PRODUCT APPLICATION

A technical bulletin for engineers, contractors and students in the air movement and control industry

The basics of fan performance tables, fan curves, system resistance curves, and fan laws

Knowledge of fan performance tables, fan curves, system resistance curves, and fan laws is vital for fan selection. Many fan and HVAC product manufacturers offer computerized selection software as well as printed performance tables and curves. A user of product selection software must understand the selection data (output) that is generated by the program and can confirm that the data makes engineering sense. The information presented in this application article provides "fan engineering" to assist with understanding a selection program's output.

Fan performance tables

Manufacturers create fan selection programs that generate specific selections or publish catalogs containing performance or rating tables for each specific fan size. Tables, however, are printed in a compact format, showing only the minimum information necessary to select a fan to match a desired performance. Performance tables are very easy to use for making an initial selection, and in most cases, only include stable operating points.

Rating tables are published in one of two basic formats arranged with pressure columns and rows of either RPM (Revolutions per Minute) or CFM (Cubic Feet per Minute). Adjacent to the table, qualifying statements describe how the fan was tested and what losses are included in the performance rating. In many cases, these tables also show sound ratings in either sones or LwA (Sound Power Level, A weighted).

Using the performance tables

The following is a portion of a typical performance table as published for low to medium pressure fans. This table is common to most centrifugal and axial fans used for roof mounting, wall mounting, and inline applications. This table is for a roof-mounted, spun aluminum upblast exhaust fan (model CUE).

To use the table, find the required static pressure on the upper horizontal axis (example 0.375 inches wg) then read down the static pressure column and find the required CFM (example 16532 cfm). Directly below the CFM is the required BHP for that performance (example 2.89). Also shown in this example is the sound rating for the selected performance (14.7 sones). Reading to the left of the selected CFM, you will find the fan RPM, the motor size, and the model identifier.

Model Size

Motor HP		Fan RPM		Static Pressure in Inches wg: 0	0.125	0.25	0.375	0.5	0.75	1	1.25	1.5	1.75
420													
1/2	VG-1	220	CFM	9353	7846	5075							
			BHP	0.31	0.37	0.35							
			Sones	6.5	6.0	5.5							
		245	CFM	10416	9104	7304							
			BHP	0.43	0.50	0.53							
			Sones	7.2	6.7	6.1							
3/4		280	CFM	11904	10785	9418	7419						
			BHP	0.64	0.73	0.78	0.77						
			Sones	8.3	7.7	7.1	6.6						
1		305	CFM	12966	11959	10781	9272						
			BHP	0.82	0.94	1.00	1.02						
			Sones	9.4	8.8	8.0	7.3						
1½	VG-2	350	CFM	14879	14037	13050	11925	10562					
			BHP	1.24	1.38	1.46	1.52	1.54					
			Sones	11.9	11.2	10.1	9.4	8.6					
2		385	CFM	16367	15629	14731	13791	12701	9246				
			BHP	1.65	1.81	1.91	1.99	2.05	1.92				
			Sones	14.4	13.5	12.4	11.7	10.7	8.5				
3	VG-3	415	CFM	17643	16982	16148	15303	14363	12028				
			BHP	2.07	2.24	2.37	2.45	2.53	2.56				
			Sones	17.2	16.1	14.9	13.8	13.0	10.9				
		440	CFM	18706	18103	17316	16532	15691	13652	10151			
			BHP	2.47	2.65	2.81	2.89	2.98	3.07	2.82			
			Sones	17.7	17.1	16.0	14.7	14.6	12.8	10.6			

MAXIMUM BHP AT A GIVEN RPM = $(RPM/303)^3$
MAXIMUM RPM = 600
TIP SPEED (ft/min) = RPM x 11.06
MAXIMUM MOTOR FRAME SIZE = 213T
AVERAGE DISCHARGE VELOCITY (FPM) = CFM/8.99

Motor HP required — *RPM Required* — *Sones at selected performance* — *BHP at selected performance* — *CFM selected*

Performance certified is for installation type A: Free inlet, Free outlet. Power rating (Bhp) does not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories). The sound ratings shown are loudness values in fan sones at 5 ft. (1.5 m) in a hemispherical free field calculated per AMCA Standard 301. Values shown are for installation type A: Free inlet hemispherical sone levels.

The following performance table is typical for higher-pressure fans, such as housed centrifugal fans. There are individual tables for each fan size and wheel type. In most cases, these tables will have shaded areas (not illustrated here) representing Class I, II, and III RPM limits. To use this table, find the required CFM along the left vertical axis (example 14,000 cfm), then move horizontally to the right to the required static pressure column (example 6.00 inches wg).

At this intersection, you can read both the fan RPM and the BHP (example 1091 rpm and 19.06 bhp).

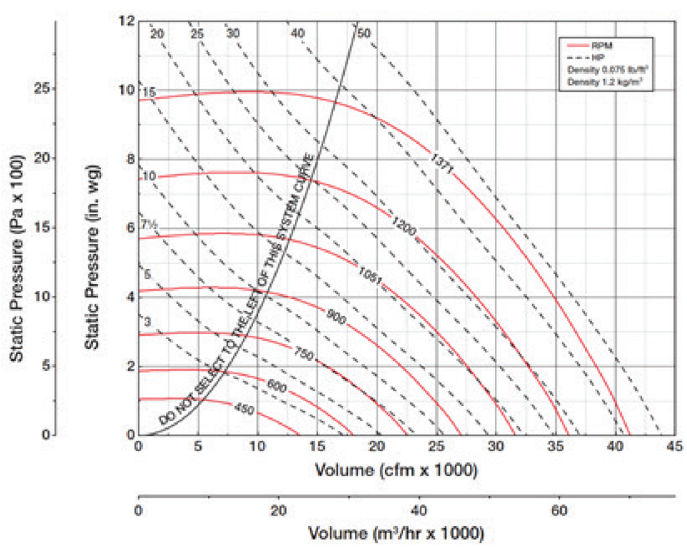
Model USF-36-BI — *Model size*

CFM	OV		Static									
			.5	1	2	3	4	5	6	7	8	9
800	1044	RPM	377	472	629							
		BHP	0.96	1.75	3.64							
		LwiA / LwoA	67 / 72	71 / 75	80 / 81							
11000	1436	RPM	449	527	662	780	888					
		BHP	1.63	2.61	4.8	7.28	10.1					
		LwiA / LwoA	72 / 76	75 / 78	83 / 83	84 / 86	88 / 89					
14000	1828	RPM	532	596	713	819	915	1006	1091			
		BHP	2.63	3.82	6.39	9.18	12.2	15.5	19.06			
		LwiA / LwoA	78 / 81	80 / 82	83 / 85	85 / 89	87 / 90	90 / 92	93 / 94			
17000	2219	RPM	620	674	776	871	957	1042	1119	1193	1267	1336
		BHP	4.07	5.44	8.44	11.6	14.93	18.52	22.23	26.18	30.43	34.8
		LwiA / LwoA	83 / 86	84 / 86	86 / 89	87 / 91	89 / 92	91 / 94	93 / 95	95 / 97	98 / 98	100 / 100
20000	2611	RPM	711	758	848	933	1012	1087	1161	1231	1297	1359
		BHP	6.07	7.6	10.98	14.59	18.32	22.17	26.24	30.49	34.85	39.3
		LwiA / LwoA	68 / 90	88 / 91	89 / 92	90 / 93	91 / 94	92 / 96	94 / 97	95 / 99	97 / 100	98 / 101

Required CFM — *Outlet Velocity @ CFM* — *RPM required* — *Inlet & Outlet A weighted sound power levels* — *BHP @ performance*

The ratings shown are based on tests and procedures performed in accordance with AMCA Publication 211 and AMCA Publication 311 and comply with the requirements of the AMCA Certified Ratings Program. Performance certification is for installation type B: Free Inlet, Ducted outlet. Performance ratings do not include the effects of appurtenances (accessories). Power ratings (BHP/kW) do not include transmission losses. The sound power level ratings shown are in decibels, referred to 10^{-12} watts calculated per AMCA Standard 301. The A-weighted sound ratings shown have been calculated per AMCA International Standard 301. Values shown are for inlet, LwiA, and outlet, LwoA sound power levels for installation type B: Free inlet Ducted outlet. Outlet ratings include the effects of duct end correction.

It's also common to see fan performance curves (a family of RPM curves) covering the full range of performance printed on the same or adjacent page to the performance table. This format provides a quick snapshot of the total capabilities of one given fan model and size. Locate the desired flow along the x-axis and the specified pressure on the left y-axis. At the point of intersection, you can determine the approximate Fan RPM required. To find the motor size required, move upward to the closest HP line (dotted line). You can quickly review charts for several different fan sizes to determine the most desirable selection.



Fan Curves

One of the most valuable pieces of information supplied by fan manufacturers is the fan performance curve. Curves are normally supplied for each specific fan on a given project. These curves show the relationship between the quantity of air a fan will deliver, and the pressure generated at various air quantities. The curves also show horsepower for a given quantity of flow.

Figure 1 represents the performance for a given fan size and RPM. The flow scale is presented along the x-axis. The pressure scale is presented along the left y-axis. Find the required CFM and move vertically to the SP curve. Read horizontally to the left to read the pressure at that flow.

Figure 2 illustrates the effects of speed change. According to the fan laws, CFM varies directly with RPM. The result of reducing the speed is a similar curve in a lower position. Increasing speed results in a similar curve in a higher position.

Figure 3 illustrates the addition of the BHP curve. The power scale is presented along the right y-axis. Find the volume on the SP curve and move vertically to the BHP curve. At this intersection, move horizontally to the right-hand scale to read the BHP at that flow.

The curve shapes in figures 1-3 are typical of centrifugal wheels. Other impeller types have both fan and power curve shapes that vary from those shown. However, the principle of reading the curves is the same.

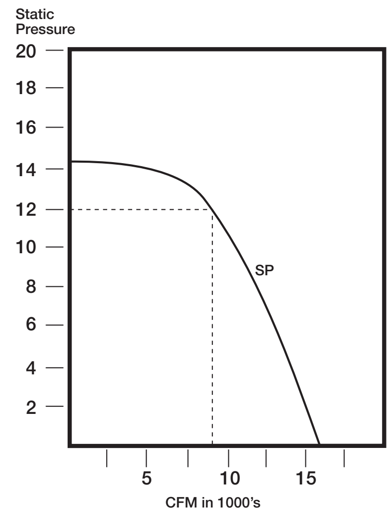


figure 1

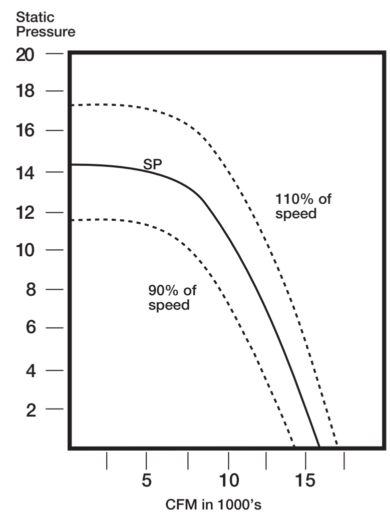


figure 2

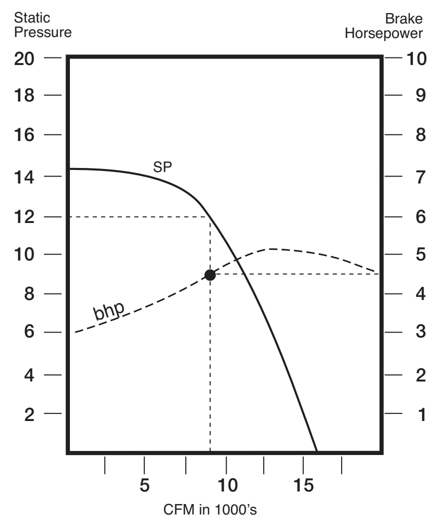


figure 3

System Resistance Curves

System resistance curves are a graphical representation of how a system reacts to a given airflow. The system resistance is the sum of all pressure losses through the duct, all elbows, filters, dampers, coils, and any other device that resists flow.

Figure 4 shows that the system curve always starts at the origin where flow and pressure are zero. The fan will operate at the point where the system resistance curve intersects the fan curve. For a constant system, with no change in damper settings, etc. the pressure at a given flow varies as the square of the airflow. The only time the shape of the system resistance curve changes is when the system physically changes. For instance, if a damper is opened, the system resistance is reduced. The result is a lower pressure drop. Closing a damper, or when filters become dirty, increases the system's resistance.

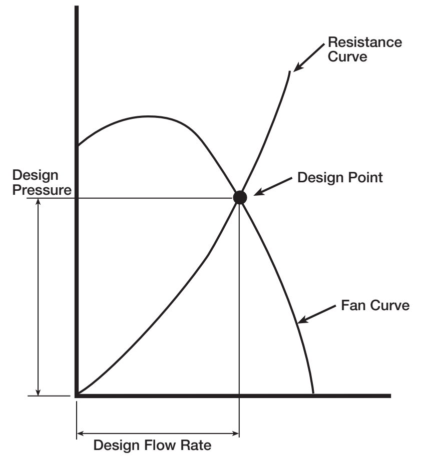


figure 4

Figure 5 illustrates how the system resistance curve changes with a decrease or an increase in resistance. The new curve shows that as the system's resistance changes, so does the air volume the system pressure at a constant fan RPM.

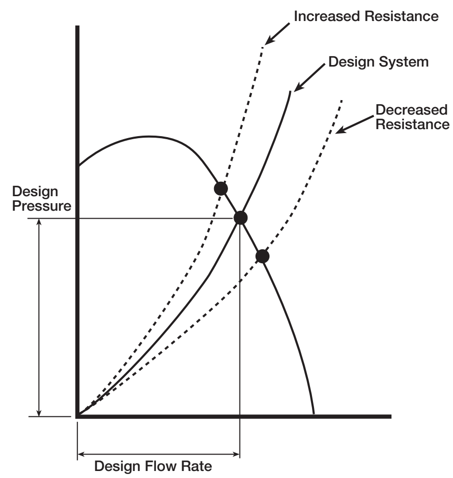


figure 5

Figure 6 is a sample print-out from Greenheck's CAPS® program for a specific fan selection. This illustrates the fan curve, the BHP curve, the system design curve, plus a fan surge curve. Fan selection close to, or to the left of the surge curve, is not recommended. Referring to this surge curve aids the designer in selecting fans that are stable and will not go into surge with a minor change to the system. We have learned that a fan curve is the series of points at which a given fan model and size can operate at a constant RPM. The system resistance curve is the series of points at which the system can operate. The operating point is where these two curves intersect. Any changes to the fan RPM will cause the point of operation to move along the system curve and changes to the system resistance will cause the point of operation to move up or down the fan curve.

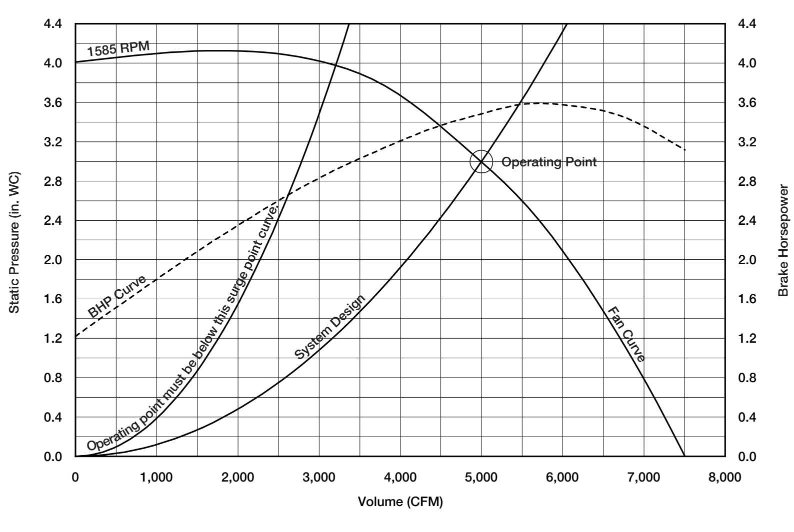


figure 6

Fan Laws

Our next step is to understand fan laws. Fan laws can be used to accurately predict changes, assuming the fan diameter and air density are constant.

Fan law equations

$$CFM_2 = \left(\frac{RPM_2}{RPM_1}\right) \times CFM_1$$

$$SP_2 = \left(\frac{RPM_2}{RPM_1}\right)^2 \times SP_1$$

$$BHP_2 = \left(\frac{RPM_2}{RPM_1}\right)^3 \times BHP_1$$

Subscript 1: Describes the existing conditions
Subscript 2: Describes the new conditions

The following example is typical of how the fan laws are applied:

A fan installed in a fixed system is operating at:

- CFM = 10,000
- SP = 1.50 in. wg
- BHP = 5.00
- RPM = 1,000

What RPM is required to move 25% more air (12,500 cfm) through this system?

NOTE: You can view this example as either the installation now desires more air than planned, or the balancing report showed 25% less air than specified.

By rearranging the cfm fan law:

$$RPM_2 = \left(\frac{CFM_2}{CFM_1}\right) \times RPM_1$$

$$RPM_2 = \left(\frac{12{,}500}{10{,}000}\right)^2 \times 1{,}000 = 1250 \text{ RPM}$$

The corresponding static pressure is:

$$SP_2 = SP_1 \left(\frac{RPM_2}{RPM_1}\right)^2$$

$$SP_2 = 1.50 \left(\frac{1250}{1000}\right)^2 = 2.34 \text{ in. wg}$$

The resulting BHP is:

$$BHP_2 = BHP_1 \left(\frac{RPM_2}{RPM_1}\right)^3$$

$$BHP_2 = 5.00 \left(\frac{1250}{1000}\right)^3 = 9.77 \text{ BHP}$$

According to the fan laws, in order to use the original fan, the speed must be increased from 1000 rpm to 1250 rpm; the motor must be changed from a 5 hp to a 10 hp.

Figure 7 illustrates fan curves for both the original and new fan performance.

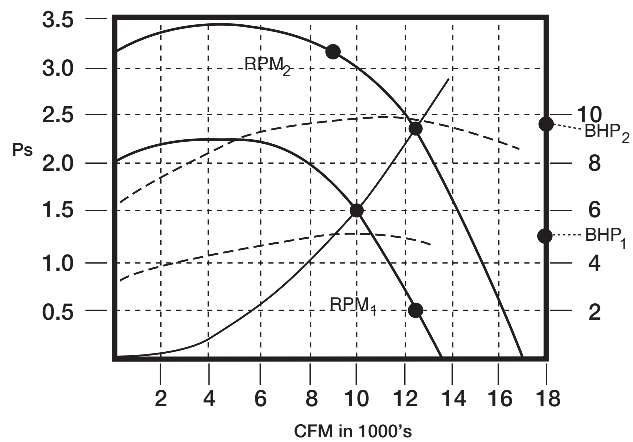


figure 7

Important: Check to make sure that the new RPM does not exceed the maximum allowable RPM for the existing fan. Maximum RPMs are shown in fan catalogs. You should consult the fan manufacturer for additional information or if you would like to review the application.

Verified Performance

Additionally, it is important for the user to understand that the data used within a product selection program has been verified by an independent third party in accordance with accepted industry standards. The organization that creates industry test standards for fans and certifies both aerodynamic and acoustic performance is the Air Movement and Control Association International, Inc. (AMCA). AMCA registers air test chambers to determine aerodynamic performance in accordance with AMCA Standard 210, “Laboratory Methods of Testing Fans for Aerodynamic Performance Rating." Acoustic (sound) performance is obtained by tests in an AMCA-registered sound facility to determine inlet and outlet sound power levels. Tests are conducted in strict accordance with AMCA Standard 300, “Reverberant Room Method for Sound Testing of Fans.” Another acoustic consideration for many fan applications is that of sound radiating from the fan’s casing. AMCA Standard 320, “Laboratory Method of Sound Testing Fans Using Sound Intensity”, allows a manufacturer to establish the sound power level of the sound radiating from a fan’s casing. The casing-radiated sound is particularly useful when fans are to be applied in buildings next to offices, conference rooms, or other sound-critical rooms.

AMCA Certified Ratings

A manufacturer that participates in AMCA’s Certified Ratings Program (CRP) assures the industry that the products and equipment will perform as stated by the manufacturer. The program stipulates the various rules and regulations for presenting cataloging data: AMCA 211 for aerodynamic performance and AMCA 311 for acoustic performance.

P.O. Box 410 • Schofield, WI 54476
Phone: 715.359.6171 • greenheck.com