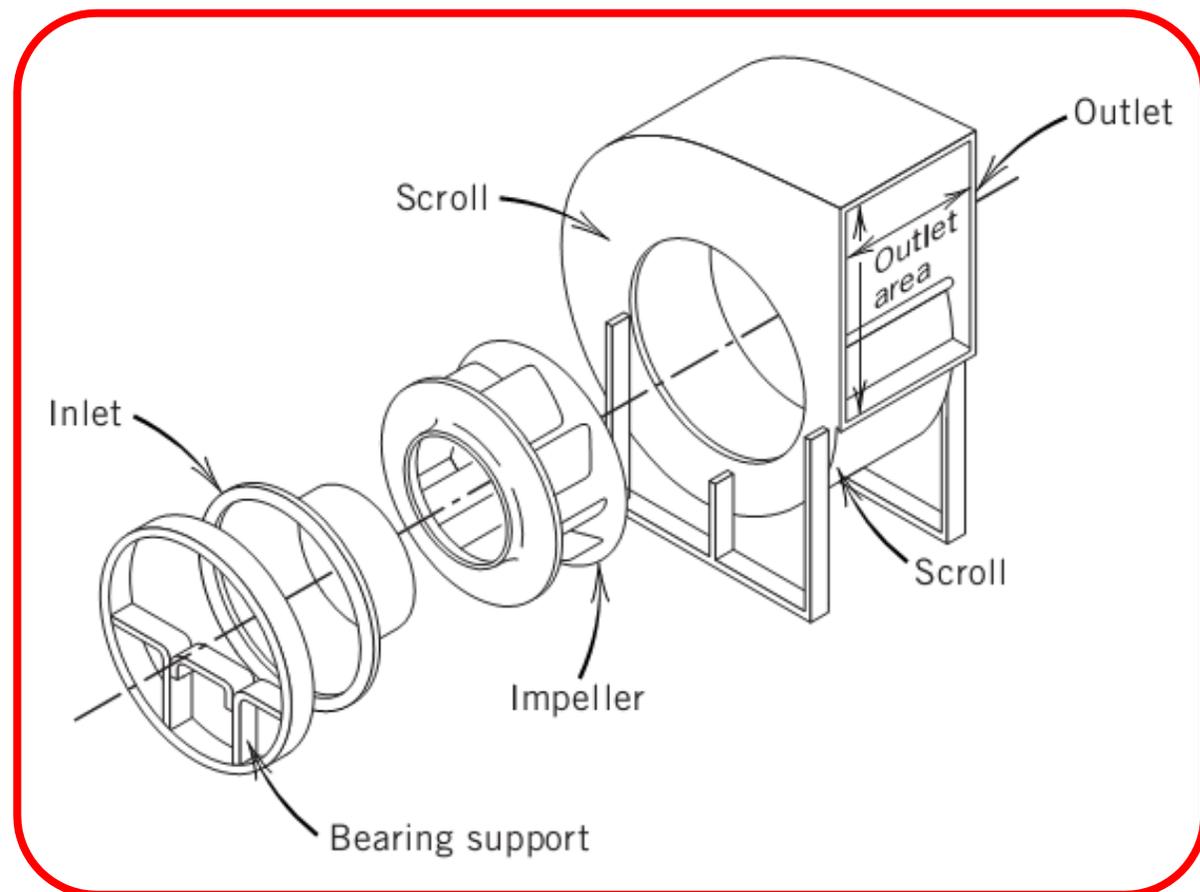


Fans and Building Air Distribution

- ❑ Last section considered the distribution and movement of the air within the conditioned space and described methods for location and selection of diffusers to deliver the proper amount of air with the required total pressure at acceptable noise level .
- ❑ This section discusses fan selection and the details of distributing the air optimally through ducts to each of the diffusers.
- ❑ Proper duct design and fan selection are important to avoid unnecessary inefficiencies, unacceptable indoor air quality and noise levels, and discomfort of the occupant in the various space.
- ❑ Correction of a poorly designed duct system is expensive and sometimes practically impossible.

FANS

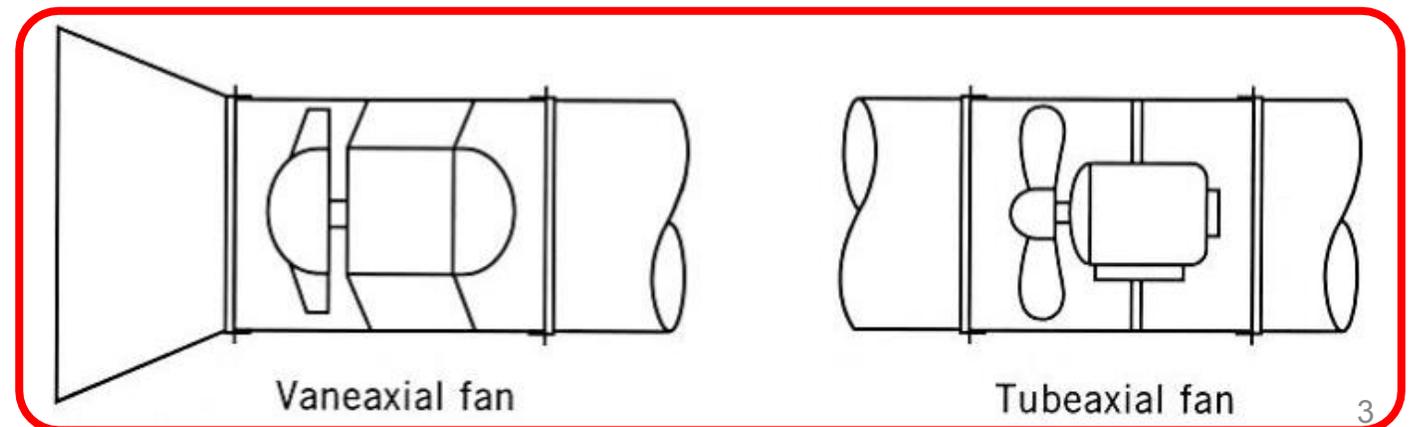
- ❑ The fan is an essential component of almost all HVAC systems.
- ❑ The fan is used to move air through ducts and to induce air motion in the space except in cases where free convection creates air motion.
- ❑ The centrifugal fan, shown, is the most widely used, because it can efficiently move large or small quantities of air over a wide range of pressures.
- ❑ The principle of operation is similar to the centrifugal pump in that a rotating impeller mounted inside a scroll-type housing impart energy to the air.
- ❑ The blade design influences the fan characteristics.



FANS

- ❑ The impeller blades may be forward-curved, backward-curved, or radial.
- ❑ The vane axial fan, shown below, is mounted on the center line of the duct and produce an axial flow of the air.
- ❑ Guide vanes are provided before and after the wheel to reduce rotation of the air stream.
- ❑ The tube axial fan is quite similar to the vane axial fan but do not have the guide vane as shown below
- ❑ Axial flow fan are not capable of producing pressure as high a those of the centrifugal fan, but they can move large quantities of air at low pressure.

- ❑ Axial flow fans generally produce higher noise level than centrifugal fans.



FAN RELATIONS

- ❑ The performance of fan is generally given in the form of a graph showing pressure, efficiency, and power as a function of capacity.
- ❑ The energy transferred to the air by the impeller results in an increase in static and velocity pressure; their sum give the total pressure.
- ❑ **The total power imparted to the air is given by:**

$$\dot{W}_t = \dot{m} \frac{(P_{01} - P_{02})}{\rho} \quad (24-1)$$

The *static power* is the part of the total power that is used to produce the change in static pressure:

$$\dot{W}_s = \frac{\dot{m}(P_1 - P_2)}{\rho} = \dot{Q}(P_1 - P_2) \quad (24-2)$$

- where \dot{Q} is the volume flow rate in cfm or m³/s

FAN RELATIONS

Fan efficiency may be expressed in two ways. The total fan efficiency is the ratio of total air power \dot{W}_t to the shaft power input \dot{W}_{sh} :

$$\eta_t = \frac{\dot{W}_t}{\dot{W}_{sh}} = \frac{\dot{m}(P_{01} - P_{02})}{\rho \dot{W}_{sh}} = \dot{Q} \frac{P_{01} - P_{02}}{\dot{W}_{sh}} \quad (24-3a)$$

It has been common practice in the United States for \dot{Q} to be in ft^3/min , $P_{01} - P_{02}$ to be in in. wg, and \dot{W}_{sh} to be in horsepower. In this special case

$$\eta_t = \frac{\dot{Q}(P_{01} - P_{02})}{6350 \dot{W}_{sh}} \quad (24-3b)$$

The *static fan efficiency* is the ratio of the static air power to the shaft power input:

$$\eta_s = \frac{\dot{W}_s}{\dot{W}_{sh}} = \frac{\dot{m}(P_1 - P_2)}{\rho \dot{W}_{sh}} = \frac{\dot{Q}(P_1 - P_2)}{\dot{W}_{sh}} \quad (24-4a)$$

Using the units of Eq. (24-3b) we get

$$\eta_s = \frac{\dot{Q}(P_1 - P_2)}{6350 \dot{W}_{sh}} \quad (24-4b)$$

General Performance For Typical Fan Types

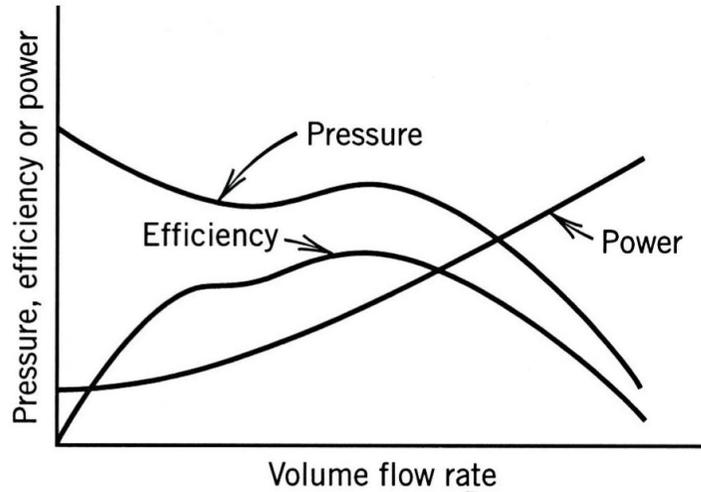


Figure 24-3 Forward-tip fan characteristics.

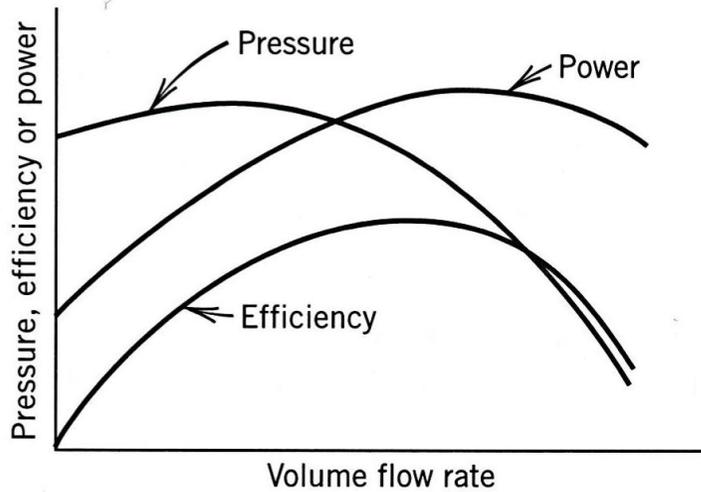


Figure 24-2 Backward-tip fan characteristics.

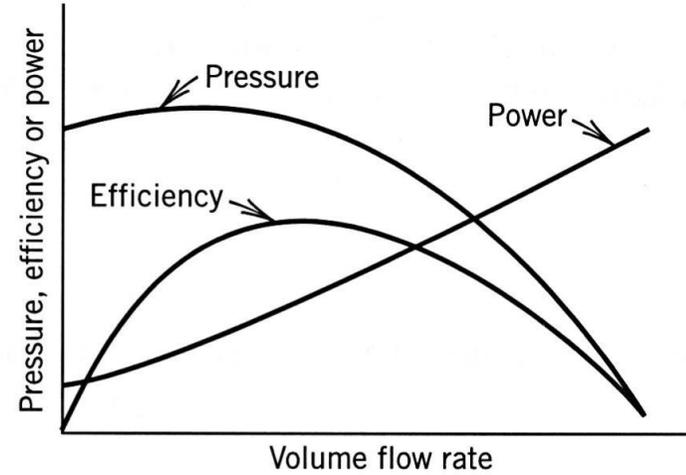


Figure 24-1 Radial-tip fan characteristics.

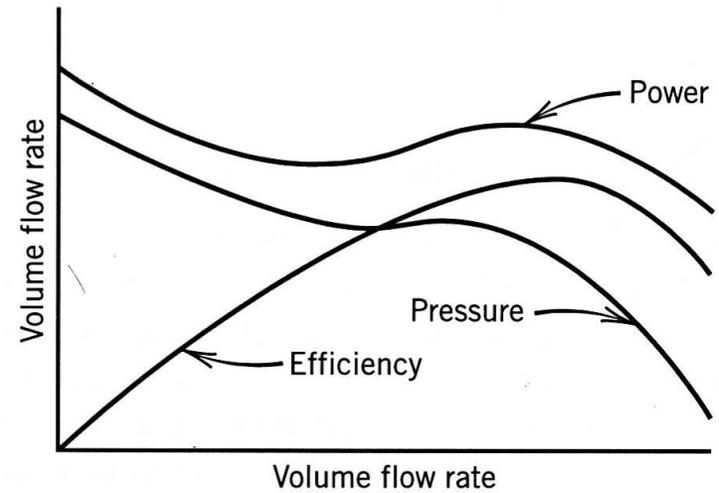
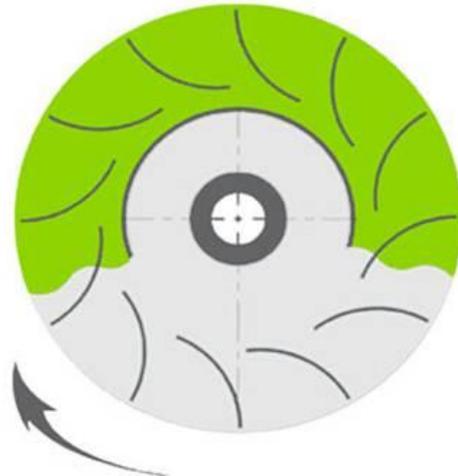


Figure 24-4 Vaneaxial fan characteristics.

General Performance For Typical Fan Types



Radial – 72%



Radial Tip – 79%



Forward Curved – 76%



Backward Flat – 81%



Backward Curved – 83%



Airfoil – 88%

General Performance For Typical Fan Types

- ❑ The power characteristic of vaneaxial fans are distinctly different from those of centrifugal fans. The power increases as the flow rate approaches zero for a vaneaxial fan, which is opposite the behavior of a centrifugal fan.
- ❑ The power curve for vaneaxial and backward-tip fans reaches a peak and decreases as flow becomes high.
- ❑ The noise emitted by a fan is significant in many applications.
- ❑ For a given pressure the noise level is proportional to the tip speed of the impeller, the air velocity leaving the wheel, and the pressure developed.
- ❑ Fan may be operated in series to develop higher pressure, and multistage fan are also constructed.
- ❑ Combining the system and fan characteristics on one plot is very useful in matching a fan to a system and ensuring fan operation at the desired condition

General Performance For Typical Fan Types

□ There are several simple relationship between fan capacity, pressure, speed, and power, which are referred to as the fan laws. The first three fan laws are the most useful and are stated as follows:

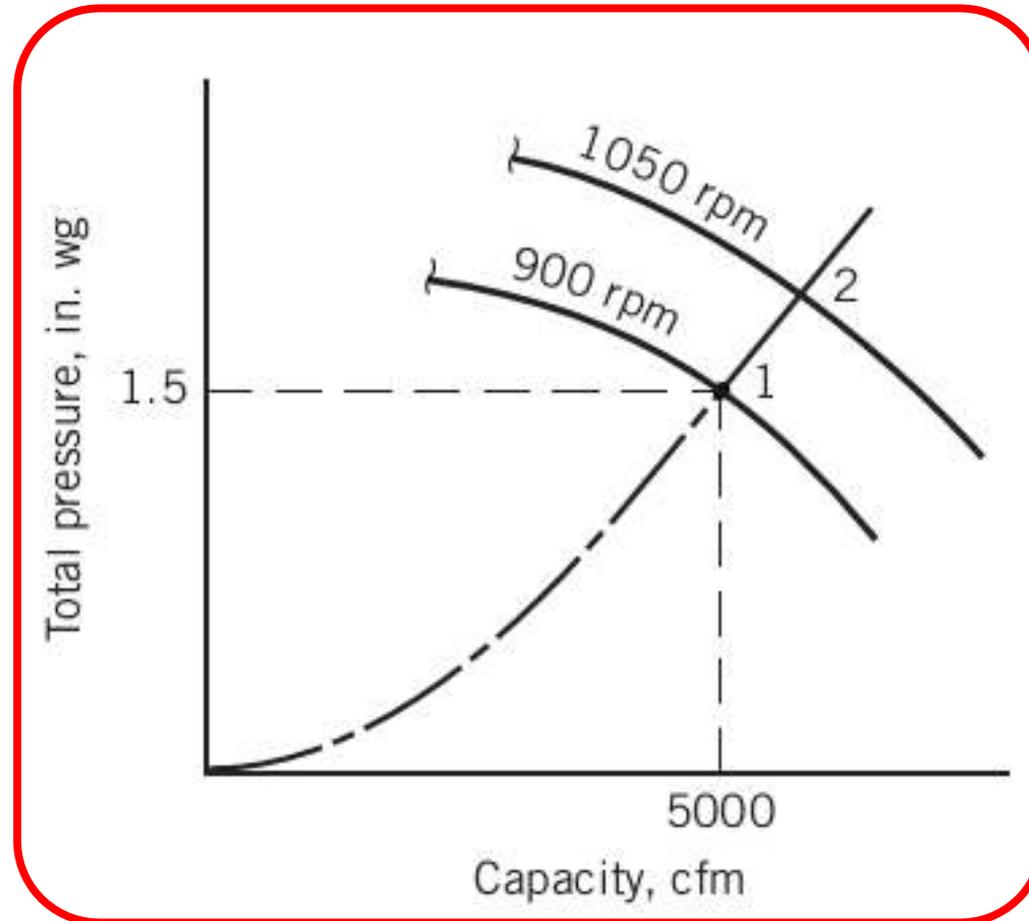
1. The capacity is directly proportional to the fan speed.
2. The pressure is proportional to the square of the fan speed.
3. The power required is proportional to the cube of the fan speed.

□ The other three fan laws are:

4. The pressure and power are proportional to the density of the air at constant speed and capacity.
5. The speed, capacity, and power are inversely proportional to the square root of the density at constant pressure.
6. The capacity, speed, and pressure are inversely proportional to the density, and the power is inversely proportional to the square of the density at a constant mass flow rate.

General Performance – Example 1

- ❖ A centrifugal fan is operating as shown in the figure below at point 1. Estimate the capacity, total pressure, and power requirement when the speed increased to 1050 rpm. The initial power requirement is 2 hp.
- ✓ The first 3 fan laws may be used to estimate the new capacity, total pressure and power



General Performance

– Example 1

Capacity:

$$\frac{\dot{Q}_1}{\dot{Q}_2} = \frac{\text{rpm}_1}{\text{rpm}_2}$$

so that

$$\dot{Q}_2 = \dot{Q}_1 \frac{\text{rpm}_2}{\text{rpm}_1} = 5000 \left(\frac{1050}{900} \right) = 5833 \text{ ft}^3/\text{min (cfm)}$$

Total pressure:

$$\frac{P_{01}}{P_{02}} = \left(\frac{\text{rpm}_1}{\text{rpm}_2} \right)^2$$

$$P_{02} = P_{01} \left(\frac{\text{rpm}_2}{\text{rpm}_1} \right)^2 = 1.5 \left(\frac{1050}{900} \right)^2 = 2.04 \text{ in. wg}$$

Power:

$$\frac{\dot{W}_1}{\dot{W}_2} = \left(\frac{\text{rpm}_1}{\text{rpm}_2} \right)^3$$

$$\dot{W}_2 = \dot{W}_1 \left(\frac{\text{rpm}_2}{\text{rpm}_1} \right)^3 = 2 \left(\frac{1050}{900} \right)^3 = 3.2 \text{ hp}$$

FAN PERFORMANCE AND SELECTION

- ❑ The first consideration for any fan application is
 - ✓ The required capacity (cfm)
 - ✓ The system total pressure at the design point.
- ❑ The second consideration is
 - ✓ Selecting a fan with a good combination of efficiency, relative cost, acoustics, and physical size
- ❑ The performance of a fan for a variable air-volume system is an important consideration because the fan will operate at partial capacity a considerable amount of time.

Backward-Curved Blade Fans

- ❑ This type of fan is used for general heating, ventilating, and air-conditioning systems, especially where system size offer significant horsepower savings.
- ❑ Such fans can be used in low, medium, and high-pressure HVAC systems.
- ❑ These are the highest efficiency designs of all centrifugal fan types.
- ❑ For a given duty, these fans will operate at the highest speed of the different centrifugal fans.
- ❑ The performance curve is stable, and this type of fan has a load-limiting horsepower characteristic (Figure 24-6).
- ❑ The horsepower curve reaches a maximum near the peak efficiency area and becomes lower for free delivery.
- ❑ These fans are also used in industrial application where power savings will be significant.
- ❑ The aerofoil-type blade should be used only in those applications where the air is clean and the blade is not subject to erosion or corrosion.

Backward-Curved Blade Fans

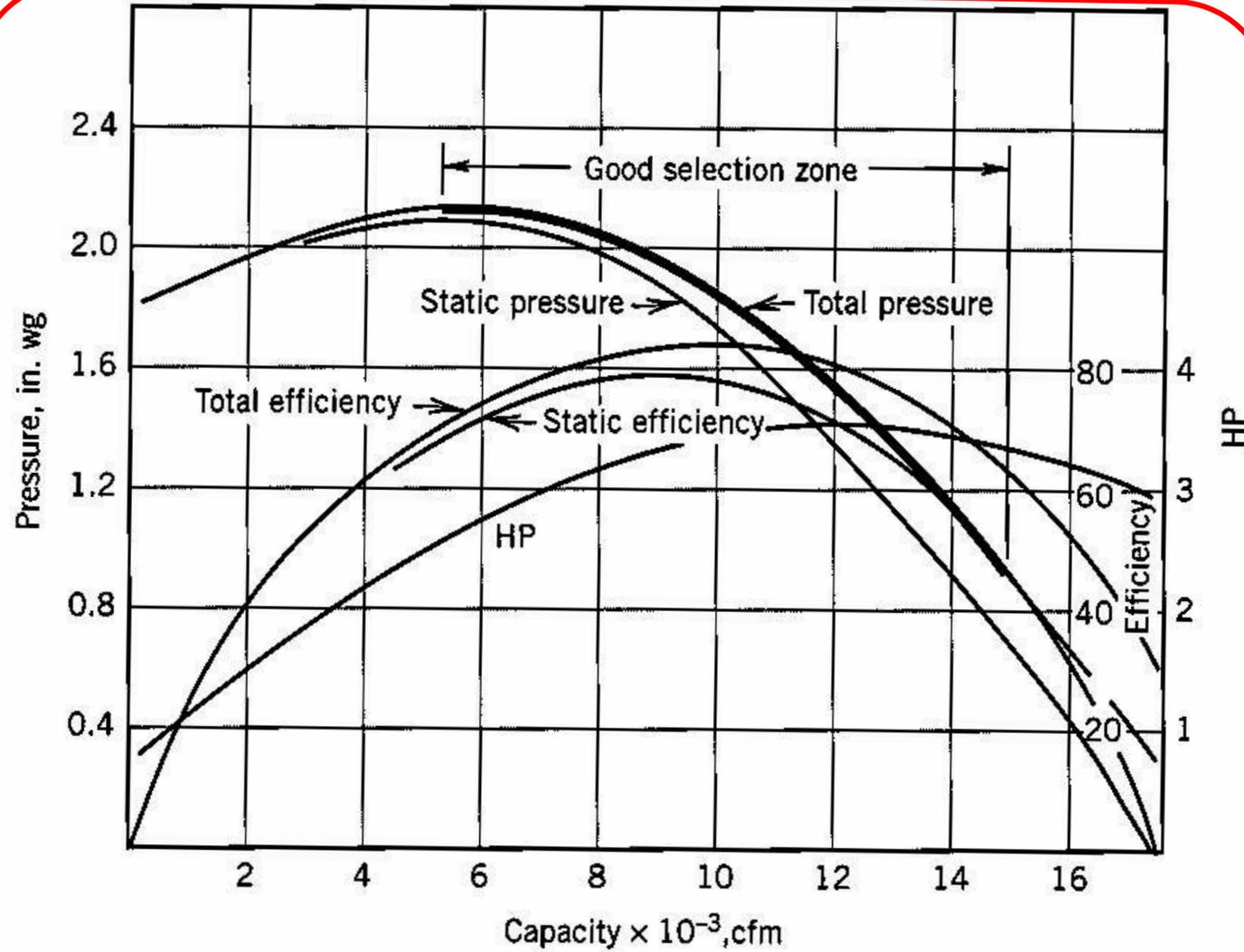


Figure 24-6 Conventional curves for backward-curved blade fan. (Reprinted by permission of ASHRAE Journal, Vol. 14, Part I, No. 1, 1972.)

Backward-Curved Blade Fans

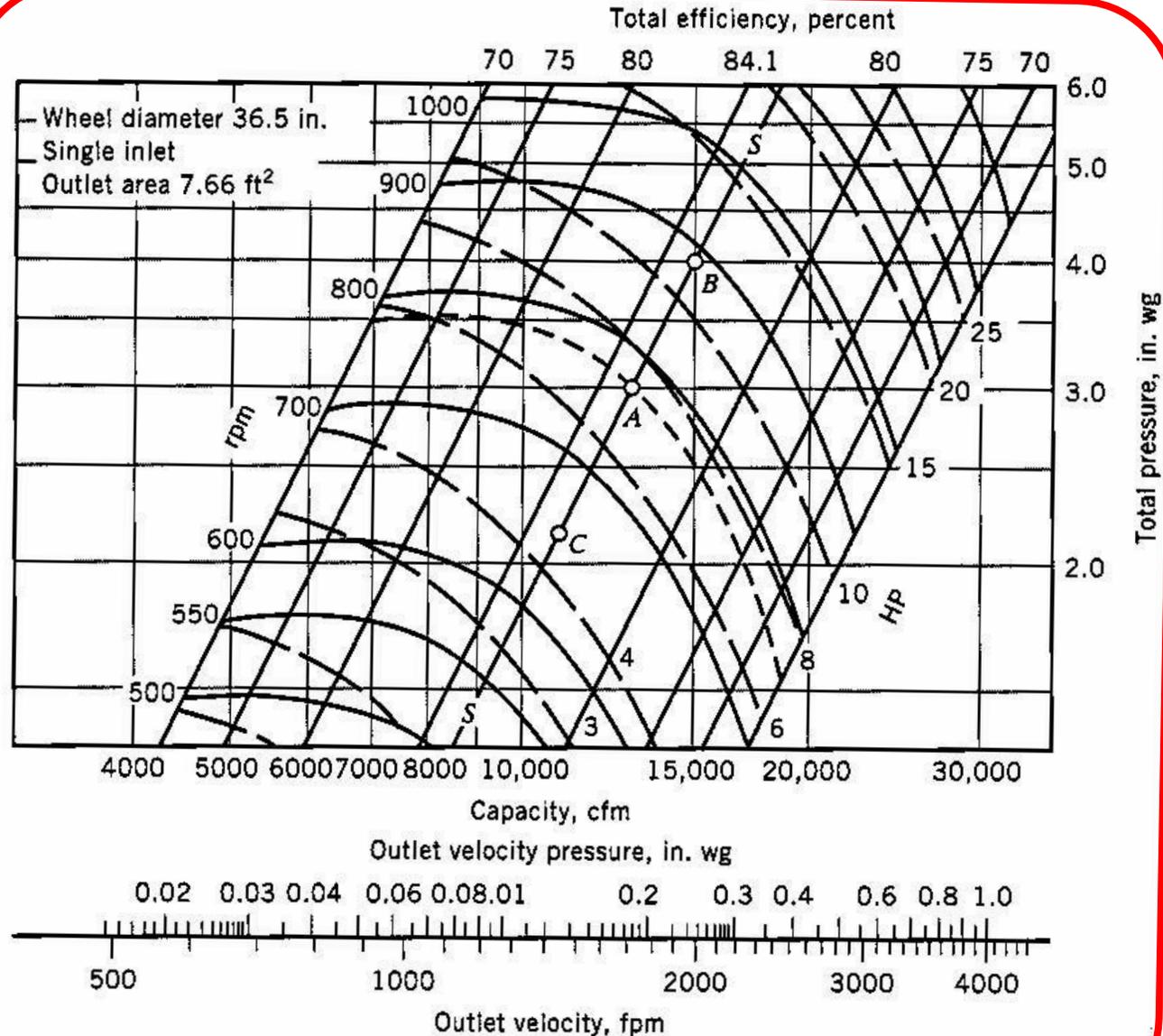


Figure 24-7 Performance chart showing combination of fan and system. (Reprinted

Forward-Curved Blade Fans

- ❑ This type of fan is usually used in low-pressure HVAC application such as domestic furnaces, central station units, and packaged air-conditioning equipment.
- ❑ This design tends to have the lowest efficiency and will operate at the lowest speed of the various centrifugal fan.
- ❑ The pressure curve is less steep than that of the other designs.
- ❑ There is a dip in the pressure curve to the left of peak pressure, and the highest efficiency occur just to the right of peak pressure.

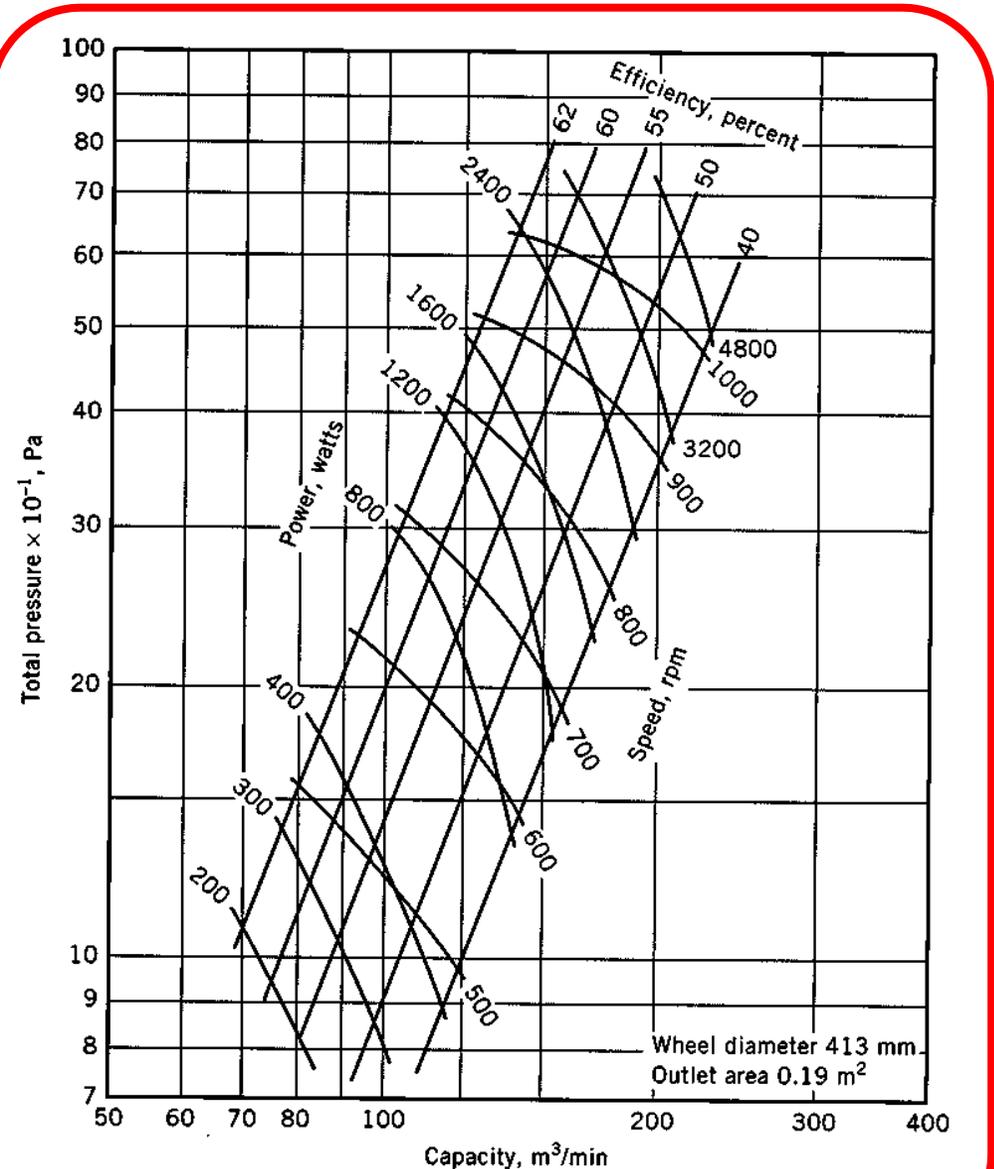


Figure 24-8 Performance data for a forward-curved blade fan.

Forward-Curved Blade Fans

Table 24-1 Pressure-Capacity Table for a Forward-Curved Blade Fan

Volume Flow Rate, cfm	Outlet Velocity, ft/min	$\frac{1}{4}$ in. wg ^a		$\frac{5}{8}$ in. wg		$\frac{3}{4}$ in. wg		1 in. wg		$1\frac{1}{4}$ in. wg		$1\frac{1}{2}$ in. wg	
		rpm	bhp ^b	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp	rpm	bhp
851	1200	848	0.13	933	0.16	1018	0.19	—	—	—	—	—	—
922	1300	866	0.15	945	0.18	1019	0.21	—	—	—	—	—	—
993	1400	884	0.17	957	0.20	1030	0.23	1175	0.30	—	—	—	—
1064	1500	901	0.19	973	0.22	1039	0.26	1182	0.32	—	—	—	—
1134	1600	926	0.22	997	0.24	1057	0.29	1190	0.35	1320	0.43	—	—
1205	1700	954	0.25	1020	0.27	1078	0.31	1200	0.38	1325	0.46	1436	0.55
1276	1800	983	0.28	1044	0.31	1100	0.34	1210	0.42	1330	0.50	1440	0.59
1347	1900	1011	0.31	1068	0.35	1126	0.38	1230	0.46	1341	0.54	1447	0.63
1418	2000	1039	0.35	1092	0.39	1152	0.42	1250	0.50	1352	0.59	1458	0.66
1489	2100	1068	0.39	1115	0.43	1178	0.47	1275	0.54	1370	0.62	1470	0.72
1560	2200	1096	0.44	1147	0.47	1204	0.51	1300	0.59	1390	0.67	1482	0.77
1631	2300	1124	0.48	1179	0.52	1230	0.56	1325	0.64	1420	0.73	1500	0.83
1702	2400	1152	0.53	1210	0.58	1256	0.62	1350	0.70	1448	0.78	1525	0.88

^aStatic pressure.

^bShaft power in horsepower.

Note: Data are for a 9 in. wheel diameter and an outlet of 0.71 ft².

Table 24-1 , Examples of Forward-Curved Blade Fan Performance Data

Table 24-1b Pressure-Capacity Table for a Forward-Curved Blade Fan

Volume Flow Rate, m ³ /s	Outlet Velocity, m/s	0.7 kPa ^a		0.8 kPa		0.9 kPa		1.0 kPa		1.1 kPa		1.2 kPa	
		rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW	rpm	kW
3.35	7	692	4.33	—	—	—	—	—	—	—	—	—	—
3.83	8	688	4.79	737	5.44	—	—	—	—	—	—	—	—
4.32	9	679	5.20	732	6.06	778	6.90	825	7.68	—	—	—	—
4.78	10	664	5.48	721	6.48	770	7.46	819	8.43	864	9.47	—	—
5.27	11	654	5.82	704	6.82	755	7.98	808	9.02	855	10.1	900	11.2
5.75	12	656	6.38	699	7.31	743	8.43	790	9.47	840	10.5	887	11.7
6.23	13	663	7.12	702	7.98	741	8.87	781	9.84	825	11.0	871	12.3
6.72	14	674	7.90	710	8.72	747	9.62	781	10.6	817	11.6	855	12.7
7.18	15	686	8.95	720	9.77	755	10.7	787	11.6	820	12.5	853	13.5
7.67	16	702	10.1	733	10.8	765	11.6	797	12.6	828	13.6	860	14.5
8.13	17	—	—	748	12.0	778	12.9	808	13.9	839	14.8	869	15.8
8.62	18	—	—	—	—	793	14.3	822	15.4	851	16.3	880	17.3
9.10	19	—	—	—	—	—	—	—	—	—	—	891	18.9

^aStatic pressure.

Note: Outlet area = 0.479 m². Wheel diameter = 660 mm. Tip speed = rpm × 2.07 m/s.

Vaneaxial Fan

- ❑ This type of fan is becoming more commonly used in HVAC system in low, medium, and high-pressure application and is particularly advantageous where straight-through flow is required.
- ❑ Vaneaxial fan usually have blade of airfoil design, which permits medium- to high-pressure capability at relatively high efficiency.
- ❑ The performance curve (Fig. 24-4) show the highest pressure characteristic of the axial designs at medium volume flow rate.
- ❑ Some fans of this design have the capability of changing the pitch of the blade to meet different application requirement.
- ❑ In some cases this is accomplished by shutting the fan down, changing the blade angle to a new position, and restarting the fan.
- ❑ In other case, the pitch of the fan blade can be changed with the fan in operation. This latter method provides good control characteristic for the fan in VAV system.

Example 2

- ❑ Comment on the suitability of using the fan described by Figure 24-6 to move 15,000 cfm at 3.5 in. wg total pressure. Estimate the speed and power requirement
- ✓ Examination of Fig. 24-6 shows that the fan would be quite suitable.
- ✓ The operating point would be just to the right of the point of maximum efficiency and the fan speed between 800 and 900 rpm.
- ✓ Therefore, the fan would operate in a relatively quiet manner.
- ✓ The speed and power required may be estimated directly from the graph as 830 rpm and 9.5 hp, respectively.

Fans and Building Air Distribution – Example 25-1

A duct system requires a fan that will deliver 6 m³/s of air at 1.2 kPa total pressure. Is the fan of Table 24-1b suitable? If so, determine the speed, shaft power, and total efficiency.

The required volume flow rate falls between 5.75 and 6.23 m³/s in the left-hand column of Table 24-1b. The corresponding outlet velocities are 12 and 13 m/s and the velocity pressure for each case is

$$(P_v)_{5.75} = \rho_a \frac{\bar{V}^2}{2} = 1.2 \frac{(12)^2}{2} = 86.4 \text{ Pa}$$
$$(P_v)_{6.23} = \frac{1.2(13)^2}{2} = 101.4 \text{ Pa}$$

Assuming 1.1 kPa static pressure, the total pressure at 5.75 m³/s is

$$(P_0)_{5.75} = 1100 + 86.4 = 1186.4 \text{ Pa}$$

And at 6.23 m³/s

$$(P_0)_{6.23} = 1100 + 101.4 = 1201.4 \text{ Pa}$$

By interpolation the total pressure at 6 m³/s is

$$(P_0)_{6.0} = 1186.4 + \frac{6 - 5.75}{6.23 - 5.75} (1201.4 - 1186.4)$$
$$= 1190 \text{ Pa} = 1.19 \text{ kPa}$$

Fans and Building Air Distribution – Example 25-1

A duct system requires a fan that will deliver 6 m³/s of air at 1.2 kPa total pressure. Is the fan of Table 12-b suitable? If so, determine the speed, shaft power, and total efficiency.

Although the total pressure at 6 m³/s is barely adequate, the fan speed can be increased to obtain total pressures up to almost 1.3 kPa at a capacity of 5.75 to 6.23 m³/s.

The fan speed may be determined by interpolation to be

$$\text{rpm} = 840 - \frac{6 - 5.75}{6.23 - 5.75}(840 - 825) = 832$$

and the shaft power is likewise found to be

$$\dot{W}_{sh} = 10.5 + \frac{6 - 5.75}{6.23 - 5.75}(0.5) = 10.76 \text{ kW}$$

The total power imparted to the air is given by Eq. 12-2:

$$\dot{W}_t = \frac{\dot{m}}{\rho}(P_{01} - P_{02}) = \dot{Q}(P_{01} - P_{02}) \quad (24-5c)$$

where \dot{Q} is in m³/s, $(P_{01} - P_{02})$ is in N/m² (Pa), and W_t is in watts. Then

$$\dot{W}_t = (6)(1.2)(1000)/(1000) = 7.2 \text{ kW}$$

The total efficiency is then given by **24-1**,

$$\eta_t = \frac{\dot{W}_t}{\dot{W}_{sh}} = \frac{7.2}{10.76} = 0.67$$