

AMCA Publication 201-02 (R2011)

Fans and Systems



**AIR MOVEMENT AND CONTROL
ASSOCIATION INTERNATIONAL, INC.**

The International Authority on Air System Components



Documents

Document Sharing Hub

AMCA PUBLICATION 201-02 (R2011)

Fans and Systems



Air Movement and Control Association International, Inc.
30 West University Drive
Arlington Heights, IL 60004-1893

© 2011 by Air Movement and Control Association International, Inc.

All rights reserved. Reproduction or translation of any part of this work beyond that permitted by Sections 107 and 108 of the United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Executive Director, Air Movement and Control Association International, Inc. at 30 West University Drive, Arlington Heights, IL 60004-1893 U.S.A.

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.

AMCA 201 Review Committee

Bill Smiley	The Trane Company / LaCrosse
James L. Smith	Aerovent, A Twin City Fan Company
Tung Nguyen	Emerson Ventilation Products
Patrick Chinoda	Hartzell Fan, Inc.
Rick Bursh	Illinois Blower, Inc.
Sutton G. Page	Austin Air Balancing Corp.
Paul R. Saxon	AMCA Staff

Disclaimer

AMCA International uses its best efforts to produce standards for the benefit of the industry and the public in light of available information and accepted industry practices. However, AMCA International does not guarantee, certify or assure the safety or performance of any products, components or systems tested, designed, installed or operated in accordance with AMCA International standards or that any tests conducted under its standards will be non-hazardous or free from risk.

Objections to AMCA Standards and Certifications Programs

Air Movement and Control Association International, Inc. will consider and decide all written complaints regarding its standards, certification programs, or interpretations thereof. For information on procedures for submitting and handling complaints, write to:

Air Movement and Control Association International
30 West University Drive
Arlington Heights, IL 60004-1893 U.S.A.

or

AMCA International, Incorporated
c/o Federation of Environmental Trade Associations
2 Waltham Court, Milley Lane, Hare Hatch
Reading, Berkshire
RG10 9TH United Kingdom

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.

TABLE OF CONTENTS

1. Introduction	1
1.1 Purpose	1
1.2 Some limitations	1
2. Symbols and Subscripts	1
2.1 Symbols and subscripted symbols	1
2.2 Subscripts	1
3. Fan Testing	1
3.1 ANSI/AMCA Standard 210	1
3.2 Ducted outlet fan tests	3
3.3 Free inlet, free outlet fan tests	4
3.4 Obstructed inlets and outlets	4
4. Fan Ratings	4
4.1 The Fan Laws	4
4.2 Limitations	4
4.3 Fan performance curves	9
5. Catalog Performance Tables	13
5.1 Type A: Free inlet, free outlet fans	13
5.2 Ducted fans	13
6. Air Systems	16
6.1 The system	16
6.2 Component losses	16
6.3 The system curve	17
6.4 Interaction of system curve and fan performance curve	18
6.5 Effect of changes in speed	18
6.6 Effect of density on system resistance	19
6.7 Fan and system interaction	21
6.8 Effects of errors in estimating system resistance	21



6.9	Safety factors	22
6.10	Deficient fan/system performance	23
6.11	Precautions to prevent deficient performance	23
6.12	System effect	23
7.	System Effect Factor (SEF)	24
7.1	System Effect Curves	24
7.2	Power determination	29
8.	Outlet System Effect Factors	29
8.1	Outlet ducts	29
8.2	Outlet diffusers	30
8.3	Outlet duct elbows	31
8.4	Turning vanes	35
8.5	Volume control dampers	35
8.6	Duct branches	37
9.	Inlet System Effect Factors	38
9.1	Inlet ducts	38
9.2	Inlet duct elbows	38
9.3	Inlet vortex (spin or swirl)	40
9.4	Inlet turning vanes	44
9.5	Airflow straighteners	44
9.6	Enclosures (plenum and cabinet effects)	46
9.7	Obstructed inlets	47
10.	Effects of Factory Supplied Accessories	49
10.1	Bearing and supports in fan inlet	50
10.2	Drive guards obstructing fan inlet	50
10.3	Belt tube in axial fan inlet or outlet	50
10.4	Inlet box	50
10.5	Inlet box dampers	50
10.6	Variable inlet vane (VIV)	51

Annex A. SI / I-P Conversion Table (Informative)	.52
Annex B. Dual Fan Systems - Series and Parallel	.53
B.1 Fans operating in series	.53
B.2 Fans operating in parallel	.53
Annex C. Definitions and Terminology	.55
C.1 The air	.55
C.2 The fan	.55
C.3 The system	.58
Annex D. Examples of the Convertibility of Energy from Velocity Pressure to Static Pressure	.62
D.1 Example of fan (tested with free inlet, ducted outlet) applied to a duct system	.62
D.2 Example of fan (tested with free inlet, ducted outlet), connected to a duct system and then a plenum	.63
D.3 Example of fan with free inlet, free outlet - fan discharges directly into plenum and then to duct system (abrupt expansion at fan outlet)	.65
D.4 Example of fan used to exhaust with obstruction in inlet, inlet elbow, inlet duct, free outlet	.66
Annex E. References	.69

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.

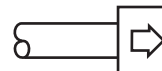
AMCA INSTALLATION TYPE A:
Free Inlet, Free Outlet



AMCA INSTALLATION TYPE B:
Free Inlet, Ducted Outlet



AMCA INSTALLATION TYPE C:
Ducted Inlet, Free Outlet



AMCA INSTALLATION TYPE D:
Ducted Inlet, Ducted Outlet



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	<i>System Effect Factor</i>	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.

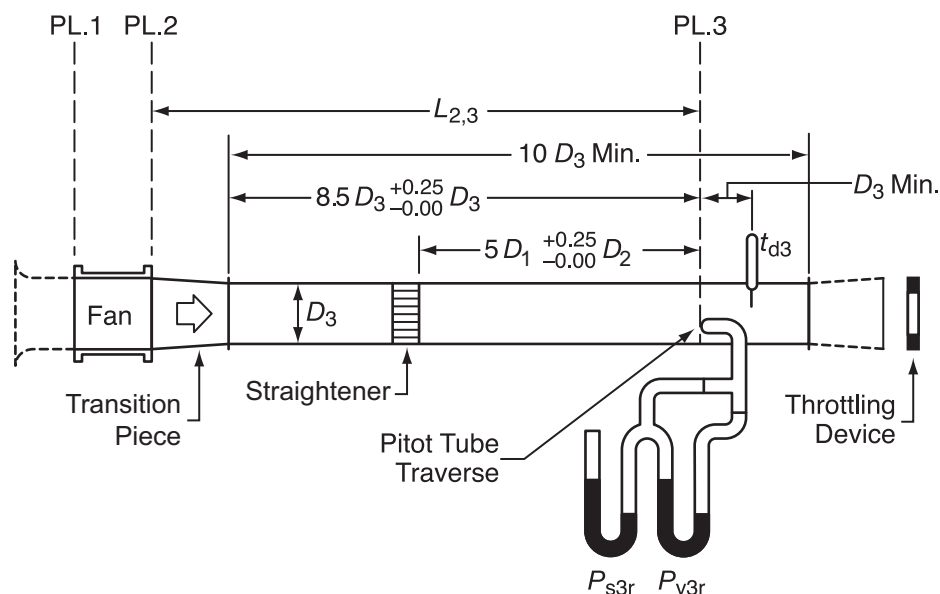
Uniform airflow conditions ensure consistency and reproducibility of test results and permit the fan to develop its maximum performance. *In any installation where uniform airflow conditions do not exist, the fan's performance will be measurably reduced.*

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.



FOR FAN INSTALLATION TYPES:
B: Free Inlet, Ducted Outlet D: Ducted Inlet, Ducted Outlet

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.

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

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

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

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

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

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

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

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

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 various fans, the fan industry

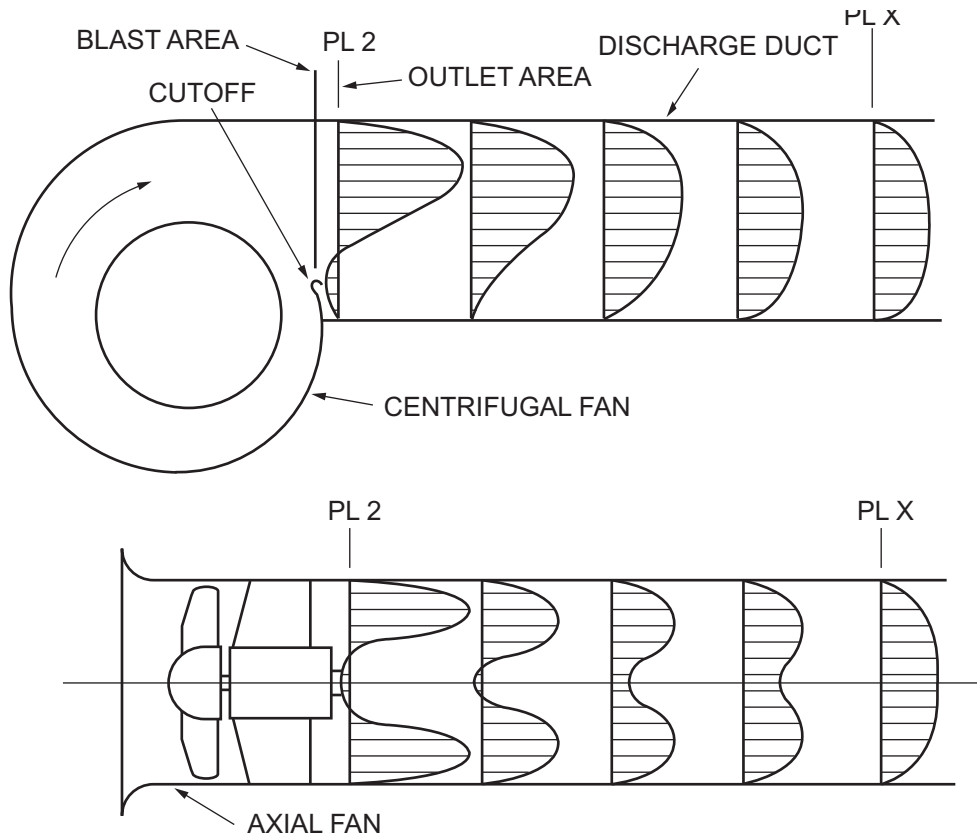


Figure 3.3 - Controlled Diffusion and Establishment of a Uniform Velocity Profile in a Straight Length of Outlet Duct

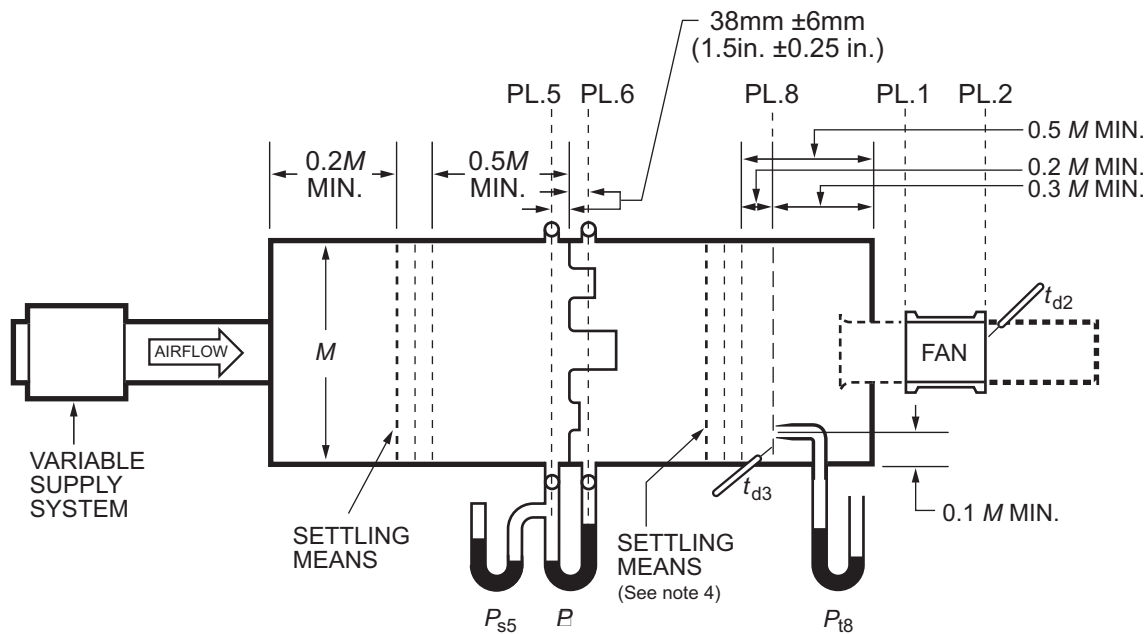
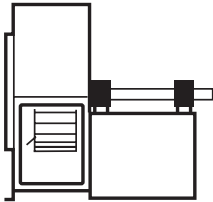
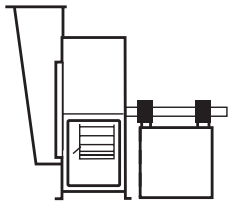
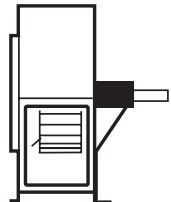
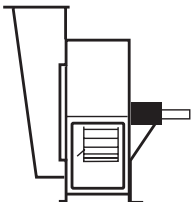
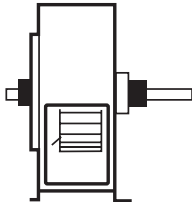
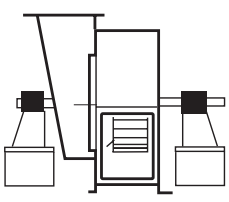
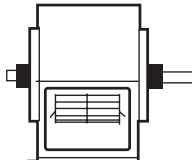
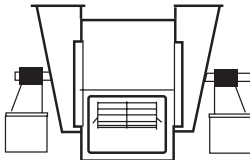
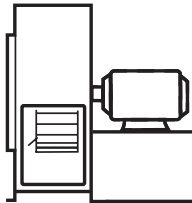
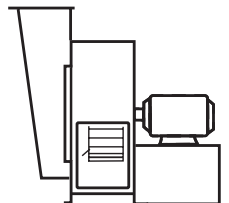
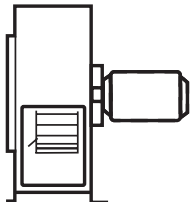
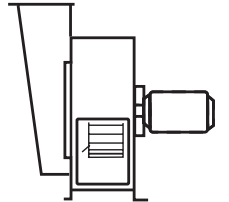


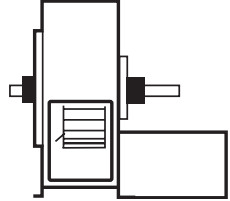
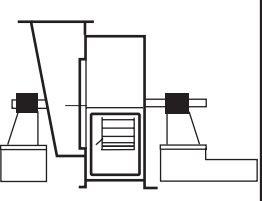
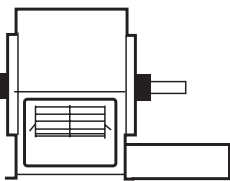
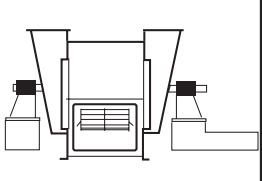
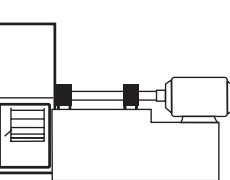
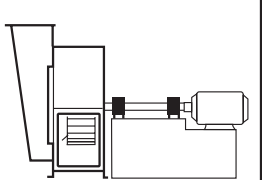
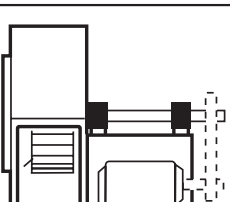
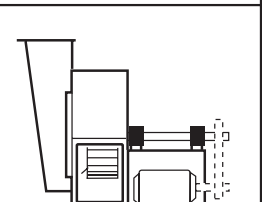
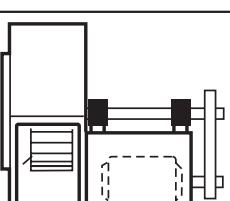
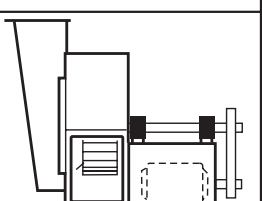
Figure 3.4 - Inlet Chamber Setup - Multiple Nozzles in Chamber
(ANSI/AMCA 210-99, Figure 15)

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 independent 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.		

AMCA International, Inc. | 30 W. University Dr. | Arlington Heights, IL, 60004-1893 | U.S.A

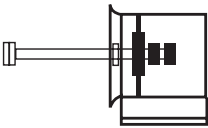
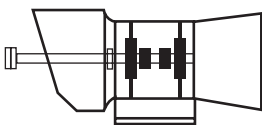
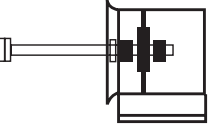
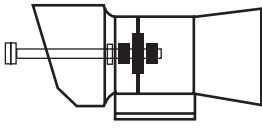
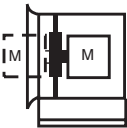
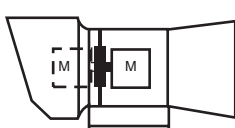
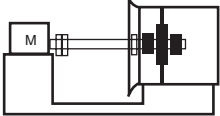
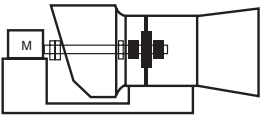
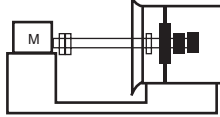
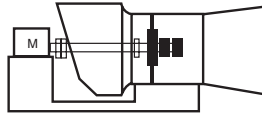
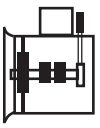
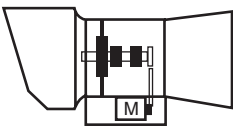
AMCA Drive Arrangement	ISO 13349 Drive Arrangement	Description	Fan Configuration	Alternative Fan Configuration
7 SWSI	7	For coupling drive. Generally the same as Arr. 3, with base for the prime mover. Alternative: Bearings mounted on independent pedestals with or without inlet box.		
7DWDI	17 (Arr. 6 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.		

AMCA International, Inc. | 30 W. University Dr. | Arlington Heights, IL, 60004-1893 | U.S.A

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		

AMCA International, Inc. | 30 W. University Dr. | Arlington Heights, IL, 60004-1893 | U.S.A

has adopted the term *Fan Reynolds Number*.

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

where: N = impeller rotational speed, rpm
 D = impeller diameter, m(ft)
 ρ = air density, kg/m³ (lbm/ft³)
 μ = absolute viscosity,
 1.8185×10^{-3} Pa•s (5°C to 38°C) (SI)
 $(1.22 \times 10^{-5}$ 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.

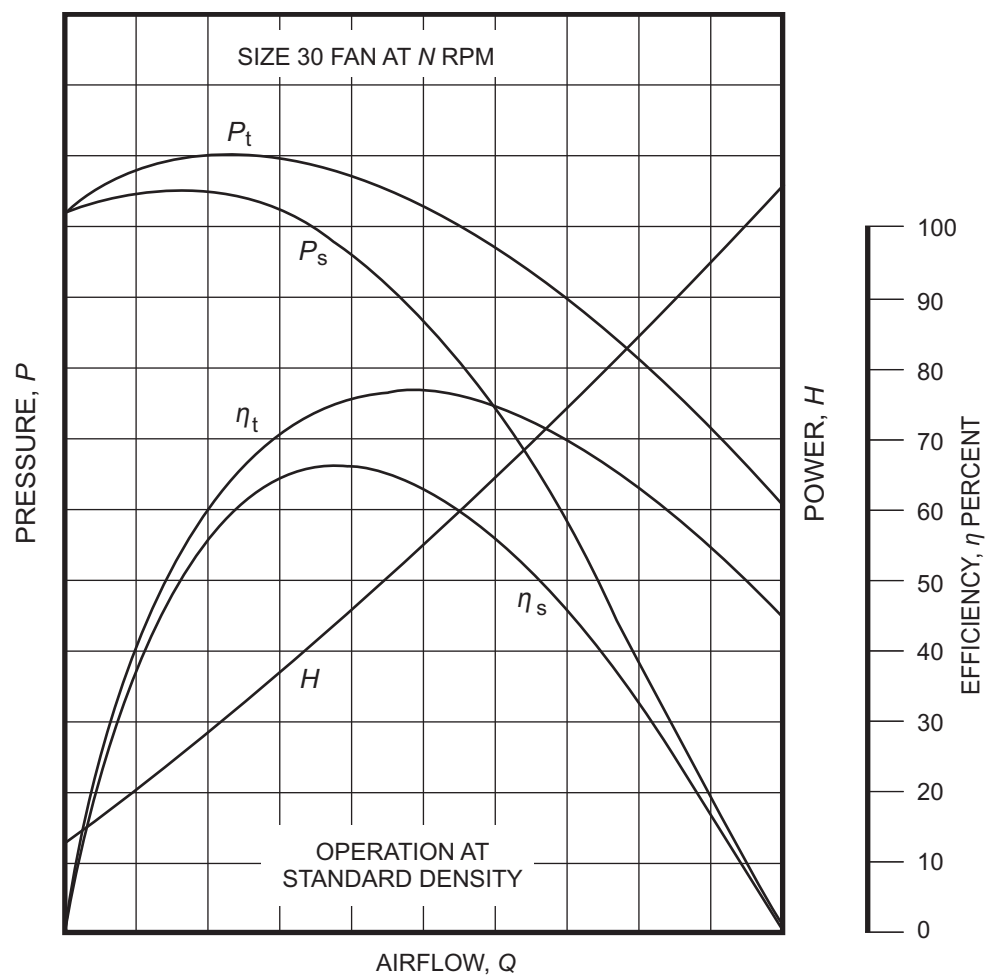


Figure 4.1 - Fan Performance Curve at N RPM

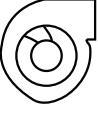
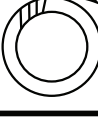
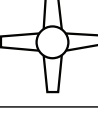
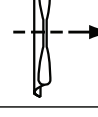
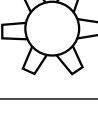
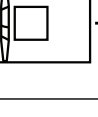
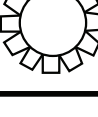
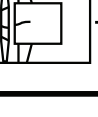
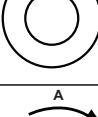
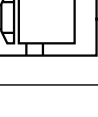
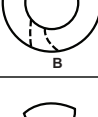
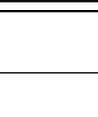
	TYPE	IMPELLER DESIGN		HOUSING DESIGN	
CENTRIFUGAL FANS	AIRFOIL		• Highest efficiency of all centrifugal fan designs. • Ten to 16 blades of airfoil contour curved away from direction of rotation. Deep blades allow for efficient expansion within blade passages • Air leaves impeller at velocity less than tip speed. • For given duty, has highest speed of centrifugal fan designs		• Scroll-type design for efficient conversion of velocity pressure to static pressure. • Maximum efficiency requires close clearance and alignment between wheel and inlet
	BACKWARD-INCLINED BACKWARD-CURVED		• Efficiency only slightly less than airfoil fan. • Ten to 16 single-thickness blades curved or inclined away from direction of rotation • Efficient for same reasons as airfoil fan.		• Uses same housing configuration as airfoil design.
	RADIAL		• Higher pressure characteristics than airfoil, backward-curved, and backward-inclined fans. • Curve may have a break to left of peak pressure and fan should not be operated in this area. • Power rises continually to free delivery.		• Scroll. Usually narrowest of all centrifugal designs. • Because wheel design is less efficient, housing dimensions are not as critical as for airfoil and backward-inclined fans.
	FORWARD-CURVED		• Flatter pressure curve and lower efficiency than the airfoil, backward-curved, and backward-inclined. • Do not rate fan in the pressure curve dip to the left of peak pressure. • Power rises continually toward free delivery. Motor selection must take this into account.		• Scroll similar to and often identical to other centrifugal fan designs. • Fit between wheel and inlet not as critical as for airfoil and backward-inclined fans.
AXIAL FANS	PROPELLER		• Low efficiency. • Limited to low-pressure applications. • Usually low cost impellers have two or more blades of single thickness attached to relatively small hub. • Primary energy transfer by velocity pressure.		• Simple circular ring, orifice plate, or venturi. • Optimum design is close to blade tips and forms smooth airfoil into wheel.
	TUBEAXIAL		• Somewhat more efficient and capable of developing more useful static pressure than propeller fan. • Usually has 4 to 8 blades with airfoil or single-thickness cross section. • Hub usually less than transfer by velocity pressure.		• Cylindrical tube with close clearance to blade tips.
	VANEAXIAL		• Good blade design gives medium- to high-pressure capability at good efficiency. • Most efficient of these fans have airfoil blades. • Blades may have fixed, adjustable, or controllable pitch. • Hub is usually greater than half fan tip diameter.		• Cylindrical tube with close clearance to blade tips. • Guide vanes upstream or downstream from impeller increase pressure capability and efficiency.
SPECIAL DESIGNS	TUBULAR CENTRIFUGAL		• Performance similar to backward-curved fan except capacity and pressure are lower. • Lower efficiency than backward-curved fan. • Performance curve may have a dip to the left of peak pressure.		• Cylindrical tube similar to vaneaxial fan, except clearance to wheel is not as close. • Air discharges radially from wheel and turns 90° to flow through guide vanes.
	CENTRIFUGAL		• Low-pressure exhaust systems such as general factory, kitchen, warehouse, and some commercial installations. • Provides positive exhaust ventilation, which is an advantage over gravity-type exhaust units. • Centrifugal units are slightly quieter than axial units.		• Normal housing not used, since air discharges from impeller in full circle. • Usually does not include configuration to recover velocity pressure component.
	AXIAL		• Low-pressure exhaust systems such as general factory, kitchen, warehouse, and some commercial installations. • Provides positive exhaust ventilation, which is an advantage over gravity-type exhaust units.		• Essentially a propeller fan mounted in a supporting structure • Hood protects fan from weather and acts as safety guard. • Air discharges from annular space at bottom of weather hood.

Figure 4.2 - Types of Fans
Adapted with permission from 1996 ASHRAE Systems and Equipment Handbook (SI)

PERFORMANCE CURVES ^a	PERFORMANCE CHARACTERISTICS	APPLICATIONS
	- Highest efficiencies occur at 50 to 60% of wide open volume. This volume also has good pressure characteristics. - Power reaches maximum near peak efficiency and becomes lower, or self-limiting, toward free delivery.	- General heating, ventilating, and air-conditioning applications. - Usually only applied to large systems, which may be low-, medium-, or high-pressure applications. - Applied to large, clean-air industrial operations for significant energy savings.
	Similar to airfoil fan, except peak efficiency slightly lower.	- Same heating, ventilating, and air-conditioning applications as airfoil fan. - Used in some industrial applications where airfoil blade may corrode or erode due to environment.
	- Higher pressure characteristics than airfoil and backward-curved fans. - Pressure may drop suddenly at left of peak pressure, but this usually causes no problems. - Power rises continually to free delivery.	- Primarily for materials handling in industrial plants. Also for some high-pressure industrial requirements. - Rugged wheel is simple to repair in the field. Wheel sometimes coated with special material. - Not common for HVAC applications.
	- Pressure curve less steep than that of backward-curved fans. Curve dips to left of peak pressure. - Highest efficiency to right of peak pressure at 40 to 50% of wide open volume. - Rate fan to right of peak pressure. - Account for power curve, which rises continually toward free delivery, when selecting motor.	Primarily for low-pressure HVAC applications, such as residential furnaces, central station units, and packaged air conditioners.
	- High flow rate, but very low-pressure capabilities. - Maximum efficiency reached near free delivery. - Discharge pattern circular and airstream swirls.	- For low-pressure, high-volume air moving applications, such as air circulation in a space or ventilation through a wall without ductwork. - Used for makeup air applications.
	- High flow rate, medium-pressure capabilities. - Performance curve dips to left of peak pressure. Avoid operating fan in this region. - Discharge pattern circular and airstream rotates or swirls.	- Low- and medium-pressure ducted HVAC applications where air distribution downstream is not critical. - Used in some industrial applications, such as drying ovens, paint spray booths, and fume exhausts.
	- High-pressure characteristics with medium-volume flow capabilities. - Performance curve dips to left of peak pressure due to aerodynamic stall. Avoid operating fan in this region. - Guide vanes correct circular motion imparted by wheel and improve pressure characteristics and efficiency of fan.	- General HVAC systems in low-, medium-, and high-pressure applications where straight-through flow and compact installation are required. - Has good downstream air distribution - Used in industrial applications in place of tubeaxial fans. - More compact than centrifugal fans for same duty.
	- Performance similar to backward-curved fan, except capacity and pressure is lower. - Lower efficiency than backward-curved fan because air turns 90°. - Performance curve of some designs is similar to axial flow fan and dips to left of peak pressure.	- Primarily for low-pressure, return air systems in HVAC applications. - Has straight-through flow.
	- Usually operated without ductwork; therefore, operates at very low pressure and high volume. - Only static pressure and static efficiency are shown for this fan.	- Low-pressure exhaust systems, such as general factory, kitchen, warehouse, and some commercial installations. - Low first cost and low operating cost give an advantage over gravity flow exhaust systems. - Centrifugal units are somewhat quieter than axial flow units.
	- Usually operated without ductwork; therefore, operates at very low pressure and high volume. - Only static pressure and static efficiency are shown for this fan.	- Low-pressure exhaust systems, such as general factory, kitchen, warehouse, and some commercial installations. - Low first cost and low operating cost give an advantage over gravity flow exhaust systems.

a: These performance curves reflect general characteristics of various fans as commonly applied. They are not intended to provide complete selection criteria, since other parameters, such as diameter and speed, are not defined.

Figure 4.2 - Types of Fans
Adapted with permission from 1996 ASHRAE Systems and Equipment Handbook (SI)

5. Catalog Performance Tables

5.1 Type A: Free inlet, free outlet fans

Fans designed for use other than with 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.

Typical fans in this group are propeller fans and power roof ventilators. They are usually available in direct or belt-drive arrangements and performance ratings are published in a modified form of the multi-rating table. Figure 5.1 illustrates such a table for part of a line of belt-drive propeller fans.

5.2 Ducted fans

There are three types of ducted fans, as described in Section 3:

- 1) Type B: Free inlet, ducted outlet
- 2) Type C: Ducted inlet, free outlet
- 3) Type D: Ducted inlet, ducted outlet

The performance of fans intended for use with duct systems is usually published in the form of a "multi-rating" table. A typical multi-rating table, as illustrated in Figure 5.2 shows:

- a) the speed (N) in rpm
- b) the power (H) in kw (hp)
- c) the fan static pressure (P_s) in Pa (in. wg)
- d) the outlet velocity (V) in m/s, (fpm)
- e) the airflow (Q) in m³/s (cfm)

Figure 5.3 shows constant speed characteristic curves superimposed on a section of the multi-rating table for the same fan. A brief study of this figure will assist in understanding the relationship between curves and the multi-rating tables.

SIZE (cm)	No. of Blades	Motor kW	rpm	Peak kW	AIRFLOW (m ³ /s) @ STATIC PRESSURE (Pa)								
					0	31	62	93	124	155	186	217	248
61	3	0.19	862	0.13	2.02	1.58	0.58						
		0.19	960	0.20	2.25	1.87	0.97						
		0.25	1071	0.27	2.51	2.18	1.76	0.76					
		0.37	1220	0.40	2.86	2.57	2.24	1.70	0.81				
69	3	0.19	806	0.20	2.89	2.36	1.05						
		0.25	883	0.27	3.17	2.68	1.94	0.76					
		0.37	1035	0.43	3.71	3.30	2.85	1.56	0.95				
		0.56	1165	0.62	4.18	3.83	3.44	3.01	1.60	1.10			
84	3	0.37	825	0.42	4.36	3.76	3.04	1.27					
		0.56	945	0.62	4.99	4.48	3.92	2.38	1.42				
		0.75	1045	0.82	5.23	5.08	4.57	4.01	2.31	1.52			
		1.12	1190	1.19	6.29	5.90	5.47	5.01	4.48	2.79	1.94		
		1.49	1306	1.64	6.91	6.53	6.15	5.75	5.32	4.81	3.05	2.24	1.84

TYPICAL RATING TABLE FOR A SERIES OF BELT-DRIVEN PROPELLER FANS

SIZE (in.)	No. of Blades	Motor hp	rpm	Peak bhp	AIRFLOW (ft ³ /min) @ STATIC PRESSURE (in. wg)								
					0	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1
24	3	1/4	862	0.18	4,283	3,350	1,230						
		1/4	960	0.27	4,770	3,960	2,050						
		1/3	1071	0.36	5,321	4,620	3,730	1,600					
		1/2	1220	0.54	6,062	5,450	4,750	3,600	1,710				
27	3	1/4	806	0.27	6,123	4,990	2,230						
		1/3	883	0.36	6,708	5,675	4,100	1,620					
		1/2	1035	0.57	7,862	7,000	6,035	3,315	2,020				
		3/4	1165	0.83	8,850	8,110	7,290	6,385	3,400	2,330			
33	3	1/2	825	0.56	9,240	7,970	6,430	2,700					
		3/4	945	0.83	10,580	9,500	8,300	5,040	3,010				
		1	1045	1.1	11,710	10,755	9,685	8,490	4,890	3,215			
		1½	1190	1.6	13,335	12,490	11,580	10,610	9,500	5,905	4,100		
		2	1306	2.2	14,630	13,845	13,030	12,185	11,280	10,200	6,470	4,740	3,900

TYPICAL RATING TABLE FOR A SERIES OF BELT-DRIVEN PROPELLER FANS

Figure 5.1 - Propeller Fan Performance Table

IMPELLER DIAMETER: 927 mm OUTLET AREA: .71 SQ METERS
 TIP SPEED IN m/s: .0485 × RPM MAXIMUM kW: 13.65 × (RPM/1000)³

Volume m ³ /s	Outlet Vel. (m/s)	62 Pa		93 Pa		124 Pa		155 Pa		186 Pa		217 Pa		246 Pa		310 Pa		373 Pa	
		rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW
1.81	2.55	222	0.14																
2.17	3.06	236	0.17	270	0.25														
2.53	3.56	253	0.22	284	0.30	313	0.39												
2.89	4.07	272	0.27	300	0.36	327	0.45	352	0.55										
3.25	4.58	292	0.34	317	0.43	343	0.53	366	0.64	389	0.75	411	0.87						
3.61	5.08	314	0.42	337	0.52	360	0.63	382	0.74	403	0.86	424	0.98	443	1.10				
3.97	5.59	338	0.51	358	0.62	378	0.73	399	0.85	419	0.98	438	1.10	458	1.19	494	1.52		
4.33	6.10	361	0.62	379	0.74	398	0.86	417	0.98	436	1.11	455	1.25	472	1.39	507	1.68	540	1.99
4.69	6.61	385	0.74	402	0.87	419	1.00	437	1.13	454	1.26	472	1.41	489	1.56	522	1.86	554	2.18
5.06	7.13	409	0.88	426	1.01	441	1.16	457	1.30	473	1.44	489	1.58	506	1.74	538	2.06	568	2.39
5.42	7.63	434	1.03	449	1.18	464	1.33	479	1.49	494	1.63	509	1.79	524	1.95	555	2.28	584	2.62
5.78	8.14	458	1.21	473	1.37	488	1.53	501	1.69	515	1.86	529	2.01	543	2.18	572	2.53	600	2.89
6.14	8.65	483	1.41	498	1.58	511	1.75	525	1.92	537	2.09	550	2.26	564	2.43	590	2.78	617	3.16
6.50	9.15	508	1.63	522	1.81	535	1.99	538	2.16	560	2.35	572	2.54	585	2.71	610	3.07	635	3.45
6.86	9.66			547	2.06	559	2.25	571	2.44	584	2.62	595	2.82	606	3.01	630	3.39	654	3.78
7.22	10.17			571	2.34	585	2.54	595	2.74	607	2.93	616	3.14	629	3.34	651	3.74	674	4.15
7.94	11.18			621	2.99	633	3.20	644	3.41	654	3.63	665	3.85	675	4.07	695	4.52	715	4.96
8.67	12.21					682	3.98	693	4.20	703	4.44	712	4.68	721	4.93	741	5.40	759	5.89
9.39	13.23							742	5.13	752	5.38	761	5.64	769	5.90	788	6.41	805	6.94
10.11	14.24							791	6.20	801	6.47	810	6.73	818	7.01	834	7.57	852	8.11
10.83	15.25									850	7.70	859	7.99	867	8.27	883	8.87	898	9.47
11.55	16.27											908	9.40	916	9.70	932	10.32	946	10.96
12.28	17.30													965	11.30	981	11.95	995	12.62
13.00	18.31													1015	13.06	1030	13.77	1044	14.46
13.72	19.32															1072	15.78	1093	16.50
14.44	20.34															1129	17.98	1142	18.76

TYPICAL MULTISPEED RATING TABLE FOR A SINGLE WIDTH, SINGLE INLET CENTRIFUGAL FAN

IMPELLER DIAMETER: 36.5 IN OUTLET AREA: 7.65 SQ FT
 TIP SPEED IN FPM: 9.56 × RPM MAXIMUM BHP: 18.3 × (RPM/1000)³

Volume CFM	Outlet Vel. (fpm)	1/4 in. wg		3/8 in. wg		1/2 in. wg		5/8 in. wg		3/4 in. wg		7/8 in. wg		1 in. wg		1-1/4 in. wg		1-1/2 in. wg	
		rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp
3825	500	222	0.185																
4590	600	236	0.233	270	0.334														
5355	700	253	0.292	284	0.400	313	0.519												
6120	800	272	0.365	300	0.483	327	0.608	352	0.743										
6885	900	292	0.450	317	0.579	343	0.716	366	0.856	389	1.01	411	1.17						
7650	1000	314	0.560	337	0.695	360	0.840	383	0.992	403	1.15	424	1.31	443	1.48				
8415	1100	338	0.682	358	0.832	378	0.981	399	1.144	419	1.31	438	1.48	458	1.60	494	2.04		
9180	1200	361	0.826	379	0.988	398	1.149	417	1.314	436	1.49	455	1.68	472	1.86	507	2.25	540	2.67
9945	1300	385	0.989	402	1.163	419	1.340	437	1.514	454	1.69	472	1.89	489	2.09	522	2.49	554	2.92
10710	1400	409	1.175	425	1.360	441	1.553	457	1.741	473	1.93	489	2.12	506	2.34	538	2.76	568	3.20
11475	1500	434	1.387	449	1.587	464	1.780	479	1.993	494	2.19	509	2.40	524	2.61	555	3.06	584	3.52
12240	1600	458	1.626	473	1.837	488	2.048	501	2.269	515	2.49	529	2.70	543	2.92	572	3.39	600	3.87
13005	1700	483	1.895	498	2.115	511	2.346	525	2.570	537	2.80	550	3.03	564	3.26	590	3.73	617	4.24
13770	1800	508	2.191	522	2.424	535	2.665	538	2.901	560	3.15	572	3.40	585	3.64	610	4.12	635	4.63
14535	1900			547	2.767	559	3.017	571	3.275	584	3.52	595	3.78	606	4.04	630	4.55	654	5.07
15300	2000			571	3.144	585	3.403	595	3.672	607	3.93	618	4.21	629	4.48	651	5.02	674	5.56
16830	2200			621	4.003	633	4.289	644	4.577	654	4.87	665	5.16	675	5.46	695	6.06	715	6.65
18360	2400					682	5.335	693	5.632	703	5.96	712	6.28	721	6.61	741	7.24	759	7.90
19890	2600							742	6.885	752	7.22	761	7.56	769	7.91	788	8.60	805	9.30
21420	2800							791	8.308	801	8.67	810	9.03	818	9.40	834	10.15	852	10.88
22950	3000									850	10.32	859	10.71	867	11.09	883	11.89	898	12.70
24480	3200											908	12.50	916	13.01	932	13.84	946	14.70
26010	3400													965	15.16	981	16.03	995	16.92
27540	3600													1015	17.52	1030	18.47	1044	19.39
29070	3800															1072	21.16	1093	22.13
30600	4000															1129	24.11	1142	25.16

TYPICAL MULTISPEED RATING TABLE FOR A SINGLE WIDTH, SINGLE INLET CENTRIFUGAL FAN

Figure 5.2 - Centrifugal Fan Performance Tables

PRESSURE IN IN. WG
BRAKE HORSEPOWER

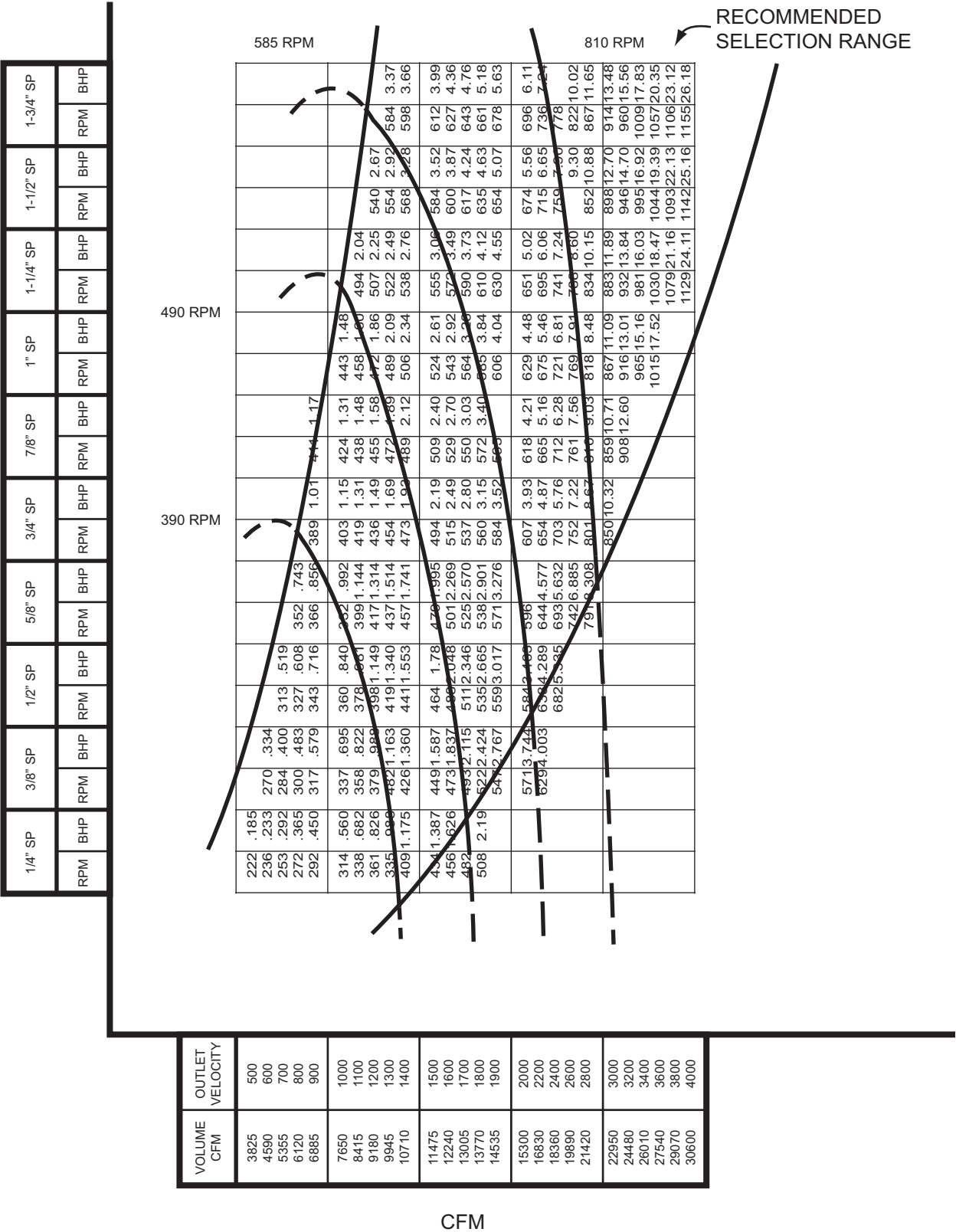


Figure 5.3 - Typical Fan Performance Table Showing Relationship to a Family of Constant Speed Performance Curves

Most performance tables do not cover the complete range from no delivery to free delivery but cover only the typical operating range. Figure 5.4 illustrates the recommended performance range of a centrifugal fan. Comparison of Figure 5.4 with Figure 5.3 will show that the published performance table also covers only the recommended performance range of the fan.

It should be remembered that fans are generally tested without obstructions in the inlet and outlet and without any optional airstream accessories in place. Catalog ratings will, therefore, usually apply only to the bare fan with unobstructed inlet and outlet.

Fan performance adjustment factors for airstream accessories are normally available from either the fan catalog or the fan manufacturer.

Fans are usually tested in arrangement 1, or similar (see Figure 3.5). Rating tables will, therefore, also apply only to the tested arrangement. Allowances for the effect of bearing supports used in other arrangements should be obtained from the manufacturer if not shown in the catalog.

6. Air Systems

6.1 The system

An air system may consist simply of a fan with ducting connected to either the inlet or outlet or to both. A more complicated system may include a fan, ductwork, air control dampers, cooling coils, heating coils, filters, diffusers, sound attenuation, turning vanes, etc. See AMCA Publication 200 *Air Systems*, for more information.

6.2 Component losses

Every system has a combined resistance to airflow that is usually different from every other system and is dependent upon the individual components in the system.

The determination of the "pressure loss" or "resistance to airflow," for the individual components can be obtained from the component manufacturers. The determination of pressure losses for ductwork design is well documented in standard handbooks such as the ASHRAE *Handbook of Fundamentals*.

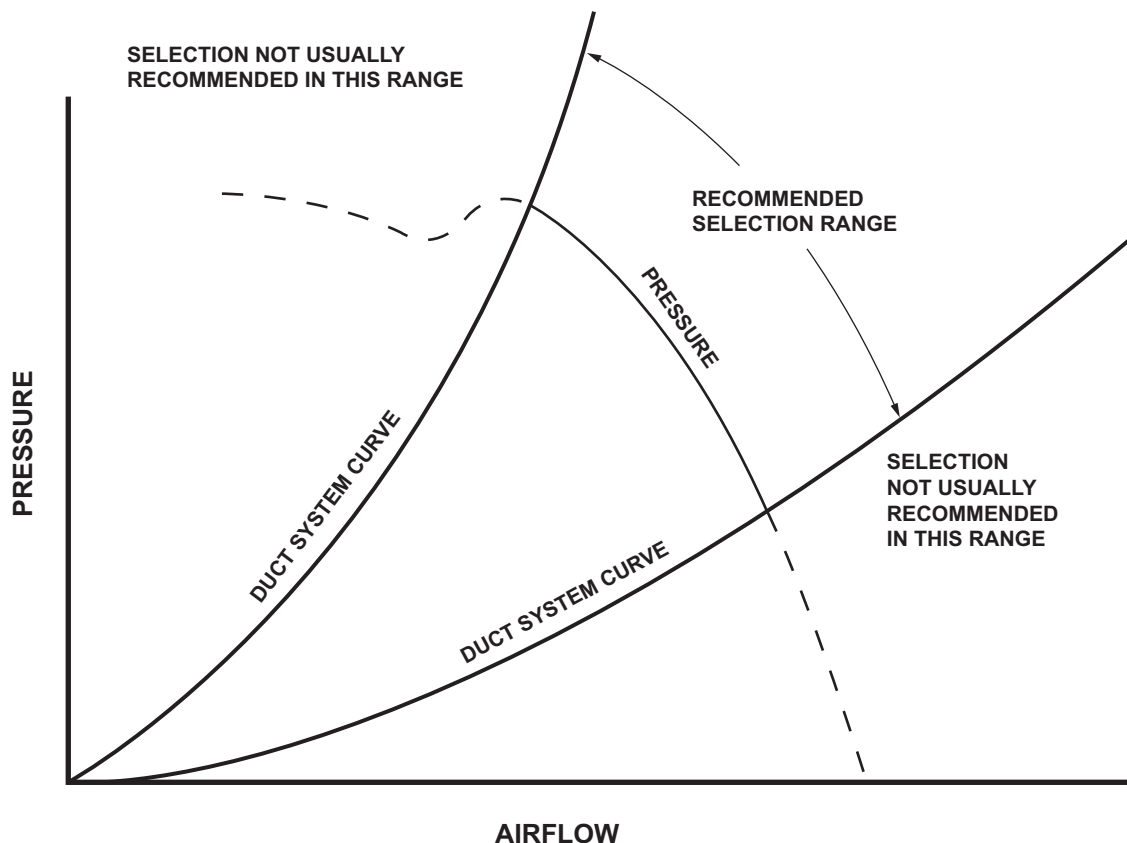


Figure 5.4 - Recommended Performance Range of a Typical Centrifugal Fan