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Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating

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**ANSI/AMCA STANDARD 210-07
ANSI/ASHRAE STANDARD 51-07**

**Laboratory Methods of Testing Fans for
Certified Aerodynamic Performance Rating**



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Foreword

This edition of AMCA 210/ASHRAE 51 is the eleventh revision, spanning over eighty years of improvements in its test methods. The major changes reflected in this revision are:

- Added requirements for checking effectiveness of the airflow settling means (Annex A)
- Added methods for testing chamber leakage (Annex B)
- Introduced usage of a Star type straightener
- Refined the conversion from in. wg to Pa, which necessitated small but important changes in the constants used in I-P equations

Authority

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Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating

1. Purpose and Scope

This standard establishes uniform test methods for a laboratory test of a fan or other air moving device to determine its aerodynamic performance in terms of airflow rate, pressure developed, power consumption, air density, speed of rotation, and efficiency for rating or guarantee purposes.

This standard applies to a fan or other air moving device when air is used as the test gas with the following exceptions:

- (a) air circulating fans (ceiling fans, desk fans);
- (b) positive pressure ventilators;
- (c) compressors with inter-stage cooling;
- (d) positive displacement machines;
- (e) test procedures to be used for design, production, or field testing.

2. Normative References

The following standards contain provisions that, through specific reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

IEEE 112-96 *Standard Test Procedure for Polyphase Induction Motors and Generators*, The Institute of Electrical and Electronic Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, U.S.A. (AMCA #1149)

3. Definitions/Units of Measure/Symbols

3.1 Definitions

3.1.1 Fan. A device that uses a power-driven rotating impeller to move air or gas. The internal energy increase imparted by a fan to air or a gas is limited to 25 kJ/kg (10.75 Btu/lbm). This limit is approximately equivalent to a pressure of 30 kPa (120 in. wg). (AMCA 99-0066)

3.1.2 Fan inlet and outlet boundaries. The interfaces between a fan and the remainder of the air system; the respective planes perpendicular to an airstream entering or leaving a fan. Various appurtenances (inlet box(es), inlet vanes, inlet cone(s), silencer(s), screen(s), rain hood(s), damper(s), discharge cone(s), evasé, etc.), may be included as part of a fan between the inlet and outlet boundaries.

3.1.3 Fan input power boundary. The interface between a fan and its driver.

3.1.4 Fan outlet area. The gross inside area measured in the plane(s) of the outlet opening(s).

3.1.5 Fan inlet area. The gross inside area measured in the plane(s) of the inlet connection(s). For converging inlets without connection elements, the inlet area shall be considered to be that where a plane perpendicular to the airstream first meets the mouth of the inlet bell or inlet cone.

3.1.6 Dry-bulb temperature. Air temperature measured by a temperature sensing device without modification to compensate for the effect of humidity. (AMCA 99-0066)

3.1.7 Wet-bulb temperature. The air temperature measured by a temperature sensor covered by a water-moistened wick and exposed to air in motion. (AMCA 99-0066)

3.1.8 Wet-bulb depression. Wet-bulb depression is the difference between the **dry-bulb** and **wet-bulb** temperatures at the same location. (AMCA 99-0066)

3.1.9 Stagnation (total) temperature. The temperature that exists by virtue of the internal and kinetic energy of the air. If the air is at rest, the stagnation (total) temperature will equal the **static temperature**. (AMCA 99-0066)

3.1.10 Static temperature. The temperature that exists by virtue of the internal energy of the air. If a portion of the internal energy is converted into kinetic energy, the static temperature is decreased accordingly.

3.1.11 Air density. The mass per unit volume of air. (AMCA 99-0066)

3.1.12 Standard air. Air with a standard density of 1.2 kg/m^3 (0.075 lbm/ft^3) at a standard barometric pressure of 101.325 kPa (29.92 in. Hg).

3.1.12.1 Standard air properties. Standard air has a ratio of specific heats of 1.4 and a viscosity of $1.8185 \times 10^{-3} \text{ Pa}\cdot\text{s}$ ($1.222 \times 10^{-5} \text{ lbm/ft}\cdot\text{s}$). Air at 20°C (68°F) temperature, 50% relative humidity, and standard barometric pressure has the properties of standard air, approximately.

3.1.13 Pressure. Force per unit area. This corresponds to energy per unit volume of fluid. In the I-P system, pressures are expressed in manometric head pressure, such as inches of water or inches of mercury. The conversion of 1 in. wg = 249.089 Pa is used throughout this standard.

3.1.14 Absolute pressure. The **pressure** when the datum pressure is absolute zero. It is always positive.

3.1.15 Barometric pressure. The **absolute pressure** exerted by the atmosphere.

3.1.16 Gauge pressure. The differential **pressure** when the datum pressure is the **barometric pressure** at the point of measurement. It may be positive or negative.

3.1.17 Velocity pressure. The portion of air pressure that exists by virtue of the rate of motion of the air.

3.1.18 Static pressure. The portion of air pressure that exists by virtue of the degree of compression. If expressed as a gauge pressure, it may be positive or negative.

3.1.19 Total pressure. The air pressure that exists by virtue of the degree of compression and the rate of motion of the air. It is the algebraic sum of **velocity pressure** and **static pressure** at a point. If air is at rest, its total pressure will equal the **static pressure**.

3.1.20 Pressure loss. A decrease in total pressure due to friction and/or turbulence.

3.1.21 Fan air density. The density of the air corresponding to the total pressure and the stagnation (total) temperature of the air at the fan inlet.

3.1.22 Fan airflow rate. The volumetric airflow rate at fan air density.

3.1.23 Fan total pressure. The difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

3.1.24 Fan velocity pressure. The velocity pressure corresponding to the average velocity at the fan outlet.

3.1.25 Fan static pressure. The difference between the fan total pressure and the **fan velocity pressure**. Therefore, it is the difference between static pressure at the fan outlet and total pressure at the fan inlet.

3.1.26 Fan rotational speed. The rotational speed of the impeller. If the fan has more than one impeller, fan rotational speed is the rotational speed of each impeller.

3.1.27 Compressibility coefficient. The ratio of the mean airflow rate through the fan to the airflow rate at **fan air density**; 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, i.e., air, the test gas. The compressibility coefficient is a thermodynamic factor that must be applied to determine **fan total efficiency** from **fan airflow rate**, **fan total pressure**, and **fan power input**. The coefficient is derived in Annex D.

3.1.28 Fan power output. The useful power delivered to air by the fan; it is proportional to the product of the **fan airflow rate**, the **fan total pressure**, and the **compressibility coefficient**.

3.1.29 Fan power input. The power required to drive the fan and any elements in the drive train that are considered a part of the fan.

3.1.30 Fan total efficiency. The ratio of **fan power output** to **fan power input**.

3.1.31 Fan static efficiency. The **fan total efficiency** multiplied by the ratio of **fan static pressure** to **fan total pressure**.

3.1.32 Point of operation. The relative position on a fan characteristic curve corresponding to a particular airflow rate. It is controlled during a test by adjusting the position of a throttling device, by changing flow nozzles or auxiliary fan characteristics, or by any combination of these.

3.1.33 Free delivery. The **point of operation** where the **fan static pressure** is zero.

3.1.34 Shall and should. The word "shall" is to be understood as mandatory; the word "should" as advisory.

3.1.35 Shut-off. The **point of operation** where the **fan airflow rate** is zero.

3.1.36 Determination. A complete set of measurements for a particular **point of operation** of a fan.

3.1.37 Test. A series of **determinations** for various **points of operation** of a fan.

3.1.38 Energy factor. The ratio of the total kinetic energy of the airflow to the kinetic energy corresponding to the average velocity of the airflow.

3.1.39 Demonstrated accuracy. Demonstrated accuracy is defined for the purposes of this standard as the accuracy of an instrument or the method established by testing of the instrument or the method against a primary or calibrated instrument or method in accordance with the requirements of this standard.

3.2 Units of measure

3.2.1 System of units. SI units (The International System of Units – Le Système International d’Unités) [1] are the primary units employed in this standard, with I-P (inch-pound) units given as the secondary reference. SI units are based on the fundamental values of the International Bureau of Weights and Measures [2], 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. Conversion factors between SI and I-P systems are given in AMCA 99-0100.

3.2.2 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) in both systems. 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-force (lbf).

3.2.3 Airflow rate and velocity. The unit of airflow is the cubic meter per second (m^3/s); the I-P unit is the cubic foot per minute (ft^3/min or cfm). The unit of velocity is the meter per second (m/s); the I-P unit is the foot per minute (ft/min or fpm).

3.2.4 Pressure. The unit of pressure is the Pascal (Pa); the I-P unit is either the inch water gauge (in. wg) or the inch mercury column (in. Hg). Values of pressure in in. Hg, shall be used only for barometric pressure measurements. The standard pressures in the I-P system are based on the standard density of water of $1000 \text{ kg}/\text{m}^3$ ($62.428 \text{ lbm}/\text{ft}^3$) or standard density of mercury of $13595.1 \text{ kg}/\text{m}^3$ (848.714

lbm/ft^3) and the standard gravitational acceleration of $9.80665 \text{ m}/\text{s}^2$ ($32.17405 \text{ ft}/\text{s}^2$).

3.2.5 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-force ($\text{ft}\cdot\text{lbf}$). The unit of torque is the Newton-meter ($\text{N}\cdot\text{m}$); the I-P unit is the pound-force inch ($\text{lbf}\cdot\text{in.}$).

3.2.6 Efficiency. Efficiency is based on a per-unit basis. Percentages are obtained by multiplying by 100.

3.2.7 Rotational speed. The unit of rotational speed is the revolution per minute (rev/min or rpm).

3.2.8 Density, viscosity and gas constant. The unit of density is the kilogram per cubic meter (kg/m^3); the I-P unit is the pound-mass per cubic foot (lbm/ft^3). The unit of viscosity is the Pascal second ($\text{Pa}\cdot\text{s}$); the I-P unit is the pound-mass per foot-second ($\text{lbm}/\text{ft}\cdot\text{s}$). The unit of gas constant is the joule per kilogram Kelvin ($\text{J}/(\text{kg}\cdot\text{K})$); the I-P unit is the foot pound-force per pound-mass degree Rankine ($(\text{ft}\cdot\text{lb})/(\text{lbm}\cdot^\circ\text{R})$).

3.2.9 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.

3.3 Symbols and subscripts

See Table 1

4. Instruments and Methods of Measurement

4.1 Accuracy [3]

The specifications for instruments and methods of measurement that follow include both instrument accuracy and measurement accuracy requirements and specific examples of equipment capable of meeting those requirements. Equipment other than the examples cited may be used provided the accuracy requirements are met or improved upon.

4.1.1 Instrument accuracy. The specifications regarding accuracy correspond to two standard deviations based on an assumed normal distribution. The calibration procedures given in this standard shall be employed in order to minimize errors. Instruments shall be set up, calibrated and read by qualified personnel trained to minimize errors.

Table 1 - Symbols and Subscripts

SYMBOL	DESCRIPTION	SI	IP
A	Area of cross section	m^2	ft^2
C	Nozzle discharge coefficient	dimensionless	
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	Beam load	N	lbf
f	Coefficient of friction	dimensionless	
H	Fan power input	W	hp
H_o	Fan power output	W	hp
K_p	Compressibility coefficient	dimensionless	
L	Nozzle throat dimension	m	ft
L_e	Equivalent length of straightener	m	ft
$L_{x,x'}$	Length of duct between planes x and x'	m	ft
l	Length of moment arm	m	$in.$
$\ln$	Natural logarithm	---	---
M	Chamber diameter or equivalent diameter	m	ft
N	Rotational speed	rpm	
n	Number of readings	dimensionless	
P_s	Fan static pressure	Pa	$in. \text{ wg}$
P_{sx}	Static pressure at plane x	Pa	$in. \text{ wg}$
P_t	Fan total pressure	Pa	$in. \text{ wg}$
P_{tx}	Total pressure at plane x	Pa	$in. \text{ wg}$
P_v	Fan velocity pressure	Pa	$in. \text{ wg}$
P_{vx}	Velocity pressure at plane x	Pa	$in. \text{ wg}$
p_b	Corrected barometric pressure	Pa	$in. \text{ Hg}$
p_e	Saturated vapor pressure at t_w	Pa	$in. \text{ Hg}$
p_p	Partial vapor pressure	Pa	$in. \text{ Hg}$
Q	Fan airflow rate	m^3/s	$cfm, ft^3/min$
Q_x	Airflow rate at plane x	m^3/s	$cfm, ft^3/min$
R	Gas constant	$J/kg \cdot K$	$ft \cdot lb/lbm \cdot ^\circ R$
Re	Reynolds number	dimensionless	
T	Torque	$N \cdot m$	$lbf \cdot in.$
t_d	Dry-bulb temperature	$^\circ C$	$^\circ F$
t_s	Stagnation (total) temperature	$^\circ C$	$^\circ F$
t_w	Wet-bulb temperature	$^\circ C$	$^\circ F$
V	Velocity	m/s	$ft/min, fpm$
W	Power input to motor	W	W
x	Function used to determine K_p	dimensionless	
Y	Nozzle expansion factor	dimensionless	
y	Thickness of airflow straightener element	mm	$in.$
z	Function used to determine K_p	dimensionless	
α	Static pressure ratio for nozzles	dimensionless	
σ	Diameter ratio for nozzles	dimensionless	
γ	Ratio of specific heats	dimensionless	
ΔP	Pressure differential	Pa	$in. \text{ wg}$
H	Motor efficiency	per unit	
η_s	Fan static efficiency	per unit	
η_t	Fan total efficiency	per unit	
μ	Dynamic air viscosity	$Pa \cdot s$	$lbm/ft \cdot s$
ρ	Fan air density	Kg/m^3	lbm/ft^3
ρ_x	Air density at plane x	Kg/m^3	lbm/ft^3

Table 1 (continued)

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 (duct piezometer station)
5	Plane 5 (nozzle inlet station in chamber)
6	Plane 6 (nozzle discharge station)
7	Plane 7 (outlet chamber measurement station)
8	Plane 8 (inlet chamber measurement station)

4.1.2 Measurement uncertainty. Every test measurement contains some error and the true value cannot be known because the magnitude of the error cannot be determined exactly. However, it is possible to perform an uncertainty analysis to identify a range of values within which the true value probably lies. A probability of 95% has been chosen as acceptable for this standard.

The standard deviation of random errors can be determined by statistical analysis of repeated measurements. No statistical means are available to evaluate systematic errors, so these must be estimated. The estimated upper limit of a systematic error is called the systematic uncertainty, and, if properly estimated, it will contain the true value 99% of the time. The two standard deviation limit of a random error has been selected as the random uncertainty. Two standard deviations yield 95% probability for random errors.

4.1.3 Uncertainty of results. The results of a fan test are the various fan performance variables listed in Sections 3.1.21 through 3.1.31. Each result is based on one or more measurements. The uncertainty in any result can be determined from the uncertainties in the measurement. It is best to determine the systematic uncertainty and then the random uncertainty of the result before combining them into the total uncertainty of the result. This may provide clues on how to reduce the total uncertainty. When the systematic uncertainty is combined in quadrature with the random uncertainty, the total uncertainty will give 95% coverage. In most test situations, it is wise to perform a pre-test uncertainties analysis to identify potential problems. A pre-test uncertainties analysis is not required for each test covered by this standard because it is recognized that most laboratory tests for rating are conducted in facilities where similar tests are repeatedly run. Nevertheless, a pre-test analysis is recommended, as is a post-test analysis. The

simplest form of analysis is through verification that all accuracy and calibration requirements of this standard have been met. The most elaborate analysis would consider all of the elemental sources of error including those due to calibration, data acquisition, data reduction, calculation assumptions, environmental effects, and operational steadiness.

The sample analysis given in Annex F calculates the uncertainty in each of the fan performance variables, and in addition, combines certain ones into a characteristic uncertainty and others into an efficiency uncertainty.

4.2 Pressure

The total pressure at a point shall be measured on an indicator such as a manometer with one leg open to atmosphere and the other leg connected to a total pressure sensor, such as the total pressure tube or the impact tap of a Pitot-static tube.

The static pressure at a point shall be measured on an indicator such as a manometer with one leg connected to atmosphere and the other leg connected to a static pressure sensor, such as a static pressure tap or the static tap of a Pitot-static tube.

The velocity pressure at a point shall be measured on an indicator such as a manometer with one leg open to a total pressure sensor, such as the impact tap of a Pitot-static tube, and the other leg connected to a static pressure sensor such as the static tap of the same Pitot-static tube.

The differential pressure between two points shall be measured on an indicator, such as a manometer, with one leg connected to the upstream sensor, such as a static pressure tap, and the other leg connected to the downstream sensor, such as a static pressure tap.

4.2.1 Manometers and other pressure indicating instruments. Pressure shall be measured on manometers of the liquid column type using inclined or vertical legs, or other instrument that provides a maximum uncertainty of 1% of the maximum observed reading during the test or 1 Pa (0.005 in. wg), whichever is larger.

Note: The specification permitting an uncertainty based on the maximum observed test reading during the test leads to combined relative uncertainties in both fan pressure and fan airflow rate that are higher at low values of the fan pressure or fan airflow rate than at high values of those test results. This is generally acceptable because fans are not usually rated at the low pressure or low flow portions of their characteristic curves. If there is a need to reduce the uncertainty at either low flow or low pressure, then the instruments chosen to measure the corresponding quantity must be selected with suitable accuracy (lower uncertainties) for those conditions.

4.2.1.1 Calibration. Each pressure indicating instrument shall be calibrated at both ends of the measurement scale plus at least nine equally spaced intermediate points in accordance with the following:

- (1) When the pressure to be indicated falls in the range of 0 to 2.5 kPa (0 to 10 in. wg), calibration shall be against a water-filled hook gauge of the micrometer type or a precision micromanometer.
- (2) When the pressure to be indicated is above 2.5 kPa (10 in. wg), calibration shall be against a water-filled hook gauge of the micrometer type, a precision micromanometer, or a water-filled U-tube.

4.2.1.2 Averaging. To obtain a representative reading, an instrument must either be damped or the reading must be averaged in a suitable manner. Averaging can be accomplished mentally if the fluctuations are small and regular. Multi-point or continuous-record averaging can be accomplished with instruments or analyzers designed for this purpose. The user is cautioned that this latter type of equipment may yield unreliable readings for a fan operating in an unstable region of its performance curve.

4.2.1.3 Correction. Manometer of the liquid column type readings should be corrected for any difference in change of length of the graduated scale of the manometer if the temperature of the ambient air differs from the temperature at which it was calibrated. The manufacturer of the manometer must supply the information for correction of the graduated scale due to temperature changes.

In case of using manometric head pressure, such as inches of water or mercury, the readings should be corrected for any difference in density of gauge liquid from standard and any difference in local gravitational acceleration from standard. The standard density of water or mercury and the standard gravitational acceleration are defined in Section 3.2.4

4.2.2 Pitot-static tube [4][5]. The total pressure or static pressure at a point may be sensed with a Pitot-static tube of the proportions shown in Figure 1A and 1B. Either or both of these pressure signals can then be transmitted to a manometer or other indicator. If both pressure signals are transmitted to the same indicator, the differential is considered velocity pressure at the point of the impact opening.

4.2.2.1 Calibration. A Pitot-static tube having the proportions shown in Figures 1A and 1B is considered a primary instrument and need not be calibrated, provided it is maintained in a condition conforming to this standard.

4.2.2.2 Size. The Pitot-static tube shall be of sufficient size and strength to withstand the pressure forces exerted upon it. The outside diameter of the tube shall not exceed 1/30 of the test duct diameter except that when the length of the supporting stem exceeds 24 tube diameters, the stem may be progressively increased beyond this distance. The minimum practical tube diameter is 2.5 mm (0.10 in.).

4.2.2.3 Support. Rigid support shall be provided to hold the Pitot-static tube axis parallel to the axis of the duct within 3 degree and at the head locations specified in Figure 3 within 1 mm (0.05 in.) or 0.25% of the duct diameter, whichever is larger.

4.2.3 Static pressure tap. The static pressure at a point may be sensed with a pressure tap of the proportions shown in Figure 2A. The pressure signal can then be transmitted to an indicator.

4.2.3.1 Calibration. A static pressure tap meeting the requirements shown in Figure 2A is considered a primary instrument and need not be calibrated provided it is maintained in a condition conforming to this standard. Every precaution should be taken to ensure that the air velocity does not influence the pressure measurement.

4.2.3.2 Averaging. A pressure tap is sensitive only to the pressure in the immediate vicinity of the opening. In order to obtain an average, at least four taps meeting the requirements of Figure 2A shall be manifolded into a piezometer ring. The manifold shall have an inside area at least four times that of each tap. An example is shown in Annex

4.2.3.3 Piezometer ring. A piezometer ring is specified for pressure measurement at upstream and downstream nozzle taps and for outlet duct or chamber measurement, unless a Pitot traverse is specified. Measurement planes shall be located as shown in setup Figures 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C, 11, 12, 13, 14 or 15. See Annex C.

4.2.4 Total pressure tube. The total pressure in an inlet chamber may be sensed with a stationary tube of the proportions and requirements shown in Figure 2B. The tube shall face directly into the airflow.

4.2.4.1 Calibration. A total pressure tube is considered a primary instrument and need not be calibrated provided if it is maintained in a condition conforming to this standard.

4.2.4.2 Total pressure tubes used with setup Figures 13, 14, and 15. A total pressure tube is sensitive only to the pressure in the immediate vicinity of the open end. Locate the tube as shown in the setup figure. Since the air velocity in an inlet chamber is considered uniform due to the settling means employed, a single measurement is representative of the average chamber pressure.

4.2.5 Other pressure measurement systems. A pressure measurement system consisting of indicators and sensors other than manometers and Pitot-static tubes, pressure taps, or total pressure tubes may be used if the combined uncertainty of the system, including any transducers, does not exceed the combined uncertainty for an appropriate combination of manometers and Pitot-static tubes, pressure taps, or total pressure tubes. For a system used to determine fan pressure, the contribution to combined uncertainty in the pressure measurement shall not exceed that corresponding to 1% of the maximum observed static or total pressure reading during a test (indicator accuracy), plus 1% of the actual reading (averaging accuracy). For a system used to determine fan airflow rate, the combined uncertainty shall not exceed that corresponding to 1% of the maximum observed velocity pressure or differential pressure reading during a test (indicator accuracy), plus 1% of the actual reading (averaging accuracy). See Note in Section 4.2.1.

4.3 Airflow rate

Airflow rate shall be calculated as required by Section 7.3 either from measurements of pressure differential across a flow nozzle or from measurements of velocity pressure obtained by Pitot traverse.

4.3.1 Pitot traverse. Airflow rate may be calculated from velocity pressure measurements obtained by

traverses of a duct with a Pitot-static tube for any point of operation from free delivery to shut-off, provided that average velocity corresponding to the airflow rate at free delivery at the test speed is at least 12 m/s (2400 fpm) [6]. See Note in Section 4.2.1.

4.3.1.1 Stations. The number and locations of the measuring stations on each diameter and the number of diameters shall be as specified in Figure 3.

4.3.1.2 Averaging. The stations shown in Figure 3 are located on each diameter according to the log-linear rule [7]. The arithmetic mean of the individual velocity pressure measurements made at these stations will be the mean air velocity through the measurement section for a wide variety of profiles [8].

4.3.2 Flow nozzle. Airflow rate may be calculated from the pressure differential measured across a flow nozzle or bank of flow nozzles for any point of operation from free delivery to shut-off, provided that the average velocity at the flow nozzle discharge corresponding to the airflow rate at free delivery at the test speed is at least 14 m/s (2800 fpm) [6].

4.3.2.1 Size. The flow nozzle or flow nozzles shall conform to Figure 4. A flow nozzle may be any convenient size except when a duct is connected to the inlet of a flow nozzle, in which case the ratio of flow nozzle throat diameter to the diameter of the inlet duct shall not exceed 0.5.

4.3.2.2 Calibration. A flow nozzle meeting the requirements of this standard is considered a primary instrument and need not be calibrated if maintained in a condition conforming to this standard. Coefficients have been established for flow nozzle throat proportions $L = 0.5D$ and $L = 0.6D$, shown in Figure 4 [9]. Flow nozzle proportion $L = 0.6D$ is recommended for new construction.

4.3.2.3 Chamber flow nozzle. A flow nozzle without an integral throat tap may be used in a multiple nozzle chamber, in which case, upstream and downstream pressure taps shall be located as shown in the figure for the appropriate setup. An acceptable alternative is the use of a nozzle with a throat tap in which case the throat tap located as shown in Figure 4 shall be used in place of the downstream pressure tap shown in the figure for the setup and the piezometer for each flow nozzle shall be connected to its own indicator.

4.3.2.4 Ducted flow nozzle. A flow nozzle with an integral throat tap shall be used for a ducted flow nozzle setup. An upstream pressure tap shall be located as shown in the figure for the appropriate setup. The downstream tap is the integral throat tap

and shall be located as shown in Figure 4.

4.3.2.5 Pressure tap. Each pressure tap shall conform to the requirements in Section 4.2.3.

4.3.3 Other airflow measurement methods. An airflow measurement method that utilizes a meter or traverse other than an airflow nozzle or Pitot traverse shall be acceptable under this standard if the uncertainty introduced by the method does not exceed that introduced by an appropriate flow nozzle or Pitot-static traverse method. The contribution to the combined uncertainty in the airflow measurement shall not exceed that corresponding to 1.2% of the discharge coefficient for a flow nozzle [10].

4.4 Fan input power

Power shall be determined from the rotational speed and beam load measured on a reaction dynamometer, from the rotational speed and torque measured on a torsion element, or the electrical input measured on a calibrated motor.

4.4.1 Reaction dynamometers. A cradle or torque-table type reaction dynamometer having a demonstrated accuracy of $\pm 2\%$ of observed reading may be used to determine fan input power.

4.4.1.1 Calibration. A reaction dynamometer shall be calibrated through its range of usage by suspending weights from a torque arm. The weights shall have certified accuracies of $\pm 0.2\%$. The length of the torque arm from rotational center to any given point of weight suspension shall be determined to an accuracy of $\pm 0.2\%$.

4.4.1.2 Tare. The zero torque equilibrium (tare) shall be checked before and after each test. The difference between the two tare values shall be within 0.5% of the maximum value measured during the test.

4.4.2 Torque. A torque meter having a demonstrated accuracy of $\pm 2\%$ of observed reading may be used to determine fan input power.

4.4.2.1 Calibration. A torque measurement device shall have a static calibration and may have a running calibration through its range of use. The static calibration shall be accomplished by suspending weights from a torque arm. The weights shall have certified accuracies of $\pm 0.2\%$. The length of the torque arm from its rotational center to any given point of weight suspension shall be determined to an accuracy of $\pm 0.2\%$.

4.4.2.2 Tare. The zero torque equilibrium (tare) and the span of the readout system shall be checked

before and after each test. In each case, the difference between the two readings shall be within 0.5% of the maximum respective value measured during the test.

4.4.3 Calibrated motor. Fan input power can be determined by measuring the electrical power input to the fan's motor only if the motor is calibrated. Calibrated motors shall have a demonstrated accuracy of $\pm 2\%$.

4.4.3.1 Motor calibration. A motor shall be calibrated throughout its range of use against an absorption dynamometer except as provided in Section 4.4.3.4. The absorption dynamometer shall be calibrated by suspending weights from a torque arm. The weights shall have accuracies of $\pm 0.2\%$. The length of the torque arm from rotational center to any given point of weight suspension shall be determined to an accuracy of $\pm 0.2\%$.

4.4.3.2 Electrical meter. An electrical meter shall have a certified accuracy of $\pm 1.0\%$ of observed reading.

4.4.3.3 Voltage. The motor input voltage during the test shall be within 1% of the voltage observed during calibration.

4.4.3.4 IEEE Calibration. A polyphase induction motor may be calibrated by using the IEEE Segregated Loss Method [11].

4.4.4 Averaging. The torque measured on any instrument will fluctuate with time. In order to obtain a representative reading, either the instrument must be damped or the readings must be averaged in a suitable manner. Averaging can be accomplished mentally if the fluctuations are small and regular. Multi-point or continuous-record averaging can be accomplished with instruments or analyzers designed for this purpose. The user is cautioned that this latter type of equipment may yield unreliable readings for a fan operating in an unstable region of its performance curve, and care must be taken to ensure that the fan operates without pressure/airflow instability.

4.5 Rotational speed

Rotational speed shall be measured with a revolution counter and chronometer, with a stroboscope and chronometer, with a precision instantaneous tachometer, or with an electronic counter-timer. The fan shaft speed shall be measured at regular intervals throughout the period of test for each test point, so as to ensure the determination of average rotational speed during each such period with an

uncertainty not exceeding $\pm 0.5\%$. No device used shall significantly affect the rotational speed of the fan under test or its performance.

4.5.1 Stroboscope. 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.

4.5.2 Direct readout mechanical or electrical tachometer. These devices shall be free from slip and calibrated. The smallest division on the scale of such an instrument should represent not more than 0.25% of the measured rotational speed.

4.5.3 Other devices. Any other device that has a demonstrated accuracy of $\pm 0.5\%$ of the value being measured may be used. A friction-driven counter shall not be used when it can influence the rotational speed due to drag.

4.6 Air density

Air density shall be determined from measurements of wet-bulb temperature, dry-bulb temperature, and barometric pressure. Other parameters may be measured and used if the maximum error in the calculated density does not exceed 0.5%.

4.6.1 Thermometer. Wet-bulb and dry-bulb temperatures shall be measured with thermometer or other instruments with a demonstrated accuracy of $\pm 1^\circ\text{C}$ ($\pm 2^\circ\text{F}$) and a readability of 0.5°C (1°F) or finer.

4.6.1.1 Calibration. A thermometer shall be calibrated over the range of temperatures to be encountered during test against a thermometer with a calibration traceable to the National Institute of Standards and Technology (NIST) or other national physical measure recognized as equivalent by NIST.

4.6.1.2 Measurement conditions. A wet-bulb thermometer shall have an air velocity over the water-moistened wick-covered bulb of 3.5 to 10 m/s (700 to 2000 fpm) [12]. A dry-bulb thermometer shall be mounted upstream of the wet-bulb thermometer. Wet-bulb and dry-bulb thermometers should be of the same type.

4.6.2 Barometer. Ambient barometric pressure shall be measured with a mercury column barometer or other instrument having a demonstrated accuracy of $\pm 170\text{ Pa}$ ($\pm 0.05\text{ in. Hg}$) and readable to 34 Pa (0.01 in. Hg) or finer.

4.6.2.1 Calibration. Mercury column barometers shall have a calibration traceable to the National Institute of Standards and Technology (NIST) or other

national physical measure recognized as equivalent by NIST. A transducer type barometer shall be calibrated for each test.

4.6.2.2 Corrections. A barometer reading shall be corrected for any difference in mercury density from standard or for any change in the length of the graduated scale due to temperature. Refer to barometer manufacturer's instructions and ASHRAE 41.3, Annex B.

5. Test Setups and Equipment

5.1 Setup

Sixteen test setups are diagrammed in Figures 7A, 7B, 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C, 11, 12, 13, 14, 15 and 16.

5.1.1 Installation types. A fan shall be tested under this standard according to one of the four general Installation Types that exist in actual applications. These types are [13]:

- A: Free Inlet, Free Outlet
- B: Free Inlet, Ducted Outlet
- C: Ducted Inlet, Free Outlet
- D: Ducted Inlet, Ducted Outlet

5.1.2 Selection guide. Table 2 may be used as a guide to the selection of an appropriate setup.

Table 2 – Selection Guide

Setup Figure	Installation Type			
	A	B	C	D
7A, 7B, 8A, 8B, 9A, 9B, 9C, 10A, 10B, 10C		NS		NS (a)
11, 12, 13, 14, or 15	Y (b)	Y (c)	Y (a,d)	Y (a,c)
16			Y	Y (c)

NS = Not suitable for fans with significant swirl

Y = Suitable for all fan types

Notes:

- (a) A simulated inlet duct may be used
- (b) An auxiliary inlet bell or outlet duct may not be used
- (c) An outlet duct or a short outlet duct, per Section 5.2.3, may be used
- (d) No outlet duct may be used

5.1.3 Leakage. All joints in the chamber, ducts and other equipment between the fan and the flow measuring plane, including the nozzle wall, if applicable, should be designed and constructed to practically eliminate leakage.

Leakage through the chamber and the duct walls between the flow measurement plane and the fan under the test shall be practically eliminated for the pressure range in the chamber during the test.

A leakage test should be performed prior to initial use and periodically thereafter, with corrective action taken if necessary. See Annex B for two recommended leakage test methods.

5.2 Duct

A duct may be incorporated in a laboratory test setup to provide a measurement plane or to simulate the conditions the fan is expected to encounter in service, or both. Dimension D_3 or D_4 in the test setup figures are the inside diameter of a circular cross-section duct or equivalent diameter of a rectangular cross-section duct with inside traverse dimensions a and b , where:

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

5.2.1 Long Ducts

5.2.1.1 Airflow measurement duct. A duct with a measurement plane for airflow determination shall be straight and have a uniform circular cross-section. A Pitot traverse duct shall be at least 10 diameters long with the traverse plane located between 8.5 and 8.75 diameters from the upstream end. Such a duct may serve as an inlet duct or an outlet duct as well as to provide a measurement plane. A duct connected to the upstream side of a flow nozzle shall be between 6.5 and 6.75 diameters long when used only to provide a measurement plane or between 9.5 and 9.75 diameters long when used as an outlet duct as well.

5.2.1.2 Pressure measurement duct. A duct with a plane for pressure measurement shall be straight and may have either a uniform circular or rectangular cross-section. An outlet duct with a Piezometer ring shall be at least 10 diameters long with the Piezometer plane located between 8.5 and 8.75 diameters from the upstream end.

5.2.1.3 Transition pieces. Transition pieces shall be used when a duct with a measuring plane is to be connected to the fan and it is of a size or shape that differs from the fan connection. Such pieces shall not contain any converging element that makes an angle with the duct axis greater than 7.5° or a diverging element that makes an angle with the duct axis of greater than 3.5° . The axes of the fan opening and duct shall coincide. See Figure 5. Connecting ducts and elbows of any size and shape may be used

between a duct that provides a measurement plane and a chamber. This will lead to non-reproducible results unless actual duct configuration is identified.

5.2.1.4 Duct area. An outlet duct used to provide a measurement station shall not have an area more than 5.0% larger or smaller than the fan outlet area. An inlet duct used to provide a measurement station shall not be more than 12.5% larger, nor 7.5% smaller than the fan inlet area.

5.2.1.5 Roundness. The portion of a Pitot traverse duct within $0.5D$ of either side of the plane of measurement shall be round within 0.5% of the duct diameter. The remainder of the duct shall be round within 1% of the duct diameter. The area of the plane of measurement shall be determined from the average of 4 diameters measured at 45° increments. The diameter measurements shall be accurate to within 0.2%.

5.2.1.6 Airflow straightener. An airflow straightener is specified so that flow lines will be approximately parallel to the duct axis. An airflow straightener shall be used in any duct that provides a measurement plane. The form of the airflow straightener shall be as specified in Figure 6A or 6B. To avoid excessive pressure drop through the airflow straightener, careful attention to construction tolerances and details is important [14].

5.2.2 Common segment. A standardized air path of a controlled geometry used to provide consistent test results between different test configurations. The geometry of the common segment is adapted from ISO 5801.

5.2.2.1 Common segment on the fan outlet. The geometry of the common segments used for testing on the outlet side of the fan is defined in Figures 18, 19 and 20. It incorporates a flow straightener per Figure 6B and a pressure measurement station one diameter from the exit end. Figures 19 and 20 also define the geometry of transition pieces from the fan outlet to the duct, and the limits of the duct area's deviation from the fan outlet area.

5.2.3 Simulated ducts

5.2.3.1 Short outlet duct. A short outlet duct that is used to simulate Installation Types B and D, but in which no measurements are taken shall be between 2 and 3 equivalent diameters long, have an area within 1% of the fan outlet area, and of a uniform shape to fit the fan outlet [15].

5.2.3.2 Short inlet duct. An inlet bell or an inlet bell and one equivalent duct diameter of inlet duct may be

mounted on the fan inlet to simulate an inlet duct. The bell and duct shall be of the same size and shape as the fan inlet boundary connection.

5.3 Chamber

A chamber may be incorporated in a laboratory test setup to provide a measurement station or to simulate the conditions the fan is expected to encounter in service, or both. The chamber may have either a circular or rectangular cross-sectional shape. The dimension M in the test setup diagram is the inside diameter of a circular chamber or the equivalent diameter of dimensions a and b , where:

$$M = \sqrt{(4ab/\pi)} \quad \text{Eq. 6.3}$$

5.3.1 Outlet chamber. An outlet chamber (Figure 11 or 12) shall have a cross-sectional area at least nine times the area of the fan outlet or outlet duct for a fan with axis of rotation perpendicular to the discharge airflow and a cross-sectional area at least sixteen times the area of the fan outlet or outlet duct for a fan with axis of rotation parallel to the discharge airflow. [16]

5.3.2 Inlet chamber. An inlet chamber (Figure 13, 14 or 15) shall have a cross-sectional area at least five times the fan inlet area.

5.3.3 Airflow settling means. Airflow settling means shall be installed in chambers where indicated on the test setup figures. When the tested fan or a pressure measurement plane is located downstream of the settling means, the purpose of the settling means is to provide a substantially uniform flow ahead of the tested fan or pressure measurement plane. When the test fan or airflow measurement nozzles are located upstream of the settling means, the purpose of the settling means is to absorb the kinetic (velocity) energy of the upstream jet velocity and allow its expansion as if in an unconfined space.

Generally, several screens in each airflow settling means will be required. Any combination of screens or perforated sheets may be used. However, three or four screens with decreasing percent of open area in the direction of airflow are suggested. It is also suggested that, within each settling means, screens of square mesh round wire be used upstream with perforated sheet used downstream. An open area of 50% to 60% is suggested for the initial screen.

All chambers must meet the requirements described in Annex A for the purposes of this standard.

5.3.4 Multiple nozzles. Multiple nozzles shall be

located as symmetrically as possible. The centerline of each nozzle shall be at least 1.5 nozzle throat diameters from the chamber wall. The minimum distance between the centers of any two nozzles in simultaneous use shall be three times the throat diameter of the larger nozzle.

The uncertainty of the airflow rate measurement can be reduced by changing to a smaller nozzle or combination of nozzles for the lower airflow rate range of the fan.

Unused nozzles may be sealed on any test.

5.4 Variable air supply and exhaust systems

A means of varying the fan point of operation shall be provided in a laboratory test setup.

5.4.1 Throttling device. A throttling device may be used to control the fan point of operation. Such a device shall be located on the end of the test duct or test chamber and should be symmetrical about the duct or chamber axis.

5.4.2 Auxiliary fan. Auxiliary fans may be used to control the point of test fan operation. They shall provide sufficient pressure at the desired airflow to overcome losses through the test setup. Airflow adjustment means, such as dampers, auxiliary fan blade or auxiliary fan inlet vane pitch control, or speed control may be required. An auxiliary fan shall not surge or pulsate during a test.

6. Observations and Conduct of Test

6.1 General test requirements

6.1.1 Determinations. The number of determinations required to establish the performance of a fan over the range from shut-off to free delivery will depend upon the shape of the characteristic curve of the fan under test. Plans shall be made to vary the opening of the throttling device in such a way that the test determinations will be well-spaced. At least 8 determinations shall be made. Additional determinations may be required to define the curve or a portion thereof for a fan that exhibits a dip or other discontinuity. When performance at only one point of fan operation or performance only over a portion of the characteristic curve is required, the number of determinations shall be sufficient to define the performance range of interest, but at least 3 determinations are required to define a single point of fan operation.

6.1.2 Equilibrium. Equilibrium conditions shall be established before each determination. To test for

equilibrium, trial observations shall be made until steady readings are obtained. The range of airflow over which equilibrium cannot be established shall be recorded and reported.

6.1.3 Stability. Any bi-stable performance points (airflow rates at which two different pressure values can be measured) shall be reported. When a result of hysteresis, the points shall be identified as that for decreasing airflow rate and that for increasing airflow rate.

6.2 Data to be recorded

6.2.1 Test fan. The description of the test fan shall be recorded. The nameplate data should be copied. Dimensions should be checked against a drawing and a copy of the drawing attached to the recorded data.

6.2.2 Test setup. The description of the test setup, including specific dimensions, shall be recorded. Reference may be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup may be attached to the recorded data.

For setups using nozzles, the nozzle diameters shall be recorded.

6.2.3 Instruments. The instruments and apparatus used in the test shall be listed. Names, model numbers, serial numbers, scale ranges and calibration information should be recorded.

6.2.4 Test data. The test data which must be recorded varies by setup figure and is shown in Table 3. One reading for each checked parameter is required for each test point with the following exceptions:

- (1) When environmental conditions are varying, a minimum of three readings shall be taken for t_{d0} , t_{w0} , t_{d2} , and p_b .
- (2) One reading for each Pitot station shall be recorded for P_{v3r} and P_{s3r} .
- (3) For a test where P_s is less than 1 kPa (4 in. wg), the temperatures t_{d3} , t_{d4} , t_{d5} , t_{d7} , and t_{d8} need not be measured. The value t_{d0} may be used.
- (4) For setups Figure 11 and 12, t_{d2} may be considered equal to t_{d5} and P_{s5} may be considered equal to P_{s7} .
- (5) A piezometer can be used to measure P_{s8} instead

of P_{18} . See Figures 13 or 14, Note 5, or Figure 15, Note 6, for requirements.

- (6) For setup Figure 15, P_{s5} may be calculated. See Figure 15, Note 5.

6.2.5 Personnel. The names of test personnel shall be listed with the data for which they are responsible.

7. Calculations

7.1 Calibration correction

Calibration correction, when required, shall be applied to individual readings before averaging or other calculations. Calibration correction need not be made if the correction is smaller than one-half the maximum allowable uncertainty, as specified in Section 4.

7.2 Density and viscosity of air

7.2.1 Atmospheric air density. The atmospheric air density (ρ_0) shall be determined from measurements taken in the general test area, and of ambient dry-bulb temperature (t_{d0}), ambient wet-bulb temperature (t_{w0}), and ambient barometric pressure (p_b) using the following formulae [17]:

$$p_e = 3.25t_{w0}^2 + 18.6t_{w0} + 692 \quad \text{Eq. 7.1 SI}$$

$$p_e = (2.96 \times 10^{-4})t_{w0}^2 - (1.59 \times 10^{-2})t_{w0} + 0.41 \quad \text{Eq. 7.1 I-P}$$

$$p_p = p_e - p_b \left(\frac{t_{d0} - t_{w0}}{1500} \right) \quad \text{Eq. 7.2 SI}$$

$$p_p = p_e - p_b \left(\frac{t_{d0} - t_{w0}}{2700} \right) \quad \text{Eq. 7.2 I-P}$$

$$\rho_0 = \frac{p_b - 0.378p_p}{R(t_{d0} + 273.15)} \quad \text{Eq. 7.3 SI}$$

$$\rho_0 = \frac{70.73(p_b - 0.378p_p)}{R(t_{d0} + 459.67)} \quad \text{Eq. 7.3 I-P}$$

Equation 7.1 is approximately correct for p_e for a range of t_{w0} between 4°C and 32°C (40°F and 90°F). The gas constant R, for air, may be taken as 287.1 J/kg•K (53.35 ft•lbf/lbm•°R).

7.2.2 Duct or chamber air density. The air density in a duct or chamber at static pressure p_s (ρ_s) may be

Table 3 – Test Data to be Recorded

Item Description	Parameter	Setup Figure															
		7A	7B	8A	8B	9A	9B	9C	10A	10B	10C	11	12	13	14	15	16
Barometric Pressure	P_b	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Rotational Speed	N	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Beam Load or Torque or Input Power	F or T or W	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Velocity Pressure	P_{v3r}	x	x	x										x			x
Static Pressure	P_{s3r}	x	x	x										x			x
	P_{s4}			x	x	x	x	x	x	x	x				x		
	P_{s5}					x	x	x	x	x	x	x	x			x	
	P_{s7}											x	x				
Total Pressure	P_{t8}													x	x	x	
Temperature	t_{d0}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	t_{w0}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	t_{d2}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	t_{d3}	x	x											x			x
	t_{d4}			x	x	x	x	x	x	x	x				x		
	t_{d5}					x	x	x	x	x	x	x	x			x	
	t_{d8}													x	x	x	
Nozzle Pressure Drop	ΔP			x	x	x	x	x	x	x	x	x	x		x	x	

calculated by correcting the density of atmospheric air (ρ_0) for the static pressure (P_{sx}) and dry-bulb temperature (t_{dx}) at Plane x using:

$$\rho_x = \rho_0 \left[\frac{t_{d0} + 273.15}{t_{dx} + 273.15} \right] \left[\frac{P_{sx} + P_b}{P_b} \right] \quad \text{Eq. 7.4 SI}$$

$$\rho_x = \rho_0 \left[\frac{t_{d0} + 459.67}{t_{dx} + 459.67} \right] \left[\frac{P_{sx} + 13.595P_b}{13.595P_b} \right] \quad \text{Eq. 7.4 I-P}$$

7.2.3 Fan air density. The fan air density (ρ) shall be calculated from the atmospheric air density (ρ_0), the total pressure at the fan inlet (P_{t1}), and the stagnation (total) temperature at the fan inlet (t_{s1}) using:

$$\rho = \rho_0 \left[\frac{P_{t1} + P_b}{P_b} \right] \left[\frac{t_{d0} + 273.15}{t_{s1} + 273.15} \right] \quad \text{Eq. 7.5 SI}$$

$$\rho = \rho_0 \left[\frac{P_{t1} + 13.595P_b}{13.595P_b} \right] \left[\frac{t_{d0} + 459.67}{t_{s1} + 459.67} \right] \quad \text{Eq. 7.5 I-P}$$

On all outlet duct and outlet chamber setups, P_{t1} is equal to zero and t_{s1} is equal to t_{d0} . On all inlet

chamber setups, P_{t1} is equal to P_{t8} and t_{s1} is equal to t_{d8} . On the inlet duct setup, t_{s1} is equal to t_{d3} and P_{t1} may be considered equal to P_{t3} for fan air density calculations.

7.2.4 Dynamic air viscosity. The viscosity (μ) shall be calculated from:

$$\mu = (17.23 + 0.048t_d) \times 10^{-6} \quad \text{Eq. 7.6 SI}$$

$$\mu = (11.00 + 0.018t_d) \times 10^{-6} \quad \text{Eq. 7.6 I-P}$$

The value for 20°C (68°F) air, which is 1.819×10^{-5} Pa•s (1.222×10^{-5} lbfm/ft•s), may be used between 4°C (40°F) and 40°C (100°F) [9].

7.3 Fan airflow rate at test conditions

7.3.1 Velocity traverse. The fan airflow rate may be calculated from velocity pressure measurements (P_{v3}) taken by Pitot traverse.

7.3.1.1 Velocity pressure. The velocity pressure (P_{v3}) corresponding to the average velocity shall be obtained by taking the square roots of the individual measurements (P_{v3r}), summing the roots, dividing by

the number of measurements (n), and squaring the quotient as indicated by:

$$P_{v3} = \left(\frac{\sum \sqrt{P_{v3r}}}{n} \right)^2 \quad \text{Eq. 7.7}$$

7.3.1.2 Velocity. The average velocity (V_3) shall be obtained from the air density at the plane of traverse (ρ_3) and the corresponding velocity pressure (P_{v3}) using:

$$V_3 = \sqrt{\frac{2P_{v3}}{\rho_3}} \quad \text{Eq. 7.8 SI}$$

$$V_3 = 1097.8 \sqrt{\frac{P_{v3}}{\rho_3}} \quad \text{Eq. 7.8 I-P}$$

7.3.1.3 Airflow rate. The airflow rate (Q_3) at the Pitot traverse plane shall be obtained from the velocity (V_3) and the area (A_3) using:

$$Q_3 = V_3 A_3 \quad \text{Eq. 7.9}$$

7.3.1.4 Fan airflow rate. The fan airflow rate at test conditions (Q) shall be obtained from the equation of continuity:

$$Q = Q_3 \left(\frac{\rho_3}{\rho} \right) \quad \text{Eq. 7.10}$$

7.3.2 Nozzle. The fan airflow rate may be calculated from the pressure differential (ΔP) measured across a single nozzle or a bank of multiple nozzles [16].

7.3.2.1 Alpha ratio. The ratio of absolute nozzle exit pressure to absolute approach pressure shall be calculated from:

$$\alpha = \frac{P_{s6} + p_b}{P_{sx} + p_b} \quad \text{Eq. 7.11 SI}$$

$$\alpha = \frac{P_{s6} + 13.595 p_b}{P_{sx} + 13.595 p_b} \quad \text{Eq. 7.11 I-P}$$

Or:

$$\alpha = 1 - \left\{ \frac{\Delta P}{\rho_x R [t_{dx} + 273.15]} \right\} \quad \text{Eq. 7.12 SI}$$

$$\alpha = 1 - \left\{ \frac{5.2014 \Delta P}{\rho_x R [t_{dx} + 459.67]} \right\} \quad \text{Eq. 7.12 I-P}$$

The gas constant (R) may be taken as 287.1 J/kg•K (53.35 ft•lb/lbm•°R) for air. Plane x is Plane 4 for duct approach or Plane 5 for chamber approach.

7.3.2.2 Beta ratio. The ratio (β) of nozzle exit diameter (D_6) to approach duct diameter (D_x) shall be calculated from:

$$\beta = \frac{D_6}{D_x} \quad \text{Eq. 7.13}$$

For a duct approach, $D_x = D_4$. For a chamber approach, $D_x = D_5$, and β may be taken as zero.

7.3.2.3 Expansion factor. The expansion factor Y may be obtained from:

$$Y = \sqrt{\left(\frac{\gamma}{\gamma - 1} \right) \left(\alpha^{2/\gamma} \right) \left(\frac{1 - \alpha^{(\gamma-1)/\gamma}}{1 - \alpha} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 \alpha^{2/\gamma}} \right)} \quad \text{Eq. 7.14}$$

The ratio of specific heats γ may be taken as 1.4 for air. Alternatively, the expansion factor for air may be approximated with sufficient accuracy by:

$$Y = 1 - (0.548 + 0.71\beta^4)(1 - \alpha) \quad \text{Eq. 7.15}$$

7.3.2.4 Energy factor. The energy factor E may be determined by measuring velocity pressures P_{vr} upstream of the nozzle at standard traverse stations and calculating:

$$E = \frac{\left[\frac{\sum (P_{vr}^{1.5})}{n} \right]}{\left[\frac{\sum (P_{vr}^{0.5})}{n} \right]^3} \quad \text{Eq. 7.16}$$

Sufficient accuracy can be obtained for setups qualifying under this standard by setting $E = 1.0$ for chamber approach or $E = 1.043$ for duct approach (8).

7.3.2.5 Reynolds number. The Reynolds Number, Re , based on nozzle exit diameter D_6 in meters (ft), shall be calculated from:

$$Re = \frac{D_6 V_6 \rho_6}{\mu} \quad \text{Eq. 7.17 SI}$$



$$Re = \frac{D_6 V_6 \rho_6}{60 \mu} \quad \text{Eq. 7.17 I-P}$$

Using properties of air as determined in Section 7.2 and the appropriate velocity V_6 in m/s (fpm). Since the velocity determination depends on Reynolds Number, an approximation must be employed. It can be shown that:

$$Re = \frac{\sqrt{2}}{\mu} C D_6 Y \sqrt{\frac{\Delta P \rho_x}{1 - E \beta^4}} \quad \text{Eq. 7.18 SI}$$

$$Re = \frac{1097}{60 \mu} C D_6 Y \sqrt{\frac{\Delta P \rho_x}{1 - E \beta^4}} \quad \text{Eq. 7.18 I-P}$$

For duct approach, $\rho_x = \rho_4$. For chamber approach, $\rho_x = \rho_5$, and β may be taken as zero.

Refer to Annex G for an example of an iterative process to determine Re and C.

7.3.2.6 Discharge coefficient. The nozzle discharge coefficient (C) shall be calculated from:

$$C = 0.9986 - \left(\frac{7.006}{\sqrt{Re}} \right) + \left(\frac{134.6}{Re} \right)$$

$$\text{For : } L/D = 0.6 \quad \text{Eq. 7.19}$$

$$C = 0.9986 - \left(\frac{6.688}{\sqrt{Re}} \right) + \left(\frac{131.5}{Re} \right)$$

$$\text{For : } L/D = 0.5 \quad \text{Eq. 7.20}$$

For Re of 12,000 and above [9].

Refer to Annex G for an example of an iterative process to determine Re and C.

7.3.2.7 Airflow rate for ducted nozzle. The airflow rate Q_4 at the entrance to a ducted nozzle shall be calculated from:

$$Q_4 = \frac{\left\{ C A_6 Y \sqrt{\frac{2 \Delta P}{\rho_4}} \right\}}{\sqrt{1 - E \beta^4}} \quad \text{Eq. 7.21 SI}$$

$$Q_4 = \frac{\left\{ 1097.8 C A_6 Y \sqrt{\frac{\Delta P}{\rho_4}} \right\}}{\sqrt{1 - E \beta^4}} \quad \text{Eq. 7.21 I-P}$$

The area A_6 is measured at the plane of the throat taps.

7.3.2.8 Airflow rate for chamber nozzles. The airflow rate (Q_5) at the entrance to a nozzle or multiple nozzles with chamber approach shall be calculated from:

$$Q_5 = Y \sqrt{\frac{2 \Delta P}{\rho_5}} \Sigma(C A_6) \quad \text{Eq. 7.22 SI}$$

$$Q_5 = 1097.8 Y \sqrt{\frac{\Delta P}{\rho_5}} \Sigma(C A_6) \quad \text{Eq. 7.22 I-P}$$

The coefficient C and the area A_6 must be determined for each nozzle, and their products must be summed as indicated. The area A_6 is measured at the plane of the throat taps, or the nozzle exit for nozzles without throat taps.

7.3.2.9 Fan airflow rate. The fan airflow rate Q at test conditions shall be obtained from the equation of continuity:

$$Q = Q_x \left(\frac{\rho_x}{\rho} \right) \quad \text{Eq. 7.23}$$

Where Plane x is either Plane 4 or Plane 5, as appropriate.

7.4 Fan velocity pressure at test conditions

7.4.1 Pitot traverse. When Pitot traverse measurements are made, the fan velocity pressure (P_v) shall be determined from the velocity pressure (P_{v3}) using:

$$P_v = P_{v3} \left(\frac{\rho_3}{\rho_2} \right) \left(\frac{A_3}{A_2} \right)^2 \quad \text{Eq. 7.24}$$

Whenever P_{s3} and P_{s2} differ by less than 1 kPa (4 in. wg), ρ_2 may be considered equal to ρ_3 .

7.4.2 Nozzle. When airflow rate (Q) is determined from nozzle measurements, the fan velocity pressure (P_v) shall be calculated from the velocity (V_2) and air density (ρ_2) at the fan outlet using: