ANSI/AMCA Standard 500-D-07

Laboratory Methods of Testing Dampers for Rating

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AIR MOVEMENT AND CONTROL ASSOCIATION INTERNATIONAL, INC.

The International Authority on Air System Components

ANSI/AMCA STANDARD 500-D-07

Laboratory Methods of Testing Dampers for Rating

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Related AMCA Standards and Publications

AMCA Publication 502	*Damper Application Manual for Heating, Ventilation and Air Conditioning*
AMCA Publication 503	*Fire, Ceiling(Radition), Smoke and Fire/Smoke Dampers Application Manual*
ANSI/AMCA Standard 510	*Methods of Testing Heavy Duty Dampers for Rating*
AMCA Publication 511	*Certified Ratings Program for Air Control Devices*
ANSI/AMCA Standard 520	*Laboratory Methods for Testing Actuators*

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TABLE OF CONTENTS

تهویه سازه شار
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تهویه سازه شار
SHAR CONSTRUCTION & HVAC
TEL: 021 - 91016677

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Laboratory Methods of Testing Dampers for Rating

1. Purpose

The purpose of this standard is to establish uniform laboratory test methods for dampers. The characteristics to be determined include, as appropriate, air leakage, pressure drop, dynamic closure, and operational torque.

It is not the purpose of this standard to specify the testing procedures to be used for design, production, or field testing. Similarly, it is not the purpose of this standard to indicate or establish minimum or maximum performance ratings to be used for specifying these products.

2. Scope

This standard may be used as a basis for testing dampers when air is used as the test gas.

A test conducted in accordance with the requirements of this standard is intended to demonstrate the performance of a damper and is not intended to determine acceptability level for a damper. It is not within the scope of this standard to indicate the actual sequence of testing.

The parties to a test for guarantee purposes may agree to exceptions to this standard in writing prior to the test. However, only a test that does not violate any mandatory requirement of this standard shall be designated as a test conducted in accordance with this standard.

3. Units of Measurement

3.1 System of units

SI units (The International System of Units, Le Systéme International d'Unités) [1]* are the primary units employed in this standard, with I-P units (Inch-Pound) given as the secondary reference. SI units are based on the fundamental values of the International Bureau of Weights and Measures [1], 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. Annex A provides conversion factors for SI and I-P units.

*Bibliographic references are indicated by brackets; mandatory references are indicated by superscripts.

3.2 Basic units

The unit of length is the meter (m), or millimeter (mm); I-P units are the foot (ft) or the 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 degree Celsius (°C), or the degree kelvin (K). I-P units are either the degree Fahrenheit (°F), or the degree Rankine (°R). The unit of force is the newton (N); the I-P unit is the pound (lbf).

3.3 Airflow rate and velocity

3.3.1 Airflow rate. The unit of volumetric airflow rate is the cubic meter per second (m^3/s); the I-P unit is the cubic foot per minute (cfm).

3.3.2 Airflow velocity. The unit of airflow 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 the pascal (Pa) or the millimeter of mercury (mm Hg); the I-P unit is either the inch water gauge (in. wg), or the inch mercury column (in. Hg). Values in mm Hg or 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*. The mm Hg shall be based on a one mm column of mercury at 0°C under standard gravity *in vacuo*.

3.5 Torque

The unit of torque is the newton-meter (N-m); the I-P unit is the pound-inch (lbf-in.).

3.6 Gas properties

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 (Pa-s); the I-P unit is the pound mass per foot-second

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(lbm/ft-s). The SI 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-lbf/lbm-°R).

3.7 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.

3.8 Physical constants

The value of standard gravitational acceleration shall be taken as 9.80665 m/s^2 (32.174 ft/s^2) at mean sea level at 45° latitude [2]. The density of distilled water at saturation pressure shall be taken as 998.278 kg/m^3 (62.3205 lbm/ft^3) at 20°C (68°F) [3]. The density of mercury at saturation pressure shall be taken at 13595.1 kg/m^3 (848.714 lbm/ft^3) at 0°C (32°F) [3]. The specific weights in kg/m^3 (lbm/ft^3) of these fluids in vacuo 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 UNIT	I -P UNIT
a	Duct Width	m	ft
A	Area of Cross-Section	m^2	ft^2
b	Duct Height	m	ft
C	Nozzle Discharge Coefficient	dimensionless	
D	Diameter and Equivalent Diameter	m	ft
E	Energy Factor	dimensionless	
H	Damper Height	m	ft
K_s	System Leakage Constant	dimensionless	
L	Nozzle Throat Dimension	m	ft
$L_{x,x'}$	Length of Duct Between Planes x and x'	m	ft
M	Chamber Dimension	m	ft
n	Number of Readings	dimensionless	
P_s	Static Pressure	Pa	in. wg
P_{sx}	Static Pressure at Plane x	Pa	in. wg
P_t	Total Pressure	Pa	in. wg
P_{tx}	Total Pressure at Plane x	Pa	in. wg
P_v	Velocity Pressure	Pa	in. wg
P_{vx}	Velocity Pressure at Plane x	Pa	in. wg
p_b	Corrected Barometric Pressure	Pa	in. Hg
p_e	Saturated Vapor Pressure at tw	Pa	in. Hg
p_p	Partial Vapor Pressure	Pa	in. Hg
Q	Damper Volumetric Airflow Rate	m^3/s	cfm
Q_s	Test Damper Volumetric Airflow at Standard Air Conditions	m^3/s	cfm
Q_x	Volumetric Airflow Rate at Plane x	m^3/s	cfm
R	Gas Constant	J/kg-K	ft-lbf/lbm-°R
Re	Reynolds Number	dimensionless	
T	Torque	N-m	lb- in.
t_d	Dry-Bulb Temperature	°C	°F
t_s	Static Temperature	°C	°F
t_t	Total Temperature	°C	°F
t_w	Wet-Bulb Temperature	°C	°F
V	Velocity	m/s	fpm
W	Damper Width	m	ft
y	Thickness of Straightener Element	m	ft

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Y	Nozzle Expansion Factor	dimensionless	
α	Static Pressure Ratio for Nozzles	dimensionless	
β	Diameter Ratio for Nozzles	dimensionless	
γ	Ratio of Specific Heats	dimensionless	
ΔP	Damper Pressure Differential	Pa	in. wg
ΔP_n	Pressure Differential Across Nozzle	Pa	in. wg
$\Delta P_{x,x'}$	Pressure Differential Between Planes x and x'	Pa	in. wg
ΔP_s	Pressure Drop Across Test Damper at Standard Air Conditions	Pa	in. wg
μ	Air Viscosity	Pa-s	lbm/ft-s
ρ	Air Density	kg/m^3	lbm/ft^3
ρ_x	Air Density at Plane x	kg/m^3	lbm/ft^3

4.2 Additional subscripts (planes of measurement)

SUBSCRIPT	DESCRIPTION
c	Converted parameter
d	Damper
DS	Damper and system
n	Nozzle
r	Reading
s	System
t	Test parameter
t1	Test number 1
t2	Test number 2
x	Plane 0, 1, 2, ..., as appropriate
0	Plane 0 (general test area)
1	Plane of inlet of damper being tested
2	Plane of outlet of damper being tested
3	Plane of Pitot traverse
4	Plane of duct P_s measurement downstream of damper being tested
5	Plane of P_s measurement at nozzle inlet
6	Plane of P_s measurement at nozzle discharge station
7	Plane of P_s measurement in chamber downstream of damper being tested
8	Plane of P_s measurement in chamber upstream of damper being tested
9	Plane of duct P_s measurement upstream of damper being tested

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5. Definitions

5.1 Damper

A device mounted in a duct or opening which is used to vary the volume of air flowing through the duct or opening. It may be operated manually or mechanically and may have one or more blades.

5.1.1 Single blade damper. A damper having one blade.

5.1.2 Multi-blade damper. A damper having more than one blade. The damper is a parallel blade damper if the blades rotate in the same direction; and an opposed blade damper if adjacent blades rotate in opposite directions.

5.1.3 Curtain damper. A damper which uses a folded, interlocked series of blades.

5.1.4 Backdraft damper (shutter). A backdraft damper is a damper which, when mounted in a duct or opening, permits the flow of air in one direction only. It is normally opened by the energy of the air stream, but may be opened and/or closed by mechanical means. A counter-balanced backdraft damper has weights and/or springs added to the blade or blades to facilitate or impede the opening or closing action.

5.2 Air control damper

A mechanical device which does not fit the definition of a damper and which when placed in a duct or opening is used to regulate airflow.

5.3 Free area

The minimum area through which air can pass. It is determined by multiplying the sum of the minimum distances between intermediate blades, top blade and head and bottom blade and sill, by the minimum distance between jambs. The percent of free area is the free area thus calculated, divided by the gross area of the air control damper × 100. See damper cross-sections (Figure 1).

5.3.1 Free area velocity. Airflow through a damper divided by its free area.

5.4 Face area

The total cross-sectional area of a damper, duct or wall opening.

5.4.1 Face area velocity. Airflow through a damper divided by its face area.

5.5 Psychrometrics

5.5.1 Dry-bulb. Dry-bulb temperature is the air temperature measured by a dry temperature sensor.

5.5.2 Wet-bulb. Wet-bulb temperature is the temperature measured by a temperature sensor covered by a water-moistened wick and exposed to air in motion. When properly measured, it is a close approximation of the temperature of adiabatic saturation.

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

5.5.4 Static temperature. The temperature which exists by virtue of the internal energy of the air only.

If a portion of the internal energy is converted into kinetic energy, the static temperature will be decreased accordingly.

5.5.5 Air density. The mass per unit volume of air.

5.5.6 Standard air. Standard air is air with a density of 1.2 kg/m^3 (0.075 lbm/ft^3), a ratio of specific heats of 1.4, a viscosity of 1.8185 × 10^{-5} Pa-s (1.222 × 10^{-5} lbm/ft-s). Air at 20°C (68°F) temperature, 50% relative humidity, and 101.3207 kPa (29.92 in. Hg) barometric pressure has these properties, approximately.

5.6 Pressure

5.6.1 Pressure. Pressure is force per unit area. This corresponds to energy per unit volume of fluid.

5.6.2 Absolute pressure. Absolute pressure is the value of a pressure when the datum pressure is absolute zero. It is always positive.

5.6.3 Barometric pressure. Barometric pressure is the absolute pressure exerted by the atmosphere at the location of measurement.

5.6.4 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.

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

5.6.6 Static pressure. Static pressure is that portion of the air pressure which exists by virtue of the degree of compression only. If expressed as gauge pressure, it may be negative or positive.

5.6.7 Total pressure. Total pressure is 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.

5.6.8 Pressure differential. Pressure differential is the change in static pressure across a damper.

5.7 Performance variables

5.7.1 Pressure drop. Pressure drop is a measure of the resistance to airflow across a damper. It is expressed as the difference in static pressure across a damper for a specific rate of airflow.

5.7.2 Closure pressure. Closure pressure is the differential pressure across the damper when the damper is closed.

5.7.3 Airflow leakage. Airflow leakage is the amount of air passing through a damper when it is in the closed position and at a specific pressure differential. It is expressed as the volumetric rate of air passing through the damper divided by the face area.

5.7.4 Ambient temperature dynamic closure. Ambient temperature (0°C - 49°C (32°F - 120°F)) dynamic closure is the ability of a damper to properly travel from the full open to the full closed position while exposed to specific airflow conditions at ambient temperature. The specific airflow conditions are the airflow face velocity when the damper is in the open position and the pressure differential across the damper in the closed position. The airflow face velocity is the velocity established with the damper in the open position. The pressure differential is established when the damper is in the closed position. All airflow measurements and pressure differential measurements are established at ambient conditions and are corrected to standard air. The damper can be tested in either a ducted or in-wall installation.

5.7.5 Elevated temperature dynamic closure. Elevated temperature dynamic closure is the ability of a damper to properly travel from the full open to the full closed position while exposed to specific airflow conditions at a specified elevated air temperature.

The specific airflow conditions are the airflow face velocity when the damper is in the open position and the pressure differential across the damper in the closed position. The airflow face velocity is the velocity established with the damper in the open position. The pressure differential is established when the damper is in the closed position. All airflow measurements and pressure differential measurements are established at ambient conditions and are corrected to standard air. This test is conducted in a ducted installation only.

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5.7.6 Ambient temperature operation. Ambient temperature (0°C - 49°C (32°F - 120°F)) operation is the ability of a damper to properly travel from the full open to full closed position and, if a motorized damper, back to a full open position while exposed to specific airflow conditions at ambient temperature. The specific airflow conditions are the airflow face velocity when the damper is in the open position and the pressure differential across the damper in the closed position. The airflow face velocity is the velocity established when the damper is in the open position. The pressure differential is established when the damper is in the closed position. All airflow measurements are established at ambient conditions and are corrected to standard air.

5.7.7 Elevated temperature operation. Elevated temperature operation is the operational ability of a damper to properly travel from full open to full closed position at elevated temperatures and, if a motorized damper, operate back to a full open position while exposed to specified airflow conditions. The specified airflow conditions are the airflow face velocity when the damper is in the open position and the pressure differential across the damper in the closed position. The airflow face velocity is the velocity established when the damper is in the open position. The pressure differential is established when the damper is in the closed position. All airflow measurements are established at ambient temperature conditions and are corrected to standard air.

5.7.8 Dynamic operation torque. Dynamic operation torque is the torque at varying angles of rotation of the axle which operates the damper from the full open, to the full closed, and back to the full open position while exposed to specific airflow conditions. The specific airflow conditions are the airflow face velocity when the damper is in the open position and the pressure differential across the damper in the closed position. All airflow measurements and pressure differential measurements are established at ambient conditions and are corrected to standard air.

5.8 Miscellaneous

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

5.8.2 Determination. A determination is a complete set of measurements for a particular point of operation of the test damper. The measurements must be sufficient to determine all appropriate performance variables as defined in Section 5.7.

5.8.3 Test. A determination or a series of determinations for various points of operation of a damper.

5.8.4 Energy factor. Energy factor is the ratio of the total kinetic energy of the flow to the kinetic energy corresponding to the average velocity.

5.8.5 Seating torque. Seating torque is the torque specified to properly seal the test damper.

6. Instruments and Methods of Measurement

6.1 Accuracy [4]

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

6.2 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 a 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 open to the 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 connected 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.

6.2.1 Manometers and other pressure indicating instruments. Pressure shall be measured on manometers of the liquid column type using inclined or vertical legs or other instruments which provide a maximum uncertainty of 1% of the maximum observed test reading during the test or 3 Pa (0.01 in. wg) whichever is larger.

6.2.1.1 Calibration. Each pressure indicating instrument shall be calibrated at both ends of the scale and 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.

6.2.1.2 Averaging. Since the airflow and pressures through a damper in a typical system are never strictly steady, the pressure indicated 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 sometimes be accomplished mentally, particularly if the fluctuations are small and regular. Multi-point or continuous record averaging can be accomplished with instruments and analyzers designed for this purpose.

6.2.1.3 Corrections. Manometer readings shall be corrected for any difference in specific weight of gauge fluid from standard, any difference in gas column balancing effect from standard, or any change in length of the graduated scale due to temperature. However, corrections may be omitted for temperatures between 14°C and 26°C (58°F and 78°F), latitudes between 30° and 60°, and elevations up to 1500 m (5000 ft).

6.2.2 Pitot-static tubes [5]. The total pressure or the static pressure at a point may be sensed with a Pitot-static tube of the proportions shown in Figure 2. 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 shall be considered the velocity pressure at the point of the impact opening.

6.2.2.1 Calibration. Pitot-static tubes having the proportions shown in Figure 2 are considered primary instruments and need not be calibrated provided they are maintained in the specified condition.

6.2.2.2 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.).

6.2.2.3 Support. Rigid support shall be provided to hold the Pitot-static tube axis parallel to the axis of the duct within 1 degree at the head locations specified in Figure 3 within 1.2 mm (0.05 in.) or 0.25% of the duct diameter, whichever is larger. Straighteners are specified so that flow lines will be approximately parallel to the duct axis.

6.2.3 Static pressure taps [6]. The static pressure at a point may be sensed with a pressure tap of the proportions shown in Figure 4. The pressure signal can then be transmitted to an indicator.

6.2.3.1 Calibration. Pressure taps having the proportions shown in Figure 4 are considered primary instruments and need not be calibrated provided they are maintained in the specified condition. Every precaution should be taken to ensure that the air velocity does not influence the pressure measurement.

6.2.3.2 Averaging. An individual pressure tap is sensitive only to the pressure in the immediate vicinity of the hole. In order to obtain an average, at least four identical taps shall be manifolded into a piezometer ring. The manifold shall have an inside

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area at least four times that of each tap.

6.2.3.3 Piezometer rings. Piezometer rings are specified for upstream and downstream nozzle taps and for outlet duct or chamber measurements unless Pitot traverse is specified. Measuring planes shall be located as shown in the figure for the appropriate setup.

6.2.4 Other pressure indicating instruments. Pressure measuring systems consisting of indicators and sensors other than manometers and Pitot-static tubes, or static pressure taps 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, or static pressure taps. These instruments shall be capable of reading data at a minimum of 100 samples per second.

6.3 Airflow rate

An airflow rate shall be calculated either from measurements of velocity pressure obtained by Pitot traverse or from measurements of pressure differential across a flow nozzle. An airflow rate less than 0.005 m^3s^{-1} (10 cfm) may be measured directly using a flow meter.

6.3.1 Pitot traverse [7]. An airflow rate may be calculated from the velocity pressures obtained by traverses of a duct with a Pitot-static tube provided the average velocity corresponding to the airflow rate is at least 6.35 m/s (1250 fpm).

6.3.1.1 Traverse point. The number and locations of the measuring points on rectangular and round ducts shall be as specified in Figure 3.

6.3.1.2 Averaging. The points shown in Figure 3 are located according to the log-linear rule for round ducts [8] and the log-Tchebycheff rule for rectangular ducts. The arithmetic mean of the individual velocity measurements made at these points will be the mean velocity through the measuring section for the subject velocity profiles [9].

6.3.2 Nozzles. Airflow rate may be calculated from the pressure differential measured across a flow nozzle or bank of nozzles for any point of operation provided the pressure differential across the nozzle bank is at least 25 Pa (0.1 in. wg). The uncertainty of the airflow rate measurement can be reduced by changing to a smaller nozzle or combination of nozzles for low airflow rates.

6.3.2.1 Size. Nozzles shall conform to Figure 7. Nozzles may be of any convenient size. However, when a duct is connected to the inlet of the nozzle, the ratio of nozzle throat diameter to the diameter of the inlet duct shall not exceed 0.525.

6.3.2.2 Calibration. The standard nozzle is considered a primary instrument and need not be calibrated if maintained in the specified condition. Reliable coefficients have been established for throat dimensions L = 0.5 D and L = 0.6 D, shown in Figure 7 [10]. Throat dimension L = 0.6 D is recommended for new construction.

6.3.2.3 Chamber nozzles. Nozzles without integral throat taps may be used for multiple nozzle chambers in which case upstream and downstream pressure taps shall be located as shown in the figure for the appropriate setup. Alternatively, nozzles with throat taps may be used in which case the throat taps located as shown in Figure 7 shall be used in place of the downstream pressure taps shown in the figure for the setup and the piezometer for each nozzle shall be connected to its own indicator.

6.3.2.4 Ducted nozzles. Nozzles with integral throat taps shall be used for ducted nozzle setups. Upstream pressure taps shall be located as shown in the figure for the appropriate setup. Downstream taps are the integral throat taps and shall be located as shown in Figure 7.

6.3.2.5 Taps. All pressure taps shall conform to the specification in Section 6.2.3 regarding geometry, number, and manifolding into piezometer rings.

6.3.3 Airflow meter. Airflow rates may be measured directly using a calibrated airflow meter capable of measuring airflow in increments of 0.0002 m^3/s (25 cubic feet per hour) or less.

6.3.4 Other airflow measuring methods. Airflow measuring methods which utilize meters or traverses other than airflow nozzles or Pitot traverses may be used if the uncertainty introduced by the method does not exceed that introduced by an appropriate airflow nozzle or Pitot traverse method. The contribution to the combined uncertainty in the flow rate measurement shall not exceed that corresponding to 1.2% of the discharge coefficient for a flow nozzle [11].

6.4 Torque

A torque meter having a demonstrated accuracy of ±2% of observed reading may be used.

6.4.1 Calibration. A torque device shall have a static calibration and may have a running calibration through its range of usage. The static calibration

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shall be made by suspending weights from a torque arm. The weights shall have certified accuracies of ±0.2%. The length of the torque arm shall be determined to an accuracy of ±0.2%.

6.4.2 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 shall be within 0.5% of the maximum value measured during the test.

6.5 Air density

Air density shall be calculated 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%.

6.5.1 Thermometers. Both wet and dry-bulb temperatures shall be measured with thermometers or other instruments with demonstrated accuracy of ±1°C (2°F) and readability of 0.5°C (1°F) or finer.

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

6.5.1.2 Wet-Bulb. The 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]. The dry-bulb thermometer shall be mounted upstream of the wet-bulb thermometer so its reading will not be depressed.

6.5.2 Barometers. The barometric pressure shall be measured with a mercury column barometer or other instrument with a demonstrated accuracy of ±170 Pa (0.05 in. Hg) and readable to 34 Pa (0.01 in. Hg) or finer.

6.5.2.1 Calibration. Barometers shall be calibrated against a mercury column barometer with a calibration that is traceable to the National Institute of Standards and Technology (NIST) 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 [13]. Barometers shall be maintained in good condition.

6.5.2.2 Corrections. Barometric readings shall be corrected for any difference in mercury density from standard or any change in length of the graduated scale due to temperature. Refer to manufacturer's instructions.

6.6 Voltage

Actuator input voltage during the test shall be within ±1% of the voltage shown on the actuator nameplate.

6.7 Meters

Electrical meters shall have certified accuracies of ±1.0% of observed reading. It is preferable that the same meters be used for the test as for the calibration.

6.8 Pneumatic actuator supply air pressure

Pneumatic actuator supply air pressure during a test shall be within 5% of the desired test pressure.

6.9 Pressure gauges

Supply air pressure for a pneumatic actuator shall be measured with a pressure gauge or other instrument with a demonstrated accuracy of 10 kPa (1 psi) and a readability of 10 kPa (1 psi) or less.

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6.10 Chronometers

Time measurements shall be made with a watch having minimum accuracy of ±0.2%.

6.11 Velocity meters

Air velocity meters shall have an accuracy ±3% (of reading) or ±0.05 m/s (10 fpm), whichever is greater.

7. Equipment and Setups

7.1 Setups

Twenty damper setups are diagramed in Figures 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8 and 5.9. Six airflow measurement setups are diagramed in Figures 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6.

7.1.1 Installation types. There are four categories of installation types which can be used with dampers.

The installation types and the corresponding test damper setup figures are:

Figure 5.1 Free inlet, ducted outlet
Figure 5.2 Ducted inlet, free outlet

Figure 5.3, 5.9 Ducted inlet, ducted outlet
Figures 5.4, 5.5, 5.7 Free inlet, free outlet

7.1.2 Leakage. The ducts, chambers and other equipment utilized should be designed to withstand the pressure and other forces to be encountered. All joints between the damper and the measuring plane, including the nozzle wall if used, shall leak no more than 10% of the total flow at the test pressure or 2 cfm whichever is greater.

7.2 Ducts

A duct may be incorporated in a laboratory setup to provide a measuring plane or to simulate the conditions the damper is expected to encounter in service or both. The dimension *D* in the test damper setup figure is the inside diameter of a circular cross-section duct or equivalent diameter of a rectangular cross-section duct with inside transverse dimensions a and b where:

$$D = \sqrt{4ab/\pi} \qquad \text{Eq. 7.1}$$

7.2.1 Transformation pieces. Transformation pieces used in the test setups shall be in compliance with Figure 8.

7.2.2 Roundness. The portion of a Pitot traverse duct within one-half duct diameter of either side of the plane of measurement shall be round within 0.5% or 1.5 mm (1/16 in.) of the duct diameter, whichever is greater. The remainder of the duct shall be round within 1% or 3 mm (0.125 in.) of the duct diameter, whichever is greater. The area of the plane of measurement shall be determined from the average of four diameters measured at 45° increments. The diameter measurements shall be accurate to 0.2%.

7.2.3 Straighteners. Straighteners or star straighteners shall be used in ducts which provide measuring planes for airflow measurement. The downstream plane of the straightener shall be located between 5 and 5.25 duct diameters upstream of the plane of the Pitot traverse or piezometer station. The form of the straightener shall be as specified in Figure 9A or Figure 9B [14].

7.3 Chambers

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

$$M = \sqrt{4ab/\pi} \qquad \text{Eq. 7.2}$$

7.3.1 Outlet chamber (Figure 5.4). An outlet chamber shall have a cross-sectional area at least fifteen times the free area of the damper being tested.

7.3.2 Inlet chamber (Figure 5.5). Inlet chambers shall have a cross-sectional area at least three times the free area of the damper being tested.

7.3.3 Outlet/inlet plenum (Figure 5.7). Plenum size shall be larger than the test damper by a minimum of 305 mm (12 in.) on all four sides. The plenum height shall be no less than the plenum length.

7.3.4 Airflow settling means. Airflow settling means shall be installed in a chamber where indicated on the test setup figures to provide proper airflow patterns.

Where a measuring plane is located downstream of the settling means, the settling means is provided to insure a substantially uniform flow ahead of the measuring plane. In this case, the maximum local velocity at a distance 0.1*M* downstream of the screen shall not exceed the average velocity by more than 25% unless the maximum local velocity is less than 2 m/s (400 fpm).

Where a measuring plane is located upstream of the settling means, the purpose of the settling screen is to absorb the kinetic energy of the upstream jet, and allow its normal expansion as if in an unconfined space. This requires some backflow to supply the air to mix at the jet boundaries, but the maximum reverse velocity shall not exceed 10% of the calculated Plane 6 mean jet velocity.

Where measuring planes are located on both sides of the settling means within the chamber, the requirements for each side as outlined above shall be met.

Any combination of screens or perforated plates that meet these requirements may be used, but in general a reasonable chamber length for the settling means is necessary to meet both requirements. Three (3) uniform square mesh round wire screens spaced 0.1*M* apart with 45%, 45%, and 40% open areas for the first, second, and third screen respectively will meet the above performance specification. Tolerances of ±2% open area are allowable. A performance check will be necessary to verify the flow settling means are providing proper flow patterns. The spacing of measurements shall be in accordance with Figure 3.

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7.3.5 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 centers of any two nozzles in simultaneous use shall be three times the throat diameter of the larger nozzle.

7.4 Variable supply and exhaust systems

A means of varying the points of operation shall be provided in a laboratory setup.

7.4.1 Throttling dampers. Throttling devices may be used to control the point of operation. Such devices shall be located on the end of the duct or chamber and shall be symmetrical about the duct or chamber axis.

7.4.2 Supply or exhaust fan. A fan may be used to control the point of operation of the test damper. The fan shall provide sufficient pressure at the desired airflow rate to overcome losses through the test setup. Airflow adjustment means, such as a damper, pitch control, or speed control may be required. A supply fan shall not surge or pulsate during a test. The airflow generating equipment is to be capable of producing the prescribed airflow and pressure conditions without the use of pressure relief dampers.

8. Objective, Observations and Conduct of Test

8.1 Air performance - pressure drop test

The objective of this test is to determine the relationship of airflow rate and the pressure drop across a damper.

8.1.1 General requirements

8.1.1.1 Determinations. A test shall consist of five or more determinations taken at approximately equal increments of flow rate covering the range desired.

8.1.1.2 Equilibrium. Equilibrium conditions shall be established before each determination. To test for equilibrium, trial observations shall be made until steady readings are obtained.

8.1.1.3 Airflow measurement. Airflow velocity at the plane of measurement when determined by using a Pitot-static tube shall not be less than 6.35 m/s (1250 fpm). When nozzles are used to determine the airflow rate, the minimum P_n shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of the test.

8.1.2 Data to be recorded

8.1.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size, and face area shall be recorded.

8.1.2.2 Test setup. The description of the test setup including specific dimensions shall be recorded.

Reference shall be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup shall be attached to the data.

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

8.1.2.4 Airflow measurement test data. Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For all types of tests, three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), and ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

8.1.2.4.1 Pitot test (Figure 6.1). For a Pitot traverse test, one reading each of velocity pressure (P_{v3r}) and static pressure (P_{s3r}) shall be recorded for each Pitot station. In addition, three readings for traverse-plane dry-bulb temperature (t_{d3}) shall be recorded unless the readings are steady in which case only one need be recorded.

8.1.2.4.2 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.1.2.4.3 Chamber nozzle test (Figures 6.3 and 6.5). For a chamber nozzle tests, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), and approach static pressure (P_{s5}) shall be recorded.

8.1.2.4.4 Single nozzle chamber test (Figure 6.4). For a single nozzle chamber tests, one reading each of chamber dry-bulb temperature (t_{d5}), nozzle pressure drop (ΔP_n), and chamber static pressure (P_{s5}) shall be recorded.

8.1.2.5 Test damper setup. Each damper shall be tested in a setup which simulates its intended field installation (see Section 7.1.1). Table 1 displays

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allowable combinations of airflow rate measurement and test damper setups.

8.1.2.5.1 Damper with outlet duct (Figure 5.1). One reading per determination of outlet duct static pressure (P_{s4}) shall be recorded.

8.1.2.5.2 Damper with inlet duct (Figure 5.2). One reading per determination of inlet duct static pressure (P_{s9}), and the plane 9 dry bulb temperature (t_{d9}) shall be recorded.

8.1.2.5.3 Damper with inlet and outlet ducts (Figure 5.3). One reading per determination of pressure drop across the test damper ($\Delta P_{9,4}$) and the plane 9 dry bulb temperature (t_{d9}) shall be recorded.

8.1.2.5.4 Damper with outlet chamber (Figure 5.4). One reading per determination of chamber static pressure (P_{s7}) shall be recorded.

8.1.2.5.5. Damper with inlet chamber (Figure 5.5). One reading per determination of chamber static pressure (P_{s8}) and chamber temperature (t_{d8}) shall be recorded.

Table 1 - Allowable combinations of airflow rate measurement and test damper setups

Test damper setups		Airflow measurement setups	
Figure	Connection plane	Figure	Connection plane
5.1	Z	6.1	B
		6.2	B
		6.3	A
		6.4	A
5.2	Y	6.1	C
		6.2	C
	X	6.5	B
5.3	Y	6.1	C
		6.2	C
	X	6.5	B
5.4	Y	6.1	B
		6.2	B
	X	6.3	B
		6.4	B
5.5	X	6.1	C
		6.2	C
	Y	6.5	A
5.7A, 5.7E	X	6.1	B
		6.2	B
		6.3	A
		6.4	A
5.7B, 5.7F	Y	6.1	C
		6.2	C
		6.5	B

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8.1.2.5.6 Damper with outlet plenum (Figures 5.7A and 5.7E). One reading per determination of chamber static pressure (P_{s7}) shall be recorded.

8.1.2.5.7 Damper with inlet plenum (Figures 5.7B and 5.7F). One reading per determination of chamber static pressure (P_{s8}) and chamber temperature (t_{d8}) shall be recorded.

8.1.3 Conduct of test

8.1.3.1 General requirements. Each test shall be conducted at ambient temperatures between (0°C - 49°C (32°F - 120°F)). A test is a complete set of measurements (or determinations), with one set of measurements for each setting of airflow and pressure drop. The damper shall be tested with airflow in both directions with the exception of a backdraft damper or a damper specifically labeled for airflow in one direction.

8.1.3.1.1 Backdraft dampers. A test shall begin with the lowest airflow value, the damper being allowed to seek its own equilibrium position with respect to pressure differential. If desired, the blade angle may be measured (degrees from closed) at each test point. To determine the differences in mechanical forces within the damper while opening vs. closing, the test may be repeated, beginning with the maximum airflow value.

8.1.3.1.2 Other dampers. The damper shall be fixed in its desired position for the duration of the test.

8.1.3.2 Damper mounted with inlet and outlet duct (Figure 5.3). For a damper mounted in a duct system, as shown in Figure 5.3, the test determinations shall be carried out with the damper set in its desired position (except for a backdraft damper, see Section 8.1.3.1.1). This test shall be referred to as the damper and system test. The damper shall then be removed from the test installation and the upstream test duct connected directly to the downstream test duct. The test shall be repeated at approximately the same airflow rate as previously tested. This test shall be referred to as the system test. For each determination the pressure drop shall be the pressure with the damper in place (damper and system) at a given airflow minus the pressure at the identical airflow with the damper removed (system). Refer to Section 9.6 if damper and system flows are not identical.

8.1.4 Presentation of results. The report and presentation of results shall include all the data outlined in Section 8.1.2. In addition, the following shall be recorded as appropriate:

Damper mounting position
Blade orientation
Blade action
Blade position (open or closed)
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Standard 500-D

8.1.4.1 Performance curves. The results of a damper test shall be presented as performance curves.

8.1.4.1.1 Coordinates. A performance curve shall be drawn with airflow rate as abscissa. Static pressure shall be plotted as ordinate. If all results were obtained at the same air density or if results were converted to a nominal density, such density shall be listed; otherwise a curve with air density as ordinate shall be drawn.

8.1.4.1.2 Test points. The results for each determination shall be shown on the performance curve as a series of circled points, one for each variable plotted as ordinate.

8.1.4.1.3 Curve-fitting. A curve for each variable shall be obtained by drawing a continuous curve using the test points for reference. The curve shall not depart from the test points by more than 1% of any test value or 3 Pa (0.01 in. wg), whichever is greater, and the sum of the deviations shall approximate zero.

8.1.4.1.4 Discontinuities. When discontinuities exist they shall be identified with a broken line. If equilibrium cannot be established for any determination, the curves joining the points for that determination with adjacent points shall be drawn as broken lines.

8.1.4.1.5 Identification. Performance curve sheets shall list the test damper, test damper setup and airflow rate measurement setup. Sufficient details shall be listed to identify clearly the damper and setup. Otherwise, a report containing such information shall be referenced.

8.2 Airflow leakage rate using ambient air

The purpose of this test is to determine the relationship between one or more sets of airflow leakage rate and static pressure for a damper, backdraft damper or other air control damper mounted on a chamber at ambient conditions.

8.2.1 General requirements

8.2.1.1 Determinations. A test shall consist of five or more determinations taken at approximately equal increments of pressure differential covering the range desired.

8.2.1.2 Equilibrium. Equilibrium conditions shall be established before each determination. To test for equilibrium, trial observations shall be made until steady readings are obtained.

8.2.1.3 Airflow measurement. When nozzles are used to determine the airflow rate, the minimum ΔP_n shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of test. A direct reading airflow meter may be used if the airflow is below 4.7 L/s (10 cfm).

8.2.1.4 Seating torque measurement. (Might not apply to backdraft damper.)

8.2.1.4.1 Calibrated weights. A test shall be conducted with calibrated weights, springs, actuators or other dampers that may be used to apply the normal seating torque. The force to develop the torque shall be applied at a location consistent with the force which will be applied by the operating damper.

8.2.1.4.2 Application of torque. The torque shall be applied with zero ΔP across the damper with its blades at the full open position. The corresponding weight shall be lowered gradually, without impact loading, until the damper reaches its closed position and without additional applied force. Similarly, springs, actuators or other dampers should be permitted to close the damper in a manner that will not apply any additional force than normally applied.

8.2.2 Data to be recorded

8.2.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size and face area shall be recorded.

8.2.2.2 Test setup. The description of the test setup including specific dimensions shall be recorded.

Reference shall be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup shall be attached to the data.

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

8.2.2.4 Airflow measurement test data. Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For each test, three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), and ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

8.2.2.4.1 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.2.2.4.2 Chamber nozzle test (Figures 6.3 and 6.5). For a chamber nozzle test, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), and approach static pressure (P_{s5}) shall be recorded. When using a chamber for airflow leakage testing, criteria for velocity profile downstream of the nozzles, and area ratio criteria may be ignored.

8.2.2.4.3 Single nozzle chamber test (Figure 6.4). For a single nozzle chamber test, one reading each of chamber dry-bulb temperature (t_{d5}), nozzle pressure drop (ΔP_n), and chamber static pressure (P_{s5}) shall be recorded.

8.2.2.4.4 Airflow meter test (Figure 5.6). For an airflow meter test, airflow shall be recorded directly from the airflow meter. Airflow measurements using this damper shall be limited to a maximum of 4.7 L/s (10 cfm).

8.2.2.5 Test damper setup. Table 2 displays allowable combinations of airflow rate measurement and test damper setups.

8.2.2.5.1 Damper with outlet chamber (Figure 5.4). One reading of chamber static pressure (P_{s7}) shall be recorded per determination.

8.2.2.5.2 Damper with inlet chamber (Figure 5.5). One reading of chamber static pressure (P_{s8}) and chamber temperature (t_{d8}) shall be recorded per determination.

8.2.2.5.3 Damper with outlet plenum (Figures 5.7A and 5.7E). One reading per determination of chamber static pressure (P_{s7}) shall be recorded.

8.2.2.5.4 Damper with inlet plenum (Figures 5.7B and 5.7F). One reading per determination of plenum static pressure (P_{s8}) and plenum temperature (t_{d8}) shall be recorded.

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Table 2 - Allowable Combinations of Airflow Rate Measurement and Test Damper Setups

Test damper setups		Airflow rate measurement setup	
Figure	Connection plane	Figure	Connection plane
5.4	Y	6.2	B
	X	6.3	B
		6.4	B
5.4 Alternate	X	6.3	B
5.5	X	6.2	C
	Y	6.2	A
5.5 Alternate	Y	6.5	A
5.6A Positive Pressure Leakage Test		----	----
5.6B Negative Pressure Leakage Test		----	----
5.8 Bubble test		----	----
5.7A, 5.7E	X	6.2	B
		6.3	A
		6.4	A
5.7B, 5.7F	Y	6.2	C
		6.5	B

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8.2.2.5.5 Damper setup for bubble test (Figure 5.8). For bubble tests, one reading per determination of test pressure P_{s9} shall be recorded. The size of bubble formation shall also be recorded by noting if any bubbles exceed 1.6 mm diameter (1/16 in.) in 1 second or if any bubbles exceed 7mm (1/4 in.) diameter in 1 minute.

8.2.3 Conduct of test

8.2.3.1 General requirements. Each test shall be conducted at ambient temperature between (0°C - 49°C (32°F - 120°F)). A test is a complete set of measurements (or determinations), one set for each one setting of airflow leakage rate and pressure drop.

8.2.3.1.1 Backdraft dampers. A backdraft damper shall be mounted in its desired position and in such a manner so that leakage airflow will force damper blades to the closed position.

8.2.3.1.2 Other dampers. The damper shall be placed in its closed position. Where torque must be applied to a blade or shaft to drive the damper to its closed position, seating torque shall be applied as described in Section 8.2.1.4. Alternatively the damper may be held in its closed position using weights, springs, actuators, or any other damper normally used to close the damper. The damper shall be tested in both directions (except backdraft damper).

8.2.3.2 Bubble test. Mount the damper as shown in Figure 5.8. A bubble solution (commercial test solution or a solution consisting of equal parts liquid detergent, glycerin and water) shall be applied to the damper seal areas. Within a few moments, and before the bubble solution can dry, the wetted areas shall be checked. Pressure and size of bubble formation shall be recorded as stated in Section 8.2.2.5.5.

8.2.3.3 Flow meter test. Mount damper as shown in Figure 5.6. Perform test as described in Section 8.2.3.1.

8.2.3.4 Damper mounted with inlet or outlet chamber or plenum. For dampers mounted with an outlet or inlet chamber or plenum, as shown in Figures 5.4, 5.5, 5.7A, 5.7B, 5.7E, and 5.7F, the test determinations shall be carried out with the damper set in its desired position.

8.2.3.4.1 The following chamber criteria is to be met for a Figure 5.5 leakage test to be valid:

Reference: Upstream is referenced as being on the inlet (fan side) of the nozzles. System Leakage is defined as the volume of air leaking into or out of the chamber with the damper blanked off or the opening covered. Damper Leakage is defined as the volume of air leaking across the plane of the damper with the blades closed and torque applied per Section 8.2.1.4.

(A) Close all nozzles and install the tail end piece (Figure 6.6) on the downstream side of chamber with the 0.013m (1/2”) nozzle open. Increase the pressure upstream of the nozzles in a minimum of five (5) approximately equal increments, to a minimum of 995 Pa (4 in.wg) static pressure or to the maximum fan pressure. If the calculated airflow is greater than $4.47 \times 10^{-5} \times (P_s)^{0.5}$ m^3/s ($1.5 \times (P_s)^{0.5}$ cfm), then the nozzle wall has excessive leakage and must be resealed and retested until the leakage value is less than $4.47 \times 10^{-5} \times (P_s)^{0.5}$ m^3/s ($1.5 \times (P_s)^{0.5}$ cfm).

(B) Blank off exiting end of chamber (location where tail end piece (Figure 6.6) is in Step A above). Open 0.013m (1/2") or 0.019m (3/4") nozzle. Increase the pressure upstream of the nozzles in a minimum of five (5) approximately equal increments, to a minimum of 995 Pa (4 in.wg) static pressure or to the maximum fan pressure. If the calculated leakage is greater than $4.47 \times 10^{-5} \times (P_s)^{0.5}$ m^3/s ($1.5 \times (P_s)^{0.5}$ cfm), then the chamber downstream of the nozzles has excessive leakage and must be resealed and retested until the leakage value is below $4.47 \times 10^{-5} \times (P_s)^{0.5}$ m^3/s ($1.5 \times (P_s)^{0.5}$) cfm).

(C) Repeat test step A to insure leakage values are not affected by downstream leakage values. If airflow across downstream tail end piece (Figure 6.6) is greater than $4.47 \times 10^{-5} \times (P_s)^{0.5}$ m^3/s ($1.5 \times (P_s)^{0.5}$ cfm), then repeat steps A and B above.

This procedure shall have been checked and documented no greater than 6 months before any AMCA certified Figure 5.5 leakage test.

8.2.3.4.2 The maximum system leakage that can be deducted is $4.47 \times 10^{-5} \times (P_s)^{0.5}$ m^3/s ($1.5 \times (P_s)^{0.5}$ cfm) or 2% of damper leakage, (whichever is higher), if system leakage is measured higher than the maximum allowed.

If system leakage is measured less than maximum allowed, then actual system leakage becomes allowable system leakage.

8.2.3.4.3 Pressure drop across the nozzle(s) for the system leakage test must be the SAME or HIGHER than the pressure drop across the nozzle(s) for the corresponding damper leakage test when the system leakage is equal to or more than 9.44×10^{-4} m^3/s (2 cfm) total. When system leakage is less than 9.44×10^{-4} m^3/s (2 cfm) the pressure drop restriction does not apply.

8.2.3.4.4 For chambers other than Figure 5.5, an equivalent method of determining nozzle wall and chamber leakage shall be used. This test shall be referred to as the damper and system test. The damper shall then be covered with a suitable solid board, or other material, which prevents airflow through the damper. The test shall be repeated at approximately the same pressure increments as previously tested. This test shall be referred to as the system test. For each determination the damper leakage shall be the leakage with the damper in place (damper and system) minus the system leakage at the identical pressure. Refer to Section 9.5 if damper and system pressures and system pressures are not identical.

8.2.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Section 8.2.2. In addition, the following shall be recorded:

Damper mounting position
Method of closure
Blade orientation
Blade action
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Standard 500-D

8.2.4.1 Performance curves. The results of a damper test shall be presented as performance curves.

8.2.4.1.1 Coordinates. A performance curve shall be drawn with airflow rate as an abscissa. Static pressure shall be plotted as ordinate. If all results were obtained at the same air density or if results were converted to a nominal density, such density shall be listed; otherwise a curve with air density as ordinate shall be drawn.

8.2.4.1.2 Test points. The results for each determination shall be shown on the performance curve as a series of circled points, one for each variable plotted as ordinate.

8.2.4.1.3 Curve-fitting. A curve for each variable shall be obtained by drawing a continuous curve using the test points for reference. The curves shall not depart from the test points by more than 1.0% or 3 Pa (0.01 in. wg) of any test value and the sum of the deviations shall approximate zero.

8.2.4.1.4 Discontinuities. When discontinuities exist they shall be identified with a broken line. If equilibrium cannot be established for any determination, the curves joining the points for that determination with adjacent points shall be drawn as broken lines.

8.2.4.1.5 Identification. Performance curve sheets shall list the test damper, test damper setup and airflow rate measurement setup. Sufficient details shall be listed to identify clearly the damper and setup. Otherwise, a report containing such information shall be referenced.

8.3 Airflow leakage rate using ambient or heated air [15]

The purpose of this test is to determine the relationship between airflow leakage rate and static pressure for a damper mounted in a duct at either ambient or elevated temperatures.

8.3.1 General requirements

8.3.1.1 Determinations. A test shall consist of one determination taken at the desired test pressure.

8.3.1.2 Equilibrium. Equilibrium conditions shall be established before each determination. To test for equilibrium, trial observations shall be made until steady readings are obtained.

8.3.1.3 Pretest ambient measurements. Prior to recording airflow data for a test, the dry-bulb temperature of the air flowing in the general test area, wet-bulb temperature, the barometric pressure and the ambient temperature at the barometer shall be recorded.

8.3.1.4 Airflow measurement. The minimum pressure drop across the nozzles, ΔP_n, shall be 25 Pa (0.1 in. wg) at the minimum flow rate of test.

8.3.1.5 Seating torque

8.3.1.5.1 Application of torque. The torque applied shall be provided by the closure mechanism, such as, weights, springs, actuators, or other closing damper, which has been activated during the conduct of the Dynamic Closure Test (Section 8.4 or 8.7), or the Damper Operational Test (Section 8.5 or 8.8)

8.3.1.6 Temperature measurement. A minimum of nine equally spaced thermocouples shall be used to measure the temperature (t_{d1}) at a plane 305 ± 25 mm (12 ± 1 in.) upstream of the damper.

8.3.2 Data to be recorded

8.3.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper, etc.) size, and face area shall be recorded.

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

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

8.3.2.4 Airflow measurement test data. Test data for the determination shall be recorded. Readings shall be made simultaneously whenever possible. Ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), and ambient barometric pressure (p_b) shall be recorded.

8.3.2.4.1 Leakage chamber test (Figure 6.6). For leakage chamber tests, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), and differential pressure across the damper ($\Delta P_{9,5}$) shall be recorded. When using a leakage chamber nozzle plate for leakage testing, the criteria for velocity profile upstream and downstream of the nozzles, and area ratio criteria may be ignored.

8.3.2.5 Test temperature. The test temperature (t_{d1}) shall be recorded (Figure 5.9).

8.3.2.6 Test damper setup. Table 3 displays the allowable combinations of airflow rate measurement and test damper setups.

8.3.3 Conduct of test

8.3.3 Conduct of test. Immediately following the damper closure from the Dynamic Closure Test (Section 8.4 or 8.7) or the Damper Operational Test (Section 8.5 or 8.8), whichever is appropriate, with the fan running, and the heat source (electric heater or gas burners at low fire) operating (if required), remove the duct section downstream of the damper and attach the Leakage Chamber (Figure 6.6).

Adjust the fan speed to obtain the desired pressure differential across the closed damper. Open a nozzle

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Table 3 – Air Leakage Flow Rate Test Using Ambient Air, Test Damper Setups

TEST DAMPER SETUPS		AIRFLOW RATE MEASUREMENT SETUPS	
Figure	Connection Plane	Figure	Connection Plane
5.2, 5.3A, 5.3B, 5.3C, 5.5, 5.7B, 5.7D, 5.7F 5.9*	2	6.6	A

*For heated or ambient air.

or nozzle combination on the Leakage Chamber such that the pressure differential across the nozzle plate is a minimum of 25 Pa (0.1 in. wg) (for nozzles that are 0.019m (0.75") diameter or less, a ΔP of 25 Pa (0.1 in. wg) is the allowable minimum. Adjust the heat source (if tested at a temperature other than ambient) such that t_{d1} is maintained between t_{d1} and t_{d1} + 30°C (t_{d1} and t_{d1} + 50°F). The elevated test temperature, pressure differential across the closed damper ($\Delta P_{9,5}$), and pressure differential (ΔP_n) across the leakage chamber nozzle plate shall be recorded. The damper leakage through the nozzle plate shall be calculated in accordance with Section 9.

Open a smaller nozzle combination such that the pressure differential across the leakage chamber nozzle plate is higher than the first determination. Adjust the fan speed to obtain the desired pressure differential across the closed damper. The test temperature, pressure differential ($\Delta P_{9,5}$) across the closed damper, and pressure differential across the leakage chamber nozzle plate shall be recorded.

The damper and system leakage through the leakage chamber nozzle plate shall be calculated using Section 9.7.

8.3.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Section 8.3.2. In addition, the following shall be recorded:

Damper mounting position
Actuator/Operator
Actuator/Operator supply source
Method of closure
Blade orientation
Actuator/Operator
Actuator/Operator supply source
Blade action
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Standard 500-D

8.3.4.1 Airflow leakage rate. A statement of the measured airflow leakage rate per face area of damper at the test temperature and test pressure shall be reported. In addition, a statement of the measured airflow leakage rate per face area of damper corrected to standard air conditions shall be reported.

8.3.4.2 Identification. Performance curve sheets shall list the test damper, test damper setup and airflow rate measurement setup. Sufficient details shall be listed to identify clearly the damper and setup. Otherwise, a report containing such information shall be referenced.

8.4 Dynamic closure test using ambient air

The purpose of this test is to determine the ability of a damper to close against a given airflow at ambient air conditions, and to maintain its integrity against the pressure resultant from closure when the damper is mounted in a duct, wall or floor.

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8.4.1 General requirements

8.4.1.1 Determinations. Each damper shall be tested a minimum of three times in both airflow directions at each selected combination of airflow rate through the open damper and pressure differential across the closed damper.

8.4.1.2 Equilibrium. Equilibrium conditions shall be established during each test. A stable pressure differential across the closed damper shall be established before commencement of the opening cycle. A stable airflow rate through the damper shall be established before commencement of the closing cycle.

8.4.1.3 Airflow measurement. Airflow velocity at the plane of measurement when determined by using a Pitot-static tube shall not be less than 6.35 m/s (1250 fpm). When nozzles are used to determine the airflow rate, the minimum ΔP_n shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of test.

8.4.2 Data to be recorded

8.4.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size, and face area shall be recorded.

8.4.2.2 Test setup. The description of the test setup including specific dimensions shall be recorded.

Reference shall be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup shall be attached to the data.

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

8.4.2.4 Airflow measurement. Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For all tests, three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), and ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

8.4.2.4.1 Pitot test (Figure 6.1). For a Pitot traverse test, one reading each of velocity pressure (P_{v3r}) and static pressure (P_{s3r}) shall be recorded for each Pitot station. In addition, three readings of traverse-plane dry-bulb temperature (t_{d3}) shall be recorded unless the readings are steady in which case only one need be recorded.

8.4.2.4.2 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.4.2.4.3 Chamber nozzle test (Figures 6.3 and 6.5). For a chamber nozzle test, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), approach static pressure (P_{s5}), shall be recorded.

8.4.2.4.4 Single nozzle chamber test (Figure 6.4). For a single nozzle chamber test, one reading each of chamber dry-bulb temperature (t_{d5}), nozzle pressure drop (ΔP_n), and chamber static pressure (P_{s5}), shall be recorded.

8.4.2.5 Test damper setup. Each damper shall be tested in a setup which simulates its intended field installation (see Section 7.1.1). Table 4 displays allowable combinations of airflow rate measurement and test damper setups.

8.4.2.5.1 Damper with inlet and outlet ducts (Figures 5.3, 5.3A, 5.3B, and 5.3C). One reading of pressure drop across the test damper ($\Delta P_{9,4}$) shall be recorded.

8.4.2.5.2 Damper with outlet chamber (Figures 5.4, 5.7A, 5.7C, and 5.7E). One reading of chamber static pressure (P_{s7}) shall be recorded.

8.4.2.5.3 Damper with inlet chamber (Figures 5.5, 5.7B, 5.7D, and 5.7F). One reading of chamber static pressure (P_{s8}) and chamber temperature (t_{d8}) shall be recorded.

8.4.2.6 Degree of closure. The degree of damper closure and any permanent deformation to the blades and frame shall be recorded.

Under conditions of the specified airflow, the damper shall completely close and latch automatically (when a latch is provided) without damage to the damper or its components. Damper closure is 100% if the damper closes fully as previously demonstrated in the static condition. Failure to close as previously demonstrated in the static condition and/or any physical damage shall be recorded.

8.4.2.7 Closure time. The time required for the damper to travel from the open to closed position shall be recorded.

8.4.2.8 Closure pressure. After closure the differential pressure after equilibrium is achieved shall be recorded.

8.4.3 Conduct of test. Each test shall be conducted at ambient temperatures between (0˚C - 49˚C (32˚F - 120˚F)). A test is a complete set of measurements (or determinations), one set for each setting of airflow with the damper in the open position and pressure drop across the damper when in the closed position. A test shall be conducted at a selected pressure drop across the damper when closed. The selected airflow rate and pressure drop shall be established prior to recording the first determination. The damper shall be maintained fully open allowing the established airflow rate to pass through. The airflow rate shall be recorded.

The damper shall be then allowed to close with the appropriate weights, springs, actuators or other closing dampers normally supplied with the damper applying the closing torque or force. During closure the pressure drop across the damper shall not be less than the value indicated by a straight line from

Table 4 – Allowable combinations of airflow rate measurement and test damper setups

TEST DAMPER SETUPS		AIRFLOW RATE MEASUREMENT SETUPS	
Figure	Connection Plane	Figure	Connection Plane
5.3, 5.3A, 5.3B, and 5.3C	Y	6.1	C
		6.2	C
	X	6.5	B
5.4	Y	6.1	B
		6.2	B
	X	6.3	B
		6.4	B
5.5	X	6.1	C
		6.2	C
	Y	6.5	A
5.7A, 5.7C, and 5.7E	X	6.1	B
		6.2	B
		6.3	A
		6.4	A
5.7B, 5.7D, and 5.7F	Y	6.1	C
		6.2	C
		6.5	B

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the pressure at the full-open position to the pressure at the full-closed position when time vs. pressure drop is plotted on linear paper. The airflow generating equipment is to be capable of producing the prescribed airflow and pressure conditions without the use of pressure relief dampers. The pressure differential across the closed damper shall be recorded. With the pressure differential maintained on the closed damper a visual inspection shall be made on the damper and the degree of closure shall be recorded.

Airflow shall then be shut off and the damper reset to its open position. The test procedure shall then be repeated for two more determinations. After three closure cycles the damper shall be reversed and retested with airflow through the damper in the reverse direction.

Any suitable means of releasing the damper may be used provided that it results in closure in a manner similar to that obtained by the use of a fusible link or heat responsive damper.

If multiple section dampers are to be tested each single section must be tested for closure with all other sections closed. Closure velocity shall be based on the total area of the multiple damper sections and not the single section velocity.

8.4.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Section 8.4.2. In addition, the following shall be recorded:

Damper mounting position
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Std. 500-D

8.5 Operational test using ambient air

The purpose of this test is to determine the ability of a damper to operate (close and open) against a given airflow at ambient air conditions when the damper is mounted in a duct or wall.

8.5.1 General requirements

8.5.1.1 Determinations. Each damper shall be tested a minimum of three times in both airflow directions at each selected combination of airflow rate through the open damper and pressure differential across the closed damper.

8.5.1.2 Equilibrium. Equilibrium conditions shall be established during each test. A stable pressure differential across the closed damper shall be established before commencement of the opening cycle. A stable airflow rate through the damper shall be established before commencement of the closing cycle.

8.5.1.3 Airflow measurement. Airflow velocity at the plane of measurement when determined by using a Pitot-static tube shall not be less than 6.35 m/s (1250 fpm). When nozzles are used to determine the airflow rate, the minimum ΔP_n shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of test.

8.5.2 Data to be recorded

8.5.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size, and face area shall be recorded.

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

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

8.5.2.4 Airflow measurement. Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For all tests, three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

8.5.2.4.1 Pitot test (Figure 6.1). For a Pitot traverse test, one reading each of velocity pressure (P_{v3r}) and static pressure (P_{s3r}) shall be recorded for each Pitot station. In addition, three readings of traverse-plane dry-bulb temperature (t_{d3}) shall be recorded unless the readings are steady in which case only one need be recorded.

8.5.2.4.2 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.5.2.4.3 Chamber nozzle test (Figures 6.3 and 6.5). For a chamber nozzle test, the nozzle combinations and one reading each of pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), approach static pressure (P_{s5}), shall be recorded.

8.5.2.4.4 Single nozzle chamber test (Figure 6.4). For a single nozzle chamber test, one reading each of chamber dry-bulb temperature (t_{d5}), nozzle pressure drop (ΔP_n), and chamber static pressure (P_{s5}) shall be recorded.

8.5.2.5 Test damper setup. Each damper should be tested in a setup which simulates its intended field installation (see Section 7.1.1). Table 5 displays allowable combinations of airflow rate measurements and test damper setups.

8.5.2.5.1 Damper with inlet and outlet ducts (Figures 5.3, 5.3A, 5.3B, and 5.3C). One reading of pressure drop across the test damper ($\Delta P_{9,4}$) shall be recorded.

8.5.2.5.2 Damper with outlet chamber (Figures 5.4, 5.7A, 5.7C, 5.7E). One reading of chamber static pressure (P_{s7}) shall be recorded.

8.5.2.5.3 Damper with inlet chamber (Figures 5.5, 5.7B, 5.7D, 5.7F). One reading of chamber static pressure (P_{s8}) and chamber temperature (t_{d8}) shall be recorded.

8.5.2.6 Degree of closure. The degree of damper closure and any permanent deformation to the blades and frame shall be recorded. Under conditions of the specified airflow, the damper shall completely close and latch automatically (when a latch is provided) without damage to the damper or its components. Damper closure is 100% if the damper closes fully as previously demonstrated in the static condition. Failure to close as previously demonstrated in the static condition and/or any physical damage shall be recorded.

8.5.2.7 Degree of opening. The degree of damper opening and any permanent deformation to the blades and frame shall be recorded. Under conditions of the specified airflow, the damper shall completely open and latch automatically (when a latch is provided) without damage to the damper or its components.

Damper opening is 100% if the damper opens fully as previously demonstrated in the static condition and original airflow values are established. Failure to open as previously demonstrated in the static condition shall be recorded.

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Table 5 – Allowable Combinations of Airflow Rate Measurement and Test Damper Setups

TEST DAMPER SETUPS		AIRFLOW RATE MEASUREMENT SETUPS	
Figure	Connection Plane	Figure	Connection Plane
5.3, 5.3A, 5.3B, and 5.3C	Y	6.1	C
		6.2	C
	X	6.5	B
5.4	Y	6.1	B
		6.2	B
	X	6.3	B
		6.4	B
5.5	X	6.1	C
		6.2	C
	Y	6.5	A
5.7A, 5.7C, and 5.7E	X	6.1	B
		6.2	B
		6.3	A
		6.4	A
5.7B, 5.7D, 5.7F	Y	6.1	C
		6.2	C
		6.5	B

8.5.2.8 Closure time. The time required for the damper to travel from the open to closed position shall be recorded.

8.5.2.9 Opening time. The time required for the damper to travel from the closed to the open position shall be recorded.

8.5.3 Conduct of test. Each test shall be conducted at ambient temperatures between (0˚C - 49˚C (32˚F - 120˚F)). A test is a complete set of measurements (or determinations) one set for each setting of airflow with the damper in the open position and pressure drop across the damper when in the closed position. A test shall be conducted at a selected airflow rate through the damper when fully open and a selected pressure drop across the damper when closed. The selected airflow rate and pressure drop shall be established prior to recording the first determination. The damper shall be maintained fully open allowing the established airflow rate to pass through. The airflow rate shall be recorded.

The damper shall be then allowed to close with the appropriate weights, springs, actuators or other closing dampers normally supplied with the damper applying the closing torque or force. During closure the pressure drop across the damper shall not be less than the value indicated by a straight line from the pressure at the full-open position to the pressure at the full-closed position when time (abscissa) vs. pressure drop (ordinate) is plotted on linear paper. The airflow generating equipment is to be capable of producing the prescribed airflow and pressure conditions without the use of pressure relief dampers. The pressure differential across the closed damper shall be recorded. With the pressure differential maintained on the closed damper an external visual inspection (through viewing ports, if necessary) shall be made on the damper and the degree of closure shall be recorded.

The damper shall then be reopened with the appropriate weights, springs, actuators or other opening damper(s) normally supplied with the damper, applying the opening torque or force. During opening, the pressure drop across the damper shall not be less than the value indicated by a straight line between the pressure drop across the damper at the full-open position to the pressure drop across the damper at the full-closed position when time (abscissa) vs. pressure drop (ordinate) is plotted on linear paper. Once the damper is opened an external visual inspection (through viewing ports, if necessary) of the damper shall be made and recorded. The original airflow shall be reestablished and recorded.

The test procedure shall then be repeated for two more determinations. After three cycles the damper shall be reversed and retested with airflow through the damper in the reverse direction.

8.5.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Section 8.5.2. In addition, the following shall be recorded:

Damper mounting position
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Standard 500-D

8.6 Damper dynamic operational torque

The purpose of this test is to determine the torque required to operate a damper from the open to closed position under airflow, and from the closed to open position against a specified differential pressure.

8.6.1 General requirements

8.6.1.1 Determinations. Each damper shall be tested a minimum of three times in both airflow directions at each selected combination of airflow rates through the open damper and pressure differential across the closed damper.

8.6.1.2 Equilibrium. A stable pressure differential across the closed damper shall be established before commencement of the opening cycle. A stable airflow rate through the damper shall be established before commencement of the closing cycle.

8.6.1.3 Airflow measurement. Airflow velocity at the plane of measurement when determined by using a Pitot-static tube shall not be less than 6.35 m/s (1250 fpm). When nozzles are used to determine the airflow rate, the minimum ΔP_n shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of test.

8.6.2 Data to be recorded

8.6.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size, and face area shall be recorded.

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

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

8.6.2.4 Airflow measurement. Test data for each determination's open and closed damper positions shall be recorded. Readings shall be made simultaneously whenever possible. Three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

8.6.2.4.1 Pitot test (Figure 6.1). For a Pitot traverse test, one reading each of velocity pressure (P_{v3r}) and static pressure (P_{s3r}) shall be recorded for each Pitot station. In addition, three readings of traverse-plane dry-bulb temperature (t_{d3}) shall be recorded unless the readings are steady in which case only one need be recorded.

8.6.2.4.2 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.6.2.4.3 Chamber nozzle test (Figures 6.3 and 6.5). For a chamber nozzle test, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), and approach static pressure (P_{s5}) shall be recorded.

8.6.2.4.4 Single nozzle chamber test (Figure 6.4). For a single nozzle chamber test, one reading each of chamber dry-bulb temperature (t_{d5}), nozzle pressure drop (ΔP_n), and chamber static pressure (P_{s5}) shall be recorded.

8.6.2.5 Test damper setup. Each damper should be tested in a setup which simulates its intended field installation (see Section 7.1.1). Table 6 displays allowable combinations of airflow rate measurements and test damper setups.

8.6.2.5.1 Damper with inlet and outlet ducts (Figures 5.3, 5.3A, 5.3B, and 5.3C). One reading of pressure drop across the test damper ($\Delta P_{9,4}$) shall be recorded.

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Table 6 - Damper Dynamic Operational Torque, Test Damper Setups

TEST DAMPER SETUPS		AIRFLOW RATE MEASUREMENT SETUPS	
Figure	Connection Plane	Figure	Connection Plane
5.3, 5.3A, 5.3B, and 5.3C	Y	6.1	C
		6.2	C
	X	6.5	B
5.4	Y	6.1	B
		6.2	B
	X	6.3	B
		6.4	B
5.5	X	6.1	C
		6.2	C
	Y	6.5	A
5.7A, 5.7C, and 5.7E	X	6.1	B
		6.2	B
		6.3	A
		6.4	A
5.7B, 5.7D, and 5.7F	Y	6.1	C
		6.2	C
		6.5	B

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8.6.2.5.2 Damper with outlet chamber (Figures 5.4, 5.7A, 5.7C, and 5.7E). One reading of chamber static pressure (P_{s7}) shall be recorded.

8.6.2.5.3 Damper with inlet chamber (Figures 5.5, 5.7B, 5.7D, and 5.7F). One reading of chamber static pressure (P_{s8}) and chamber temperature (t_{d8}) shall be recorded.

8.6.2.6 Closure time. The time required for the damper to travel from the open to closed position shall be recorded.

8.6.2.7 Opening time. The time required for the damper to travel from the closed to the open position shall be recorded.

8.6.3 Conduct of tests. Each test shall be conducted at ambient temperatures between (0˚C - 49˚C (32˚F - 120˚F)). A determination shall consist of readings of the torque developed at the damper drive shaft rotations specified in Section 8.6.1.1. At a minimum, a test shall consist of the following determinations: Torque readings at 1˚ rotational increments of damper drive shaft rotation on the opening and closing cycles.

A test shall be conducted at a selected airflow rate through the damper when fully open and a selected pressure differential across the damper when closed. The selected airflow rate and pressure differential shall be established prior to recording the first determination. The damper shall be maintained fully open allowing the established airflow rate to pass through. The airflow rate shall be recorded.

The damper shall then be powered closed. During closure, the pressure drop across the damper shall not be less than the value indicated by a straight line from the pressure at the full-open position to the pressure at the full-closed position when time (abscissa) vs. pressure drop (ordinate) is plotted on linear paper. The airflow generating equipment is to be capable of producing the prescribed airflow and pressure conditions without the use of pressure relief dampers. The pressure differential across the closed damper shall be recorded.

The damper shall then be powered back open. During opening, the pressure drop across the damper shall not be less than the value indicated by a straight line between the pressure drop across the damper at the full-open position to the pressure drop across the damper at the full-closed position when time (abscissa) vs. pressure drop (ordinate) is plotted on linear paper. The airflow generating equipment is to be capable of producing the prescribed airflow and pressure conditions without the use of pressure relief dampers. The original airflow shall be re-established and recorded.

The test procedure shall then be repeated for two more determinations. After three cycles the damper shall be reversed and retested with airflow through the damper in the reverse direction.

8.6.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Sections 8.6.2 and 8.6.3. In addition, the following shall be recorded:

Damper mounting position
Blade orientation
Blade action
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Standard 500-D

8.7 Dynamic closure test using heated air

The purpose of this test is to determine the ability of a damper to close upon activation of its heat responsive damper against a given airflow at an elevated temperature, and to maintain its integrity against the pressure resultant from closure when the damper is mounted in a duct.

8.7.1 General requirements

8.7.1.1 Determinations. Each damper shall be tested a minimum of three times in both airflow directions at each selected combination of airflow rate through the open damper and pressure differential across the closed damper. The three cycles at ambient are a preconditioning test prior to conduct of heated air closure test. After preconditioning tests one heated air test will be conducted.

8.7.1.2 Equilibrium. Equilibrium conditions shall be established before each determination.

8.7.1.3 Pretest ambient measurement. Prior to recording airflow data for a test, the dry-bulb temperature in the general test area, wet-bulb temperature, the barometric pressure and the ambient temperature at the barometer shall be recorded.

8.7.1.4 Airflow measurement. Airflow velocity at the plane of measurement when determined by using a Pitot-static tube shall not be less than 6.35 m/s (1250 fpm). When nozzles are used to determine the airflow rate, the minimum ΔP_n shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of test.

8.7.1.5 Elevated temperature measurement. A minimum of nine equally spaced thermocouples shall be used to measure the temperature at a plane 305 ± 25 mm (12 ± 1 in.) (t_{d1}) upstream of damper.

8.7.2 Data to be recorded

8.7.2.1 Test damper. The description of the test unit, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size, and face area shall be recorded.

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

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

8.7.2.4 Airflow measurement. Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For all tests, three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), and ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

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8.7.2.4.1 Pitot test (Figure 6.1). For a Pitot traverse test, one reading each of velocity pressure (P_{v3r}) and static pressure (P_{s3r}) shall be recorded for each Pitot station. In addition, three readings of traverse-plane dry-bulb temperature (t_{d3}) shall be recorded unless the readings are steady in which case only one need be recorded.

8.7.2.4.2 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.7.2.4.3 Chamber nozzles test (Figure 6.5). For a chamber nozzle test, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), and approach static pressure (P_{s5}) shall be recorded.

8.7.2.4.4 Other airflow measurement dampers. Data shall be recorded to establish accurate airflow measurement (see Section 6.3.4).

8.7.2.5 Rate of temperature rise. Heat shall be introduced into the system at a rate which will generate an average temperature rise of 15°C – 30°C per min (30°F - 50°F per min). The temperature at t_{d1} shall be recorded at a maximum of 10 second intervals from the time heat is introduced into the system until the completion of the test.

8.7.2.6 Energy input

8.7.2.6.1 The heated air test described herein anticipates the use of the combustion of natural gas as the heat source. Other methods of heat input shall be permitted to be used provided a correction is made such that there is an equivalent mass flow rate across the damper as that would occur with using natural gas as the heat source.

8.7.2.7 Closure temperature. The approximate temperature (t_{d1}) when the heat responsive damper releases shall be estimated and recorded.

8.7.2.8 Test damper setup. Table 7 displays allowable combinations of airflow rate measurement and test damper setups.

8.7.2.8.1 Damper with inlet and outlet ducts (Figure 5.9). One reading of inlet duct static pressure (P_{s9}) shall be recorded before closure. The differential pressure ($\Delta P_{9\text{-}4}$) after closure equilibrium is achieved shall be recorded.

8.7.2.9 Degree of closure. The degree of damper closure and any permanent deformation to the blades and frame shall be recorded.

Under conditions of the specified airflow and heat, the damper shall completely close and latch automatically (when a latch is provided) without damage to the damper or its components. Damper closure is 100% if the damper closes fully as previously demonstrated in the static condition. Failure to close as previously demonstrated in the static condition and/or any physical damage shall be recorded.

8.7.2.10 Closure time. The time required for the damper to travel from the open to closed position shall be recorded.

8.7.3 Conduct of test. Three cycles at ambient conditions are a preconditioning test prior to the heated air closure test.

An airflow rate measurement and pressure differential shall be conducted at ambient temperatures between (0˚C - 49˚C (32˚F - 120˚F)). The selected airflow rate shall be established through the damper while fully open. The damper shall then be closed and the selected pressure differential across the damper shall be established.

The test system must be designed in such a manner that when the test damper is open the original airflow rate will be established. A test determination is a complete set of measurements with the damper in the open position and pressure differential across the damper when it is closed.

After the test system has been set to establish the desired airflow rate through the open damper and pressure drop across the closed damper, the test damper will be opened and the system set to deliver the airflow rate established at ambient conditions. Heat shall then be introduced to the system at a rate which will generate an average temperature rise of 15°- 30°C per min. (30°- 50°F per min.). The damper shall be equipped with the heat responsive damper normally supplied with the damper. Heat shall be introduced continuously until the heat responsive damper triggers and allows the damper to close (Note: for safety reasons, it may be necessary to turn the heat source off when the test damper is closed). The damper shall close utilizing the appropriate weights, springs, actuators or other closing dampers normally supplied with the damper, applying the closing torque or force.

During closure, the pressure drop across the damper shall not be less than the value indicated by a straight line from the pressure at the full-open position to the pressure at the full-closed position when time (abscissa) vs. pressure (ordinate) is plotted on linear paper. With the pressure differential maintained on the closed damper an external visual inspection (through viewing ports, if necessary) shall be made on the damper and the degree of closure shall be recorded.

Table 7 – Dynamic Closure Test Using Heated Air Test Damper Setups

TEST DAMPER SETUPS		AIRFLOW RATE MEASUREMENT SETUPS	
Figure	Connection Plane	Figure	Connection Plane
5.9	X	6.1	C
		6.2	C
		6.5	B

During this test a damper equipped with an external actuator used as the mechanism to close the damper shall be tested with an enclosure around the actuator. The enclosure shall contain the actuator and shall be equipped with a heater which will raise the temperature inside the enclosure to the same temperature and length of time that the damper is to be rated.

8.7.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Section 8.7.2. In addition, the following shall be recorded:

Damper mounting position
Blade orientation
Damper operator/actuator
Actuator supply source (voltage or air pressure as applicable)
Airflow direction
Personnel
Date
Test ID#
Lab name
Lab location
Reference to AMCA Standard 500-D

8.8 Operational test using heated air

The purpose of this test is to determine the ability of a damper to operate (open to close to open) against airflow at an elevated temperature when the damper is mounted in a duct.

8.8.1 General requirements

8.8.1.1 Determinations. Each damper shall be tested a minimum of three times in both airflow directions at each selected combination of airflow rate through the open damper and pressure differential across the closed damper. The three cycles at ambient conditions are a preconditioning test prior to conduct of heated air operational test. After preconditioning tests one heated air test will be conducted.

8.8.1.2 Equilibrium. Equilibrium conditions shall be established before each determination. To test for equilibrium, trial observations shall be made until steady readings are obtained. Ranges of air delivery over which equilibrium cannot be established shall be recorded.

8.8.1.3 Pretest ambient measurement. Prior to recording airflow data for a test, the dry-bulb temperature of the air flowing in the general test area, wet-bulb temperature, the barometric pressure and the ambient temperature at the barometer shall be recorded.

8.8.1.4 Airflow measurement. Airflow velocity at the plane of measurement when determined by using a Pitot-static tube shall not be less than 6.35 m/s (1250 fpm). When nozzles are used to determine the airflow rate, the minimum ΔP shall be 25 Pa (0.1 in. wg) at the minimum airflow rate of test.

8.8.1.5 Elevated temperature measurement. A minimum of nine equally spaced thermocouples shall be used to measure the temperature at a plane 305 ± 25 mm (12 ± 1 in.) (t_{d1}) upstream of damper.

8.8.2 Data to be recorded

8.8.2.1 Test damper. The description of the test damper, including the model, the damper type, (i.e., curtain damper, single blade damper, multi-blade damper) size, and face area shall be recorded.

8.8.2.2 Test setup. The description of the test setup including specific dimensions shall be recorded.

Reference shall be made to the figures in this standard. Alternatively, a drawing or annotated photograph of the setup shall be attached to the data.

8.8.2.3 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.

8.8.2.4 Airflow measurement. Test data for each determination shall be recorded. Readings shall be made simultaneously whenever possible. For all tests, three readings of ambient dry-bulb temperature (t_{do}), ambient wet-bulb temperature (t_{wo}), and ambient barometric pressure (p_b) shall be recorded unless the readings are steady in which case only one need be recorded.

8.8.2.4.1 Pitot test (Figure 6.1). For a Pitot traverse test, one reading each of velocity pressure (P_{v3r}) and static pressure (P_{s3r}) shall be recorded for each Pitot station. In addition, three readings of traverse-plane dry-bulb temperature (t_{d3}) shall be recorded unless the readings are steady in which case only one need be recorded.

8.8.2.4.2 Duct nozzle test (Figure 6.2). For a duct nozzle test, one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}) and approach static pressure (P_{s5}) shall be recorded.

8.8.2.4.3 Chamber nozzle test (Figure 6.3 & 6.5). For a chamber nozzle test, the nozzle combinations and one reading each of nozzle pressure drop (ΔP_n), approach dry-bulb temperature (t_{d5}), and approach static pressure (P_{s5}) shall be recorded.

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8.8.2.4.4 Other airflow measurement dampers. Data shall be recorded to establish accurate airflow measurement (see Section 6.3.4).

8.8.2.5 Rate of temperature rise. The temperature at t_{d1} shall be recorded at 10 second intervals from the time heat is introduced into the system until completion of the test.

8.8.2.6 Degree of closure. The degree of damper closure and any permanent deformation to the blades and frame shall be recorded.

Under conditions of the specified airflow and heat, the damper shall completely close and latch automatically (when a latch is provided) without damage to the damper or its components. Damper closure is 100% if the damper closes fully as previously demonstrated in the static condition. Failure to close as previously demonstrated in the static condition and/or any physical damage shall be recorded.

8.8.2.7 Degree of opening. The degree of damper opening and any permanent deformation to the blades and frame shall be recorded. Under conditions of the specified airflow and heat, the damper shall completely open and latch automatically (when a latch is provided) without damage to the damper or its components. Damper opening is 100% if the damper opens fully as previously demonstrated in the static condition and original airflow values are established. Failure to open as previously demonstrated in the static condition shall be recorded.

8.8.2.8 Energy input

8.8.2.8.1 The gas consumption or electrical input from the heat source used during the test shall be converted to Joule (BTU) input. The heated air test described herein anticipates the use of the combustion of natural gas as the heat source. Other methods of heat input shall be permitted to be used provided a correction is made such that there is an equivalent mass flow rate across the damper as that would occur with using natural gas as the heat source.

8.8.2.8.2 Sufficient energy shall be introduced into the system to meet the required rate of temperature rise as noted in Section 8.8.2.5. Prior to closure, consideration must be given to the introduction of combustion gases if hydrocarbon fuel is used as the heat energy source to ensure that mass flow rate of air through the damper remains constant.

8.8.2.9 Test damper setup. Table 8 displays allowable combinations of airflow rate measurement and test damper setups.

8.8.2.9.1 Damper with inlet and outlet ducts (Figure 5.9). One reading of inlet duct static pressure (P_{s9}) shall be recorded. The differential pressure ($\Delta P_{9\text{-}4}$) after closure equilibrium is achieved shall be recorded.

8.8.2.10 The degree of damper closure and any permanent deformation to the blades and frame shall be recorded. Under conditions of the specified airflow and heat, the damper shall completely close and latch automatically (when a latch is provided) without damage to the damper or its components. Damper closure is 100% if the damper closes fully as previously demonstrated in the static condition. Failure to close as previously demonstrated in the static condition and/or any physical damage shall be recorded.

8.8.2.11 Closure time. The time required for the damper to travel from the open to closed position shall be recorded.

8.8.2.12 Opening time. The time required for the damper to travel from the closed to the open position shall be recorded.

8.8.3 Conduct of test. An airflow rate measurement and pressure differential shall be established and recorded at ambient temperatures between (0˚C - 49˚C (32˚F - 120˚F)). The selected airflow rate shall be established through the damper while fully open. The damper shall then be closed and the selected pressure differential across the damper shall be established. The test system must be designed in such a manner that when the test damper is open the original air flow rate will be established. A test

Table 8 - Damper Operational Test Using Heated Air Test Damper Setups

TEST DAMPER SETUPS		AIRFLOW RATE MEASUREMENT SETUPS	
Figure	Connection Plane	Figure	Connection Plane
5.9	X	6.1	C
		6.2	C
		6.5	B

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determination is a complete set of measurements with the damper in the open position and pressure differential across the damper when it is closed.

After the test system has been set to establish the desired airflow rate through the open damper and pressure differential across the closed damper, the test damper will be opened and the system set to deliver the airflow rate established at ambient conditions. Heat shall then be introduced to the system at a rate which will generate an average temperature rise of 15°- 30°C per min. (30°- 50°F per min.). Upon reaching the desired test temperature, this temperature shall be maintained within -0°C + 30°C (-0°F +50°F).

An exception shall be permitted for the recorded temperature to drop below the test temperature, provided the cumulative time the damper is at or above the test temperature is 15 minutes. After the required time at temperature, the damper shall then be allowed to close utilizing the appropriate weights, springs, actuators or other closing dampers normally supplied with the damper, applying the closing torque or force. (Note: for safety reasons, it may be necessary to turn the heat source off when the test damper is closed). During closure, the pressure drop across the damper shall not be less than the value indicated by a straight line from the pressure at the full-open position to the pressure at the full-closed position when time (abscissa) vs. pressure (ordinate) is plotted on linear paper. The airflow generating equipment is to be capable of producing the prescribed airflow and pressure conditions without the use of pressure relief dampers.

With the pressure differential maintained on the closed damper, a visual inspection shall be made on the damper and the degree of closure shall be recorded. The test sample must be at rated test temperature prior to reopening. The damper shall then be reopened with the appropriate weights, springs, actuators or other opening damper(s) normally supplied with the damper, applying the opening torque or force. During opening, the pressure drop across the damper shall not be less than the value indicated by a straight line between the pressure drop at the full-open position and the pressure drop across the damper at the full-closed position when time (abscissa) vs. pressure drop (ordinate) is plotted on linear paper. Once the damper is opened an external visual inspection (through viewing ports, if necessary) shall be made on the damper and the degree of opening shall be recorded.

During this test, a damper equipped with an external actuator used as the mechanism to close the damper shall be tested with an enclosure around the actuator. The enclosure shall contain the actuator and shall be equipped with a heater which can raise the temperature inside the enclosure to the same temperature and length of time that the damper is to be rated.

8.8.4 Presentation of results. The report and presentation of results shall include all the data as outlined in Sections 8.8.2 and 8.8.3. In addition, the following shall be recorded:

Damper Mounting Position
Blade Orientation
Actuator/Operator
Actuator/Operator Supply Source
Airflow Direction
Personnel
Date
Test ID#
Lab Name
Lab Location
Reference to AMCA Standard 500-D

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.

9.2 Density and viscosity of air

9.2.1 Atmospheric air density. The density of atmospheric air (ρ_o) 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 Equations 9.1, 9.2, and 9.3 [16].

$$p_e = 3.25t_{w0}^2 + 18.6t_{w0} + 692$$ Eq. 9.1 SI

$$p_e = (2.96\times10^{-4})t_{w0}^2 - (1.59\times10^{-2})t_{w0} + 0.41$$ Eq. 9.1 I-P

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

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

$$\rho_0 = \frac{(p_b - 0.378 p_p)}{R(t_{d0} + 273.15)} \quad \text{Eq. 9.3 SI}$$

$$\rho_0 = \frac{70.73(p_b - 0.378 p_p)}{R(t_{d0} + 459.67)} \quad \text{Eq. 9.3 I-P}$$

Equation 9.1 is approximately correct for p_e for a range of t_{w0} between 4°C and 32°C (40°F and 90°F). When t_{w0} is outside of the range of 4˚C and 32˚C (40˚F and 90˚F), values of p_e shall be obtained from the ASHRAE Handbook of Fundamentals[1]. The gas constant (R) may be taken as 287.1 J/kg-K (53.35 ft-lb$_f$/lbm-°R) for air.

9.2.2 Duct or chamber air density. The density of air in a duct or chamber at Plane x (ρ_x) may be calculated by correcting the density of atmospheric air (ρ_0) for the pressure (P_{sx}) and temperature (t_{dx}) at Plane x using:

$$\rho_x = \rho_0 \left(\frac{t_{d0} + 273.15}{t_{dx} + 273.15} \right) \left(\frac{P_{sx} + p_b}{p_b} \right) \quad \text{Eq. 9.4 SI}$$

$$\rho_x = \rho_0 \left(\frac{t_{d0} + 459.67}{t_{dx} + 459.67} \right) \left(\frac{P_{sx} + 13.63 p_b}{13.63 p_b} \right) \quad \text{Eq. 9.4 I-P}$$

If P_{sx} is numerically less than 1000 Pa (4 in. wg), x may be considered equal to 0.

9.2.3 Air viscosity. The viscosity (μ) shall be calculated from:

$$\mu_x = (17.23 + 0.048 t_{dx}) \times 10^{-6} \quad \text{Eq. 9.5 SI}$$

$$\mu_x = (11.00 + 0.018 t_{dx}) \times 10^{-6} \quad \text{Eq. 9.5 I-P}$$

The value for 20°C (68°F) air, which is 1.819 × 10^{-5} Pa-s (1.222 × 10-5 lbm/ft-s), may be used between 4°C and 40°C (40°F and 100°F) [17].

9.3 Airflow rate at test conditions

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

9.3.1.1 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}) (see Figure 3), summing the roots, dividing the sum by the number of measurement (n), and squaring the quotient as indicated by:

$$P_{V3} = \left(\frac{\Sigma \sqrt{P_{v3r}}}{n} \right)^2 \quad \text{Eq. 9.6}$$

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

$$V_3 = \sqrt{\frac{2 P_{v3}}{\rho_3}} \quad \text{Eq. 9.7 SI}$$

$$V_3 = 1097 \sqrt{\frac{P_{v3}}{\rho_3}} \quad \text{Eq. 9.7 I-P}$$

9.3.1.3 Flow 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:

$$Q_3 = V_3 A_3 \quad \text{Eq. 9.8}$$

9.3.2 Nozzle. The damper airflow rate may be calculated from the pressure differential (ΔP_n) measured across a single nozzle or bank of multiple nozzles [18].

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

$$\alpha = \frac{P_{s6} + p_b}{P_{s5} + p_b} \quad \text{Eq. 9.9 SI}$$

$$\alpha = \frac{P_{s6} + 13.63 p_b}{P_{s5} + 13.63 p_b} \quad \text{Eq. 9.9 I-P}$$

Or:

$$\alpha = 1 - \frac{\Delta P_n}{\rho_5 R (t_{d5} + 273.15)} \quad \text{Eq. 9.10 SI}$$

$$\alpha = 1 - \frac{5.187 \Delta P_n}{\rho_5 R (t_{d5} + 459.67)} \quad \text{Eq. 9.10 I-P}$$

9.3.2.2 Beta ratio. The ratio of nozzle throat diameter (D_6) to approach duct diameter (D_5) shall be calculated from:

$$\beta = D_6 / D_5 \quad \text{Eq. 9.11}$$

For a chamber approach β may be taken as zero.

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9.3.2.3 Expansion factor. The expansion factor (Y) may be obtained from:

$$Y = \left[\frac{\gamma}{\gamma - 1}\alpha^{2/\gamma}\frac{1-\alpha^{(\gamma-1)/\gamma}}{1-\alpha}\right]^{1/2}\left[\frac{1-\beta^4}{1-\beta^4\alpha^{2/\gamma}}\right]^{1/2} \qquad \text{Eq. 9.12}$$

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:

$$Y = 1-(0.548+0.71\beta^4)(1-\alpha) \qquad \text{Eq. 9.13}$$

9.3.2.4 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:

$$E = \left(\frac{\Sigma\left(P_{vr}^{3/2}\right)}{n}\right) / \left(\frac{\Sigma\left(P_{vr}^{1/2}\right)}{n}\right)^3 \qquad \text{Eq. 9.14}$$

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 [10].

9.3.2.5 Reynolds number. The Reynolds number (Re) based on nozzle exit diameter (D_6) shall be calculated from:

$$\text{Re} = \frac{D_6 V_6 \rho_6}{\mu_6} \qquad \text{Eq. 9.15 SI}$$

$$\text{Re} = \frac{D_6 V_6 \rho_6}{60\mu_6} \qquad \text{Eq. 9.15 I-P}$$

using properties of air as determined in Section 9.2 and the throat 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:

$$\text{Re} = \frac{\sqrt{2}}{\mu_6} C D_6 Y \sqrt{\frac{\Delta P_n \rho_5}{1-E\beta_4}} \qquad \text{Eq. 9.16 SI}$$

$$\text{Re} = \frac{1097}{60\mu} C D_6 Y \sqrt{\frac{\Delta P_n \rho_5}{1-E\beta_4}} \qquad \text{Eq. 9.16 I-P}$$

For chamber approach β may be taken as zero.

9.3.2.6 Discharge coefficient. The nozzle discharge coefficient (C) shall be determined from:

$$C = 0.9986 - \frac{7.006}{\sqrt{\text{Re}}} + \frac{134.6}{\text{Re}} \qquad \text{Eq. 9.17}$$

$$\text{for } \frac{L}{D} = 0.6$$

$$C = 0.9986 - \frac{6.688}{\sqrt{\text{Re}}} + \frac{131.5}{\text{Re}} \qquad \text{Eq. 9.18}$$

$$\text{for } \frac{L}{D} = 0.5$$

For Re of 12,000 and above [10].

9.3.2.7 Airflow rate for ducted nozzles. The volume flow rate (Q_5) at the entrance to a ducted nozzle shall be calculated from:

$$Q_5 = \frac{C A_6 Y \sqrt{2\Delta P_n / \rho_5}}{\sqrt{1-E\beta_4}} \qquad \text{Eq. 9.19 SI}$$

$$Q_5 = \frac{1097 C A_6 Y \sqrt{\Delta P_n / \rho_5}}{\sqrt{1-E\beta_4}} \qquad \text{Eq. 9.19 I-P}$$

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

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

$$Q_5 = Y\sqrt{\frac{2\Delta P_n}{\rho_5}}\Sigma(C A_6) \qquad \text{Eq. 9.20 SI}$$

$$Q_5 = 1097 Y\sqrt{\frac{\Delta P_n}{\rho_5}}\Sigma(C A_6) \qquad \text{Eq. 9.20 I-P}$$

The coefficient (C) and area (A_6) must be determined for each nozzle and their products 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.

For the purpose of calculating density at plane 5 (Figure 6.5), P_{s5} may be considered equal to P_{s8} + ΔP_n in Figures 5.7B, 5.7D and 5.7F. P_{s5} may not be used to calculate the damper pressure differential.

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9.4 Density correction

The resistance of a duct system or pressure drop of a damper is dependent upon the density of the air flowing through the system or damper. At constant volume airflow rate the pressure drop varies in direct proportion to the density, for example, a 10% increase in density would cause a 10% increase in pressure drop. A correction shall be made to adjust the pressure drop measured at test conditions to the pressure drop which would be measured at the same airflow rate with standard air density [1.2 kg/m^3 (0.075 lbm/ft^3)].

The correction shall be calculated from:

$$Q_S = Q_1 \qquad \text{Eq. 9.21}$$

$$\Delta P_s = \Delta P_{1,2}\left(\frac{1.2}{\rho_1}\right) \qquad \text{Eq. 9.22 SI}$$

$$\Delta P_s = \Delta P_{1,2}\left(\frac{0.075}{\rho_1}\right) \qquad \text{Eq. 9.22 I-P}$$

Since the heated air tests are not performed at a constant volume airflow rate, density corrections per this section are not applicable to heated air.

9.5 Continuity of mass flow

The volume flow rate of the damper is measured at a different plane than the damper inlet plane. In some setups, particularly Figure 6.5, the air density at the volume flow rate measuring plane will vary from the air density at the damper inlet plane. In such cases, volume flow rate shall be obtained from the equation of continuity of mass:

$$Q_1 = Q_x\left(\frac{\rho_x}{\rho_1}\right) \qquad \text{Eq. 9.23}$$

where:

Plane 1 = damper inlet plane
Plane x = volume flow rate measuring plane.

9.6 Airflow leakage - system leakage correction

For the purpose of establishing damper air leakage the "system" air leakage must be subtracted from the "damper and system" air leakage. Since it is not practical to set up and test the exact pressure differential corrected to standard air for each pair of determinations, the subtraction may be accomplished by one of the methods below.

9.6.1 Subtraction by chart. The data from both tests shall be plotted on logarithmic graph paper. A straight line shall then be drawn through each set of data points. The damper air leakage airflow rate for any given pressure differential is the airflow rate difference between the plotted lines at that pressure differential.

9.6.2 Subtraction by data points. The airflow leakage rate for a given set of pressure differential data may be subtracted directly provided the "system" air leakage airflow rate is corrected to the identical pressure differential as the "damper and system" pressure differential. The converted airflow rate (Q_c) is determined by adjusting the test airflow rate (Q_t) by the square root of the pressure ratio required to make the pressure differentials identical.

$$Q_c = Q_t\left(\frac{\Delta P_{DS}}{\Delta P_S}\right) \qquad \text{Eq. 9.24}$$

where :

Q_c = converted airflow rate, m^3/s (cfm)
Q_t = test airflow rate, m^3/s (cfm)
ΔP_{DS} = damper and system test pressure differential, Pa (in. wg)
ΔP_S = system test pressure differential, Pa (in. wg)

9.7 Pressure drop - duct system correction

For the purpose of establishing damper pressure drop, the "system" pressure drop must be subtracted from the "damper and duct system" pressure drop. Since it is not practical to set up and test the exact airflow rate, corrected to standard air, for each pair of determinations the subtraction may be accomplished by one of the methods below.

9.7.1 Subtraction by chart. The data from both tests shall be plotted on logarithmic graph paper. A straight line shall then be drawn through each set of data points. The damper pressure drop for any given flow is the pressure difference between the plotted lines at that airflow rate.

9.7.2 Subtraction by data points. The pressure drop for a given set of airflow rate data may be subtracted directly provided the "duct system" pressure drop is corrected to the identical airflow rate as the "damper and duct system" airflow rate. The converted pressure drop (ΔP_c) is determined by adjusting the tested pressure drop (ΔP_t) by the square of the airflow rate required to make the airflow rates identical.

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$$\Delta P_c = \Delta P_t \left(\frac{Q_{DS}}{Q_S} \right)^2 \qquad \text{Eq. 9.25}$$

where:

Q_{DS} = damper and duct system air flow rate, m^3/s(cfm)
Q_S = duct system air flow rate, m^3/s (cfm)
ΔP_t = test pressure drop, Pa (in. wg)
ΔP_C = converted pressure drop, Pa (in. wg)

9.8 Airflow leakage - system leakage correction for elevated temperature leakage tests

Leakage through the damper is the sum of the system leakage between plane 2 and plane 5 (nozzle plate) inclusive, and the airflow measured through the open nozzle(s) at plane 5 (nozzle plate) as shown in Figures 5.9 and 6.6. The damper leakage can be verified by performing two (2) separate leakage tests. The first test is to be performed with a given nozzle or nozzle combination open [e.g., 20 mm (0.75 in.) diameter nozzle], and the second test is to be performed with a smaller nozzle or nozzle combination open [e.g., 12 mm (0.50 in.) diameter nozzle]. The damper leakage for these two tests is given by Equations 9.26 and 9.27.

Test #1: $Q_{d,t1} = Q_{s,t1} + Q_{n,t1}$ Eq. 9.26

Test #2: $Q_{d,t2} = Q_{s,t2} + Q_{n,t2}$ Eq. 9.27

If the pressure differential across the closed damper $\Delta P_{9\text{-}5}$, the air temperature at the damper (t_{d1}) are the same for both tests, and the damper has not been disturbed, such that all clearances and gaps between adjacent damper parts are unchanged, then the damper leakage is the same for both tests and $Q_{d,t1}$ = $Q_{d,t2}$. Thus, Equations 9.26 and 9.27 can be equated as shown in Equation 9.28.

$$Q_{s,t1} + Q_{n,t1} = Q_{s,t2} + Q_{n,t2} \qquad \text{Eq. 9.28}$$

If there is no system leakage, then $Q_{s,t1}$ = $Q_{s,t2}$ = 0, and from Equation 9.28, $Q_{n,t1}$ = $Q_{n,t2}$. In this case, the leakage through the damper passes entirely through the nozzles. Since the nozzles or nozzle combinations employed for test #1 and test #2 have different diameters, the differential pressure across the nozzles or nozzle combinations ($\Delta P_{5,6}$) will be greater for the test employing the nozzle or nozzle combination with the smaller cumulative throat area. For example, test #1 may have a 1125 Pa (4.5 in. wg) pressure upstream of the closed damper, and a 125 Pa (½ in. wg) pressure downstream of the closed damper.

This provides a ($\Delta P_{9,5}$) of 1000 Pa (4 in. wg) across the closed damper and a ($\Delta P_{5\text{-}6}$) of 125 Pa (½ in. wg) across the nozzle plate. Test #2 may have a 1375 Pa (5½ in. wg) pressure upstream of the closed damper, and a 375 Pa (1½ in. wg) pressure downstream of the damper. This also provides a ($\Delta P_{9,5}$) of 1000 Pa (4 in. wg) across the closed damper but provides a ($\Delta P_{5,6}$) of 375 Pa (1½ in. wg) across the nozzle plate.

If system leakage were present, the larger ($\Delta P_{5,6}$) in test #2 would have the effect of producing more leakage through the system than was produced in test #1. In addition, the airflow through the nozzle(s) in test #1 would be greater than the airflow through the nozzle (s) in test #2 by an amount equal to $Q_{s,t2}$ – $Q_{s,t1}$ as demonstrated by rearranging Equation 9.29:

$$Q_{n,t1} - Q_{n,t2} = Q_{s,t2} - Q_{s,t1} \qquad \text{Eq. 9.29}$$

The system leakage for tests #1 and #2 can be defined by Equations 9.30 and 9.31.

$$Q_{s,t1} = K_s \sqrt{\frac{\Delta P_{n,t1}}{\rho_{n,t1}}} \qquad \text{Eq. 9.30}$$

$$Q_{s,t2} = K_s \sqrt{\frac{\Delta P_{n,t2}}{\rho_{n,t2}}} \qquad \text{Eq. 9.31}$$

Substituting Equations 9.32 and 9.33 into 9.31:

$$Q_{n,t1} - Q_{n,t2} = K_S \sqrt{\frac{\Delta P_{n,t2}}{\rho_{n,t2}}} - K_S \sqrt{\frac{\Delta P_{n,t1}}{\rho_{n,t1}}} \qquad \text{Eq. 9.32}$$

$$Q_{n,t1} - Q_{n,t2} = K_S \left(\sqrt{\frac{\Delta P_{n,t2}}{\rho_{n,t2}}} - \sqrt{\frac{\Delta P_{n,t1}}{\rho_{n,t1}}} \right) \qquad \text{Eq. 9.33}$$

Solving Equation 9.34 for K_s yields:

$$K_S = \frac{Q_{n,t1} - Q_{n,t2}}{\left(\sqrt{\frac{\Delta P_{n,t2}}{\rho_{n,t2}}} \right) - \left(\sqrt{\frac{\Delta P_{n,t1}}{\rho_{n,t1}}} \right)} \qquad \text{Eq. 9.34}$$

If K_s < 0, the test shall be repeated. The calculated value of K_s may then be substituted back into Equations 9.30 to calculate the system leakage from test #1.

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$$Q_{s,t1} = K_s \sqrt{\frac{\Delta P_{n,t1}}{\rho_{n,t1}}}$$ Eq.9.30 repeated

If the system leakage is negative and the value is less than 2 cfm, the system leakage shall be considered to be zero. If the value is above 2 cfm, the leakage test shall be repeated. The damper leakage may then be calculated by using Equation 9.26.

$$Q_{d,t1} = Q_{s,t1} + Q_{n,t1}$$ Eq. 9.26 repeated

10. References

1. Handbook of Fundamentals 2001, Table 2: Thermodynamic Properties of Moist Air, Chapter 6, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 30329-2305 U.S.A.

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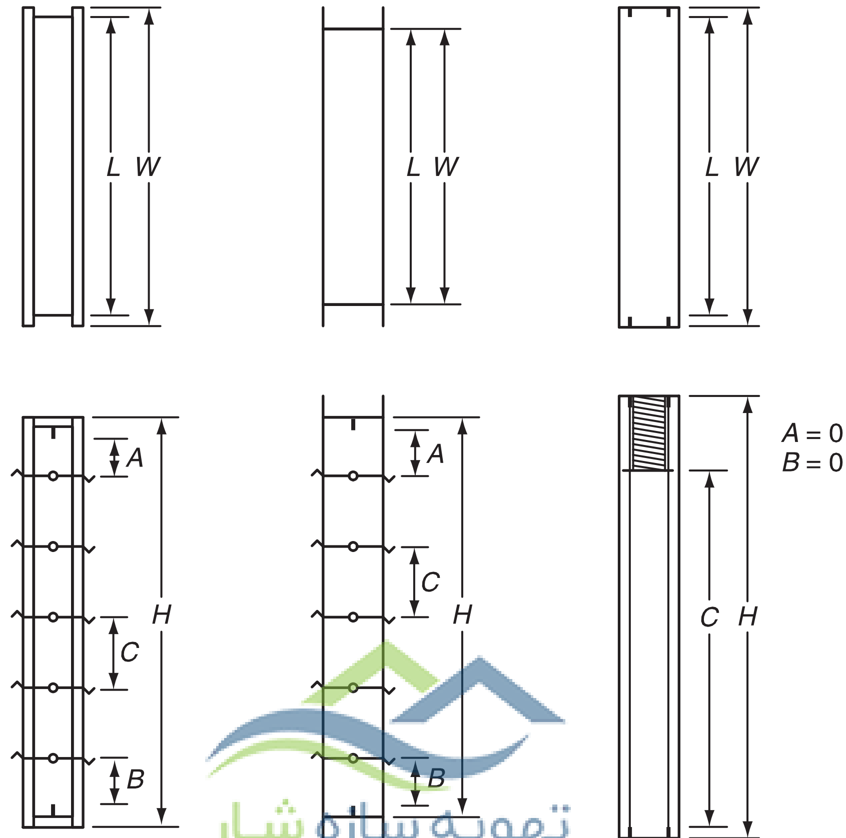

Duct Mounted Damper

Flange Mounted Damper

Curtain Mounted Damper

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Device face area = W x H

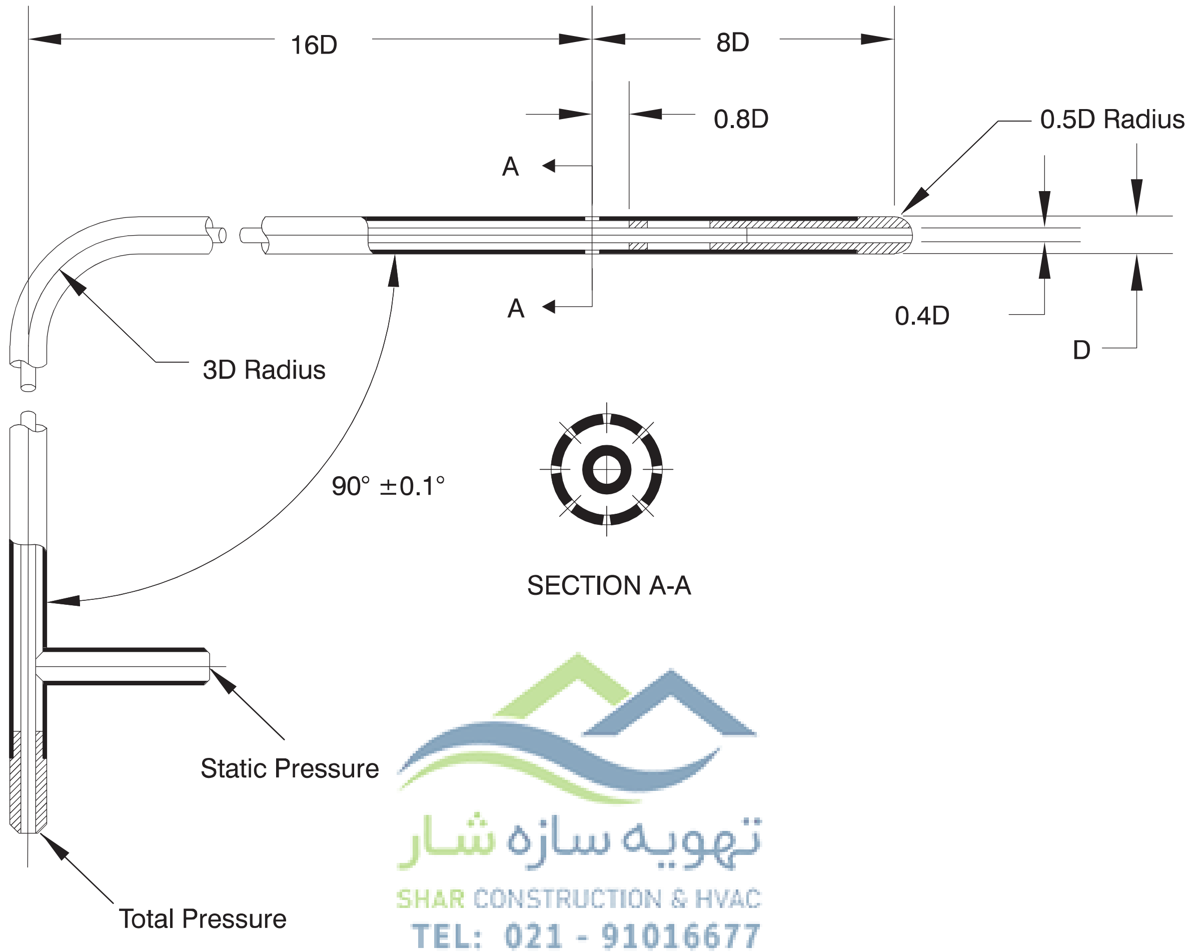
Free area = $L[A + B + (N \times C)]$

Percent free area = $\frac{L\left[A+B+(N\times C)\right]}{W\times H}$

Where:

A = Minimum distance between the head and top blade
B = Minimum distance between the sill and bottom blade
C = Minimum distance between adjacent blades
N = Number of "C" openings in the damper
L = Minimum distance between damper jambs
W = Actual damper width
H = Actual damper height

Figure 1 - AMCA Free Area Sections



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Notes:

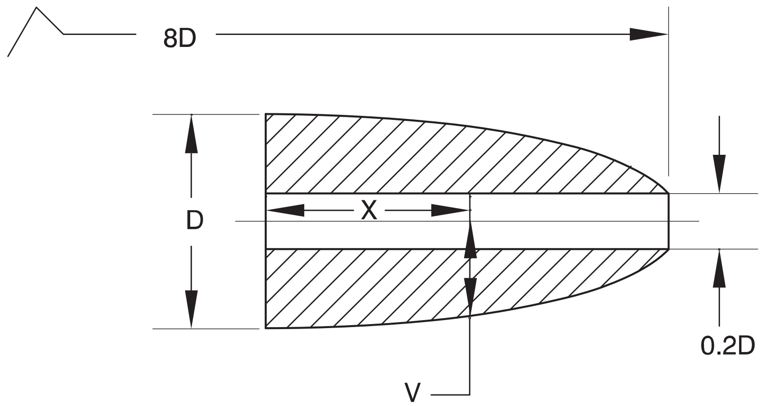
1. Surface finish shall be 0.8 micrometer (32 micro-in.) or better. The static orifices may not exceed 1 mm (0.04 in.) diameter. The minimum Pitot tube stem diameter recognized under this standard shall be 2.5 mm (0.10 in.). In no case shall the stem diameter exceed 1/30 of the test duct diameter.

2. Head shall be free from nicks and burrs.

3. All dimension shall be within ± 2%.

4. Section A-A shows 8 holes equally spaced and free from burrs. Hole diameter shall be 0.153*D*, but not exceeding 1mm (0.04 in.). Hole depth shall not be less than the hole diameter.

Figure 2A - Pitot-Static Tube with Spherical Head



X/D	*V/D*	*X/D*	*V/D*
0	0.5	1.602	0.314
0.237	0.496	1.657	0.295
0.336	0.494	1.698	0.279
0.0474	0.487	1.73	0.266
0.622	0.477	1.762	0.25
0.741	0.468	1.796	0.231
0.936	0.449	1.83	0.211
1.025	0.436	1.858	0.192
1.134	0.42	1.875	0.176
1.228	0.404	1.888	0.163
1.313	0.388	1.9	0.147
1.39	0.371	1.91	0.131
1.442	0.357	1.918	0.118
1.506	0.343	1.92	0.109
1.538	0.333	1.921	0.1
1.57	0.323		

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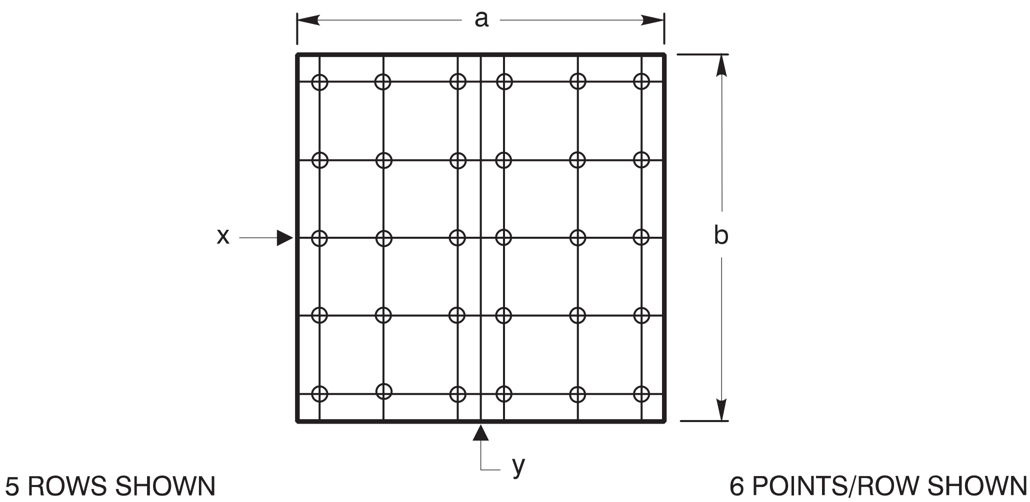
Figure 2B - Alternate Pitot-Static Tube with Ellipsoidal Head



Number of Points per Traverse Line	Distance from Centerline - *x*/*a* or *y*/*b*			
5	0	±0.212	±0.426	
6	±0.063	±0.265	±0.439	
7	0	±0.134	±0.297	±0.447

Figure 3A - Log Tchebycheff Traverse Points for Rectangular Ducts

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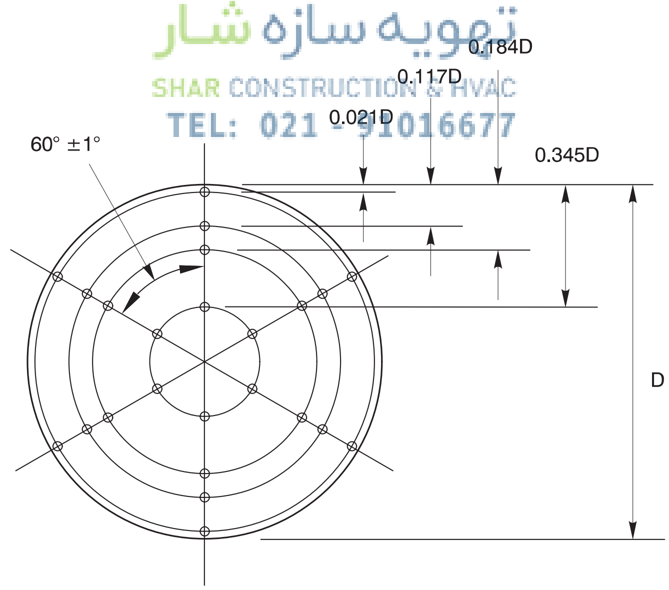


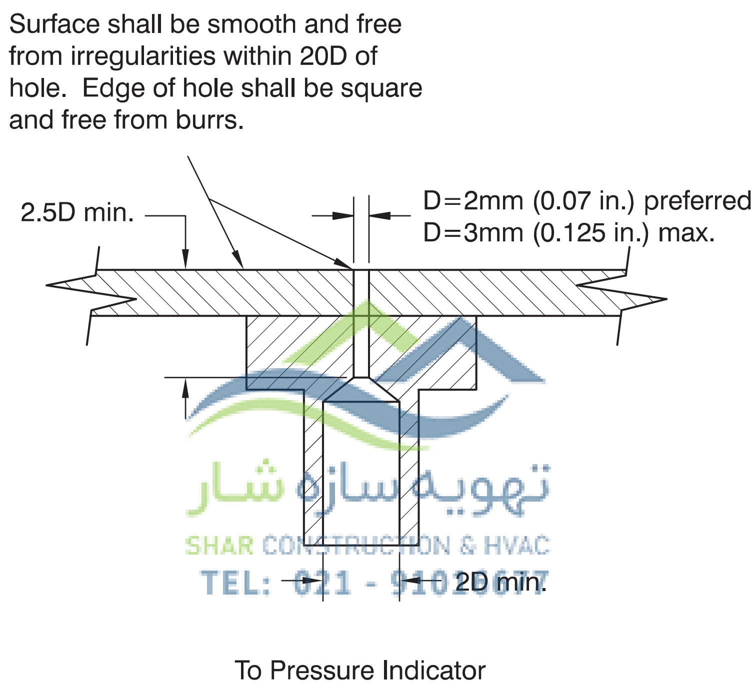
Notes:

1. *D* is the average of four measurements at traverse plane at 45° angles measured to accuracy of 0.2% *D*.

2. Traverse duct shall be round within 0.5% *D* or 1.5 mm (1/16 in.) whichever is greater, at traverse plane and for a distance of 0.5 duct diameters on either side of traverse plane.

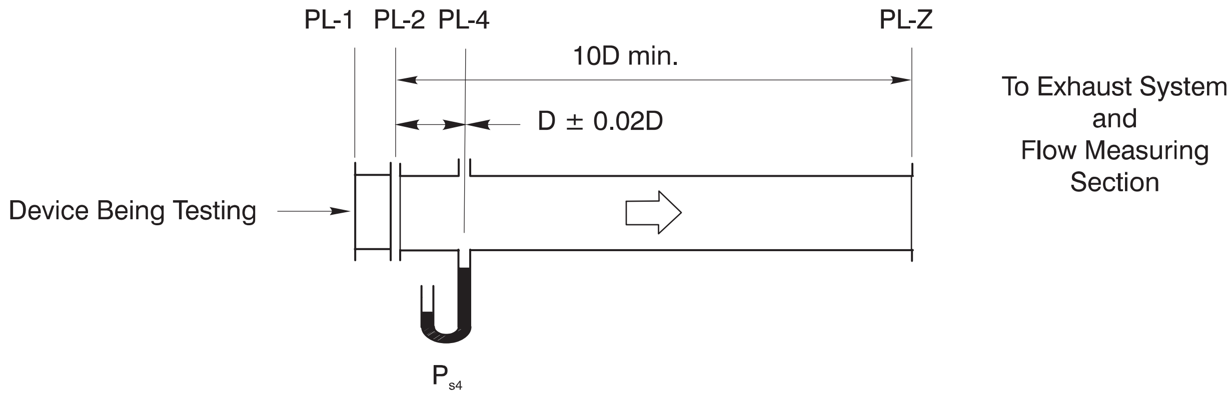
3. All Pitot positions ± 0.0025*D* relative to inside duct walls.

Figure 3B - Log Linear Traverse Points for Circular Ducts



Note: A 2 mm (0.07 in.) hole is the maximum size which will allow space for a smooth surface 20*D* from the hole when installed 38 mm (1.5 in.) from a partition, such as in Figures 6.3, 6.4, and 6.5.

Figure 4 - Static Pressure Taps



$D = \sqrt{4ab/\pi}$ for rectangular ducts (where *a* = duct width and *b* = duct height).

D = duct diameter for round ducts.

Figure 5.1 - Test Damper Setup with Outlet Duct

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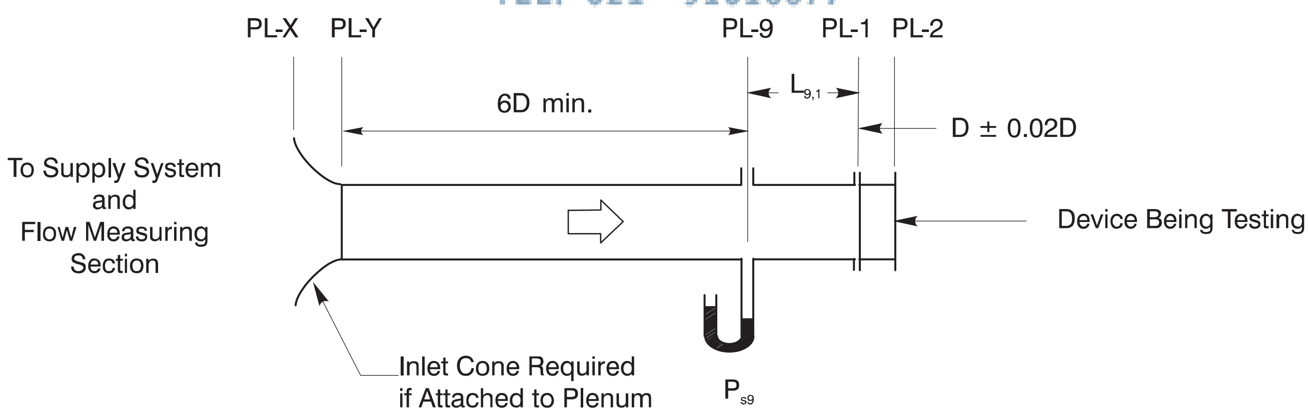
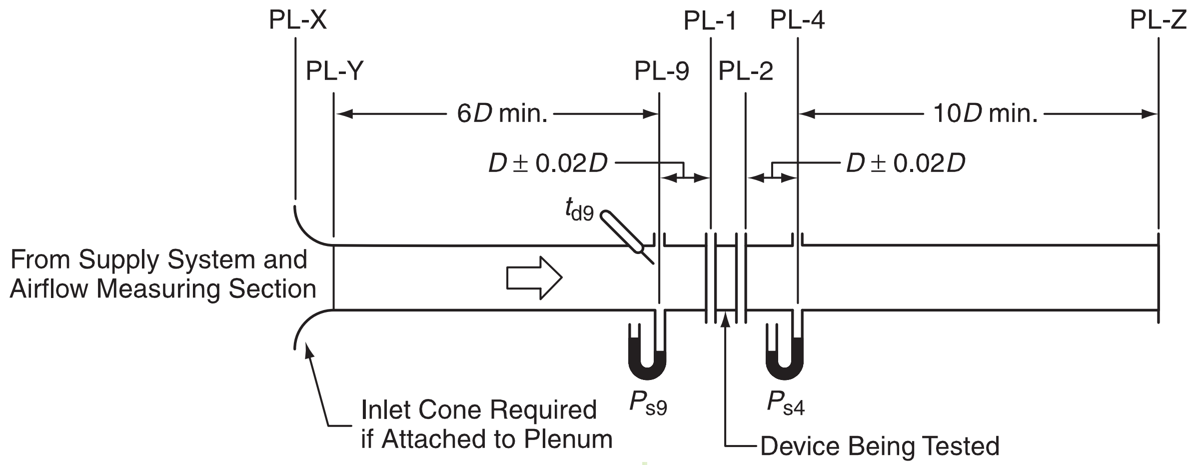


$D = \sqrt{4ab/\pi}$ for rectangular ducts (where *a* = duct width and *b* = duct height).

D = duct diameter for round ducts.

Figure 5.2 - Test Damper Setup with Inlet Duct



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$D = \sqrt{4ab/\pi}$ for rectangular ducts (where a = duct width and b = duct height).

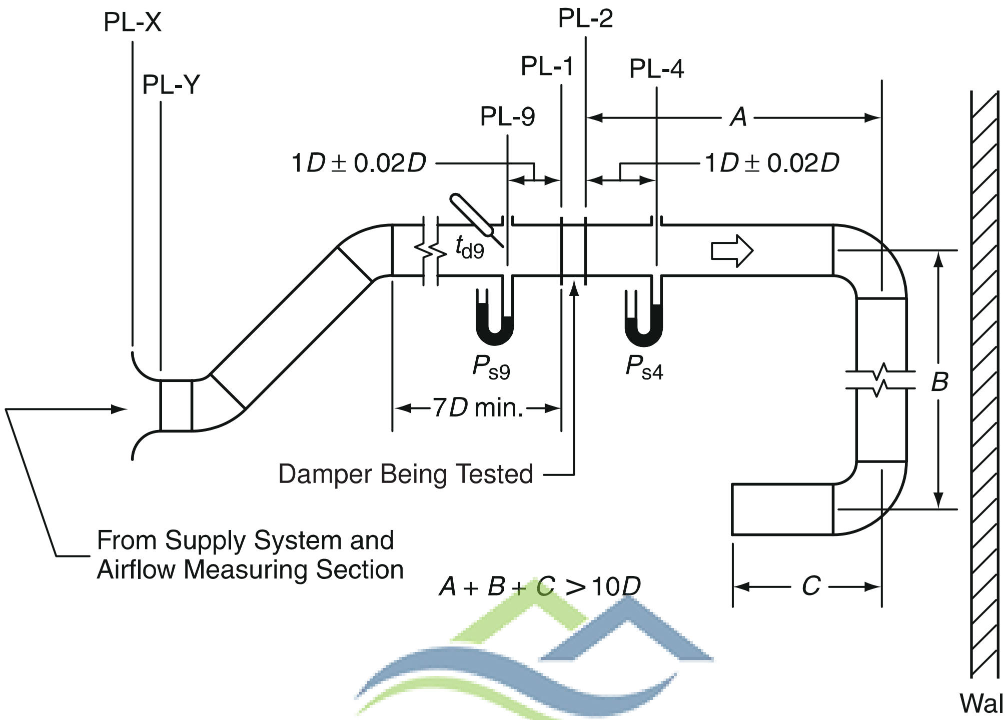
D = duct diameter for round ducts.

Notes:

1. Single or multi-blade dampers of less than 30 percent duct area blockage may be tested with 4*D* minimum upstream of Plane 9 and 6*D* minimum downstream of Plane 2 provided there is 15 percent maximum blockage at any wall. The percentage of duct area blockage shall be defined as the blockage created by the projected areas of those items within the duct dimensions such as frame members, stops, etc. excluding only blades, as a percentage of the total duct cross-section area.

2. Curtain type dampers of less than 30 percent duct area blockage may be tested with 4*D* minimum upstream of Plane 9 and 6*D* minimum downstream of Plane 2 provided there is 15 percent maximum blockage at any wall. The percentage of duct area blockage shall be defined as the blockage created by the projected area of all items within the duct dimensions including frame members, stops, blades, etc, as a percentage of the total duct cross-section area.

Figure 5.3 - Test Damper Setup with Inlet and Outlet Ducts



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$D = \sqrt{4ab/\pi}$ for rectangular ducts (where a = duct width and b = duct height).

D = duct diameter for round ducts.

Notes:

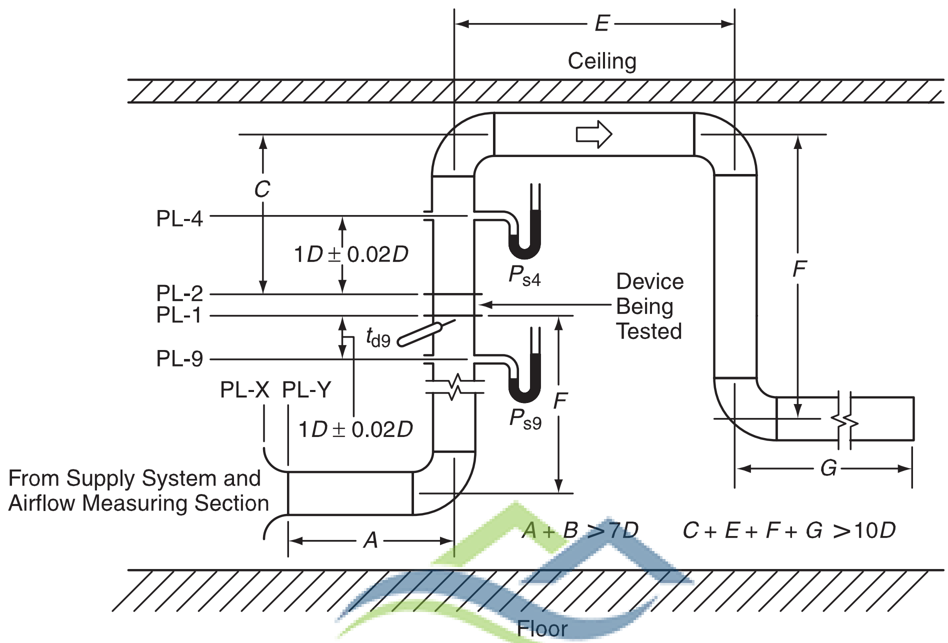
1. No more than two 90° elbows shall be allowed downstream of the damper being tested.

2. The downstream elbows should be as far as possible from the damper being tested.

3. Rectangular elbows shall be smooth radius constructed in accordance with Table 14-10.F of SMACNA HVAC Systems Duct Design, 1990 - Third Edition, centerline radius 1.5*D* or greater. Round elbows shall be either smooth radius or 3 to 5 piece, constructed in accordance with Table 14-10, A or B of SMACNA HVAC Systems Duct Design, 1990- Third Edition centerline radius 1.5*D*.

4. Turning vanes may be used to improve the velocity profile through an elbow.

Figure 5.3A - Alternate Test Damper Setup with Inlet and Outlet Ducts - Vertical Damper



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$D = \sqrt{4ab/\pi}$ for rectangular ducts (where a = duct width and b = duct height).

D = duct diameter for round ducts.

Notes:

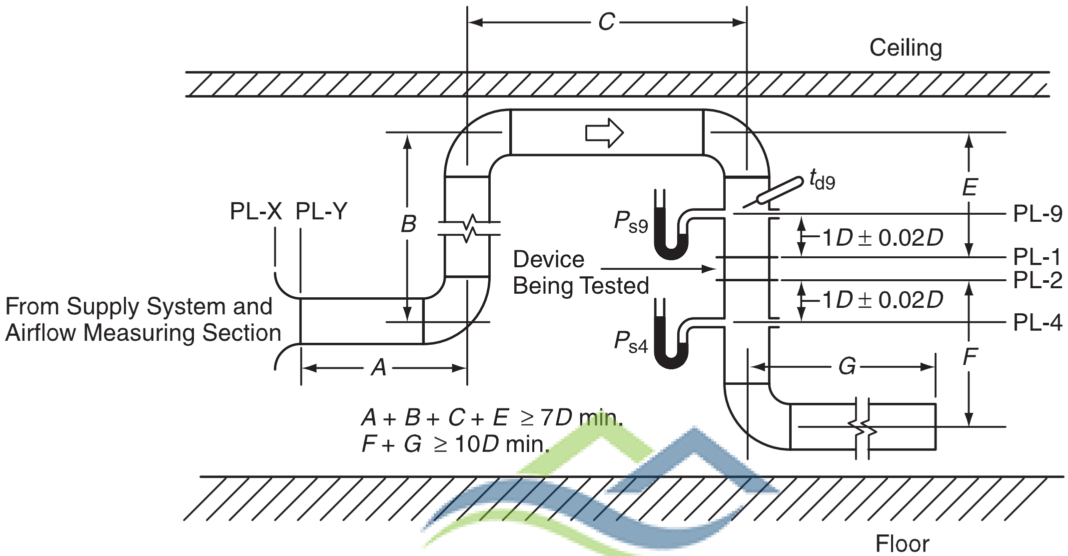
1. The upstream seven diameters may include one elbow located as far from the damper as possible.

2. The downstream ten diameters may have elbows as required.

3. Rectangular elbows shall be smooth radius constructed in accordance with Table 14-10.F of SMACNA HVAC Systems Duct Design, 1990 - Third Edition, centerline radius 1.5*D* or greater. Round elbows shall be either smooth radius or 3 to 5 piece, constructed in accordance with Table 14-10, A or B of SMACNA HVAC Systems Duct Design, 1990- Third Edition centerline radius 1.5*D* or greater.

4. Turning vanes may be used to improve the velocity profile through an elbow.

Figure 5.3B - Alternate Test Damper Setup with Inlet and Outlet Ducts - Horizontal Damper



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$D = \sqrt{4ab/\pi}$ for rectangular ducts (where a = duct width and b = duct height).

D = duct diameter for round ducts.

Notes:

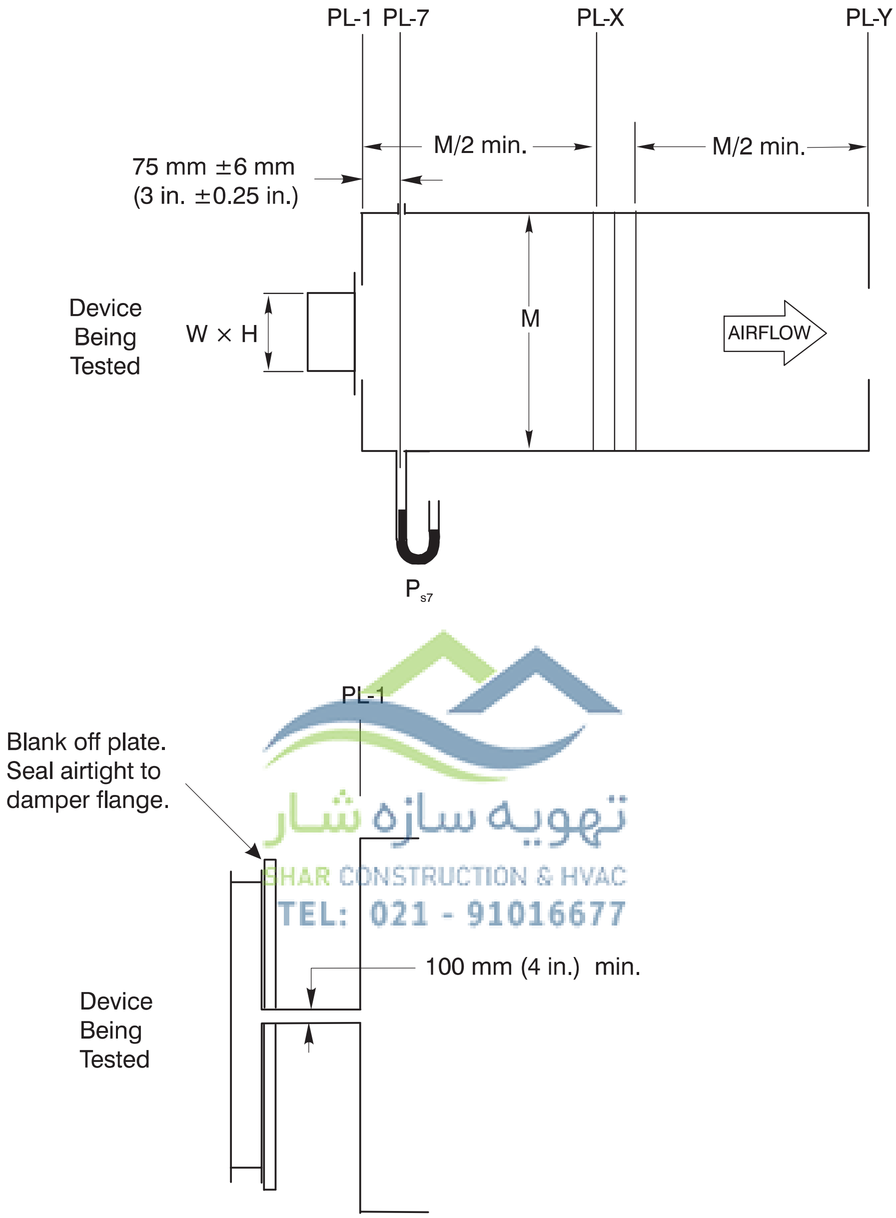
1. The upstream seven diameters may include three elbows with the nearest located as far from the damper being tested as possible.

2. The downstream ten diameters may have elbows as required.

3. Rectangular elbows shall be smooth radius constructed in accordance with Table 14-10.F of SMACNA HVAC Systems Duct Design, 1990 - Third Edition, centerline radius 1.5*D*. Round elbows shall be either smooth radius or 3 to 5 piece, constructed in accordance with Table 14-10, A or B of SMACNA HVAC Systems Duct Design, 1990- Third Edition centerline radius 1.5*D* or greater.

4. Turning vanes may be used to improve the velocity profile through an elbow.

Figure 5.3C - Alternate Test Damper Setup with Inlet and Outlet Ducts - Horizontal Damper



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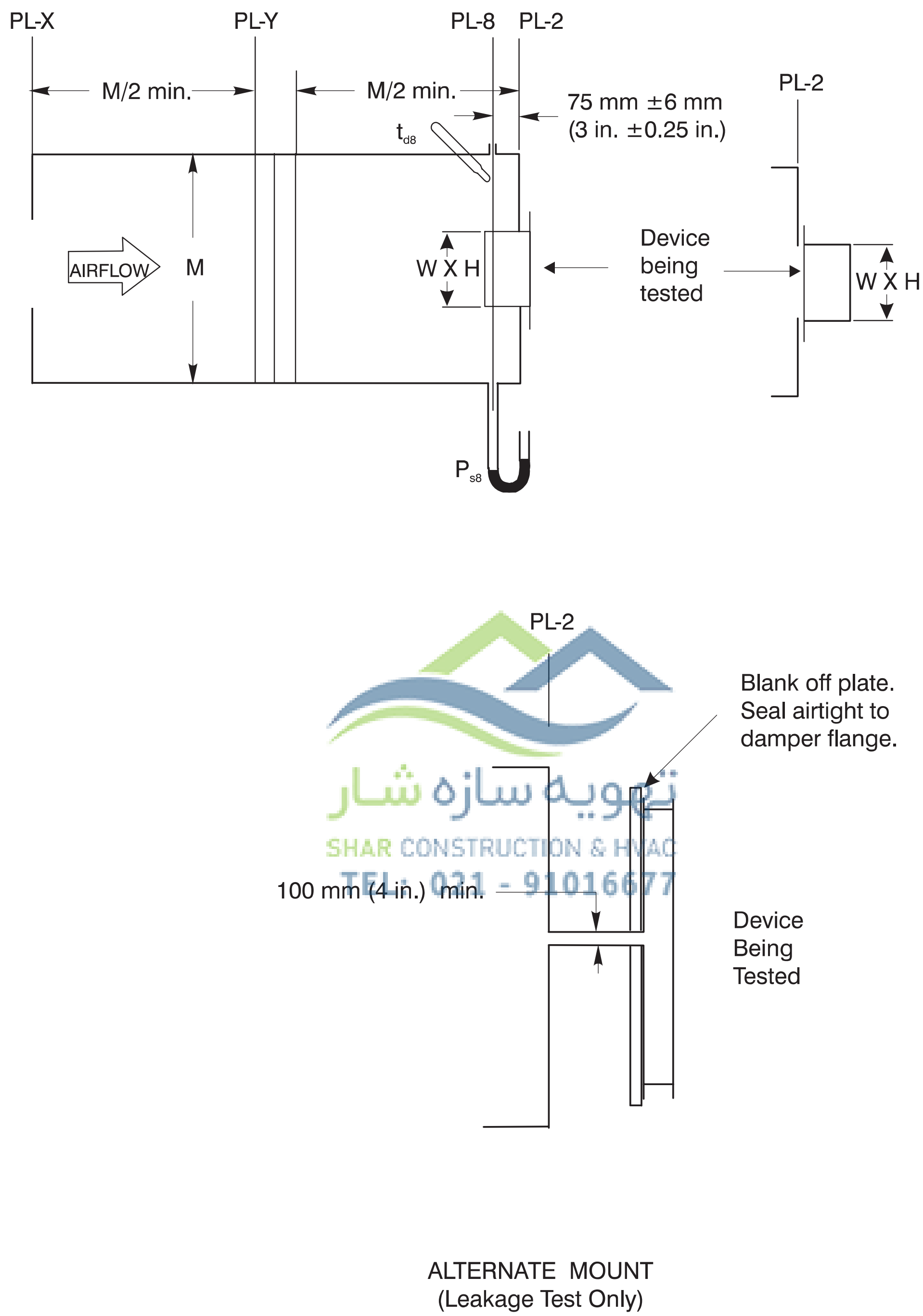
ALTERNATE MOUNT
(Leakage Test Only)

Note: For pressure drop testing an outlet chamber shall have a cross sectional area at least fifteen times the free area of the damper being tested.

Figure 5.4 - Test Damper Setup with Outlet Chamber



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Note: For pressure drop testing an inlet chamber shall have a cross sectional area at least three times the free area of the damper being tested.

Figure 5.5 - Test Damper Setup with Inlet Chamber

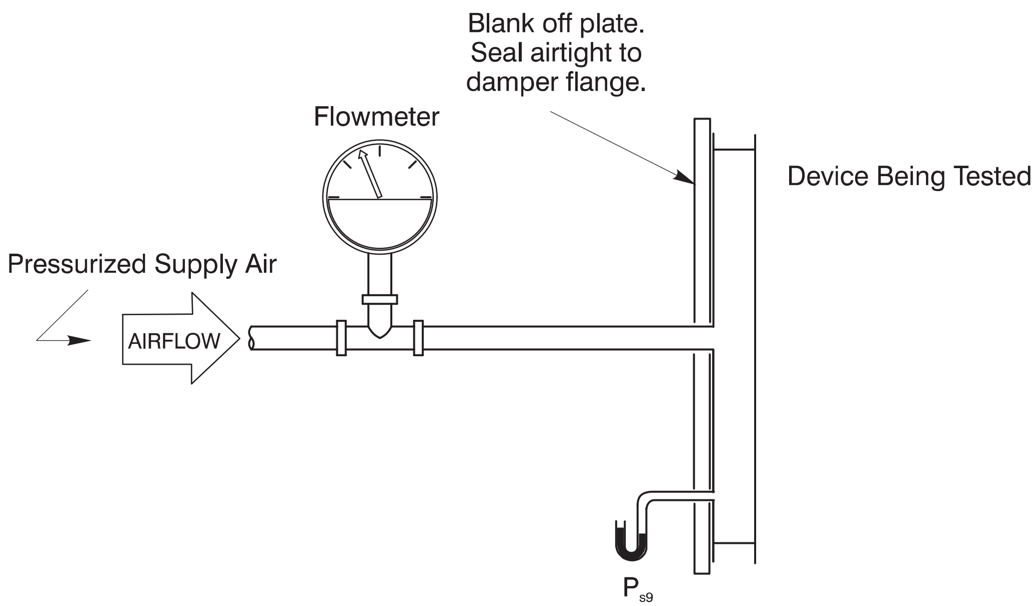

Figure 5.6A - Test Damper Setup - Leakage Test with Damper under Positive Pressure

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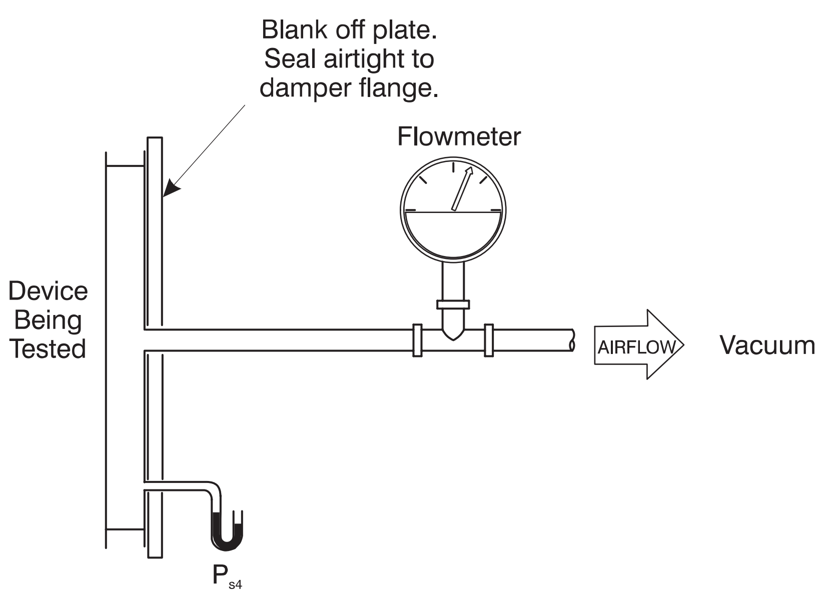

Figure 5.6B - Test Damper Setup - Leakage Test with Damper under Negative Pressure

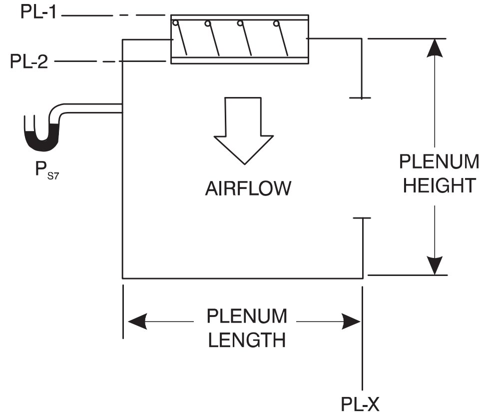

Figure 5.7A - Outlet Plenum

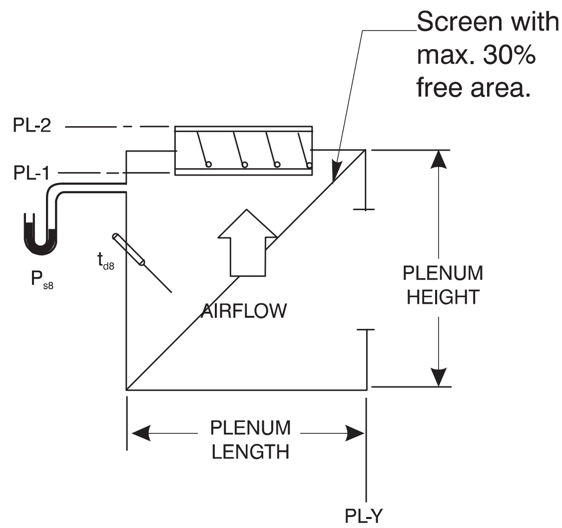

Figure 5.7B - Inlet Plenum

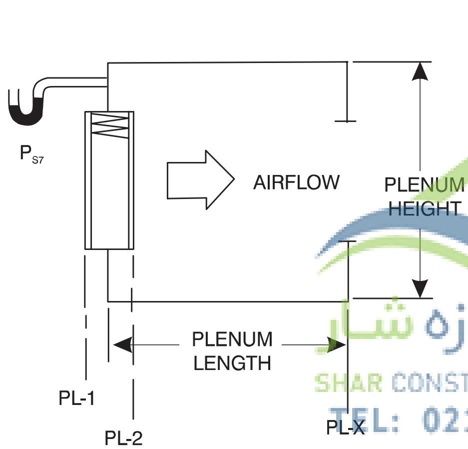

Figure 5.7C - Outlet Plenum

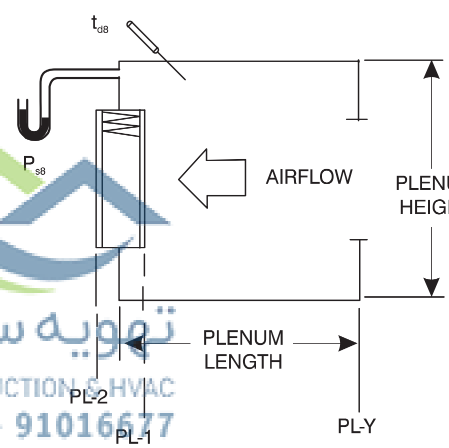

Figure 5.7D - Inlet Plenum

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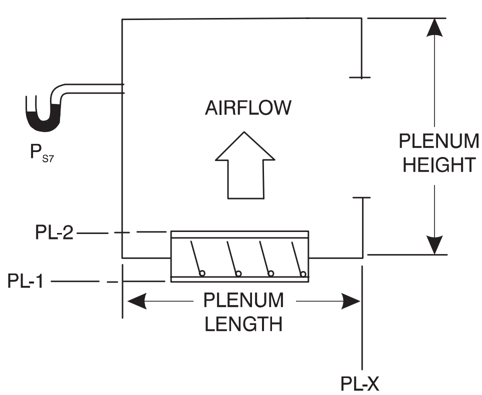

Figure 5.7E - Outlet Plenum

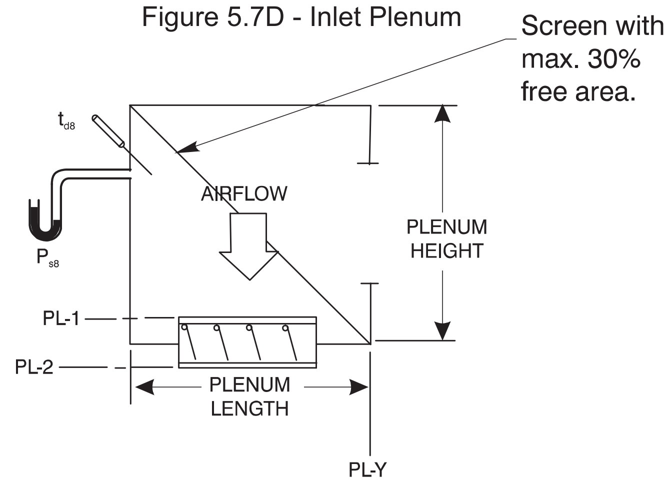

Figure 5.7F - Inlet Plenum

Note: For pressure drop testing, plenum size shall be larger than the test damper by a minimum of 305 mm (12 in.) on all four sides. The plenum height shall be no less than the plenum length.

Figure 5.7 - Test Damper Setups with Plenum

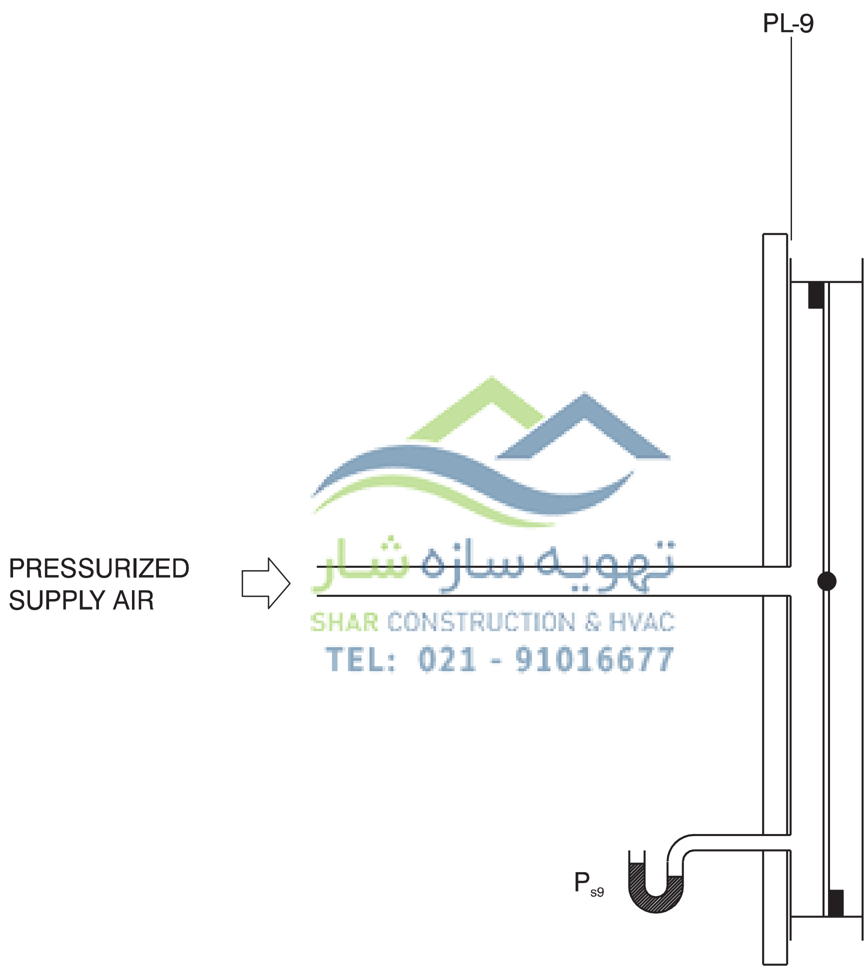

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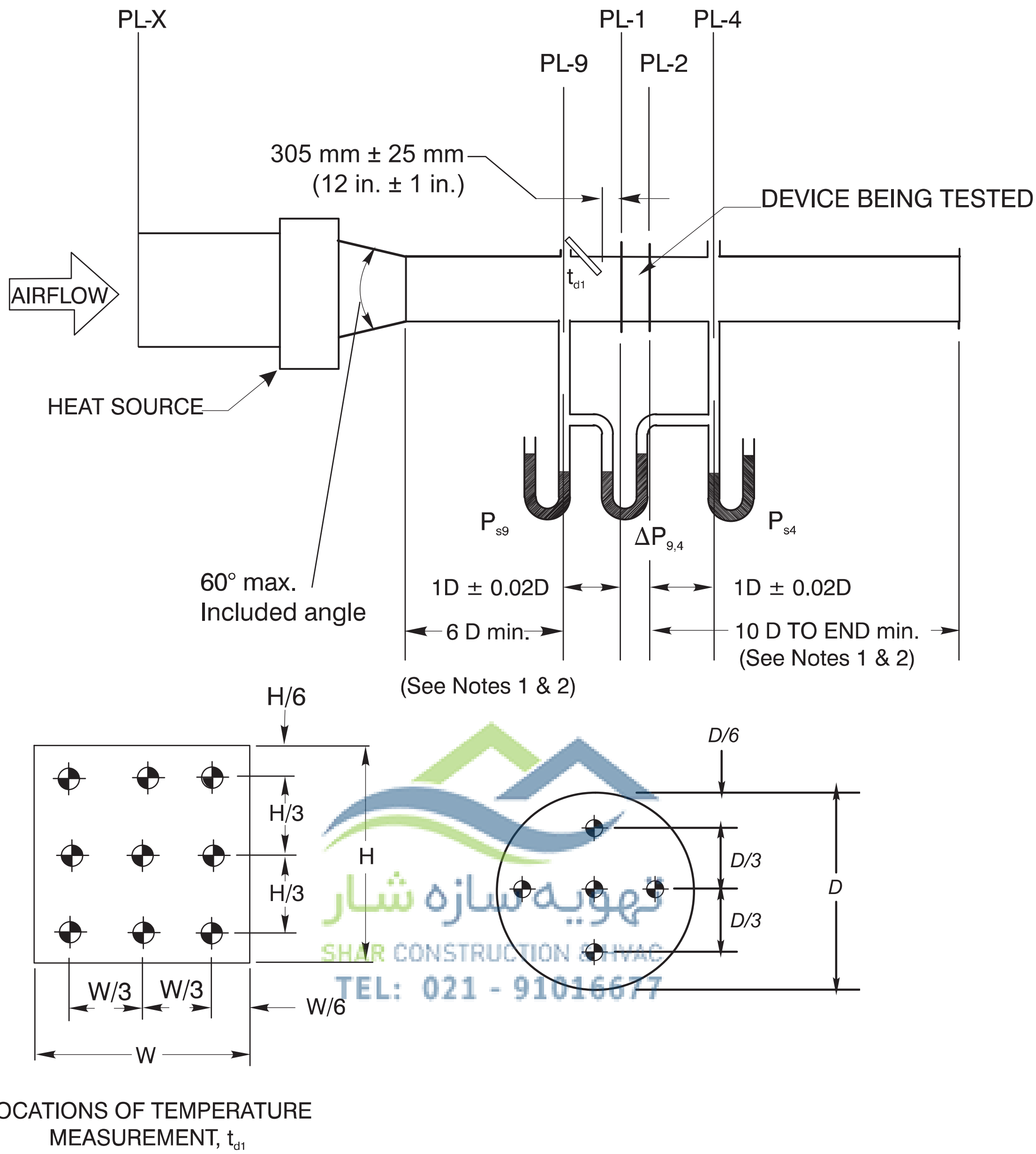
Figure 5.8 - Bubble Test Setup



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$D = \sqrt{4ab/\pi}$ for rectangular ducts (where a = duct width and b = duct height).

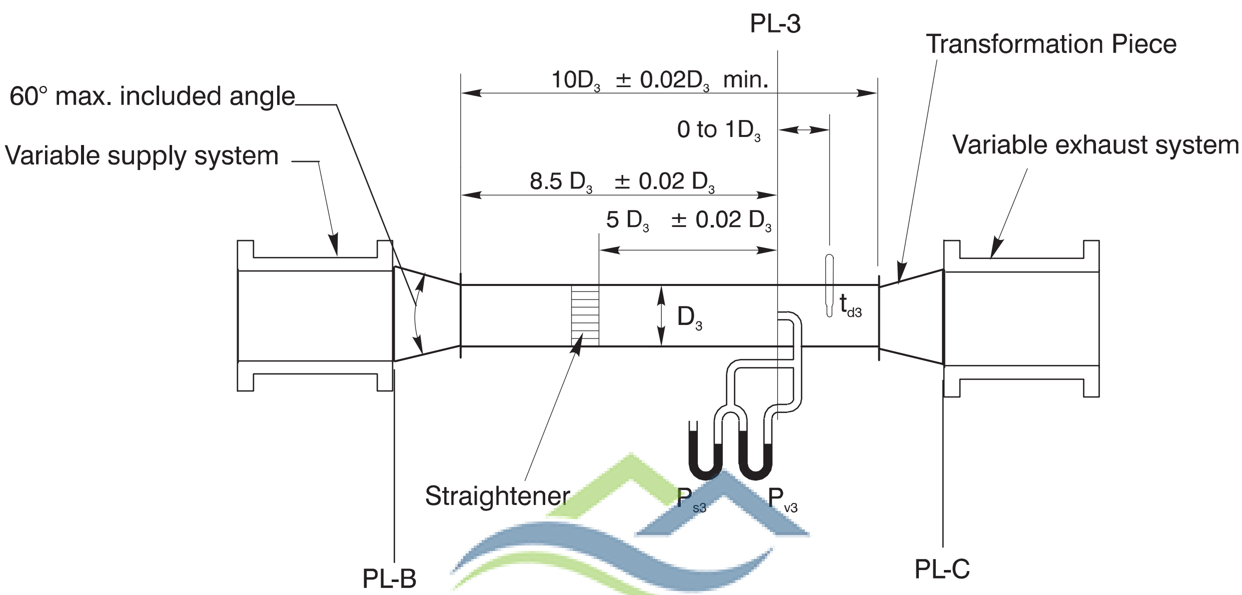
D = duct diameter for round ducts.

Notes:

1. Single or multi-blade dampers of less than 30 percent duct area blockage may be tested with 4*D* minimum upstream of Plane 9 and 6*D* minimum downstream of Plane 2 provided there is 15 percent maximum blockage at any wall. The percentage of duct area blockage shall be defined as the blockage created by the projected areas of those items within the duct dimensions such as frame members, stops, etc. excluding only blades, as a percentage of the total duct cross-section area.

2. Curtain type dampers of less than 30 percent duct area blockage may be tested with 4*D* minimum upstream of Plane 9 and 6*D* minimum downstream of Plane 2 provided there is 15 percent maximum blockage at any wall. The percentage of duct area blockage shall be defined as the blockage created by the projected area of all items within the duct dimensions including frame members, stops, blades, etc, as a percentage of the total duct cross-section area.

Figure 5.9 - Elevated Temperature System Setup



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$$P_{v3} = \left[\frac{\Sigma \sqrt{P_{v3r}}}{n} \right]^2$$

$$Q_3 = V_3 A_3$$

$$V_3 = \sqrt{\frac{2P_{v3}}{\rho_3}}$$

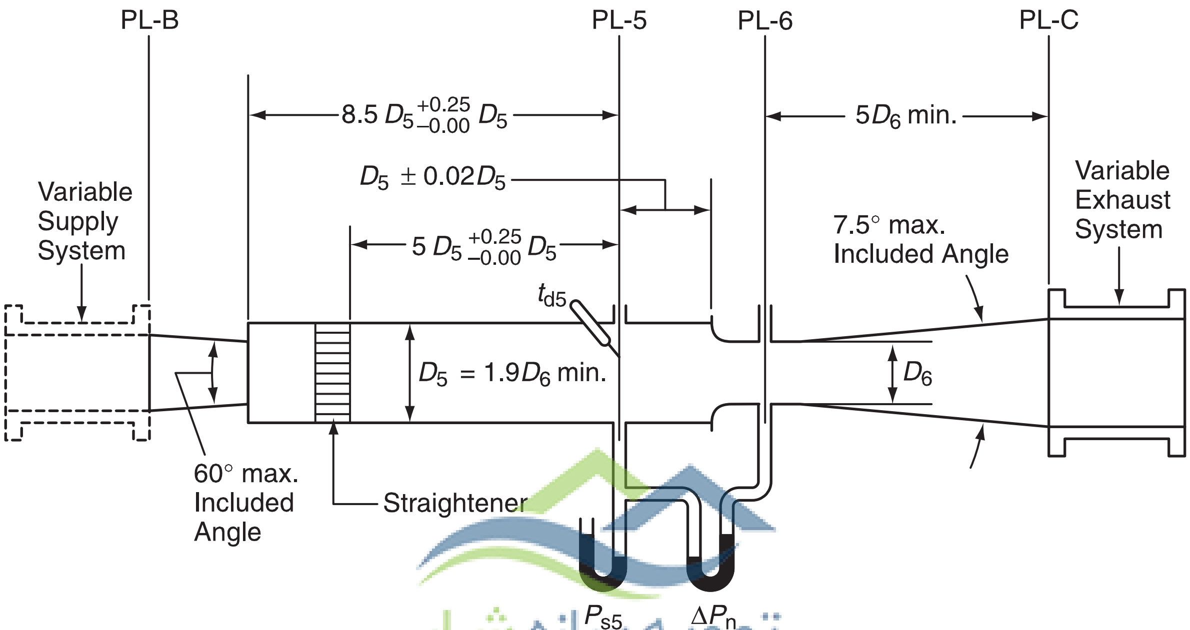
SI formula

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

$$V_3 = 1097 \sqrt{\frac{P_3}{\rho_3}}$$

I-P formula

Figure 6.1 - Airflow Rate Measurement Setup - Pitot in Duct



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$$Q_5 = \frac{CA_6Y\sqrt{\dfrac{2\Delta P_n}{\rho_5}}}{\sqrt{1-E\beta^4}}$$

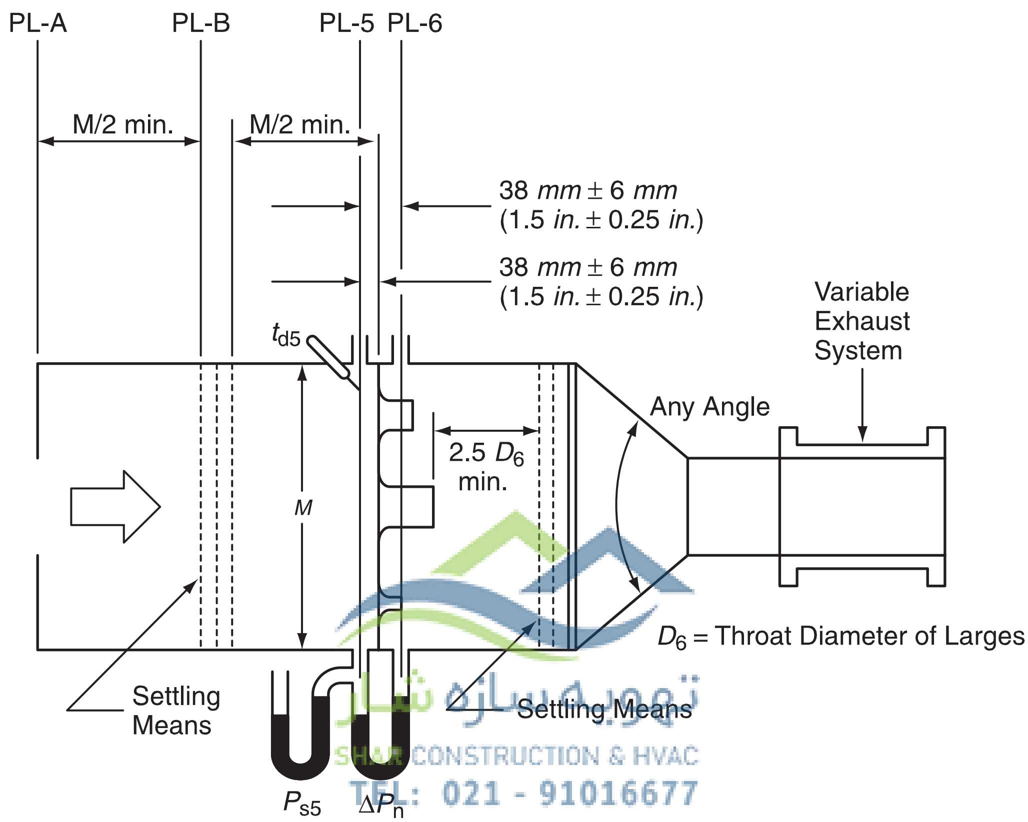
SI formula

$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

$$Q_5 = \frac{1097CA_6Y\sqrt{\dfrac{\Delta P_n}{\rho_5}}}{\sqrt{1-E\beta^4}}$$

I-P formula

Figure 6.2 - Airflow Rate Measurement Setup - Nozzle on End of Duct



$$Q_5 = Y\sqrt{\frac{2\Delta P_n}{\rho_5}}\Sigma(CA_6)$$

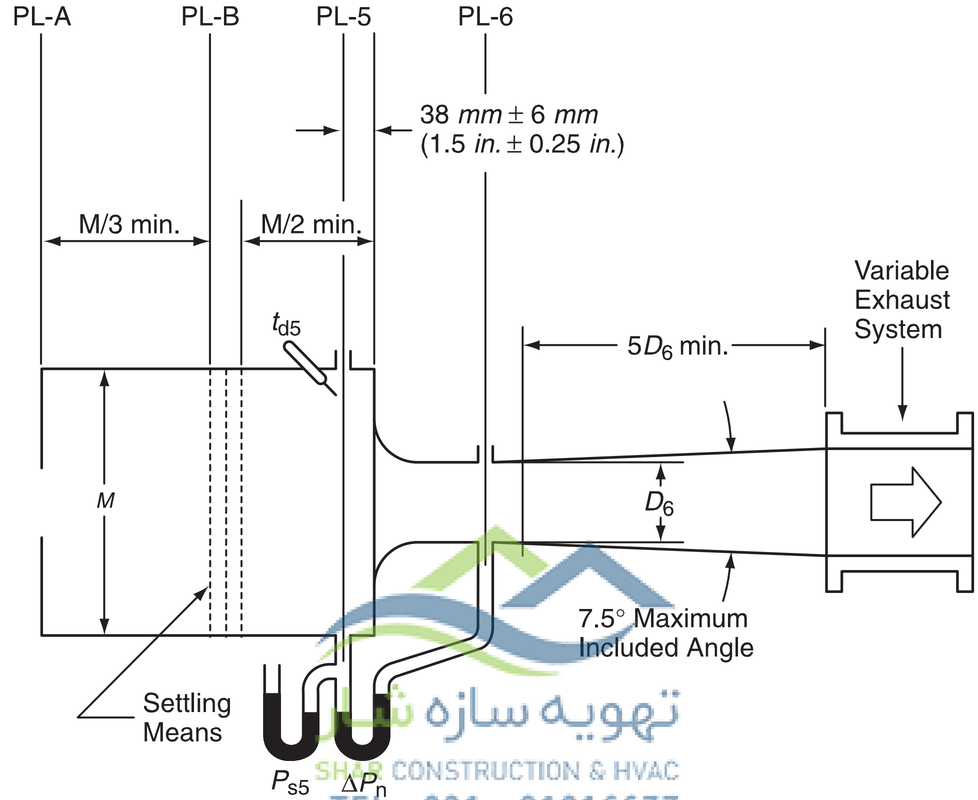
$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

SI formula

$$Q_5 = 1097Y\sqrt{\frac{\Delta P_n}{\rho_5}}\Sigma(CA_6)$$

I-P formula

Figure 6.3 - Airflow Rate Measurement Setup - Multiple Nozzle Chamber on Fan Inlet



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$$Q_5 = \frac{CA_6 Y \sqrt{\frac{2\Delta P_n}{\rho_5}}}{\sqrt{1-E\beta^4}}$$

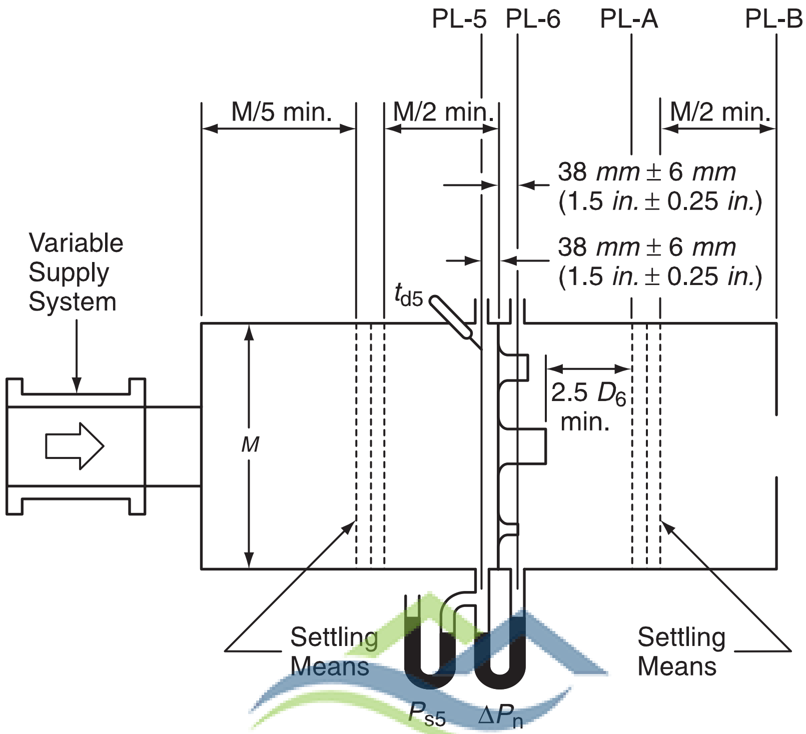
$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

SI formula

$$Q_5 = \frac{1097 CA_6 Y \sqrt{\frac{\Delta P_n}{\rho_5}}}{\sqrt{1-E\beta^4}}$$

I-P formula

Figure 6.4 - Airflow Rate Measurement Setup - Single Nozzle Chamber



D_6 = Throat Diameter of Largest Nozzle

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$$Q_5 = Y\sqrt{\frac{2\Delta Pn}{\rho 5}}\sum(CA_6)$$

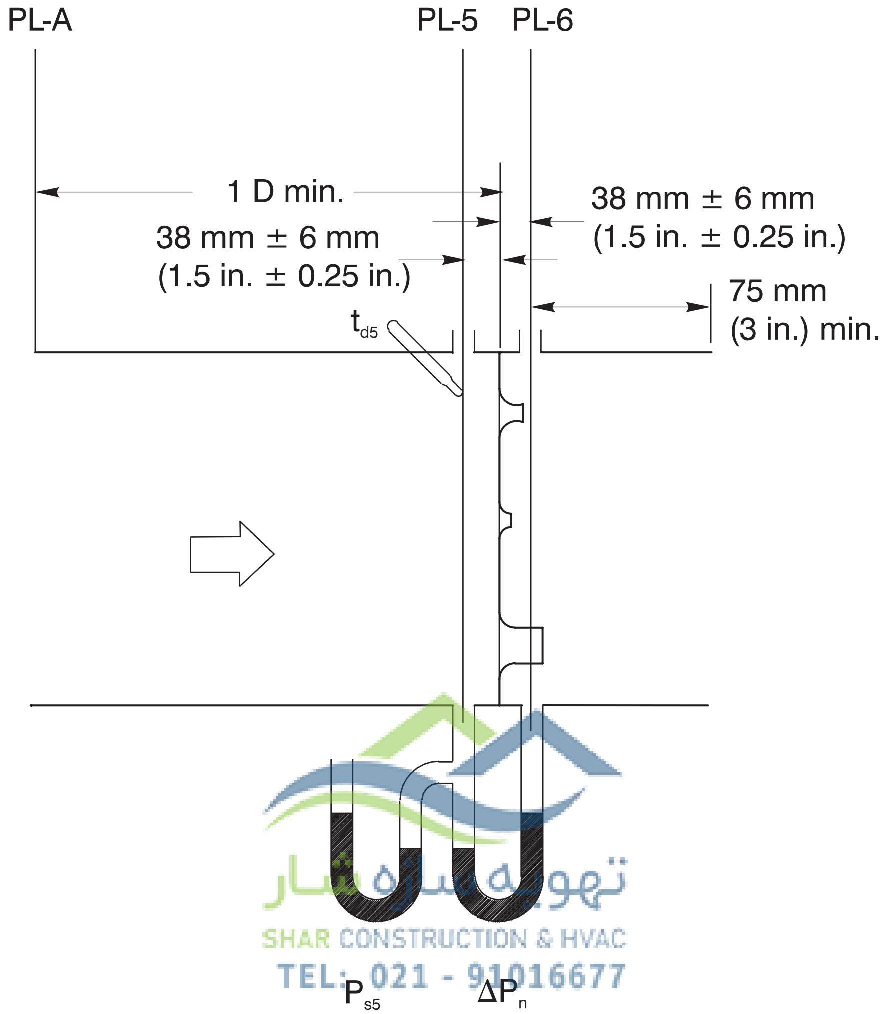
$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

SI formula

$$Q_5 = 1097Y\sqrt{\frac{\Delta Pn}{\rho 5}}\sum(CA_6)$$

I-P formula

Figure 6.5 - Airflow Rate Measurement Setup - Multiple Nozzle Chamber on Fan Outlet



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$$Q_5 = Y\sqrt{\frac{2\Delta P_n}{\rho_5}}\sum(CA_6)$$

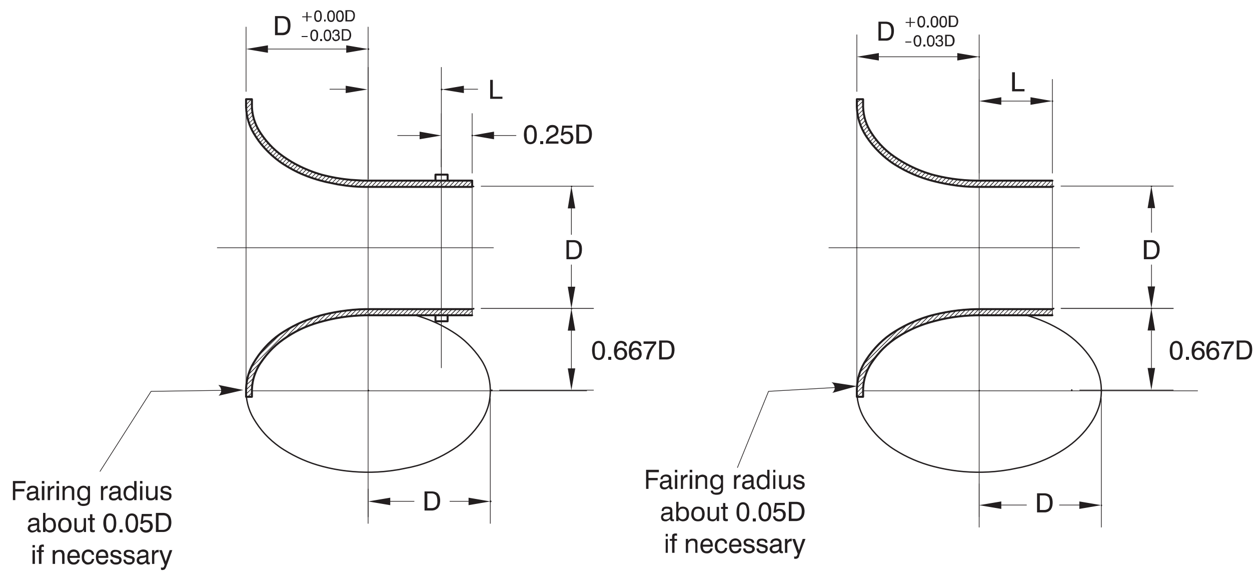
$$Q = Q_5\left(\frac{\rho_5}{\rho}\right)$$

SI formula

$$Q_5 = 1097Y\sqrt{\frac{\Delta P_n}{\rho_5}}\sum(CA_6)$$

I-P formula

Figure 6.6 - Leakage Chamber



NOZZLE WITH THROAT TAPS

NOZZLE WITHOUT THROAT TAPS

Notes:

1. The nozzle shall have a cross-section consisting of elliptical and cylindrical portions, as shown. The cylindrical portion is defined as the nozzle throat.

2. The cross-section of the elliptical portion is one quarter of an ellipse, having the large axis *D* and the small axis 0.667*D*. A three-radii approximation to the elliptical form that does not differ at any point in the normal direction more than 1.5% from the elliptical form shall be used. The adjacent arcs, as well as the last arc, shall smoothly meet and blend with the nozzle throat. The recommended approximation which meets these requirements is shown in Figure 7B by Cermak, J., Memorandum Report to AMCA 210/ASHRAE 51P Committee, June 16, 1992.

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3. The nozzle throat dimension *L* shall be either 0.6*D* ± 0.005*D* (recommended), or 0.5*D* ± 0.005*D*.

4. The nozzle throat dimension *D* shall be measured (to an accuracy of 0.001*D*) at the minor axis of the ellipse and at the nozzle exit. At each place, four diameters – approximately 45˚ apart must be within ± 0.002*D* greater, but no less than, the mean at the nozzle exit.

5. The nozzle surface in the direction of flow from the nozzle inlet towards the nozzle exit shall fair smoothly so that a straight-edge may be rocked over the surface without clicking. The macro-pattern of the surface shall not exceed 0.001*D*, peak-to-peak. The edge of the nozzle exit shall be square, sharp, and free of burrs, nicks or roundings.

6. In a chamber, the use of either of the nozzle types shown above is permitted. A nozzle with throat taps shall be used when the discharge is direct into a duct, and the nozzle outlet should be flanged.

7. A nozzle with throat taps shall have four such taps conforming to Figure 4, located 90 ± 2 apart. All four taps shall be connected to a piezometer ring.

Figure 7A - Nozzles

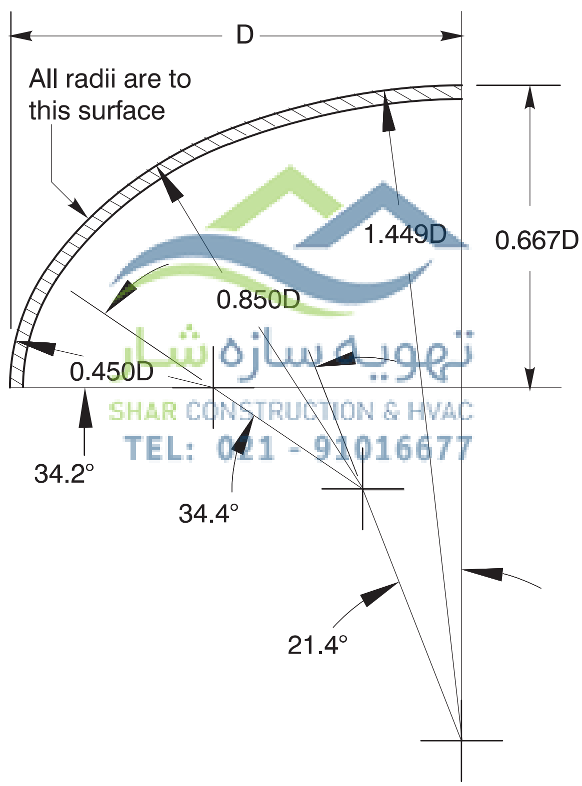

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Figure 7B - Three Arc Approximation of Elliptical Nozzle

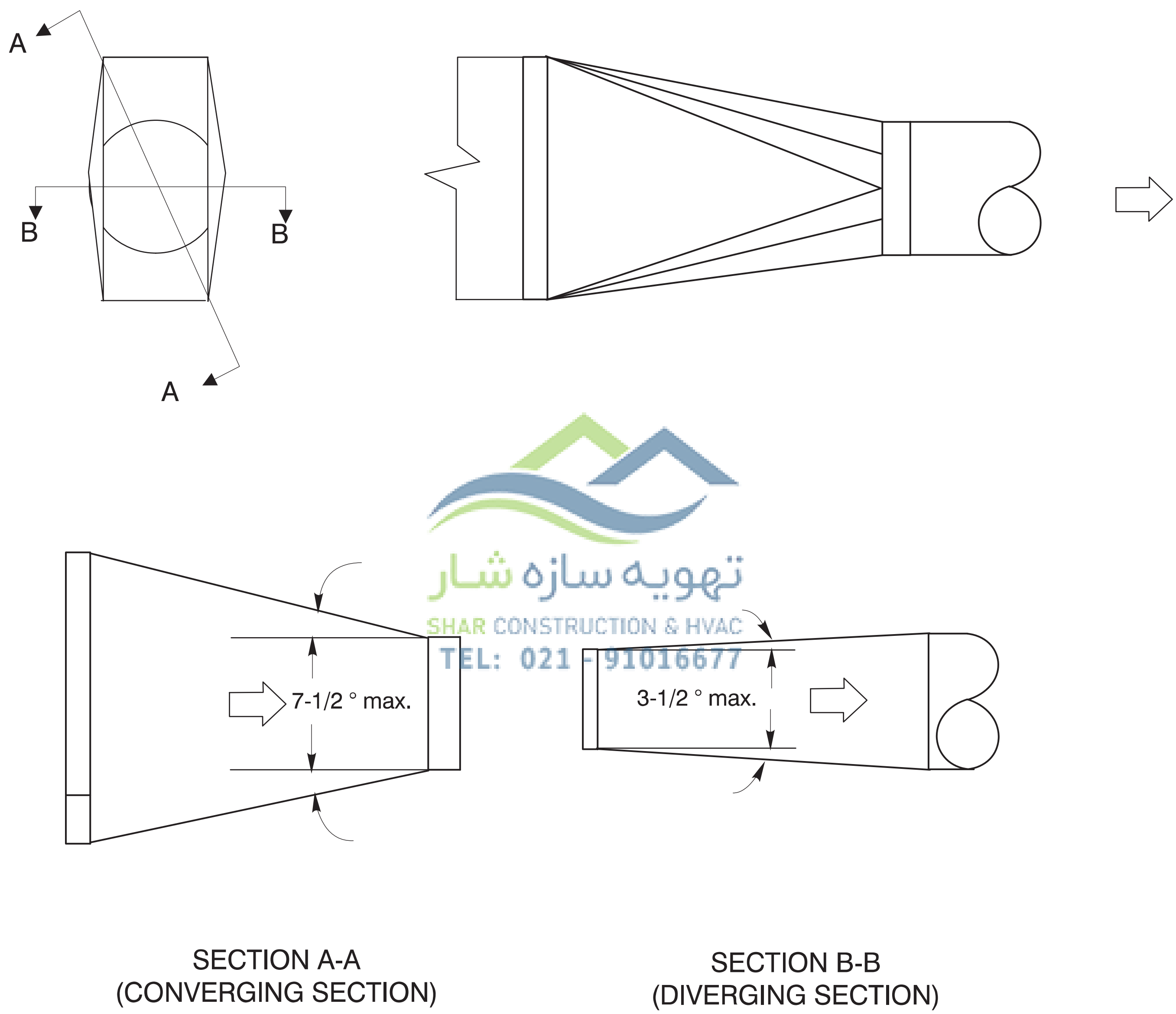

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Figure 8 - Transformation Pieces

All dimensions shall be within±0.005D except y
which shall not exceed 0.005D

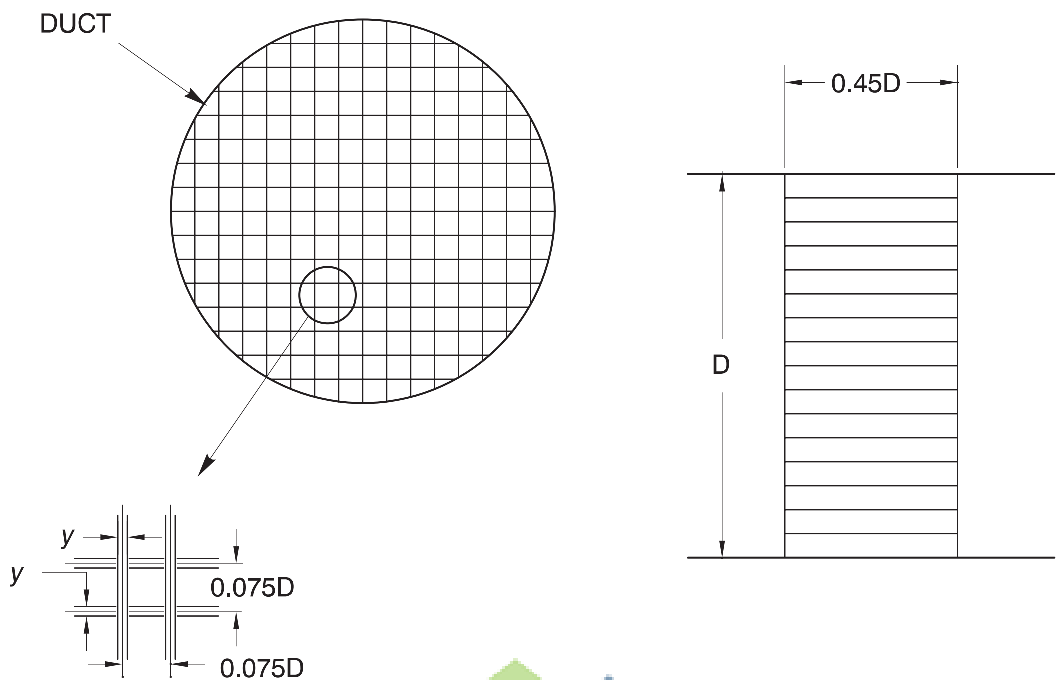

Figure 9A - Flow Straightener

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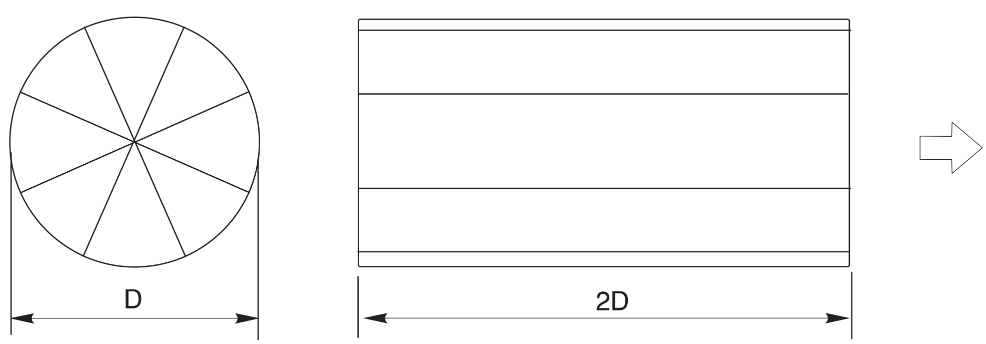

The straightener consists of eight radial vanes equally spaced. The vane thickness shall not exceed 0.007*D*.

Figure 9B - Star Straightener

Annex A. SI and I-P Conversions

[This annex is not part of this standard, but is included for information purposes only]

A.1 I-P Equivalents of SI units

Area	
1 m^2	= 10.76 ft^2
Length	
1 m (meter)	= 3.2808 ft
Mass	
1 kg	= 2.2046 lbm
Temperature	
1K	= 1.8 °R
tc	= (tF - 32)/1.8
Force	
1 N	= 0.22481 lbf
Flow Rate	
1 m^3/s	= 2118.9 cfm
1 m^3/h	= 0.58858 cfm
Velocity	
1 m/s	= 196.85 fpm
Pressure	
1 Pa (Pascal) at 20°C	= 0.0040264 in. wg at 68°F
1 Pa (Pascal) at 0°C	= 0.00029530 in. Hg at 32°F
1 Pa (Pascal) at 3.9°C	= 0.004015 in. wg at 39°F
Power	
1 W (watt)	= 0.0013410 hp
Energy	
1 J (joule)	= 0.73756 ft-lbf
Torque	
1 N-m	= 8.8507 lbf-in.
Density	
1 kg/m^3	= 0.062428 lbm/ft^3
1.200 kg/m^3 at 20°C	= 0.075 lbf/ft^3 at 68°F
Viscosity, Dynamic	
1 Pa-s	= 0.67197 lbm/ft-s
Gas Constant	
1 J/(kg-K)	= 0.18586 ft-lbf/(lbm-°R)
Gravitational Acceleration	
9.80665 m/s^2	= 32.174 ft/s^2

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A.2 SI Equivalents of I-P units

Area
1 ft^2 = 0.0929 m^2

Length
1 ft = 0.30480 m

Mass
1 lbm = 0.45359 kg

Temperature
1°R = K/1.8
tF = 1.8 tc + 32

Force
1 lbf = 4.4482 N

Flow Rate
1 cfm = 0.00047195 m^3/s
1 cfm = 1.6990 m^3/h

Velocity
1 fpm = 0.005080 m/s

Pressure
1 in. wg at 68°F = 248.36 Pa at 20°C
1 in. wg at 39°F = 249.1 Pa at 3.9°C
1 in. Hg at 32°F = 3386.4 Pa at 0°C

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Power
1 hp (horsepower) = 0.74570 kW

Energy
1 ft-lbf = 1.3558 J

Torque
1 lbf-in. = 0.11298 N-m

Density
1 lbm/ft^3 = 16.018 kg/m^3
0.075 lbm/ft^3 at 68°F = 1.2 kg/m^3 at 20°C

Viscosity, Dynamic
1 lbm/ft-s = 1.4882 Pa-s

Gas Constant
1 ft-lbf/(lbm-°R) = 5.3803 J/(kg-K)

Gravitational Acceleration
32.174 ft/s^2 = 9.80665 m/s^2

Annex B. Presentation of Air Performance Results for Rating Purposes

[This annex is not a part of this standard but is included for informational purposes only.]

See Publication 511, Certified Ratings Program for Air Control Dampers, for complete information on rating.

B.1 Rating air performance - pressure drop

For the purpose of publishing ratings, extrapolation from test data is permissible. The portion of the curve obtained by extrapolation shall be charted with a broken line and must be a smooth continuation of the adjacent portion of the curve. The static pressure drop shall not be extrapolated more than 50 percent of the range of the test either upwards or downwards.

B.1.1 Damper. The results of an air performance test shall be presented as a statement of the pressure drop Pa (in. wg) across the damper versus the free area velocity [m/s (fpm)] at standard air density.

B.2 Rating air leakage

B.2.1 In-duct or in-wall mounting. The results of an air leakage test shall be presented as a statement of the pressure differential across the damper [Pa (in. wg)] versus airflow rate per square meter (foot) of louver or damper area at standard air density. The area is determined by the installation method as shown in the sketches below. Results shall include a statement of the specific seating torque holding the damper closed, and direction of airflow.

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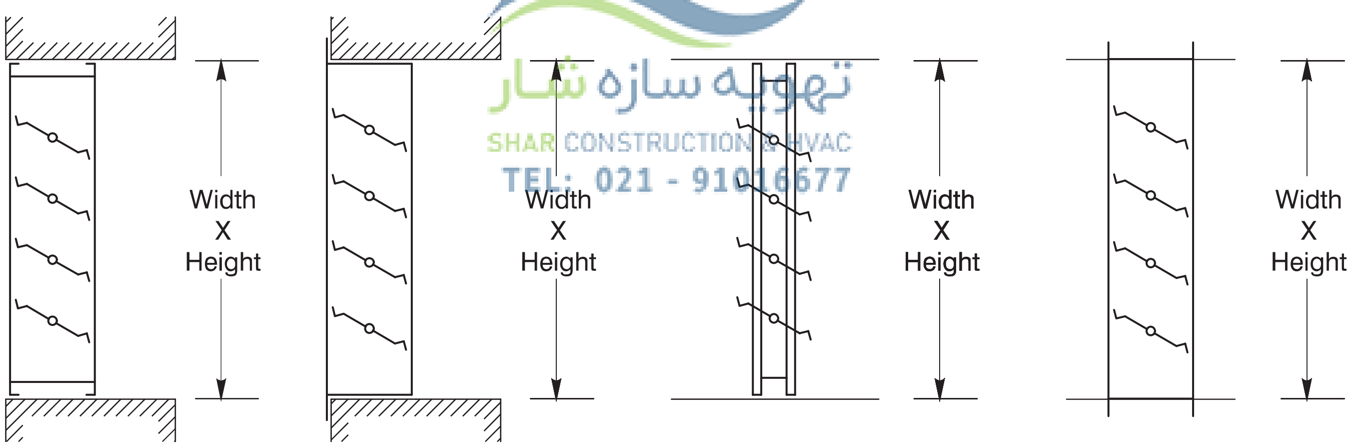

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