AMCA Publication 201-02
(R2011)

Fans and Systems

AIR MOVEMENT AND CONTROL ASSOCIATION INTERNATIONAL, INC.

The International Authority on Air System Components

AMCA PUBLICATION 201-02 (R2011)

Fans and Systems

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Forward

ANSI/AMCA Standard 210 *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*, provides a basis for accurately rating the performance of fans when tested under standardized laboratory conditions. The actual performance of a fan when installed in an air moving system will sometimes be different from the fan performance as measured in the laboratory. The difference in performance between the laboratory and the field installation can sometimes be attributed to the interaction of the fan and the duct system, i.e., duct system design can diminish the usable output of the fan.

AMCA Publication 201 *Fans and Systems*, introduced the concept of *System Effect Factor* to the air moving industry. The *System Effect Factor* quantifies the duct system design effect on performance. The *System Effect Factor* has been widely accepted since its inception in 1973. It must be remembered, however, that the "factors" provided are approximations as it is prohibitive to test all fan types and all duct system configurations. The major revision to this edition of AMCA Publication 201 *Fans and Systems*, is a change to the use of SI units of measure, with Inch-Pound units being given secondary consideration.

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Related AMCA Standards and Publications

Publication 200 ***AIR SYSTEMS***

System Pressure Losses
Fan Performance Characteristics
System Effect
System Design Tolerances

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

Publication 201 ***FANS AND SYSTEMS***

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

Fans and Systems is aimed primarily at the designer of the air moving system and discusses the effect on inlet and outlet connections of the fan's performance. System Effect Factors, which must be included in the basic design calculations, are listed for various configurations. AMCA 202 and AMCA 203 are companion documents.

Publication 202 ***TROUBLESHOOTING***

System Checklist
Fan Manufacturer's Analysis
Master Troubleshooting Appendices

Troubleshooting is intended to help identify and correct problems with the performance and operation of the air moving system after installation. AMCA 201 and AMCA 203 are companion documents.

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

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

Field Performance Measurements of Fan Systems reviews the various problems of making field measurements and calculating the actual performance of the fan and system. AMCA 201 and AMCA 202 are companion documents.

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Fans and Systems

1. Introduction

ANSI/AMCA 210 *Laboratory Methods of Testing Fans For Aerodynamic Performance Rating*, offers the system design engineer guidance as to how the fan was tested and rated. AMCA Publication 201 *Fans and Systems*, helps provide guidance as to what effect the system and its connections to the fan have on fan performance.

Recognizing and accounting for losses that affect the fan's performance, in the design stage, will allow the designer to predict with reasonable accuracy, the installed performance of the fan.

1.1 Purpose

This part of the AMCA *Fan Application Manual* includes general information about how fans are tested in the laboratory, and how their performance ratings are calculated and published. It also reviews some of the more important reasons for the "loss" of fan performance that may occur when the fan is installed in an actual system.

Allowances, called *System Effect Factors* (*SEF*), are also given in this part of the manual. *SEF* must be taken into account by the system design engineer if a reasonable estimate of fan/system performance is to be determined.

1.2 Some limitations

It must be appreciated that the *System Effect Factors* given in this manual are intended as guidelines and are, in general, approximations. Some have been obtained from research studies, others have been published previously by individual fan manufacturers, and many represent the consensus of engineers with considerable experience in the application of fans.

Fans of different types and even fans of the same type, but supplied by different manufacturers, will not necessarily react with the system in exactly the same way. It will be necessary, therefore, to apply judgment based on actual experience in applying the *SEF*.

The *SEF* represented in this manual assume that the fan application is generally consistent with the method of testing and rating by the manufacturer. Inappropriate application of the fan will result in *SEF* values inconsistent with the values presented.

Mechanical design of the fan is not within the scope of this publication.

2. Symbols and Subscripts

For symbols and subscripted symbols, see Table 2.1. For subscripts, see Table 2.2.

3. Fan Testing

Fans are tested in setups that simulate installations. The four standard installation types are as shown in Figure 3.1.

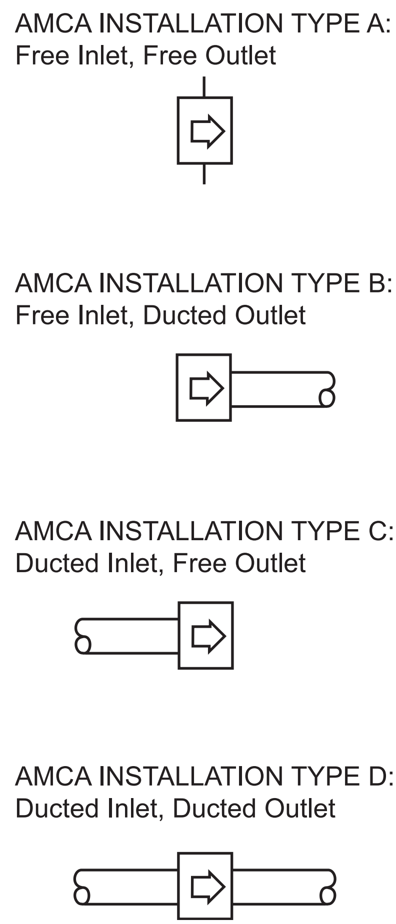

Figure 3.1 - Standard Fan Installation Types

3.1 ANSI/AMCA Standard 210

Most fan manufacturers rate the performance of their products from tests made in accordance with ANSI/AMCA 210 *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*. The purpose

Table 2.1 - Symbols and Subscripted Symbols

SYMBOL	DESCRIPTION	UNITS OF MEASURE SI	I-P
A	Area of cross section	m^2	ft^2
D	Diameter, impeller	mm	in.
D	Diameter, Duct	m	ft
H	Fan Power Input	kw	hp
H/T	Hub-to-Tip Ratio	Dimensionless	
K_p	Compressibility Coefficient	Dimensionless	
C_p	Loss Coefficient	Dimensionless	
N	Speed of Rotation	rpm	rpm
P_s	Fan Static Pressure	Pa	in. wg
P_t	Fan Total Pressure	Pa	in. wg
P_v	Fan Velocity Pressure	Pa	in. wg
p_b	Corrected Barometric Pressure	kPa	in. Hg
PL	Plane of Measurement	---	---
Q	Airflow	m^3/s	ft^3/min
Re	Fan Reynolds Number	Dimensionless	
SEF	*System Effect Factor*	Pa	in. wg
t_d	Dry-Bulb Temperature	°C	°F
t_w	Wet-Bulb Temperature	°C	°F
μ	Air Viscosity	Pa•s	lbm/ft•s
V	Velocity	m/s	fpm
W	Power Input to Motor	watts	watts
η_s	Fan Static Efficiency	%	%
η_t	Fan Total Efficiency	%	%
ρ	Air Density	kg/m^3	lbm/ft^3

Table 2.2 - Subscripts

SUBSCRIPT	DESCRIPTION
a	Atmospheric conditions
c	Converted Value
x	Plane 0, 1, 2, ...as appropriate
1	Fan Inlet Plane
2	Fan Outlet Plane
3	Pitot Traverse Plane
5	Plane 5 (nozzle inlet station in chamber)
6	Plane 6 (nozzle discharge station in chamber)
8	Plane 8 (inlet chamber measurement station)

of ANSI/AMCA 210 is to establish uniform methods for laboratory testing of fans and other air moving devices to determine performance in terms of airflow, pressure, power, air density, speed of rotation and efficiency, for rating or guarantee purposes. Two methods of measuring airflow are included: the Pitot tube and the long radius flow nozzle. These are incorporated into a number of "setups" or "figures". In general, a fan is tested on the setup that most closely resembles the way in which it will be installed in an air system. Centrifugal and axial fans are usually tested with an outlet duct. Propeller fans are normally tested in the wall of a chamber or plenum. Power roof ventilators (PRV) are tested mounted on a curb exhausting from the test chamber.

It is very important to realize that each setup in ANSI/AMCA 210 is a standardized arrangement that is not intended to reproduce *exactly* any installation likely to be found in the field. The infinite variety of possible arrangements of actual air systems makes it impractical to duplicate every configuration in the fan test laboratory.

3.2 Ducted outlet fan tests

Figure 3.2 is a reproduction of a test setup from ANSI/AMCA 210. Note that this particular setup includes a long straight duct connected to the outlet of the fan. A straightener is located upstream of the Pitot traverse to remove swirl and rotational components from the airflow and to ensure that airflow at the plane of measurement is as nearly uniform as possible.

The angle of the transition between the test duct and the fan outlet is limited to ensure that uniform airflow will be maintained. A steep transition, or abrupt change of cross section would cause turbulence and eddies. The effect of this type of airflow disturbance at the fan outlet is discussed later.

Uniform airflow conditions ensure consistency and reproducibility of test results and permit the fan to develop its maximum performance. *In any installation where uniform airflow conditions do not exist, the fan's performance will be measurably reduced*.

As illustrated in Figure 3.3 Plane 2, the velocity profile at the outlet of a fan is not uniform. The section of straight duct attached to the fan outlet controls the diffusion of the outlet airflow and establishes a more uniform velocity as shown in Figure 3.3 Plane X.

The energy loss when a gas, such as air, passes through a sudden enlargement is related to the square of the velocity. Thus the ducted outlet with its more uniform velocity significantly reduces the loss at the point of discharge to the atmosphere.

A manufacturer may test a fan with or without an inlet duct or outlet duct. For products licensed to use the AMCA Certified Ratings Seal, catalog ratings will state whether ducts were used during the rating tests.

If the fans are not to be applied with the same duct(s) as in the test setup, an allowance should be made for the difference in performance that may result.

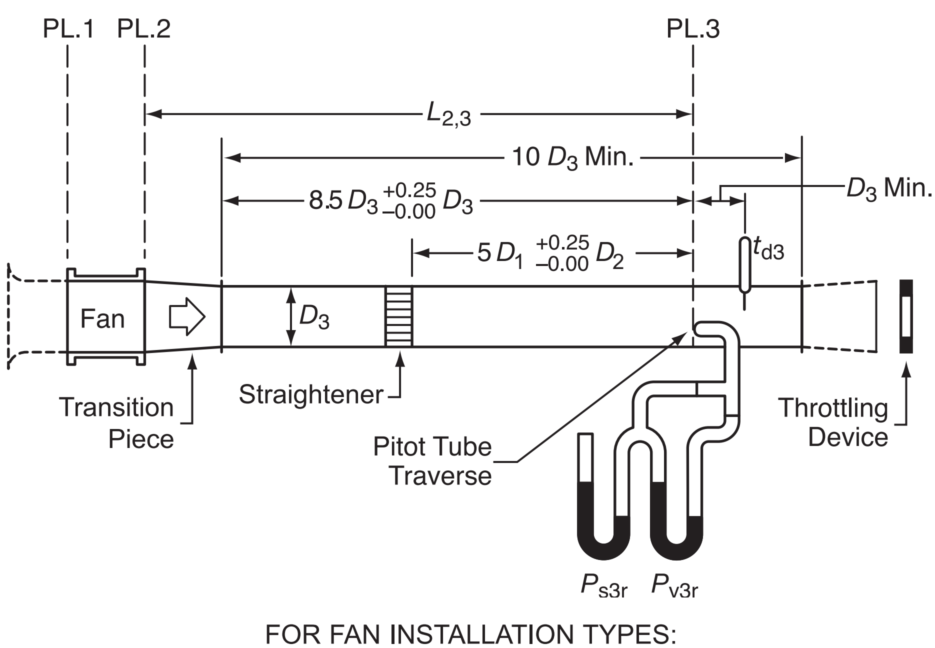

Figure 3.2 - Pitot Traverse in Outlet Duct

3.3 Free inlet, free outlet fan tests

Figure 3.4 illustrates a typical multi-nozzle chamber test setup from ANSI/AMCA 210. This simulates the conditions under which most exhaust fans are tested and rated. Fan performance based on this type of test may require adjustment when additional accessories are used with the fan. Fans designed for use without duct systems are usually rated over a lower range of pressures. They are commonly cataloged and sold as a complete unit with suitable drive and motor.

3.4 Obstructed inlets and outlets

The test setups in ANSI/AMCA 210 result in unobstructed airflow conditions at both the inlet and the outlet of the fan. Appurtenances or obstructions located close to the inlet and/or outlet will affect fan performance. Shafts, bearings, bearing supports and other appurtenances normally used with a fan should be in place when a fan is tested for rating.

Variations in construction which may affect fan performance include changes in sizes and types of sheaves and pulleys, bearing supports, bearings and shafts, belt guards, inlet and outlet dampers, inlet vanes, inlet elbows, inlet and outlet cones, and cabinets or housings.

Since changes in performance will be different for various product designs, it will be necessary to make suitable allowances based on data obtained from the applicable fan catalog or directly from the manufacturer.

Most single width centrifugal fans are tested using Arrangement 1 fans. Some allowance for the effect of bearings and bearing supports in the inlet may be necessary when using Arrangement 3 or Arrangement 7. The various AMCA standard arrangements are shown on Figures 3.5, 3.6, and 3.7.

4. Fan Ratings

4.1 The Fan Laws

It is not practical to test a fan at every speed at which it may be applied. Nor is it possible to simulate every inlet density that may be encountered. Fortunately, by use of a series of equations commonly referred to as the Fan Laws, it is possible to predict with good accuracy the performance of a fan at other speeds and densities than those of the original rating test.

The performance of a complete series of geometrically similar (homologous) fans can also be calculated from the performance of smaller fans in the series using the appropriate equations.

Because of the relationship between the airflow, pressure and power for any given fan, each set of equations for changes in speed, size or density, applies only to the same Point of Rating, and all the equations in the set must be used to define the converted condition. A Point of Rating is the specified fan operating point on its characteristic curve.

The Fan Law equations are shown below as ratios. The un-subscripted variable is used to designate the initial or test fan values for the variable and the subscript c is used to designate the converted, dependent or desired variable.

$$Q_c = Q \times (D_c/D)^3 \times (N_c/N) \times (K_p/K_{pc})$$

$$P_{tc} = P_t \times (D_c/D)^2 \times (N_c/N)^2 \times (\rho_c/\rho) \times (K_p/K_{pc})$$

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

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

$$H_c = H \times (D_c/D)^5 \times (N_c/N)^3 \times (\rho_c/\rho) \times (K_p/K_{pc})$$

$$\eta_{tc} = (Q_c \times P_{tc} \times K_p) / H_c \qquad \text{(SI)}$$

$$\eta_{tc} = (Q_c \times P_{tc} \times K_p) / (6362 \bullet H_c) \qquad \text{(I-P)}$$

$$\eta_{sc} = \eta_{tc} \times (P_{sc}/P_{tc})$$

These equations have their origin in the classical theories of fluid mechanics, and the accuracy of the results obtained is sufficient for most applications. Better accuracy would require consideration of Reynolds number, Mach number, kinematic viscosity, dynamic viscosity, surface roughness, impeller blade thickness and relative clearances, etc.

4.2 Limitations

Under certain conditions the properties of gases change and there are, therefore, limitations to the use of the Fan Laws. Accurate results will be obtained when the following limitations are observed:

a. Fan Reynolds Number (Re). The term Reynolds number is associated with the ratio of inertia to viscous forces. When related to fans, investigations of both axial and centrifugal fans show that performance losses are more significant at low Reynolds number ranges and are effectively negligible above certain threshold Reynolds numbers. In an effort to simplify the comparison of the Reynolds numbers of two fans, the fan industry

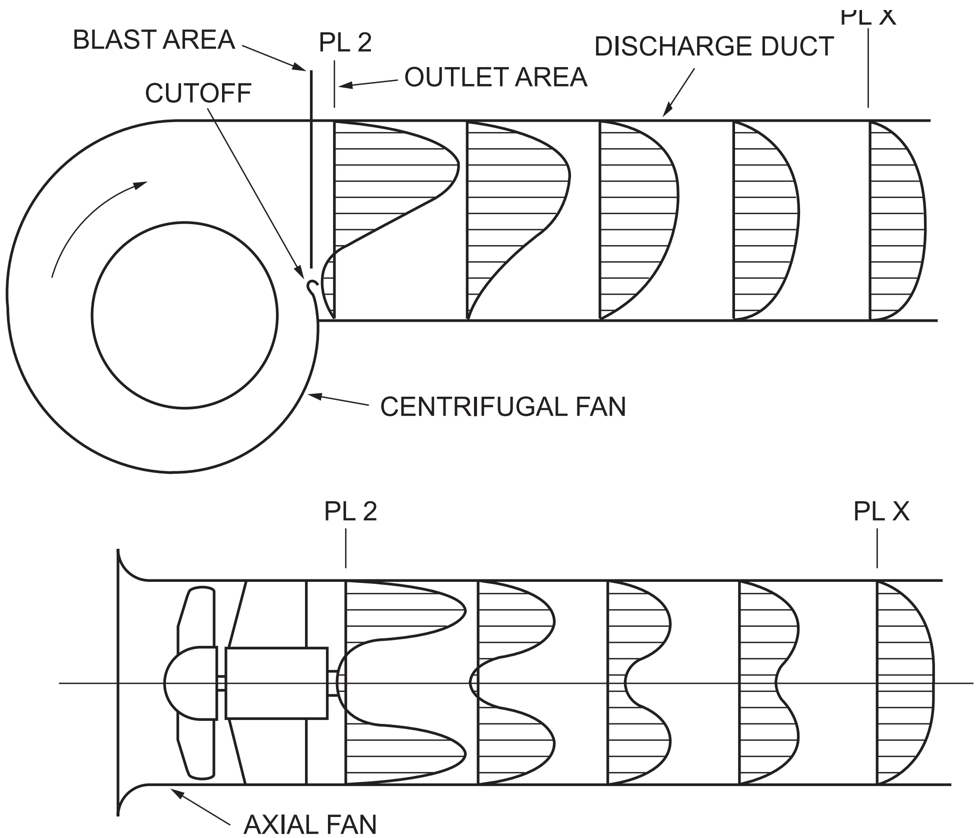

Figure 3.3 - Controlled Diffusion and Establishment of a Uniform Velocity Profile in a Straight Length of Outlet Duct

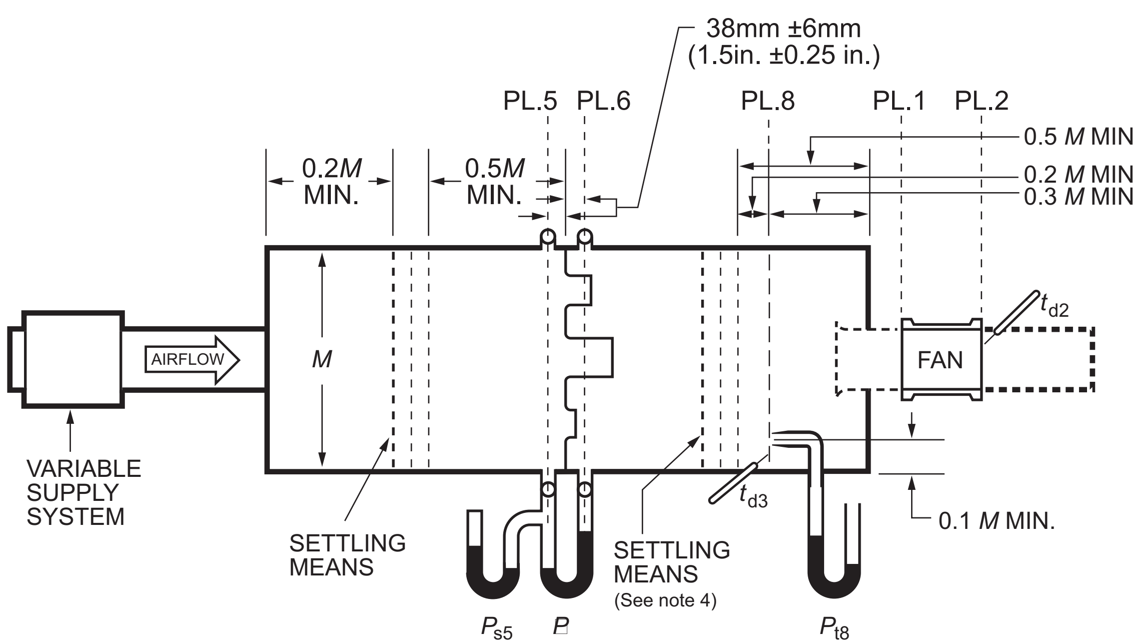

Figure 3.4 - Inlet Chamber Setup - Multiple Nozzles in Chamber (ANSI/AMCA 210-99, Figure 15)

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Drive Arrangements for Centrifugal Fans

An American National Standard - Approved by ANSI on April 17, 2003

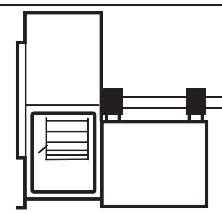
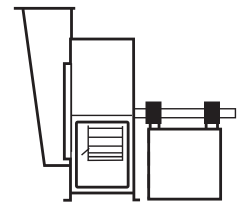
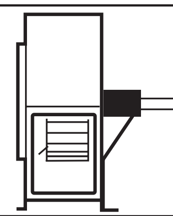
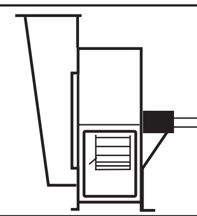
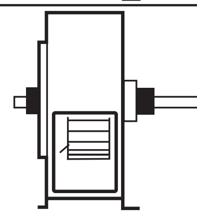
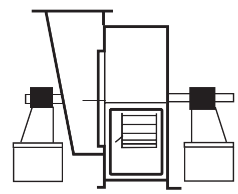
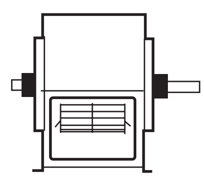
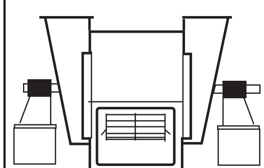
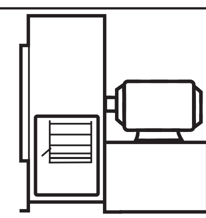
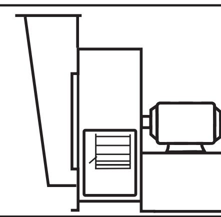
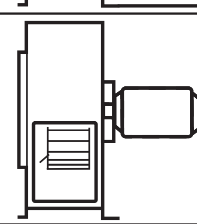
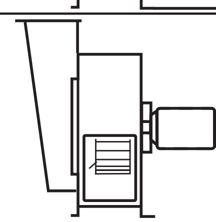
AMCA Drive Arrangement	ISO 13349 Drive Arrangement	Description	Fan Configuration	Alternative Fan Configuration
1 SWSI	1 or 12 (Arr. 1 with sub-base)	For belt or direct drive. Impeller overhung on shaft, two bearings mounted on pedestal base. Alternative: Bearings mounted on independant pedestals, with or without inlet box.		
2 SWSI	2	For belt or direct drive. Impeller overhung on shaft, bearings mounted in bracket supported by the fan casing. Alternative: With inlet box.		
3 SWSI	3 or 11 (Arr. 3 with sub-base)	For belt or direct drive. Impeller mounted on shaft between bearings supported by the fan casing. Alternative: Bearings mounted on independent pedestals, with or without inlet box.		
3 DWDI	6 or 18 (Arr. 6 with sub-base)	For belt or direct drive. Impeller mounted on shaft between bearings supported by the fan casing. Alternative: Bearings mounted on independent pedestals, with or without inlet boxes.		
4 SWSI	4	For direct drive. Impeller overhung on motor shaft. No bearings on fan. Motor mounted on base. Alternative: With inlet box.		
5 SWSI	5	For direct drive. Impeller overhung on motor shaft. No bearings on fan. Motor flange mounted to casing. Alternative: With inlet box.		

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Figure 3.5 - AMCA Standard 99-2404 / Page 1

ANSI/AMCA Standard 99-2404-03 Page 2 of 2

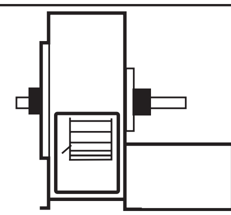
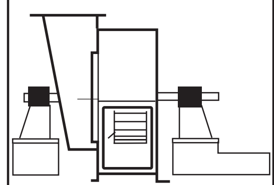
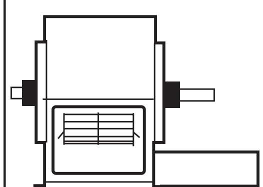
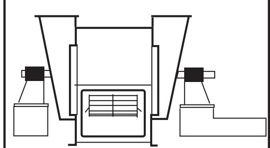
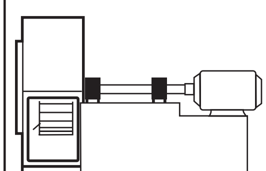
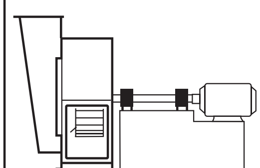
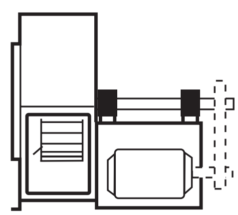
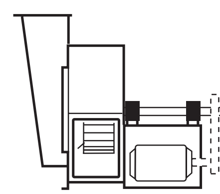
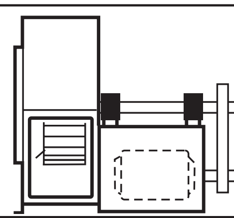
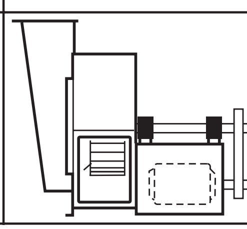
AMCA Drive Arrangement	ISO 13349 Drive Arrangement	Description	Fan Configuration	Alternative Fan Configuration
7 SWSI	7	For coupling drive. Generally the same as Arr. 3, with base for the prime mover. Alternative: Bearings mounted on independent pedestals with or without inlet box.		
7DWDI	17 (Arr. 6 with base for motor)	For coupling drive. Generally the same as Arr. 3 with base for the prime mover. Alternative: Bearings mounted on independent pedestals with or without inlet box.		
8 SWSI	8	For direct drive. Generally the same as Arr. 1 with base for the prime mover. Alternative: Bearings mounted on independent pedestals with or without inlet box.		
9 SWSI	9	For belt drive. Impeller overhung on shaft, two bearings mounted on pedestal base. Motor mounted on the outside of the bearing base. Alternative: With inlet box.		
10 SWSI	10	For belt drive. Generally the same as Arr. 9 with motor mounted inside of the bearing pedestal. Alternative: With inlet box.		

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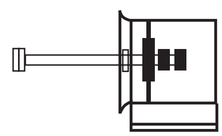
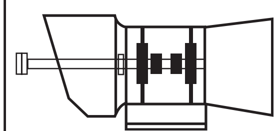
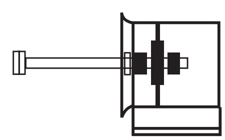
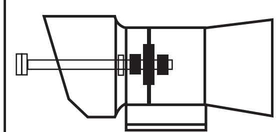
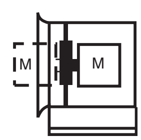
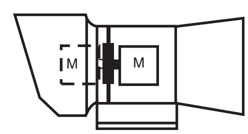
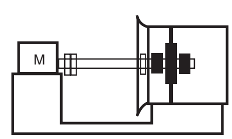
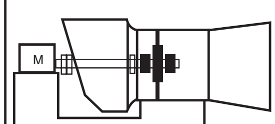
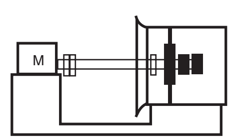
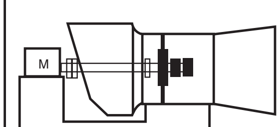
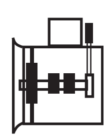
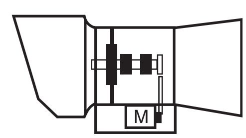
Figure 3.6 - AMCA Standard 99-2404 / Page 2

ANSI/AMCA Standard 99-3404-03 Page 1 of 1

Drive Arrangements for Axial Fans

An American National Standard - Approved by ANSI on June 10, 2003

Note: All fan orientations may be horizontal or vertical

AMCA Drive Arrangement	ISO 13349 Drive Arrangement	Description	Fan Configuration	Alternative Fan Configuration
1	1 12 (Arr. 1 with sub-base)	For belt or direct drive. Impeller overhung on shaft, two bearings mounted either upstream or downstream of the impeller. Alternative: Single stage or two stage fans can be supplied with inlet box and/or discharge evasé.		
3	3 11 (Arr. 3 with sub-base)	For belt or direct drive. Impeller mounted on shaft between bearings on internal supports. Alternative: Fan can be supplied with inlet box, and/or discharge evasé.		
4	4	For direct drive. Impeller overhung on motor shaft. No bearings on fan. Motor mounted on base or integrally mounted. Alternative: With inlet box and/or with discharge evasé.		
7	7	For direct drive. Generally the same as Arr. 3 with base for the prime mover. Alternative: With inlet box and/or discharge evasé.		
8	8	For direct drive. Generally the same as Arr. 1 with base for the prime mover. Alternative: Single stage or two stage fans can be supplied with inlet box and/or discharge evasé.		
9	9	For belt drive. Generally same as Arr. 1 with motor mounted on fan casing, and/or an integral base. Alternative: With inlet box and/or discharge evasé		

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has adopted the term *Fan Reynolds Number*.

$$Re = (\pi N D^2 \rho) / (60\mu)$$

where: N = impeller rotational speed, rpm
D = impeller diameter, m(ft)
ρ = air density, kg/m^3 (lbm/ft^3)
μ = absolute viscosity,
1.8185 × 10^{-3} Pa•s (5°C to 38°C) (SI)
(1.22 × 10^{-05} lbm/ft•s (40°F to 100°F)) (I-P)

The threshold fan Reynolds number for centrifugal and axial fans is about 3.0 × 10^6. That is, there is a negligible change in performance between the two fans due to differences in Reynolds number if both fans are operating above this threshold value. When the Reynolds number of a model fan is below 3.0 × 10^6, there may be a gain in efficiency (size effect) for a full size fan operating above the threshold compared to one operating below the threshold. This occurs only when both fans are operating near peak efficiency. Therefore, when a model test is being conducted to verify the rating of a full size fan, the Reynolds number should be above 3.0 ×10^6 to avoid any uncertainty relating to Reynolds number effects.

b. Point of Rating. To predict the performance of a fan from a smaller model using the Fan Laws, both fans must be geometrically similar (homologous), and both fans must operate at the same corresponding rating points on their characteristic curves. Two or more fans are said to be operating at corresponding "points of rating" if the positions of the operating points, relative to the pressure at shutoff and the airflow at free delivery, are the same.

c. Compressibility. Compressibility is the characteristic of a gas to change its volume as a function of pressure, temperature and composition. The compressibility coefficient (K_p) expresses the ratio of the fan total pressure developed with an incompressible fluid to the fan total pressure developed with a compressible fluid (See ANSI/AMCA 210). Differences in the compressibility coefficient between two similar fans must be calculated using the proper specific heat ratio for the gases being handled.

d. Specific Heat Ratio (C_p). Model fan tests are usually based on air with a specific heat ratio of 1.4. Induced draft fans may handle flue gas with a specific heat ratio of 1.35. Even though these differences may normally be considered small, they make a noticeable difference in the calculation of the compressibility coefficient. Refer to AMCA Publication 802, Annex A, for calculation procedures.

e. Tip Speed Mach Parameter (M_t). Tip speed Mach parameter is an expression relating the tip speed of the impeller to the speed of sound at the fan inlet condition.

When airflow velocity at a point approaches the speed of sound, some blocking or choking effects occur that reduce the fan performance.

4.3 Fan performance curves

A fan performance curve is a graphic presentation of the performance of a fan. Usually it covers the entire range from free delivery (no obstruction to airflow) to no delivery (an air tight system with no air flowing). One, or more, of the following characteristics may be plotted against volume airflow (Q).

Fan Static Pressure	P_s
Fan Total Pressure	P_t
Fan Power	H
Fan Static Efficiency	η_s
Fan Total Efficiency	η_t

Air density (ρ), fan size (D), and fan rotational speed (N) are usually constant for the entire curve and must be stated.

A typical fan performance curve is shown in Figure 4.1. Figure 4.2 illustrates examples of performance curves for a variety of fan types.