} can be 0.010

Low voltage motors are 600 volts or less.

D.7.4 Using torque meter. The per unit uncertainty of the torque will depend entirely on the instrument used and the possibility of calibration. For instruments using electrical circuits, the user must be aware of the zero drift.

For the very high quality instruments, an absolute uncertainty (Δi) of 0.002 of full range can be obtained. For other instruments, the absolute uncertainty could be as high as 0.02 full range.

D.8 Compressibility

The per unit uncertainty in the calculation of the compressibility is assumed to be 0.002 for all values: $u_{\mathrm{Kp}} = 0.002$

D.9 Pressures

Measurements of pressures are used for calculation of both airflow and fan pressure.

In principle, the absolute uncertainty can be divided into two different groups.

D.9.1 Uncertainty on the instrumentation used, Δi (useful for choosing the proper instrument)

Type of Instrument	Absolute Uncertainty, Δi
U-tube manometer	10 Pa (0.040 in. wg)
Inclined manometer:	
Slope ratio 2:1	5 Pa (0.020 in. wg)
Slope ratio 5:1	2 Pa (0.008 in. wg)
Slope ratio 10:1	1 Pa (0.004 in. wg)
Slope ratio 20:1	0.5 Pa (0.002 in. wg)
Micro manometer	0.25 Pa (0.001 in. wg)
Pressure transducer	(0.003 to 0.01) x Range

D.9.2 Uncertainty on the measured pressure (useful for judging the quality of the measurement).

D.9.2.1 Velocity pressure used for pitot traverse, u_{Pvf}

Steady readings	$u_{\mathrm{Pvf}} \sim 0.01$
Minor fluctuations	$u_{\mathrm{Pvf}} \sim 0.02$
Fluctuations	$u_{\mathrm{Pvf}} \sim 0.03$

$$\Delta P_{\mathrm{v}} = \sqrt{(\Delta i)^2 + (u_{\mathrm{Pvf}} P_{\mathrm{vf}})^2} \qquad \text{Eqn D.4}$$

$$u_{\mathrm{Pvf}} = \frac{\sqrt{(\Delta i)^2 + (u_{\mathrm{Pvf}} P_{\mathrm{vf}})^2}}{P_{\mathrm{v}}} \qquad \text{Eqn D.5}$$

D.9.2.2 Static pressure (inside a plenum using taps)

Steady readings	$u_{\mathrm{Ps}} \sim 0.005$
Minor fluctuations	$u_{\mathrm{Ps}} \sim 0.010$

If the fluctuations appear to be large, this location will not be suitable for measurement:

$$\Delta P_{\mathrm{sx}} = \sqrt{\Delta i^2 + (u_{\mathrm{Ps}} P_{\mathrm{sx}})^2} \qquad \text{Eqn D.6}$$

$$u_{\mathrm{Psx}} = \frac{\sqrt{\Delta i^2 + (u_{\mathrm{Ps}} P_{\mathrm{sx}})^2}}{P_{\mathrm{sx}}} \qquad \text{Eqn D.7}$$

D.9.2.3 Static pressure in a duct (using a pitot-static tube). If the flow rate in the duct has a mean velocity (V_{x}) and a mean velocity pressure (P_{vx}) there will be an additional error of 10% of the velocity pressure.

$$P_{\mathrm{sx}} = \sqrt{\Delta i^2 + (u_{\mathrm{Ps}} P_{\mathrm{sx}})^2 + (0.1 P_{\mathrm{vx}})^2} \qquad \text{Eqn D.8}$$

$$u_{\mathrm{Psx}} = \frac{\sqrt{\Delta i^2 + (u_{\mathrm{Ps}} P_{\mathrm{sx}})^2 + (0.1 P_{\mathrm{vx}})^2}}{P_{\mathrm{sx}}} \qquad \text{Eqn D.9}$$

D.9.2.4 Uncertainty on losses between fan and measured planes. Per unit uncertainty on the friction loss coefficient including uncertainty on duct length $u_{\mathrm{f}} = 0.04$.

Per unit uncertainty on losses between fan and measuring planes:

$$u_{\mathrm{K}} = \sqrt{u_{\mathrm{f}}^{2} + 4 u_{\mathrm{Q}}^{2}} \qquad \text{Eqn D.10}$$

Annex E. Graphical Presentation

Depending on how many test points were measured, two methods of comparison may be used.

E.1 Multiple test points

Multiple test points allow us to plot a performance curve to compare with the guarantee point. At least three well spaced test points spanning the guarantee point are necessary for meaningful conclusions. If fewer than three test points have been measured, or the test points do not span the guarantee point, then the method suggested in Annex E.2 is preferred, using the test point closest to the guarantee point.

After all test points have been calculated in accordance with Section 9, and the uncertainties at each test point have been calculated in accordance with Section 10, then each point shall be plotted on a performance curve in the center of a rectangle with boundaries defined as follows:

Air (gas) flow:
$Q_1 \pm \Delta Q_1 = Q_1\ (1 \pm u_{Q1})$

Pressure:
$P_t \pm \Delta P_t = P_t\ (1 \pm u_{Pt})$

Uncertainty boundary lines shall be drawn through the upper right corners and bottom left corners of the uncertainty rectangles as shown in Figure E.1. If the uncertainty boundaries include the guarantee point in the area between them, then the point is verified.

E.2 Single test point

If only a single test point has been taken, or multiple test points do not span the guarantee point and the point closest to the guarantee point is being considered, then the comparison between the test point and the guarantee point is rendered difficult as the system resistance of the actual installation is seldom exactly as predicted. The fan will therefore be working on a different part of its performance curve from the specified guaratnee point. The best comparison which can be made is to compare the test point with the fan manufacturer's quoted performance curve. Such comparisons are only valid if the test point air (gas) flow rate is within 5% of the specified flow rate at the guarantee point, unless prior agreement to guarantee all or part of the complete performance curve exists. If no such prior agreement exists, and the test point is not within the specified limits for air (gas) flow, then no valid comparison of the test point with the guarantee point can be made.

After the test point has been calculated at the specified guarantee operating conditions in accordance with Section 9, and the test point uncertainties have been calculated in accordance with Section 10, then the point shall be plotted in the center of an uncertainty rectangle as defined in Annex E.1. If the test point uncertainty rectangle intersects the quoted performance curve within the flow range specified above, then the point is verified (See Figure E.2).

E.3 Verification of efficiency

Verification of guaranteed efficiency may be undertaken and described graphically in exactly the same manner as for fan performance. In this case, efficiency will replace pressure as the ordinate and air (gas) flow will remain as abscissa.

Uncertainty rectangles shall again be plotted, with their boundaries defined as:

Air (gas) flow: $Q_1 \pm \Delta Q_1 = Q_1\ (1 \pm u_{Q1})$

Efficiency: $\eta \pm \Delta\eta = \eta\ (1 \pm u_1)$

In the case of multiple point tests, only the upper uncertainty boundary need be drawn through the upper corners of the rectangles (see Figure E.3).

If the guaranteed efficiency point is below the upper uncertainty boundary, then the point is verified.

For single test points, the upper corner of the uncertainty rectangle should lie above the quoted efficiency curve. The restrictions on flow rate for valid comparison of single performance test points defined in Annex E.2 also apply for comparison of efficiency.

E.4 Partial load points

Rules for comparison of partial load points with guaranteed values (if any) are identical to those for maximum design points, specified in the preceding sections.

In addition, care needs to be taken to properly regulate the fan performance by using the supplied regulating means (e.g. inlet vanes, louvers, blade pitch adjustment, etc.) and by controlling the system resistance so that the nearest measured performance point (or the only point) is within 5% of the specified air (gas) flow and within 5% of the specified pressure.

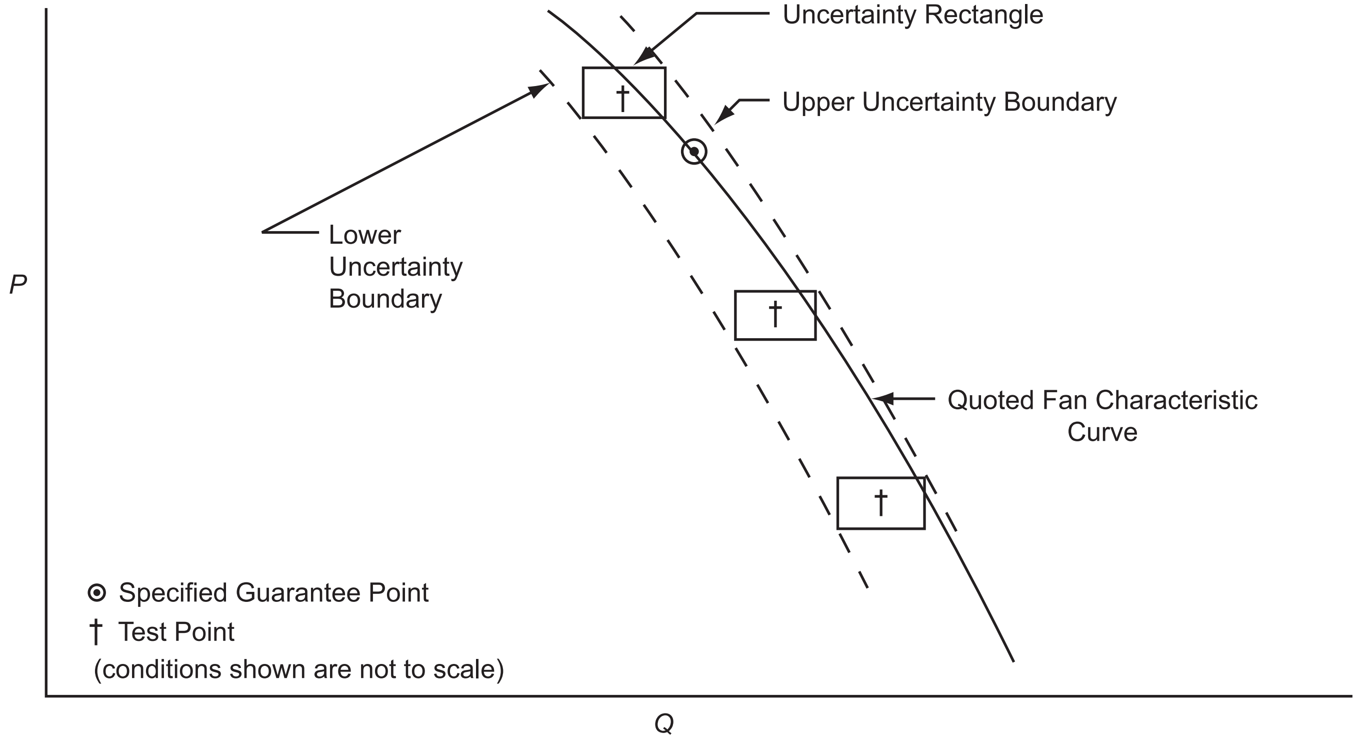

Uncertainty Rectangle
Upper Uncertainty Boundary
Lower Uncertainty Boundary
P
Quoted Fan Characteristic Curve
†
†
†
Q
⊙ Specified Guarantee Point
† Test Point
(conditions shown are not to scale)

Figure E.1

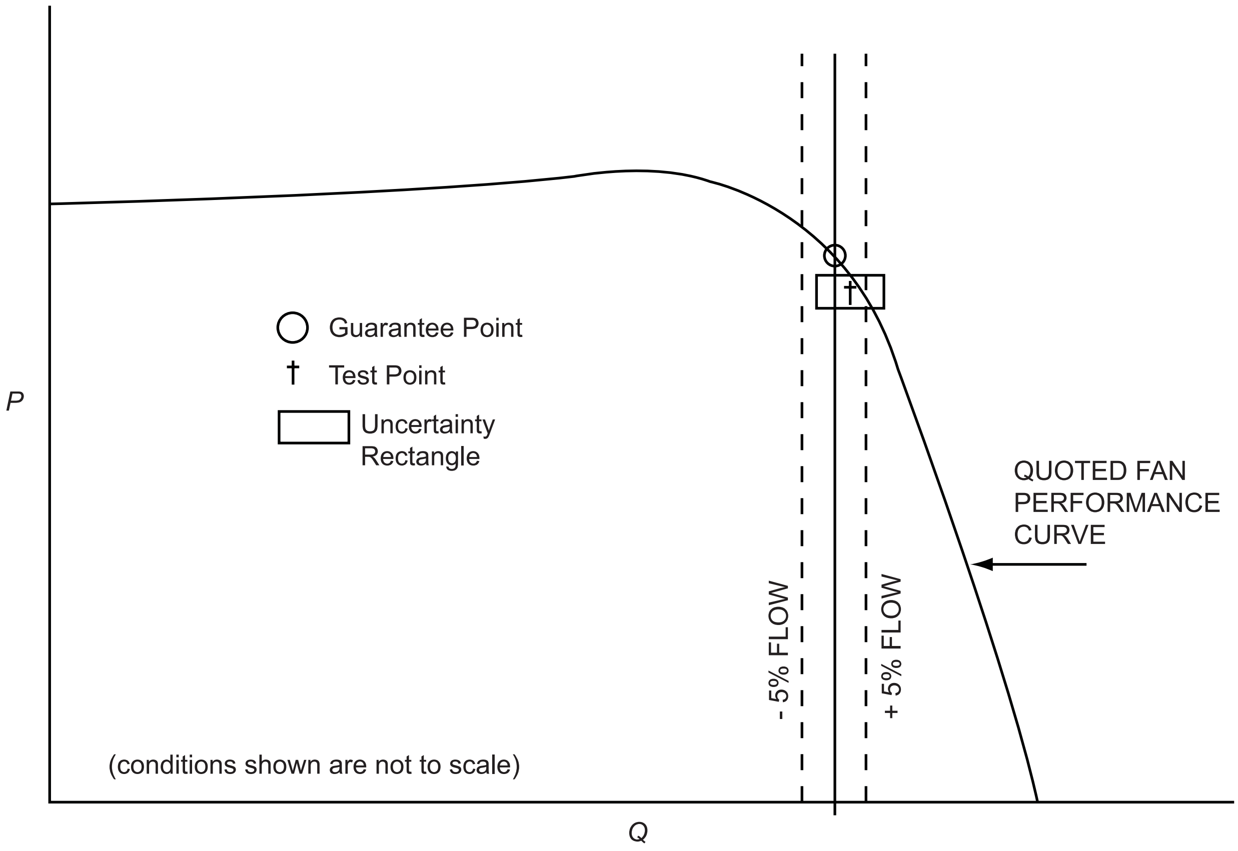


Figure E.2

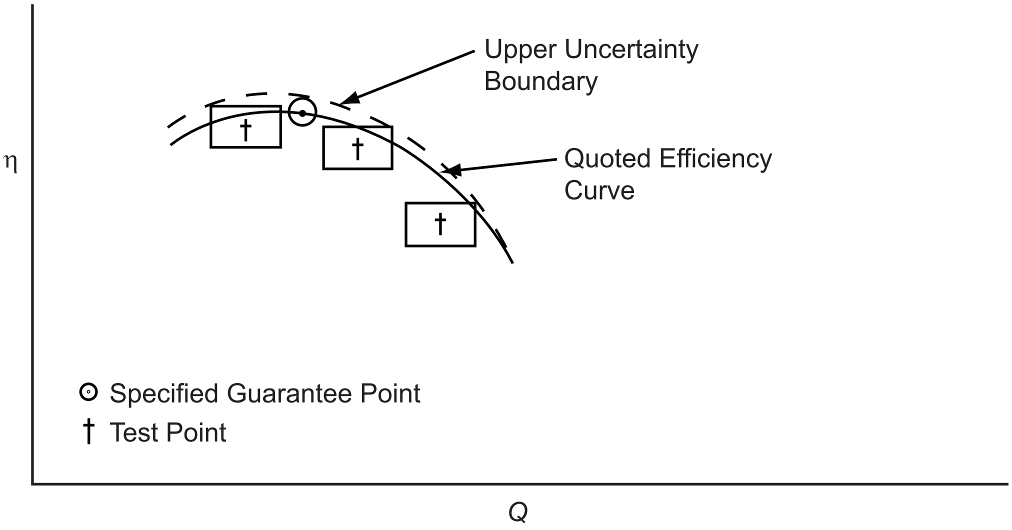


Figure E.3

Annex F. Alternatives to Conducting a Site Test Per This Standard

Alternatives to conducting a site test per this standard include those listed below as Sections F.1 through F.5. Before selecting any alternative, it is essential that the relative merits relating to the purpose, scope, test location, test method, accuracy of results and cost be studied so that an optimum choice can be made. Fan applications which are critical and/or require capital investment can benefit from the use of alternatives detailed in Sections F.4 and F.5 as part of the system design process.

F.1 Site test when the installation is unacceptable for testing per Standard 803

A site test may be conducted in accordance with methods suggested in AMCA Publication 203, *Field Performance Measurement of Fan Systems*. AMCA Publication 203 test criteria are slightly less rigorous than those given in this standard. This alternative test can define the performance of the fan in its system, but might not necessarily verify the rated performance of the fan, due to system effects.

F.2 Site test of a fan disconnected from the system

A site test may be conducted with the fan disconnected from the system. This will require modifications to existing ductwork of the installation of temporary ductwork meeting the requirements of ANSI/AMCA 210. This alternative will verify the rated performance of the fan.

F.3 Laboratory test of the fan

Tests of the fan at the fan manufacturer’s laboratory, the AMCA Laboratory, or an AMCA Accredited laboratory may be conducted using ANSI/AMCA 210 to verify the rated performance of the fan. Laboratory size, capacity, and usage cost often precludes this option.

F.4 Laboratory test of a scale model of the fan

The fan laws allow accurate prediction of full size fan performance from the test of a scale model as small as 1/5 of the size of the actual fan under consideration. Such testing is fully described in AMCA Publication 802, *Industrial Process / Power Generation Fans: Establishing Performance Using Laboratory Models*. The basic test standard employed is ANSI/AMCA 210, ensuring accurate test results, which are then scaled up to obtain the performance of the actual fan, free of system effects.

F.5 Laboratory test of a scale model of the fan and system

A fan/system may be modeled as in Section F.4 to determine the fan performance as installed in the system. The test methods utilize AMCA Publication 203 and may allow for optimizing the system configuration.

Annex G. Sample Site Test - Industrial Chemical Process Fan

Note: Only I-P units are used in this example.

G.1 General

The purpose of this sample test is to illustrate the general approach which could be used to determine the acceptability of a site test in meeting the requirements of this standard. The system consists of an industrial chemical process fan drawing air through a filter house, down a long circular duct to a system conditioning section where a spray nozzle inserts special chemicals. The ductwork then splits into each individual inlet box. The fan discharge is connected to an evasé and then to a circular tower. The tower evaporates PCB's from a liquid passing over ceramic media packed inside the tower. Refer to Section G.3.3 for reference.

G.2 Test measurements and possible locations

The following guidelines may be used in evaluating measurements and their locations.

1. Before proceeding with any tests, it is essential that any inlet box dampers, outlet dampers, or variable inlet vanes be set in the open position for the duration of the test. If this is not done, the expected fan performance will not be realized since the intial fan rating is based upon all of these items being open.

2. The flow measurement station should be in the longest straight run of ductwork. At the point of flow measurement, values of velocity pressure, area of the traverse plane, wet-bulb and dry-bulb temperature, and static pressure must be obtained.

   Consideration should be given to conducting flow measurements in one common duct instead of two or more separate locations and adding the flows together.

3. Obtain static pressure values near the fan inlet and discharge. The wet-bulb and dry-bulb temperature must be known at the fan inlet.

4. Obtain the barometric pressure at the test site. This is needed to calculate the density of the gas being handled.

5. Measure the fan speed, the motor voltage, full load amperage (and no load amperage, if required) and, if possible, the power factor and input wattage. Record all motor nameplate information.

6. Recognize and define all possible system effect conditions that may have an adverse effect on the fan performance. The velocity pressure measurements must be made to evaluate any inlet velocity profile distortion factors.

G.3 Field test data sheet

G.3.1 General

DATE ____________________ CUSTOMER ____

USER/JOBSITE ____

PERSONNEL PRESENT ____

JOBSITE REFERENCE NO. ____

G.3.2 Fan identification

ORDER NO. ___________ MODEL NO. ___________ SIZE ___________ TAG _____________

ARRG. NO. _______________ WIDTH _________________ DWG REF ___________________

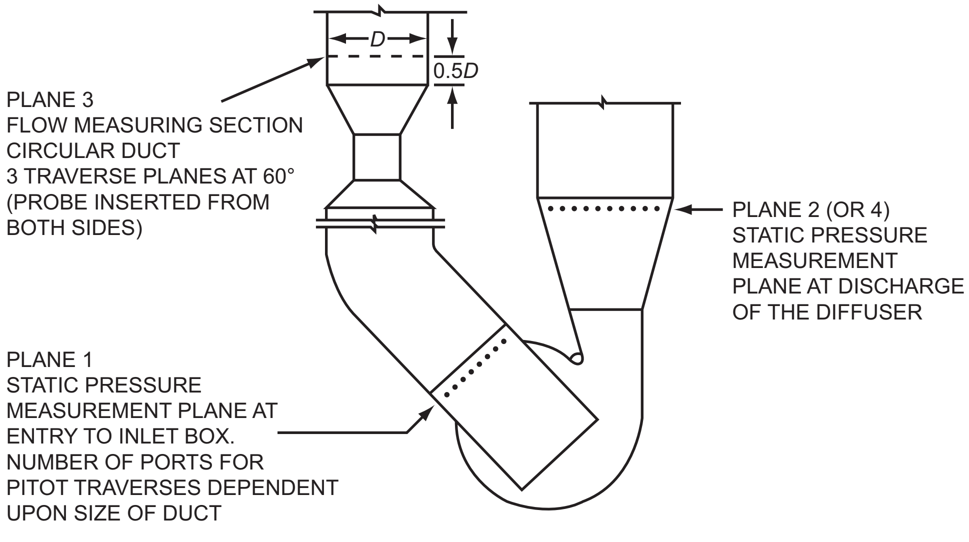
ACCESSORIES ____

MOTOR MFG. ______________________ POWER _____________ SPEED _______________

FRAME ______________________ FL AMPS ________________ FL VOLTS_______________

G.3.3 Sketch of installation and measurement locations

Sketch should show measurement planes as indicated below.



G.4 Ambient measurements

AMBIENT MEASUREMENTS				
Time	Reading	p_b	t_{d0} (°F)	t_{w0} (°F)
1:15	1	29.0	80.0	65.0
1:35	2	29.1	81.0	66.0
1:55	3	29.0	80.0	65.0

G.5 Power and speed measurements

POWER AND SPEED MEASUREMENTS					
Time	Reading	Volts	Amps	kW input	RPM
1:15	1	2300	330	1176	894
1:35	2	2300	333	1160	890
1:55	3	2300	330	1168	892
Average		2300	331	1168	892

G.6 Plane 3 measurements (flow measurement station)

Pressure fluctuation: ± 0.005 to 0.01 in. wg

VELOCITY PRESSURE READINGS (in. wg)													
Time	Position	TRAVERSE NUMBER											
		θ_1		θ_2		θ_3		θ_4		θ_5		θ_6	
		P_{v3}	P_{v3c}	P_{v3}	P_{v3c}	P_{v3}	P_{v3c}	P_{v3}	P_{v3c}	P_{v3}	P_{v3c}	P_{v3}	P_{v3c}
1:15	$r = 1$	0.44	0.437	0.49	0.486	0.52	0.517	0.54	0.537	0.48	0.476	0.51	0.506
	$r = 2$	0.50	0.496	0.54	0.537	0.54	0.537	0.56	0.557	0.50	0.496	0.57	0.568
	$r = 3$	0.53	0.527	0.58	0.578	0.62	0.619	0.59	0.588	0.55	0.547	0.63	0.629
	$r = 4$	0.60	0.589	0.65	0.649	0.73	0.731	0.68	0.680	0.59	0.588	0.70	0.701
	$r = 5$	0.61	0.608	0.67	0.670	0.68	0.680	0.68	0.731	0.60	0.598	0.71	0.711
	$r = 6$	0.64	0.639	0.62	0.619	0.64	0.639	0.69	0.649	0.56	0.557	0.69	0.690
	$r = 7$	0.55	0.547	0.53	0.527	0.63	0.629	0.59	0.588	0.54	0.537	0.62	0.619
1:55	$r = 8$	0.51	0.506	0.50	0.496	0.55	0.547	0.55	0.547	0.47	0.466	0.50	0.496
	RMS Average		0.543		0.568		0.610		0.608		0.532		0.613

Note: P_{v3c} = Velocity pressure corrected for manometer calibration. Average = 0.579 in. mg.

TEMPERATURE			
Time	Reading	t_{d3} (°F)	t_{w3} (°F)
1:15 1:35 1:55		1 2 3	94.7 94.8 95.2
Average		99.5	94.9

PHYSICAL DIMENSION	
Diameter D_3 (in.)	149.6
Area A_3 (ft^2)	122

STATIC PRESSURE		
Time	Reading Position	P_{s3c} (in. wg)
1:15	1	-1.45
	2	-1.48
	3	-1.49
	4	-1.50
	5	-1.52
	6	-1.50
	7	-1.50
	8	-1.50
1:35	1	-1.45
	2	-1.47
	3	-1.49
	4	-1.49
	5	-1.49
	6	-1.50
	7	-1.51
	8	-1.51
1:55	1	-1.47
	2	-1.49
	3	-1.50
	4	-1.51
	5	-1.51
	6	-1.51
	7	-1.50
	8	-1.50
	Average	-1.50

G.7 Plane #1 measurements (fan inlet boxes)

INLET VELOCITY PROFILE QUALIFICATION DATA SHEET - VELOCITY PRESSURE READINGS (in. wg)													
		Inboard Inlet Box						**Outboard Inlet Box**					
Time	Traverse	$j = 1$		$j = 2$		$j = 3$		$j = 1$		$j = 2$		$j = 3$	
		P_{v1}	P_{v1c}	P_{v1}	P_{v1c}	P_{v1}	P_{v1c}	P_{v1}	P_{v1c}	P_{v1}	P_{v1c}	P_{v1}	P_{v1c}
1:15p	$i = 1$	0.44	0.437	0.43	0.427	0.40	0.397	0.46	0.456	0.50	0.496	0.45	0.446
	$i = 2$	0.50	0.496	0.51	0.506	0.43	0.427	0.51	0.506	0.57	0.468	0.48	0.476
	$i = 3$	0.54	0.537	0.57	0.568	0.44	0.437	0.55	0.547	0.58	0.578	0.52	0.517
	$i = 4$	0.62	0.619	0.57	0.568	0.50	0.496	0.61	0.608	0.64	0.639	0.57	0.568
	$i = 5$	0.65	0.649	0.62	0.619	0.56	0.557	0.67	0.670	0.69	0.690	0.59	0.588
	$i = 6$	0.71	0.711	0.66	0.659	0.59	0.588	0.69	0.690	0.72	0.721	0.58	0.578
	$i = 7$	0.68	0.680	0.66	0.659	0.57	0.568	0.69	0.690	0.68	0.680	0.59	0.588
	$i = 8$	0.67	0.670	0.63	0.629	0.58	0.578	0.67	0.670	0.65	0.649	0.62	0.619
	$i = 9$	0.66	0.659	0.62	0.619	0.55	0.547	0.66	0.659	0.67	0.670	0.57	0.568
	$i = 10$	0.62	0.619	0.59	0.588	0.52	0.517	0.61	0.608	0.61	0.608	0.54	0.537
	$i = 11$	0.56	0.557	0.54	0.537	0.49	0.486	0.57	0.568	0.57	0.568	0.53	0.527
1:55	$i = 12$	0.52	0.517	0.50	0.496	0.44	0.437	0.50	0.496	0.55	0.547	0.49	0.486
	RMS Average		0.593		0.571		0.501		0.595		0.616		0.540

Note: P_{v1c} = Velocity pressure corrected for manometer calibration

GAS TEMPERATURE (°F)					
Time	Reading No.	t_{d1}	t_{w1}	t_{d2}	t_{w2}
1:15p	1	99.6	-	116.0	-
1:35	2	99.8	-	117.5	-
1:55	3	99.8	-	118.0	-
Average		99.7	-		

PHYSICAL DIMENSIONS		
	Inboard inlet box	**Outboard inlet box**
Width	55.1 in.	55.1 in.
Length	160 in.	160 in.
Area	61.2 ft^2	61.2 ft^2

G.7 Plane #1 measurements (fan inlet boxes)....continued

INLET BOX					
		Inboard		Outboard	
Time	Reading Position	P_{t1} in. wg	P_{s1} in. wg	P_{t1} in. wg	P_{s1} in. wg
1:15p	1	-	3.64	-	3.59
	2	-	3.59	-	3.60
	3	-	3.57	-	3.58
	4	-	3.67	-	3.63
	5	-	3.57	-	3.66
	6	-	3.62	-	3.60
	7	-	3.62	-	3.62
	8	-	3.60	-	3.62
1:35p	1	-	3.60	-	3.62
	2	-	3.58	-	3.60
	3	-	3.56	-	3.60
	4	-	3.63	-	3.59
	5	-	3.53	-	3.61
	6	-	3.58	-	3.56
	7	-	3.55	-	3.64
	8	-	3.53	-	3.62
1:55p	1	-	3.55	-	3.63
	2	-	3.62	-	3.62
	3	-	3.57	-	3.60
	4	-	3.65	-	3.58
	5	-	3.55	-	3.60
	6	-	3.60	-	3.57
	7	-	3.58	-	3.65
	8	-	3.60	-	3.63
	Average	N/A	3.59	N/A	3.61

G.8 Plane #4 measurements (fan outlet)

STATIC PRESSURE	
Time	P_{s4} (in. wg)
1:15p	18.00 17.95 18.00 18.10 17.80 17.90 17.90 17.80
1:35p	17.70 17.90 17.80 17.80 17.75 17.80 17.80 17.75
1:55p	17.75 17.85 17.90 18.00 17.90 17.80 17.80 17.70
Average	17.85

G.9 Calculations

G.9.1 Determine densities

G.9.1.1 Ambient density, (ρ_0)

$$\begin{aligned} p_e &= 0.000296\, t_{w0}^2 - 0.0159\, t_{w0} + 0.41 \\ &= 0.000296\,(65)^2 - 0.0159\,(65) + 0.41 \\ &= 1.2506 - 1.033 + 0.41 \\ &= 0.6276 \text{ in. Hg} \end{aligned}$$

Eqn G.1

$$p_p = p_e - p_b\left(\frac{t_{d0} - t_{w0}}{2700}\right)$$

$$= 0.6276 - 29.0\left(\frac{80.5 - 65}{2700}\right)$$

$$= 0.6276 - 0.16648$$

$$= 0.4611 \text{ in. Hg}$$

Eqn G.2

$$\rho_0 = \frac{70.73\left(p_b - 0.378 p_p\right)}{R\left(t_{d0} + 459.67\right)}$$

$$= \frac{70.73\left[29.0 - 0.378(0.4611)\right]}{53.35(80.5 + 459.67)}$$

$$= \frac{70.73(28.8)}{53.35(540.2)}$$

$$= \frac{2037.02}{28819.6}$$

$$= 0.07068 \text{ lbm/ft}^3$$

Eqn G.3

G.9.1.2 Fan gas density (ρ_1)

$$\rho_1 = \rho_0\left[\frac{P_{t1} + 13.63 p_b}{13.63 p_b}\right]\left[\frac{t_{d0} + 459.67}{t_{t1} + 459.67}\right]$$

Note:

$P_{t1} = P_{s1} + P_{v1} = -3.6 + 0.569 = -3.003$ in. wg

Eqn G.5

$$\rho_1 = 0.07068\left[\frac{-3.03 + 395.2}{395.2}\right]\left[\frac{540.2}{559.4}\right]$$

$$= (0.07068)(0.9923)(0.9656)$$

$$= 0.0677 \text{ lbm/ft}^3$$

Eqn G.6

G.9.1.3 Duct gas density (ρ_3)

Flow Measurement Station

$$\rho_3 = \rho_0\left[\frac{P_{t3} + 13.63 p_b}{13.63 p_b}\right]\left[\frac{t_{d0} + 459.67}{t_{d3} + 459.67}\right]$$

Eqn G.7

Note:

$P_{t3} = P_{s3} + P_{v3} = -1.5 + 0.579 = -0.921$ in. wg

Eqn G.8

$$\rho_3 = 0.07068\left[\frac{-0.921 + 13.63(29.0)}{(13.63)(29.0)}\right]\left[\frac{80.5 + 459.67}{99.5 + 459.67}\right]$$

$$= 0.07068\left[\frac{394.2}{395.2}\right]\left[\frac{540.2}{559.2}\right]$$

$$= (0.07068)(0.9974)(0.9660)$$

$$= 0.0681 \text{ lbm/ft}^3$$

Eqn G.9

G.9.2 Fan flow rate at test conditions

$$P_v = \left[\sum \sqrt{\frac{P_{v3r}}{n}} \right]^2$$

$$= 0.579 \text{ in. wg} \qquad \text{Eqn G.10}$$

$$V_3 = 1096 \sqrt{\frac{P_{v3}}{\rho_e}}$$

$$= 1096 \sqrt{\frac{0.579}{0.0681}}$$

$$= 3195.7 \text{ fpm} \qquad \text{Eqn G.11}$$

$Q_3 = V_3 A_3$
$= 3195.7 \times 122$
$= 389{,}875$ cfm Eqn G.12

$$Q = Q_1 = Q_3 \left(\frac{\rho_3}{\rho_1} \right)$$

$$= 389{,}875 \left(\frac{0.0681}{0.0677} \right)$$

$$= 392{,}178 \text{ cfm} \qquad \text{Eqn G.13}$$

G.9.3 Fan static pressure at test conditions

$P_s = P_{s2} - P_{t1}$
$= 17.85 - (-3.03)$
$= 20.88$ in. wg

$P_{t1} = P_{s1} + P_{v1}$
$= -3.6 + 0.569$
$= -3.03$ in. wg

G.9.4 Fan power input at test conditions

$HPI = \text{kW}_{input} \times$ Motor Efficiency / 0.746 kW/hp
= 1168 kW × 0.945
= 1479 hp

G.9.5 Fan speed at test conditions

Avg. speed = 892 rpm.

G.9.6 Summary of test results at test conditions

Q = 392,178 cfm

P_s = 20.88 in. wg

HP = 1479 hp

N = 892 rpm

ρ_1 = 0.0677 lbm/ft^3

G.9.7 Summary of test results at design conditions

$$Q_c = Q \times \frac{N_c}{N} = 392{,}178 \left(\frac{890}{892} \right) = 391{,}298 \text{ cfm}$$

$$P_{sc} = P_s \times \left(\frac{N_c}{N} \right)^2 \left(\frac{\rho_c}{\rho_1} \right) = 20.8 \left(\frac{890}{892} \right)^2 \left(\frac{0.0668}{0.0677} \right)$$

$$= (20.88)(0.9955)(0.986)$$

$$= 20.51 \text{ in. wg}$$

$$N_c = 890 \text{ rpm}$$

$$HP_c = HPI \left(\frac{N_c}{N} \right)^3 \left(\frac{\rho_c}{\rho_1} \right)$$

$$= 1479 \left(\frac{890}{892} \right)^3 \left(\frac{0.0668}{0.0677} \right)$$

$$= 1479 (0.993)(0.986)$$

$$= 1449 \text{ hp}$$

$$\rho_1 = 0.0668 \text{ lbm/ft}$$

G.10 Summary of test results

FAN MOTOR MEASUREMENTS

Power input to motor, W 1160kW
Motor power output, hp ....1555 hp
Motor efficiency 94.5%
Fan speed, *N*, rpm 892

UNCORRECTED PERFORMANCE

	Inboard	Outboard	Total
Fan flow rate, Q_3 cfm	---	---	391,848
Fan static pressure rise, P_s (P_{s2} - P_{s1}) in. wg	21.44	21.46	---
Fan static pressure, in. wg	20.87	20.88	20.88
Fan shaft power, *H*, hp	---	---	1505

CORRECTED PERFORMANCE

Total volumetric flow, Q_{3c}...390,969 cfm
Differential static pressure, P_{xc}...20.30 in. wg
Fan shaft power ....1470 hp
Fan total efficiency, η_t 86.9%
Fan static efficiency, η_s 84.9%

Annex H. Example Pre-Test Uncertainty Analysis for a Typical Centrifugal Fan

This example is a typical **pretest** calculation for a large centrifugal fan. Data are a combination of specified fan duty and customer drawings. Another analysis is required after the test, using actual test data and actual uncertainties, if different from pre-test assumptions.

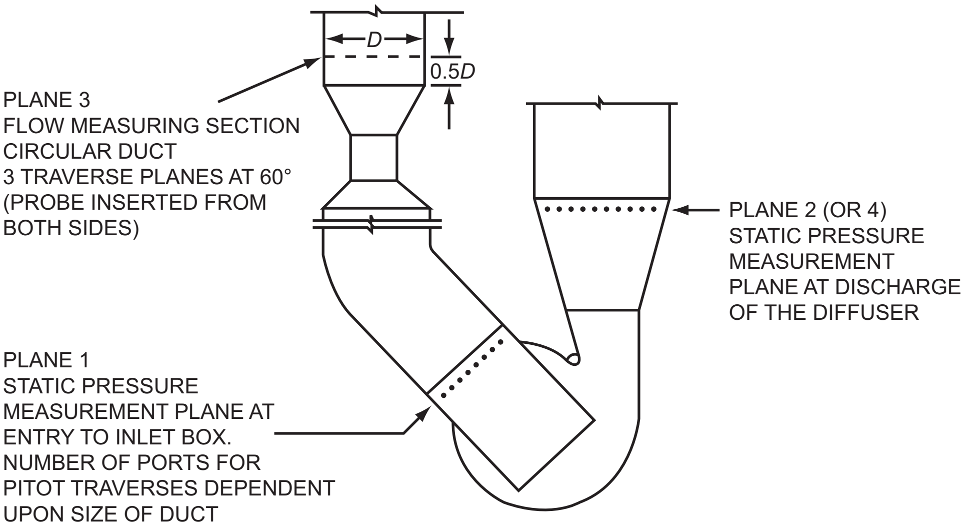


Figure H.1

H.1 General descprition

H.1.1 Fan flow rate. For this example, velocity pressure traverses are to be taken at the common intake duct. Flow rate is calculated and corrected to inlet conditions using density changes.

H.1.2 Fan static pressure. Static pressure traverses are to be conducted at the entry to the inlet box and at the discharge of the evasé to determine the fan static pressure rise. Fan static pressure is then calculated by subtracting the velocity pressure at the inlet from the fan static pressure rise.

H.1.3 Fan gas density. Wet-bulb and dry-bulb temperatures are to be recorded at each of the above planes together with barometric pressure readings. Fan gas density is cacluated using these and the static pressure readings above.

H.1.4 Fan speed. The fan speed is to be monitored by tachometer.

H.1.5 Fan shaft power. The two wattmeter method, together with the motor manufacturer’s certifed efficiency curve, is to be used to determine the power.

	SI Units	I-P Units

H.2 Typical MCR Duty

	SI Units	I-P Units
Fan flow rate	188 m^3/s	398,645 cfm
Fan static pressure	5082 Pa	20.41 in. wg
Inlet temperature	38°C	100°F

H.3 Fan Selection

	SI Units	I-P Units
DWDI centrifugal with airfoil blades Impeller diameter	2.26 m	89 in.
Speed	890 rpm	890 rpm
Fan static efficinecy	85.6%	85.6%
Fan shaft power	1094 kW	1467 hp

H.3.1 Additional values required for analysis

	SI Units	I-P Units
Inlet density, ρ	1.07 kg/m^3	0.0668 lbm/ft^3
Inlet box area, A_1	11.37 m^2	122.41 ft^2
Inlet velocity pressure, P_{v1}	146 Pa	0.59 in. wg
Inlet static pressure, P_{s1}	-896 Pa	-3.6 in. wg
Compressibility coefficient, K_p	0.982	0.982
Discharge density, ρ_2	1.1 kg/m^3	0.0685 lbm/ft^3
Discharge flow rate, Q_2	183 m^3/s	388,751 cfm
Discharge area, A_2	11.04 m^2	118.8 ft^2
Discharge velocity pressure, P_{v2}	151 Pa	0.61 in. wg
Discharge static pressure, P_{s2}	4332 Pa	17.4 in. wg
Area of flow measuring Section, A_3	11.33 m^2	122 ft^2
Velocity pressure at A_3, P_{v3}	148 Pa	0.593 in. wg

SI Units		I-P Units	

H.4 Prestest uncertainty calculations

H.4.1 Density at flow measuring Plane 3, $u_{\rho3}$

From Section 10.2.1 $u_{\rho3} = (u_b^2 + u_d^2 + u_v^2)^{0.5}$		Same as SI	Eqn 10.1
where: $u_b = 0.003$ From Annex D.1.1 barometric pressure at site to be measured with digital instruments using the same principle as aneroid		$u_b = 0.003$	
$u_d = \Delta t_d/(273.15 + t_d)$ $= 1.5/311$ $= 0.00482$ From Annex D.2-1	Eqn D.1 SI	$u_d = \Delta t_d(459.67 + t_d)$ $= 3/559.7$ $= 0.0054$	Eqn D.1 I-P
For t_d = 38°C Δt_d = 1.5°C (because the type of the thermometer varies, a mid-value is used)		For t_d = 100°F, Δt_d = 3°F	
$u_v = 0.002$ From Annex D.2.2		$u_v = 0.002$	
Then:			
$u_{\rho3} = (0.003^2 + 0.00482^2 + 0.002^2)^{0.5}$ $= 0.00602$		$u_{\rho3} = (0.003^2 + 0.0054 + 0.002)^{0.5}$ $= 0.00649$	

H.4.2 Volume flow rate and Plane 3, u_{Q3}

From Section 10.2.2			
$u_{Q3} = [u_A^2 + u_{\rho3}/2)^2 + (u_{Pvf}/2)^2 + u_{TR}^2 + u_C^2]^{0.5}$		Same as SI	Eqn 10.3
Where:			
$u_A = 0.02$ From Annex D.4.4. Dimensions from drawings used to calculate area. Uncertainty could be very much in excess of 0.02, but minimum values used for this example.		$u_A = 0.02$	
$u_{\rho3} = 0.00602$ From Annex H.4.1		$u_{\rho3} = 0.00649$	
$u_{Pv} = [\Delta i^2 + (u_{Pv\rho}P_{vf})^2]^{0.5}/P_v$ From Annex D.9.2.1		Same as SI	Eqn D.5
Where:			
Δi = 1 Pa From Annex D.9.1 inclined manometer at 10:1		Δi = 0.004 in. wg	

SI Units	I-P Units	
$u_{Pvf} = 0.02$ From Annex D.9.2.1 assuming minor fluctuations	$u_{Pvf} = 0.02$	
$P_{vf} = P_{v3} = 148$ Pa See Annex H.3.1 - Additional values	$P_{vf} = 0.593$ in. wg	
Then,		
$u_{Pv3} = [1^2 + 0.02 \times 148^2]^{0.5}/148$ $= 0.0211$	$u_{Pv3} = [0.004^2 + 0.02 \times 0.593^2]^{0.5}/0.593$ $= 0.0211$	
$u_{TR} = 0.01$ From Annex D.5 normal procedure	$u_{TR} = 0.01$	
$u_C = 0.01$ From Annex D.5 neglecting effects of Pitot tube coefficient	$u_C = 0.01$	
Then,		
$u_{Q3} = [0.02^2 + (0.00602/2)^2 + (0.0211/2)^2 + 0.01^2 + 0.01^2]^{0.5}$ $= 0.0268$	$u_{Q3} = [0.02^2 + (0.00649/2)^2 + (0.0211/2)^2 + 0.01^2 + 0.01^2]^{0.5}$ $= 0.0269$	Eqn 10.3

H.4.2.1 Converted to inlet volume flow rate, u_{Q1}

From Section 10.2.2

$u_{Q1} = [(u_{Q3}^2 + u_\rho)^2]^{0.5}$	Same as SI	Eqn 10.4
Assuming $u_{\rho 3} = u_\rho$ Same instrumentation, same uncertainty		
Then:		
$u_{Q1} = (0.0268^2 + 0.00602^2)^{0.5}$ $= 0.02747$	$u_{Q1} = (0.0269^2 + 0.00649^2)^{0.5}$ $= 0.02767$	

H.4.2.2 Converted to specified conditions, (Q, N, and K_p)

From Section 10.2.2

$u_{QNKp} = (u_{Q1}^2 + u_N^2 + u_{Kp}^2)^{0.5}$	Same as SI	Eqn 10.5
Where:		
$u_{Q1} = 0.02747$ From Annex H.4.2.1	$u_{Q1} = 0.02767$	
$u_N = 0.005$ From Annex D.6 measurement of speed	$u_N = 0.005$	
$u_{Kp} = 0.002$ From Annex D.8	$u_{Kp} = 0.002$	

SI Units	I-P Units	
Then:		
$u_{QNKp} = (0.02747^2 + 0.005^2 + 0.002^2)^{0.5}$ $= 0.0280$	$u_{QNKp} = (0.02767^2 + 0.005^2 + 0.002^2)^{0.5}$ $= 0.0282$	

H.4.3 Velocity pressure at fan inlet, u_{pV1}

From Section 10.2.3

$u_{pV1} = (4u_{Q1}^2 + u_{\rho 1}^2 + 4u_A^2)^{0.5}$ $= [(4 \times 0.02747^2) + 0.00602^2 + (4 \times 0.002^2)]^{0.5}$ $= 0.0682$	$u_{pV1} = (4u_{Q1}^2 + u_{\rho 1}^2 + 4u_A^2)^{0.5}$ $= [(4 \times 0.026767^2) + 0.00649^2 + (4 \times 0.02^2)]^{0.5}$ $= 0.0686$	Eqn 10.6

H.4.4 Fan static pressure, u_{Ps}

From Section 10.2.5. Derivation based on measurement of static pressure at entry to the fan inlet box and at the evasé discharge, therefore friction loss (K) need not be considered

$u_{Ps} = \Delta P_s / P_s$ By definition including effects of velocity	Same as SI	Eqn 10.17
Where:		
$\Delta P_s = (\Delta P_{s2}^2 + \Delta P_{t1}^2)^{0.5}$ From Section 10.2.5	Same as SI	Eqn 10.16

H.4.4.1 Absolute uncertainty in total pressure at inlet, ΔP_{t1}

$\Delta P_{t1} = (\Delta P_{s1}^2 + \Delta P_{v1}^2)^{0.5}$ From Section 10.2.4	Same as SI	Eqn 10.15
Also:		
$\Delta P_{s1} = [\Delta i^2 + (u_{Ps} P_{s1})^2 + (0.1 P_{v1})^2]^{0.5}$ From Annex D.9.2.3	Same as SI	Eqn D.8
Where:		
$\Delta i = 10$ Pa From Annex D.9.1. Normally a U-tube manometer is used for measuring static pressure.	$\Delta i = 0.04$ in. wg	
$u_{Ps} = 0.01$ From Annex D.9.2.2 minor fluctuations	$u_{Ps} = 0.01$	
$P_{s1} = -896$ Pa From Annex H.3.1 additional value	$P_{s1} = -3.6$ in. wg	
$P_{v1} = 146$ Pa From Annex H.3.1 additional value	$P_{v1} = 0.59$ in. wg	
Then:		
$\Delta P_{s1} = [10^2 + (0.01 \times 896)^2 + (0.1 \times 146)^2]^{0.5}$ $= 19.8$ Pa	$\Delta P_{s1} = [0.04^2 + (0.01 \times 3.6)^2 + (0.1 \times 0.59)^2]^{0.5}$ $= 0.08$ in. wg	Eqn D.8

SI Units	I-P Units	
Also:		
$\Delta P_{v1} = u_{Pv1}P_{v1}$ $= 0.0682 \times 146$ $= 10$ Pa	$\Delta P_{v1} = u_{Pv1}P_{v1}$ $= 0.0686 \times 0.59$ $= 0.04$ in. wg	
Therefore:		
$\Delta P_{t1} = (19.8^2 + 10^2)^{0.5}$ $= 22$ Pa	$\Delta P_{t1} = (0.08^2 + 0.04^2)^{0.5}$ $= 0.09$ in. wg	

H.4.4.2 Absolute uncertainty in static pressure at discharge, ΔP_{s2}

$\Delta P_{s2} = (\Delta P_{s4}{}^2 + \Delta K^2)^{0.5}$ Assuming the evasé discharge (Plane 2) is acceptable for measuring the static pressure using Pitot traverse, then the friction losses, K, need not be considered.	Same as SI	Eqn 10.14
$P_{s2} = P_{s4}$, the equation becomes:		
$\Delta P_{s2} = [\Delta i^2 + (u_{Ps}P_{s2})^2 + (0.1 \times P_{v2})^2]^{0.5}$ From Annex D.9.2.3	Same as SI	Eqn D.8
Where:		
$\Delta i = 10$ Pa From Annex D.9.1 U-tube manometer	$\Delta i = 0.04$ in. wg	
$u_P = 0.01$ From Annex D.9.2.2 minor fluctuations	$u_P = 0.01$	
$P_{s2} = 4332$ Pa From Annex H.3.1 additional value	$P_{s2} = 17.4$ in. wg	
$P_{v2} = 151$ Pa From Annex H.3.1 additional value	$P_{v2} = 0.61$ in. wg	
Then:		
$\Delta P_{s2} = [10^2\ (0.01 \times 4330)^2 + (0.1 \times 151)^2]^{0.5}$ $= 47$ Pa	$\Delta P_{s2} = [0.04^2 + (0.01 \times 17.4)^2 + (0.1 \times 0.61)^2]^{0.5}$ $= 0.19$ in. wg	Eqn D.8

H.4.4.3 Absolute uncertainty in fan static pressure, ΔP_s

From Section 10.2.5 $\Delta P_s = (\Delta P_{s2}{}^2 + \Delta P_{t1}{}^2)^{0.5}$ $= (47^2 + 22^2)^{0.5}$ $= 52$ Pa	Same as SI $= (0.19^2 + 0.09^2)^{0.5}$ $= 0.21$ in. wg	Eqn 10.16
Then:		
$u_{Ps} = \Delta P_s / P_s$ $= 52/5082$ $= 0.0102$	Same as SI $= 0.21/20.41$ $= 0.0103$	Eqn 10.17

SI Units	I-P Units	

H.4.4.4 Converted to specified conditions, $e_{PsN\rho Kp}$ (P, N, ρ, and K_p)

From Section 10.2.5 $u_{PsN\rho Kp} = (u_{Ps}^2 + 4u_N^2 + u_\rho^2 + u_{Kp}^2)^{0.5}$	Same as SI	Eqn 10.18
Where:		
$u_{Ps} = 0.0102$ From Annex H.4.4.3	$u_{Ps} = 0.0103$	
$u_N = 0.005$ From Annex D.6.1	$u_N = 0.005$	
$u_\rho = 0.00602$ From Annex H.4.2.1	$u_\rho = 0.00649$	
$u_{Kp} = 0.002$ From Annex D.6	Same as SI	
Therefore:		
$u_{PsN\rho Kp} = [0.0102^2 + (4 \times 0.005^2) + 0.00602^2 + 0.002^2]^{0.5} = 0.0156$	$u_{PsN\rho Kp} = [0.0103^2 + (4 \times 0.005^2) + 0.00649^2 + 0.002^2]^{0.5} = 0.0159$	

H.4.5 Fan shaft power, u_H

From Section 10.2.6 $u_H = [(u_w W)^2 + (u_L L)^2]^{0.5}/H$	Same as SI	Eqn 10.19
Where:		
$u_w = 0.02$ From Annex D.7-2 - 0.5% of full range uncertainty instruments used.	$u_w = 0.02$	
$u_L = 0.1$ From Annex D.7.2	$u_L = 0.1$	
$H = 1094$ kW From Annex H.3 fan selection	$H = 1467$	
$W = 1094/0.95 = 1151.6$ kW Assumed 95% motor efficiency	$W = 1467/0.95 = 1544$ HP	
$L = W - H = 57.6$ kW	$L = W - H = 77$ HP	
Then:		
$u_H = [(0.02 \times 1151.6)^2 + (0.1 \times 57.6)^2]^{0.5}/1094 = 0.0217$	$u_H = [(0.02 \times 1544)^2 + (0.1 \times 77)^2]^{0.5}/1467 = 0.0217$	

SI Units	**I-P Units**	
H.4.5.1 Converted to specified conditions, $u_{HN\rho Kp}$		
(HP, N, ρ, and K_p) From Section 10.2.6.1 $u_{HN\rho Kp} = (u_H^2 + 9u^2_{N2} + u_\rho^2 + u_{Kp}^2)^{0.5}$	Same as SI	
Where:		
$u_H = 0.0217$ From Annex H.4.5	$u_H = 0.0217$	
$u_N = 0.005$ From Annex D.6.1	$u_N = 0.005$	
$u_\rho = 0.00602$ From Annex H.4.2.1	$u_\rho = 0.00649$	
Then:		
$u_{HN\rho Kp} = [0.0217^2 + (9 \times 0.005^2)$ $+ 0.00602^2 + 0.002^2]^{0.5}$ $= 0.0271$	$u_{HN\rho Kp} = [0.0217^2 + (9 \times 0.005^2)$ $+ 0.00649^2 + 0.002^2]^{0.5}$ $= 0.0272$	

H.4.6 Fan static efficiency, $u_{\eta s}$

From Section 10.2.7 $u_{\eta s} = (u_{Q1}^2 + u_{Ps}^2 + u_H^2 + u_{Kp}^2)^{0.5}$	Same as SI	(Eqn 10.23)
Where:		
$u_{Q1} = 0.02747$ From Annex H.4.2.1	$u_{Q1} = 0.02767$	
$u_{Ps} = 0.0102$ From Annex H.4.4.3	$u_{Ps} = 0.0103$	
$u_H = 0.0217$ From Annex H.4.5	$u_H = 0.0217$	
$u_{Kp} = 0.002$ From Annex D.8	Same as SI	
Then: $u_{\eta s} = (0.02747^2 + 0.0102^2 + 0.0217^2 + 0.002^2)^{0.5}$ $= 0.0365$	$u_{\eta s} = (0.02767^2 + 0.0103^2 + 0.0217^2 + 0.002^2)^{0.5}$ $= 0.0367$	

H.5 Absolute uncertainties used for plotting uncertainty boundaries

By definition. Also, u_{QNKp} used since plotting boundaries on quoted characteristic curve.

SI (see Figure H.2)	**I-P** (see Figure H.3)
$\Delta Q_1 = \pm\, Q_1 u_{QNKp}$ $= \pm\, 188 \times 0.028$ $= \pm\, 5.26 \text{ m}^3/\text{s}$	$\Delta Q_1 = \pm\, Q_1 u_{QNKp}$ $= \pm\, 398{,}645 \times 0.0282$ $= \pm\, 11{,}242 \text{ cfm}$

SI Units	**I-P Units**
$\Delta P_s = \pm\ P_s u_{PsN\rho Kp}$ $= \pm\ 5082 \times 0.0156$ $= \pm\ 79.3$ Pa	$\Delta P_s = \pm\ P_s u_{PsN\rho Kp}$ $= \pm\ 20.41 \times 0.0159$ $= \pm\ 0.325$ in. wg
SI (see Figure H.4)	**I-P** (see Figure H.5)
$\Delta \eta_s = \pm\ \eta_s u_{\eta s}$ $= \pm\ 85.6 \times 0.0365$ $= \pm\ 3.12\%$	$\Delta \eta_s = \pm\ \eta_s u_{\eta s}$ $= \pm\ 85.6 \times 0.0367$ $= \pm\ 3.14\%$

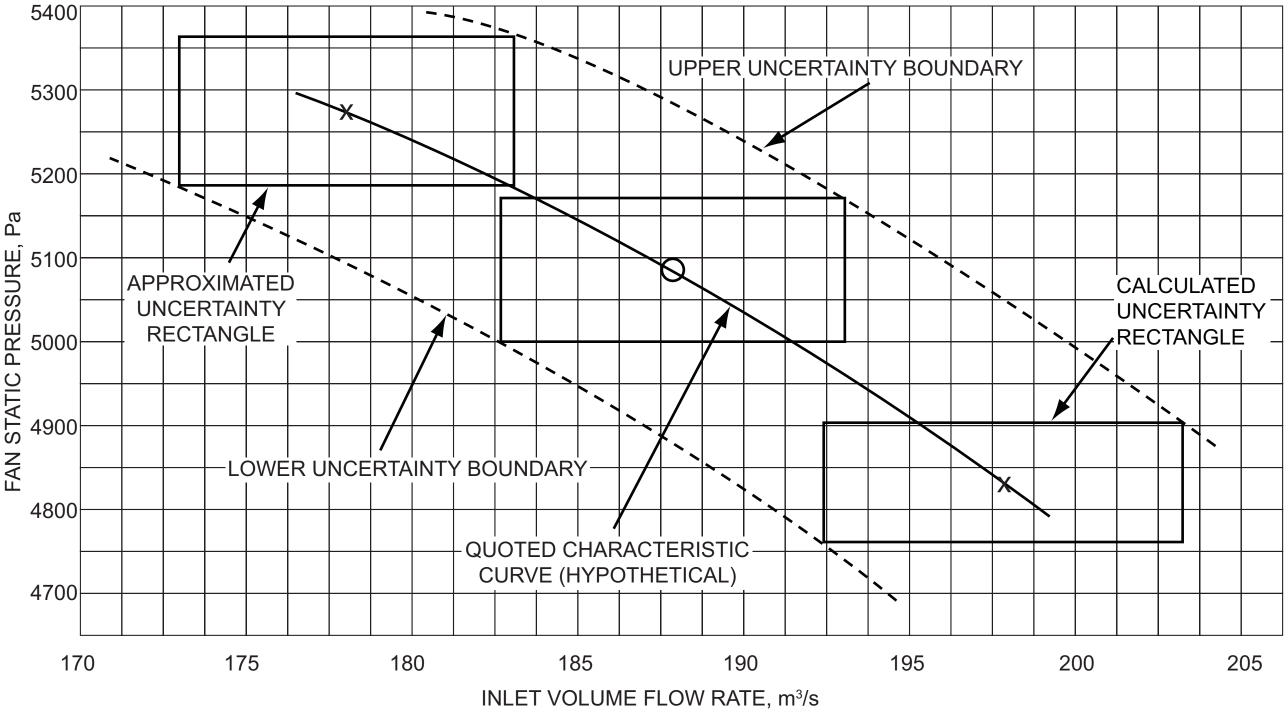


Figure H.2 - Example SI Flow Rate vs. Static Pressure Uncertainty Chart

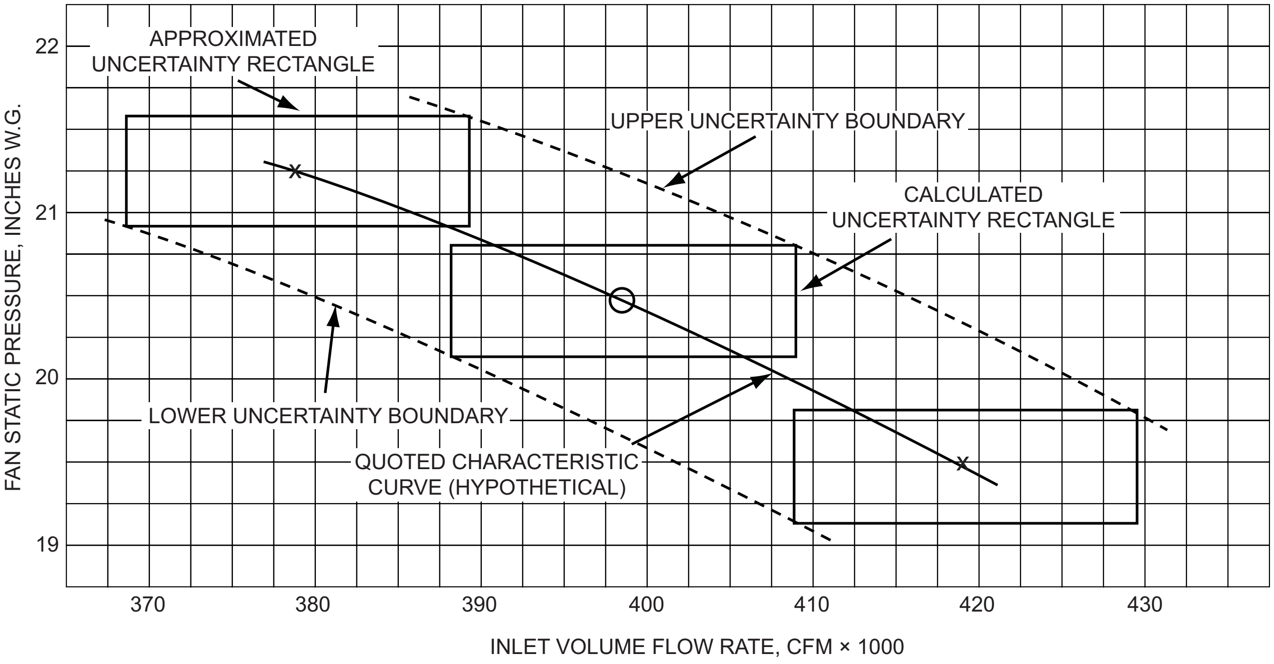


Figure H.3 - Example I-P Flow Rate vs. Static Pressure Uncertainty Chart

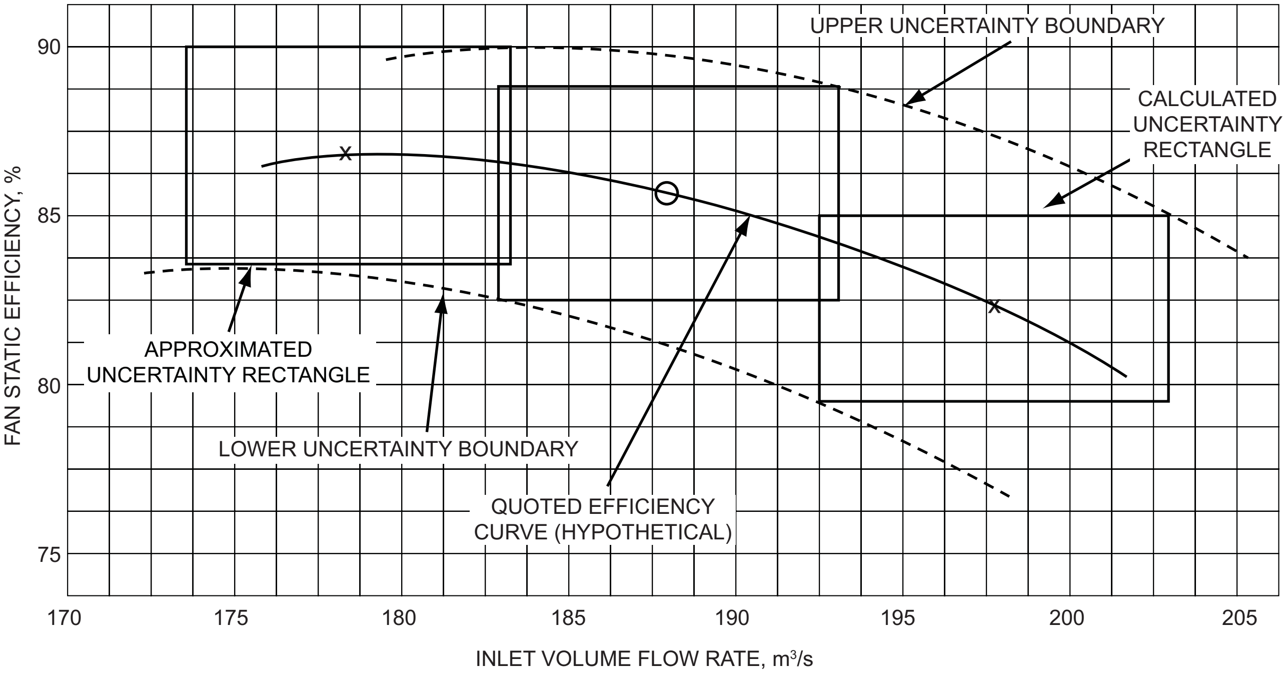


Figure H.4 - Example SI Static Flow Rate vs. Efficiency Uncertainty Chart

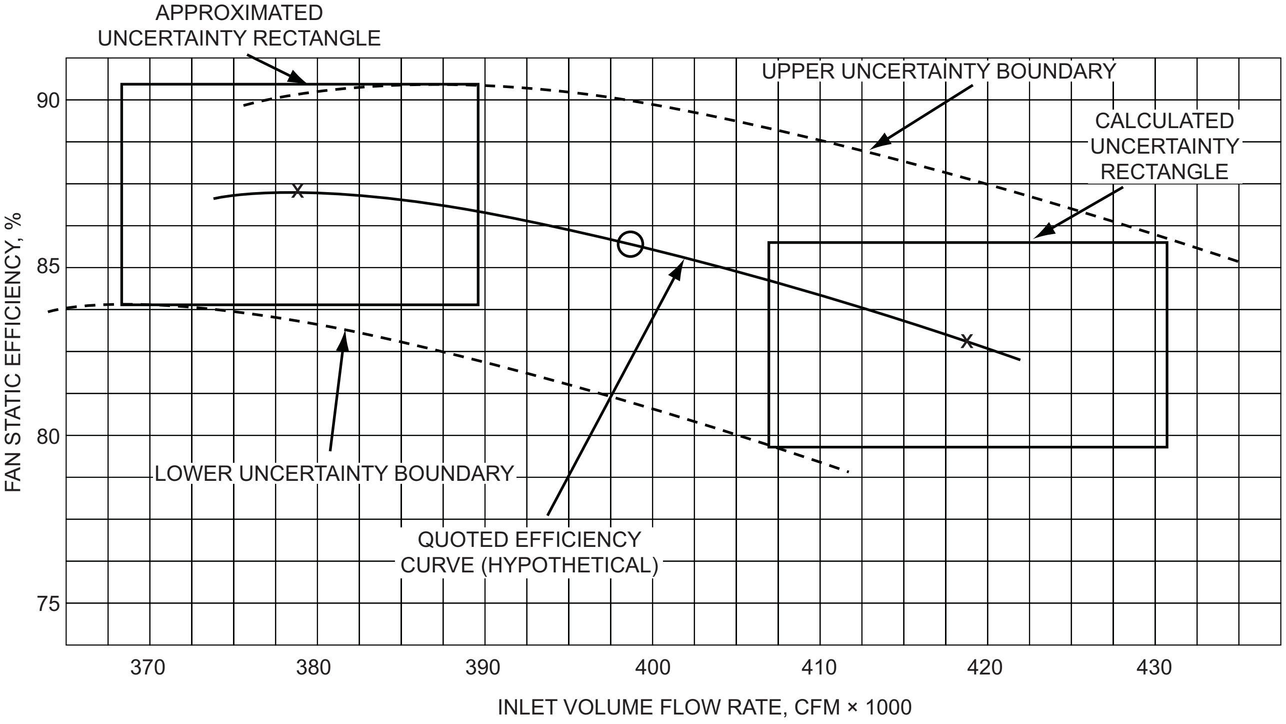


Figure H.5 - Example I-P Static Efficiency Uncertainty Chart

Annex J. Example Pre-Test Uncertainty Analysis for a Typical Axial Flow Fan

This example is a typical pretest calculation for a large axial fan. Data are a combination of specified fan duty and customer drawings. Another analysis is required after the test, using actual test data and actual uncertainties, if different from pretest assumptions.

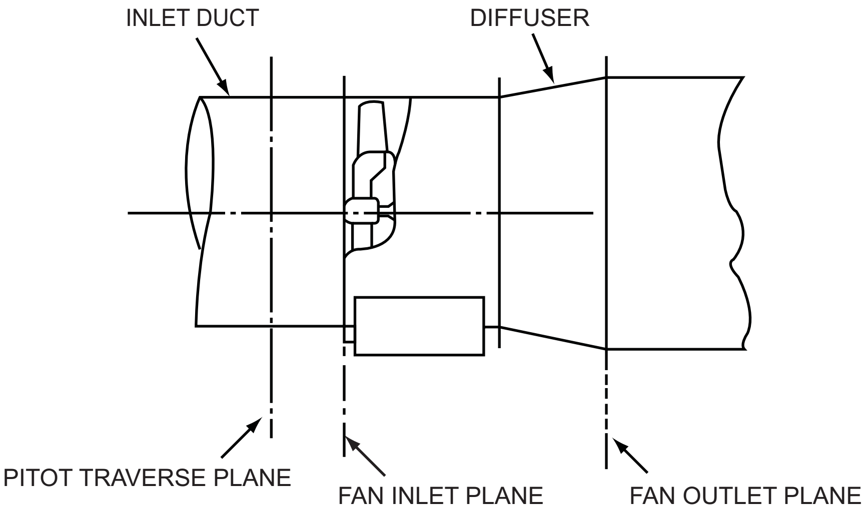


Figure J.1

J.1 Specified design point

	SI Units	I-P Units
Fan flow rate	411 m^3/s	870868 cfm
Fan total pressure	3559 Pa	14.33 in. wg
Inlet temperature	157°C	315°F

J.2 Selected fan parameters

Impeller diameter	4.623 m	182 in.
Fan speed	890 rpm	890 rpm
Fan shaft power	1722 kW	2309 hp
Fan total efficiency	83.7%	83.7%

J.2.1 Additional values required for analysis

Inlet density, ρ_1	0.7804 kg/m^3	0.0487 lbm/ft^3
Inlet duct area, A_1	16.79 m^2	180.7 ft^2
Inlet velocity pressure, P_{v1}	235 Pa	0.942 in. wg
Inlet static pressure, P_{s1}	-3338 Pa	-13.4 in. wg
Inlet total pressure, P_{t1}	-3104 Pa	-12.46 in. wg
Compressibility coefficient, K_p	0.988	0.988
Discharge density, ρ_2	0.8323 kg/m^3	0.0520 lbm/ft^3
Discharge flow rate, Q_2	385 m^3/s	815601 cfm
Discharge area, A_2	16.79 m^2	180.7 ft^2
Discharge velocity pressure, P_{v2}	220 Pa	0.882 in. wg
Discharge static pressure, P_{s2}	237 Pa	0.954 in. wg
Discharge total pressure, P_{t2}	456 Pa	1.83 in. wg
Area of flow measurement, A_3	16.79 m^2	180.7 ft^2
Velocity pressure at A_3, P_{v3}	235 Pa	0.946 in. wg

J.3 General description

J.3.1 Fan flow rate. For this example, the velocity pressure traverse is to be taken in the inlet duct. Fan flow rate is then calculated and is the same at the traverse plane as it is at the fan inlet.

J.3.2 Fan total pressure. Static pressures at the fan inlet and outlet along with the measured velocity pressure are used to determine the fan total pressure.

J.3.3 Fan gas density. The fan gas density is to be determined based on barometric pressure, wet-and dry-bulb temperatures measured at the Pitot traverse plane, and static pressure measurements.

J.3.4 Fan speed. The fan speed is to be measured by an electronic speed counter.

J.3.5 Fan shaft power. The fan shaft power is to be measured by an intergral torquemeter.

SI Units	**I-P Units**	

J.4 Pretest uncertainty calculations

J.4.1 Density at flow measurement plane, $u_{\rho 3}$

$u_{\rho 3} = (u_b{}^2 + u_d{}^2 + u_v{}^2)^{0.5}$	Same as SI	Eqn 10.1
Where:		
$u_b = 0.0018$ From Annex D.1.1 using mercurcy barometer	$u_b = 0.0018$	
$u_d = \Delta t_d/(273.15 + t_d)$ From Annex D.2.1	$u_d = \Delta t_d/(459.67 + t_d)$	
for $t_d = 157°C$	$t_d = 315°F$	
Assume: $\Delta t_d = 2.8°C$	$\Delta t_d = 5°F$	
$u_d = 2.8/(273 + 157)$ $= 0.00651$	$u_d = 5/(459.7 + 315)$ $= 0.00645$	
$u_v = 0.002$ From Annex D.2.2	$u_v = 0.002$	
$u_{\rho 3} = (0.0018^2 + 0.00651^2 + 0.002^2)^{0.5}$ $= 0.00704$	$u_{\rho 3} = (0.0018^2 + 0.00645^2 + 0.002^2)^{0.5}$ $= 0.00699$	

J.4.2 Volume flow rate at flow measurement plane, u_{Q3}

$u_{Q3} = [u_{A3}{}^2 + (u_{\rho 3}/2)^2 + (u_{Pvf}/2)^2 + u_{TR}{}^2 + u_C{}^2]^{0.5}$	Same as SI	Eqn 10.3
$u_A = 0.02$ From Annex D.4.4 using drawing values for duct area	$u_A = 0.02$	
$u_{\rho 3} = 0.00704$ From Annex J.4.1	$u_{\rho 3} = 0.00699$	

SI Units	I-P Units	
$u_{Pvf} = [\Delta i^2 + (u_{Pv3} P_{v3})^2]^{0.5} / P_{v3}$	Same as SI	Eqn D.5
Where:		
$\Delta i = 2$ Pa From Annex D.9.1 inclined manometer at 5:1	$\Delta i = 0.008$ in. wg	
$u_{Pv} = 0.02$ From Annex D.9.2.1 assume minor fluctuations	$u_{Pv} = 0.02$	
$P_{v3} = 235$ Pa	$P_{v3} = 0.94$ in. wg	
$u_{Pv3} = [2^2 + (0.02 \times 235)^2]^{0.5}/235$ $= 0.0217$	$u_{Pv3} = [0.008^2 + (0.02 \times 0.94)^2]^{0.5}/0.94$ $= 0.0217$	
$u_{TR} = 0.010$ From Annex D.5 normal procedure	$u_c = 0.010$	
$u_c = 0.010$ From Annex D.5	$u_c = 0.010$	
$u_{Q3} = [0.02^2 + (0.007/2)^2 + (0.0217/2)^2 + (0.01)^2 + (0.01)^2]^{0.5}$ $= 0.0270$	Same as SI $= 0.0270$	

J.4.2.1 Volume flow rate at fan inlet plane, u_{Q1}

SI Units	I-P Units	
$u_{Q1} = (u_{Q3}^2 + u_{\rho 1}^2)^{0.5}$	Same as SI	Eqn 10.4
Where:		
$u_{Q3} = 0.0270$ From Annex J.4.2	$u_{Q3} = 0.0270$	
$u_{\rho 1} = 0.00704$ Assume it is the same as $u_{\rho 3}$ from Annex J.4.1	$u_{\rho 1} = 0.00699$	
$u_{Q1} = (0.027^2 + 0.00704^2)^{0.5}$ $= 0.0279$	$u_{Q1} = (0.027^2 + 0.00699^2)^{0.5}$ $= 0.0279$	

J.4.2.2 Volume flow rate converted to nominal fan speed, e_{QN}

SI Units	I-P Units	
$u_{QN} = (u_{Q1}^2 + u_N^2 + u_{Kp}^2)^{0.5}$	Same as SI	Eqn 10.5
Where:		
$u_N = 0.002$	$u_N = 0.002$	
$u_{Q1} = 0.0279$	$u_{Q1} = 0.0279$	
$u_{Kp} = 0.002$	$u_{Kp} = 0.002$	
$u_{QN} = (0.002^2 + 0.0279^2 + 0.002^2)^{0.5}$ $= 0.0280$	$u_{QN} = (0.002^2 + 0.0279^2 + 0.002^2)^{0.5}$ $= 0.0280$	

J.4.3 Velocity pressure at fan inlet, e_{Pv1}

SI Units	I-P Units	
$u_{Pv1} = (4u_{Q1}{}^2 + u_{P1}{}^2 + 4u_A{}^2)^{0.5}$	Same as SI	Eqn 10.6
$u_{Pv1} = [(4 \times 0.0279^2) + 0.007^2 + (4 \times 0.020^2)]^{0.5}$ $= 0.069$	$u_{Pv1} = [(4 \times 0.0279^2) + 0.007^2 + (4 \times 0.02^2)]^{0.5}$ $= 0.069$	

J.4.4 Fan total pressure, u_{Pt}

$u_{Pt} = \Delta P_t / P_t$	Same as SI	Eqn 10.11
$\Delta P_t = (\Delta P_{t1}{}^2 + \Delta P_{t2}{}^2)^{0.5}$	Same as SI	Eqn 10.10
$\Delta P_{t1} = (\Delta P_{s1}{}^2 + \Delta P_{v1}{}^2)^{0.5}$	Same as SI	Eqn 10.9
$\Delta P_{s1} = [\Delta i^2 + (u_P P_{s1})^2 + (0.1 P_{v1})]^{0.5}$	Same as SI	Eqn D.8
Where:		
$\Delta i = 10$ Pa From Annex D.9.1, U-tube manometer	$\Delta i = 0.04$ in. wg	
$u_P = 0.01$ From Annex D.9.2.2 minor fluctuations	$u_P = 0.01$	
$P_{s1} = -3338$ Pa From Annex J.2.1 additional value	$P_{s1} = -13.4$ in. wg	
$P_{v1} = 235$ Pa From Annex J.2.1 additional value	$P_{v1} = 0.942$ in. wg	
$\Delta P_{s1} = [10^2 + (0.01 \times 3338)^2 + (0.1 \times 235)^2]^{0.5}$ $= 42$ Pa	$\Delta P_{s1} = [0.04^2 + (0.01 \times 13.4)^2 + (0.1 \times 0.942)^2]^{0.5}$ $= 0.169$ in. wg	
$\Delta P_v = u_{Pv1} P_{v1}$ By definition	Same as SI	
$u_{Pv1} = 0.069$ From Annex I.4.3	$u_{Pv1} = 0.069$	
$P_{v1} = 235$ Pa	$P_{v1} = 0.942$ in. wg	
$\Delta P_{v1} = 0.069 \times 235$ $= 16$ Pa	$\Delta P_{v1} = 0.069 \times 0.942$ $= 0.065$ in. wg	
$\Delta P_{t1} = (42^2 + 16^2)^{0.5}$ $= 45$ Pa	$\Delta P_{t1} = (0.169^2 + 0.065^2)^{0.5}$ $= 0.1811$ in. wg	
$\Delta P_{t2} = (\Delta P_{s2} + \Delta P_{v2})^{0.5}$ Assume measurement at Plane 2	Same as SI	Eqn 10.8
$\Delta P_{s2} = [\Delta i^2 + (u_P P_{s2})^2 + (0.1 \times P_{v2})^2]^{0.5}$	Same as SI	Eqn D.8

SI Units	I-P Units
Δi = 10 Pa From Annex D.9.1 U-tube manometer	Δi = 0.04 in. wg
$u_P = 0.01$ From Annex D.9.2.2 assume minor fluctuations	$u_P = 0.01$
P_{s2} = 237 Pa From Annex J.2.1	P_{s2} = 0.95 in. wg
P_{v2} = 220 Pa From Annex J.2.1	P_{v2} = 0.882 in. wg
$\Delta P_{s2} = [10^2 + (0.01 \times 237)^2 + (0.1 \times 220)^2]^{0.5}$ = 24 Pa	$\Delta P_{s2} = [0.04^2 + (0.01 \times 0.95)^2 + (0.1 \times 0.882)^2]^{0.5}$ = 0.097 in. wg
$\Delta P_{v2} = u_{Pv2} P_{v2}$ By definition	Same as SI
$u_{Pv2} = 0.069$ Assume same as u_{Pv1}	$u_{Pv2} = 0.069$
P_{v2} = 220 Pa	P_{v2} = 0.882 in. wg
$\Delta P_{v2} = 0.069 \times 220$ = 15 Pa	$\Delta P_{v2} = 0.069 \times 0.886$ = 0.061
$\Delta P_{t2} = (24^2 + 15^2)^{0.5}$ = 28 Pa	$\Delta P_{t2} = (0.097^2 + 0.061^2)^{0.5}$ = 0.115 in. wg
$\Delta P_t = (45^2 + 28^2)^{0.5}$ = 53 Pa	$\Delta P_t = (0.1811^2 + 0.115^2)^{0.5}$ = 0.2145 in. wg
$u_{Pt} = 53/3559$ $= 0.0149$	$u_{Pt} = 0.2145/14.29$ $= 0.015$

J.4.4.1 Fan total pressure converted to nominal fan speed and density, u_{PtNrKp}

SI Units	I-P Units
$u_{PtN\rho Kp} = (u_{Pt}^2 + 4u_N^2 + u_{\rho i}^2 + u_{Kp}^2)^{0.5}$	Same as SI (Eqn 10.12)
$u_{Pt} = 0.0149$ From Annex I.4.4	$u_{Pt} = 0.015$
$u_N = 0.002$ From Annex I.4.2.1	$u_N = 0.002$
$u_{\rho 1} = 0.00704$ From Annex I.4.2.1	$u_{\rho 1} = 0.00699$
$u_{PtN\rho Kp} = [0.0149^2 + (4 \times 0.002^2) + 0.00704^2 + 0.002^2]^{0.5}$ $= 0.0171$	$u_{PtN\rho Kp} = [0.015^2 + (4 \times 0.002^2) + 0.00699^2 + 0.002^2]^{0.5}$ $= 0.0171$

SI Units	**I-P Units**	

J.4.5 Fan shaft power, u_H

$u_H = (u_T^2 + u_N^2)^{0.5}$ — Same as SI — Eqn 10.21

Where:

SI	I-P
$u_T = 0.02$ From Annex D.7.4 high quality torquemeter is to be used	$u_T = 0.02$
$u_N = 0.002$ From Annex D.6 electronic speed measurement	$u_N = 0.002$
$u_H = (0.02^2 + 0.002^2)^{0.5}$ $= 0.020$	$u_H = (0.02^2 + 0.002^2)^{0.5}$ $= 0.020$

J.4.5.1 Fan shaft power converted to specified speed and density, $u_{HN\rho}$

$u_{HN\rho} = (u_H^2 + 4u_N^2 + u_{\rho 1}^2)^{0.5}$ — Same as SI — Eqn 10.20

SI	I-P
$= [0.02^2 + (4 \times 0.002^2) + 0.00704^2]^{0.5}$ **= 0.0216**	$= [0.02^2 + (4 \times 0.002^2) + 0.00699^2]^{0.5}$ **= 0.0216**

J.4.6 Fan total efficiency, $u_{\eta t}$

$u_{\eta t} = (u_{Q1}^2 + u_{Pt}^2 + u_H^2 + u_{Kp}^2)^{0.5}$ — Same as SI — Eqn 10.24

SI	I-P
$u_{\eta t} = (0.0279^2 + 0.0149^2 + 0.02^2 + 0.002^2)^{0.5}$ **= 0.0375**	$u_{\eta t} = (0.0279^2 + 0.015^2 + 0.02^2 + 0.002^2)^{0.5}$ **= 0.0375**

J.5 Absolute uncertainties used for plotting uncertainty boundaries

By definition, use u_{QN} since boundaries are to be plotted on the quoted characteristic curve.

SI (see Figure J.2)	**I-P** (see Figure J.3)
$\Delta Q_1 = \pm Q_1 u_{QN}$ $= \pm 411 \times 0.028$ $= \pm 11.51$ m^3/s	$\Delta Q_1 = \pm Q_1 u_{QN}$ $= \pm 870868 \times 0.028$ $= \pm 24384$ cfm
$\Delta P_t = \pm P_t u_{PtN\rho Kp}$ $= \pm 3559 \times 0.0171$ $= \pm 61$ Pa	$\Delta P_t = \pm P_t u_{PtN\rho Kp}$ $= \pm 14.29 \times 0.0171$ $= \pm 0.24$ in. wg

SI (see Figure J.4)	**I-P** (see Figure J.5)
$\Delta \eta_t = \pm \eta_t u_{\eta t}$ $= \pm 83.7 \times 0.0375$ $= \pm 3.14\%$	$\Delta \eta_t = \pm \eta_t u_{\eta t}$ $= \pm 83.7 \times 0.0375$ $= \pm 3.14\%$

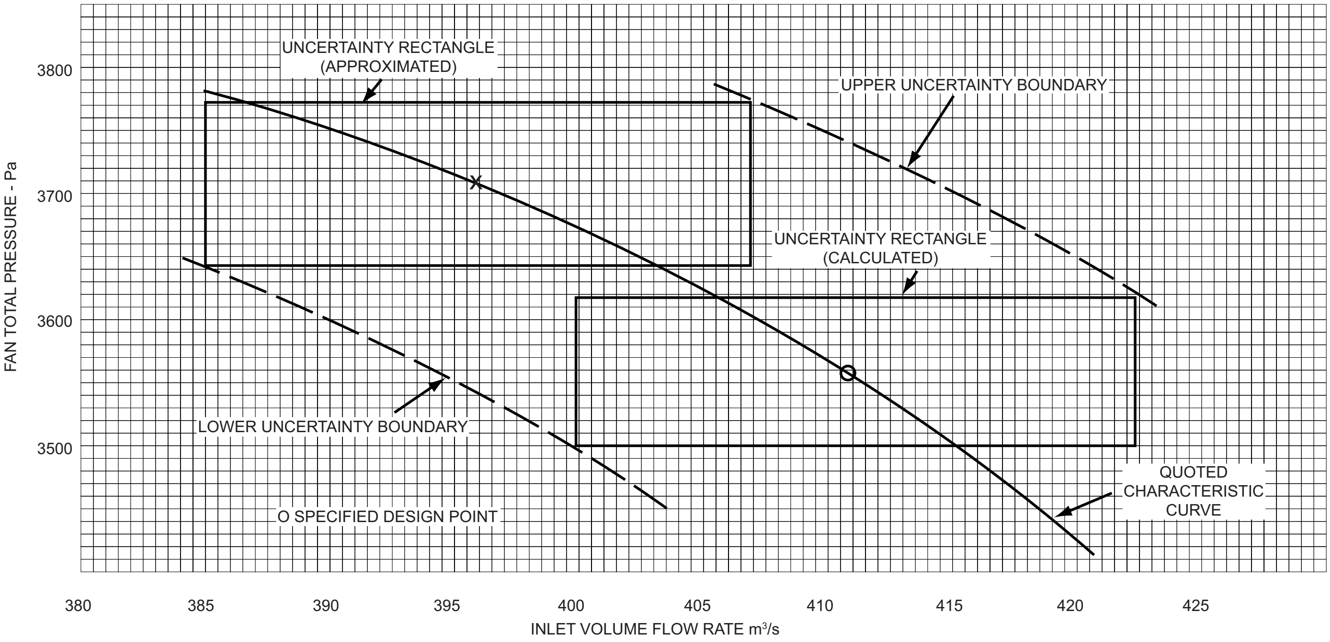


Figure J.2 - Example SI Flow Rate vs Total Pressure Uncertainty Chart

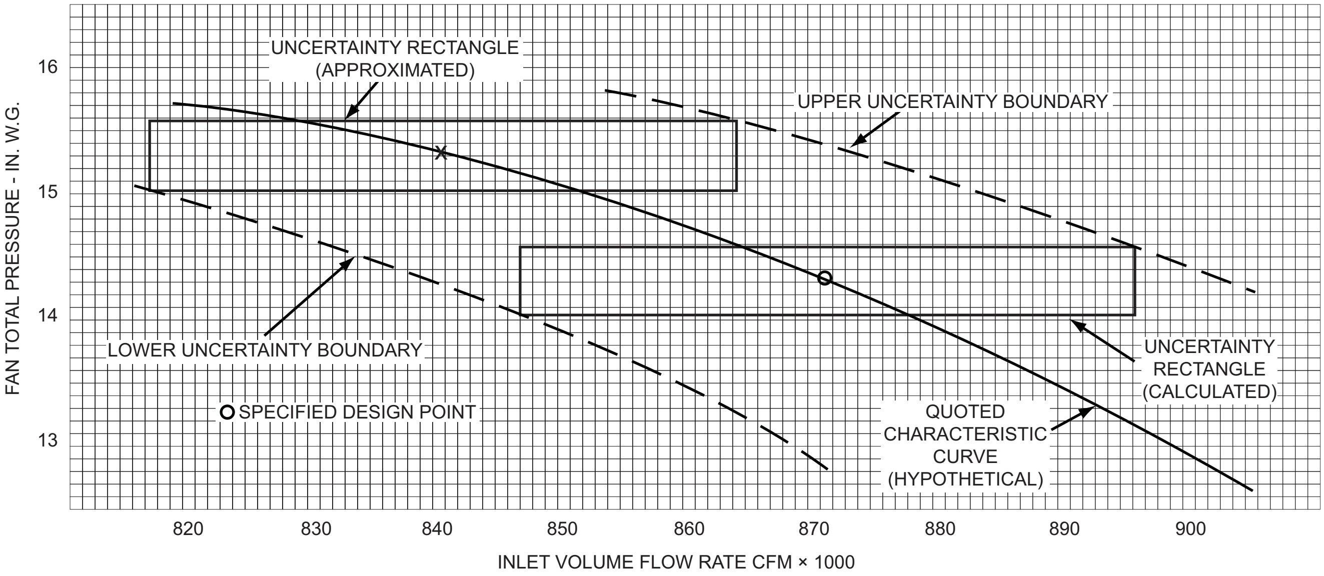


Figure J.3 - Example I-P Flow Rate vs Total Pressure Uncertainty Chart

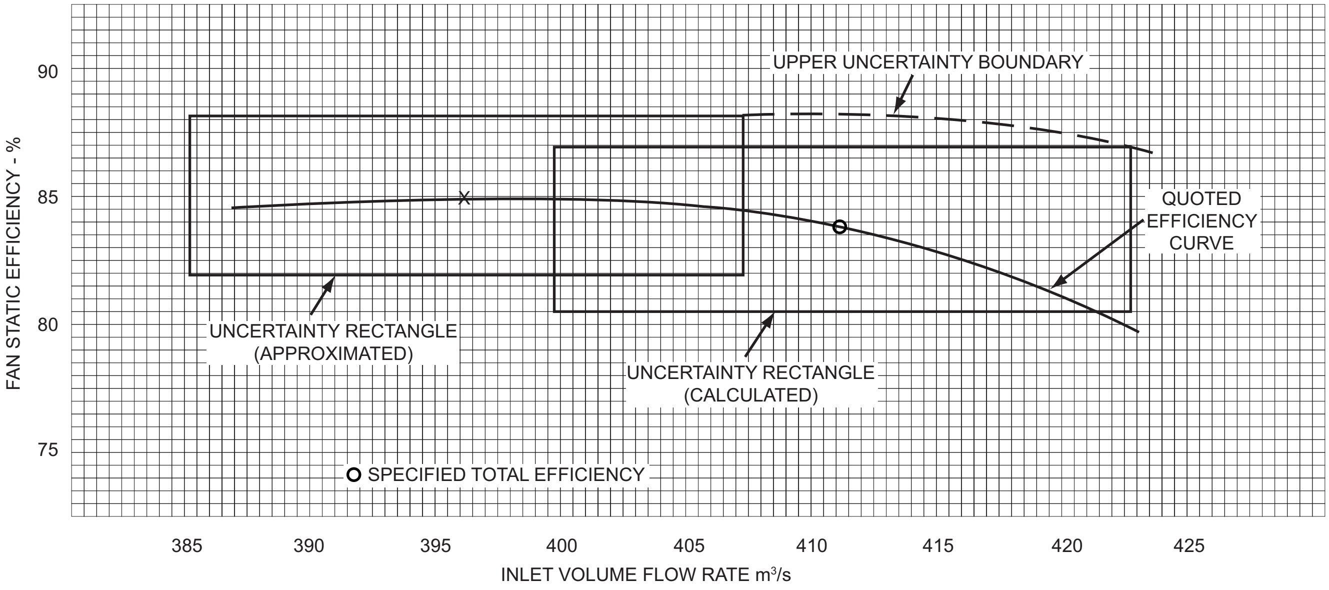


Figure J.4 - Example SI Total Efficiency Uncertainty Chart

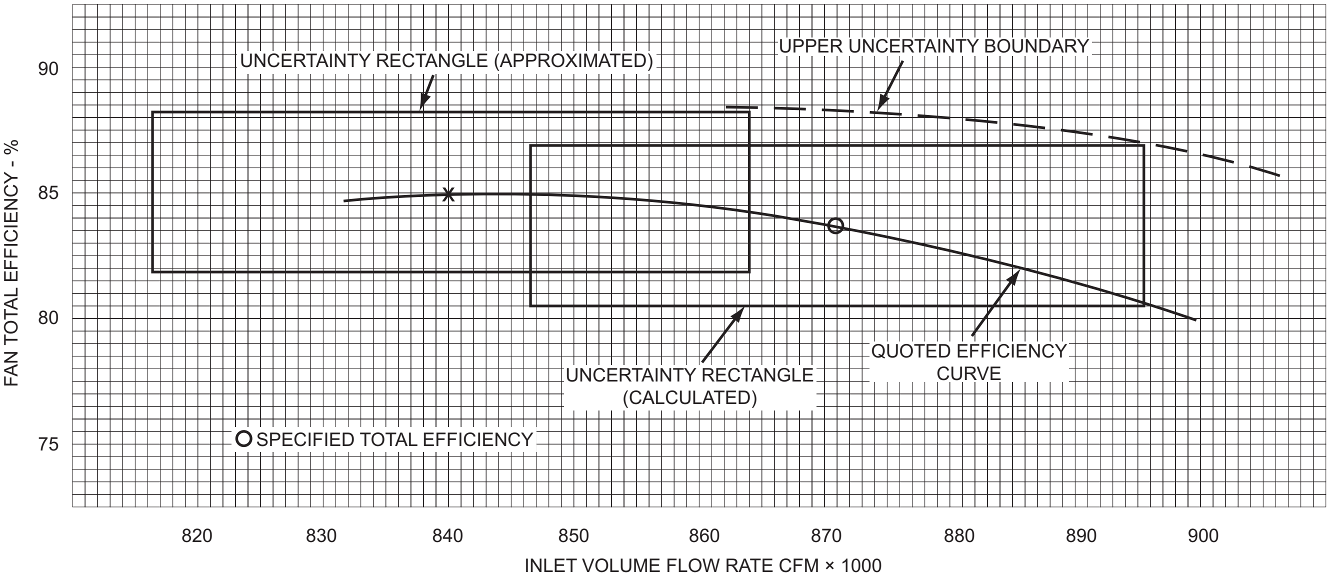


Figure J.5 - Example I-P Total Efficiency Uncertainty Chart

Annex K. Test Data Sheets

AMCA STANDARD 803 TEST DATA SHEET

Plant: ____________________ Unit No.: ______________ Test No.: ______________ Date: __________

Fan Type and Size: ________________________________ Test Supervisor: ___________________________

Fan Owner: ____

System Description: ____

Fan Manufacturer: ____

Test Conducted By: ____

Agreements Prior to Conduct of Test[1]:

☐ Object of Test
☐ Duration of Operation Under Test Conditions
☐ Test Personnel and Assignments
☐ Test Supervisor
☐ Test Methods
☐ Instrumentation and Calibration
☐ Location of Measurement Points
☐ Number and Frequency of Reference Measurements
☐ Method of Computing Results
☐ Pretest Uncertainty Analysis
☐ Arbritrator
☐ Application Contract Performance and Operating Conditions
☐ Tolerance on Performance
☐ Number of Test Runs
☐ ____
☐ ____
☐ ____

Test Supervisor: ____

Title: ____

____

Test Supervisor Signature Date

Fan Owner Representative: ____

Title: ____

____

Representative Signature Date

---

[1] Reference AMCA Standard 803 Section 8.2

AMCA STANDARD 803 TEST DATA SHEET

Plant: ____________________ Unit No.: ______________ Test No.: ______________ Date: __________

Fan Type and Size: _______________________________ Test Supervisor: ___________________________

Test Personnel: ____

Measurement Equipment Data Sheet[1]

Measurement and Test Equipment shall meet the requirements of Section 6.
The devices shall be listed below.

Measurement	Equipment/Model	Units	Accuracy	Cal. Period	Next Cal. Due	Pre-Test	Post-Test
Speed[2]:							
Power[3]:							
Volts:							
Current:							
Power Fact:							
Static Pres.[4]:							
Velocity Pres.[5]:							
Temps[6]							
Dry-Bulb:							
Wet-Bulb:							
Barometric Pressure[7]:							
Gas Stream Composition[8]							

Each instrument shall be verified as operational prior to (Pre-Test) and after the test (Post-Test).

[1] Reference AMCA Standard 803 Section 6 and Section 8.4
[2] Reference AMCA Standard 803 Section 6.5.6
[3] Reference AMCA Standard 803 Section 6.5.7
[4] Reference AMCA Standard 803 Section 6.5.2
[5] Reference AMCA Standard 803 Section 6.5.2
[6] Reference AMCA Standard 803 Section 6.5.4
[7] Reference AMCA Standard 803 Section 6.5.3
[8] Reference AMCA Standard 803 Section 6.5

AMCA STANDARD 803 TEST DATA SHEET

Plant: ____________________ Unit No.: ______________ Test No.: ______________ Date: __________

Fan Type and Size: _______________________________ Test Supervisor: ___________________________

Test Personnel: ____

Reference Measurement Data Sheet[1]

Reference measurements shall be averaged and recorded over a one (1) minute window of time, every twenty (20) minutes.

Time:___________________________________

Measurement	Reading	Unit of Measure
Speed[2]:		
Power[3]:		
Volts θ A:		
Volts θ B:		
Volts θ C:		
Current θ A:		
Current θ B:		
Current θ C:		
Power Factor θ A:		
Power Factor θ B:		
Power Factor θ C:		
Static Pressure[4]:		
Plane 1, Tap Location 1:		
Plane 1, Tap Location 2:		
Plane 1, Tap Location 3:		
Plane 1, Tap Location 4:		
Plane 2, Tap Location 1:		
Plane 2, Tap Location 2:		
Plane 2, Tap Location 3:		
Plane 2, Tap Location 4:		
Temperatures[5]:		
Dry-Bulb Temperature Plane 1:		
Wet-Bulb Temperature Plane 1:		
Dry-Bulb Temperature Plane 2:		
Velocity Pressure Plane 1 or 2[6]:		
Barometric Pressure[7]:		
Gas Stream Composition[8]:		

[1] Reference AMCA Standard 803 Section 8.4, Section 8.5, and Section 6.5

[2] Reference AMCA Standard 803 Section 6.5.6

[3] Reference AMCA Standard 803 Section 6.5.7

[4] Reference AMCA Standard 803 Section 6.5.2

[5] Reference AMCA Standard 803 Section 6.5.4

[6] Reference AMCA Standard 803 Section 6.5.1

[7] Reference AMCA Standard 803 Section 6.5.3

[8] Reference AMCA Standard 803 Section 6.5

AMCA STANDARD 803 TEST DATA SHEET

Plant: ____________________ Unit No.: ______________ Test No.: ______________ Date: __________
Fan Type and Size: ________________________________ Test Supervisor: ___________________________
Test Personnel: ____

Inlet Velocity Profile Qualification Data Sheet[1]

Fan Inlet (Plane 1)

The location of Plane 1 shall meet the requirements of Section 7.2 and the cross sectional area shall be determined in accordance with Section 8.5. (A drawing or sketch of the plane location should be attached.)

INLET DUCT SHAPE:

Measurement	Reading	Units of Measure
Dimension A		
Dimension B		
Dimension C		
Dimension D		

Velocity Pressure Readings[2]

The velocity pressure measurements shall be taken in accordance with the requirements of Section 6.5.2.

UNITS OF MEASUREMENT:

Position	Traverse Number					
	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

---

[1] Reference AMCA Standard 803 Section 7.2, Section 7.3, Section 7.4, and Section 7.6
[2] Reference AMCA Standard 803 Section 7.7

The location of Plane 2 shall meet the requirements of Section 7.2. (A drawing or sketch of the plane location should be attached.) It is possible that Plane 2 will also meet the requirements for Plane 3 and possibly Plane 4. Plane 2 shall be a reference Plane for fan performance. The pressure loss between Plane 2 and Plane 4 shall be mutually agreed upon before the test.

AMCA STANDARD 803 TEST DATA SHEET

Plant: ____________________ Unit No.: ______________ Test No.: ______________ Date: __________
Fan Type and Size: ________________________________ Test Supervisor: ___________________________
Test Personnel: ____

Flow Rate (Plane 3) Data Sheet[1]

The location of Plane 3 shall meet the requirements of Section 7.2 and the cross sectional area shall be determined in accordance with Section 8.5. (A drawing or sketch of the plane location should be attached.) It is possible that Plane 1 will also meet the requirements for Plane 3. In this case, one set of measurements shall suffice for both planes.

DUCT SHAPE:

Measurement	Reading	Units of Measure
Dimension A		
Dimension B		
Dimension C		
Dimension D		

Velocity Pressure Readings[2]

The velocity pressure measurements shall be taken in accordance with the requirements of Section 6.5.2.

UNITS OF MEASUREMENT:

Position	Traverse Number					
	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

---

[1] Reference AMCA Standard 803 Section 7.2 and Section 7.5
[2] Reference AMCA Standard 803 Section 7.7

AMCA STANDARD 803 TEST DATA SHEET

Plant: ____________________ Unit No.: ______________ Test No.: ______________ Date: __________

Fan Type and Size: ______________________________ Test Supervisor: __________________________

Test Personnel: ____

Downstream Static Pressure Measurement (Plane 4) Data Sheet[1]

The location of Plane 4 shall meet the requirements of Section 7.2 and the cross sectional area shall be determined in accordance with Section 8.5. (A drawing or sketch of the plane location should be attached.) It is possible that Plane 3 or Plane 2 will also meet the requirements for Plane 4. In this case, one set of measurements shall suffice for both planes.

DUCT SHAPE:

Measurement	Reading	Units of Measure
Dimension A		
Dimension B		
Dimension C		
Dimension D		

Static Pressure Readings[2]

The static pressure measurements shall be taken in accordance with the requirements of Section 6.5.2 by Pitot traverse or by static pressure tap in accordance with Figure 6.6.

UNITS OF MEASUREMENT:

Position	Traverse Number					
	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

---

[1] Reference AMCA Standard 803 Section 7.2 and Section 7.6

[2] Reference AMCA Standard 803 Section 7.7

Annex L. References

[1] Air Movement and Control Association, Inc., *Laboratory Methods of Testing Fans for Rating*, ANSI/AMCA Standard 210, ANSI/ASHRAE Standard 51.

[2] Air Movement and Control Association, Inc., *Industrial Process/Power Generation Fans: Specifications Guidelines*, Publication 802-02.

[3] Page, C. H. and Vigoureux, P., *The International System of Units (SI)*, National Bureau of Standards, NBS Special Publication 330, 1972. (Now known as NIST).

[4] ibid, p. 19

[5] American Society of Mechanical Engineers, 1967 ASME *Steam Tables*, p. 283.

[6] Air Movement and Control Association, Inc., *Standards Handbook*, AMCA Standard 99-1986.

[7] Benedict, R. P., *Fundamentals of Temperature, Pressure and Flow Measurements*, P. 360-365.

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[9] American Society of Mechanical Engineers, *Instruments and Apparatus, Pressure Measurement*, ASME PTC 19.2.

[10] The Institue of Electrical and Electronic Engineers, *Standard Test Code for D C Machines*, IEEE 113-1985.

[11] American Society of Mechanical Engineers, *Performance Test Code-Gas Turbine Power Plants*, ASME PTC 22-1974-R1980.

[12] American Society of Mechanical Engineers, *Hydraulic Prime Movers*, ASME PTC 18-1949.

[13] American Society of Mechanical Engineers, *Performance Test Code-Steam Turbines, Simplified Procedures for Routine Tests*, ASME PTC 6S-1947-R1980.

[14] The Institute of Electrical and Electronic Engineers, *Test Procedure for Synchronous Machines*, IEEE 115-1983.

[15] International Organization for Standardization, *Fans for General Purposes - Methods of Testing Performance In-Situ*, ISO DIS 5802.

[16] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., ASHRAE Handbook 1997 *Fundamentals*, Chapter 32, Duct Design.

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