Fan Performance and Selection

References

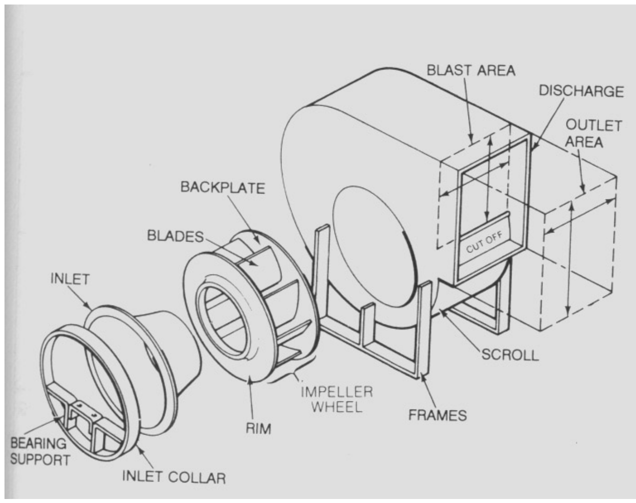
Burmeister, L.C., Elements of Thermal-Fluid System Design, Prentice Hall, 1998.

ASHRAE Handbook: HVAC Systems and Equipment, 1992.

Overview

- Common fan types: centrifugal ("squirrel cage"), axial, special designs (including radial)
- Fan rotation direction (clockwise or counterclockwise) is important because the blades and housing are designed to direct flow only in one direction
- Pressure drop through the system must be known to choose a fan.
- Fans are quietest when they operate near peak efficiency; efficiencies are often provided on fan curves.

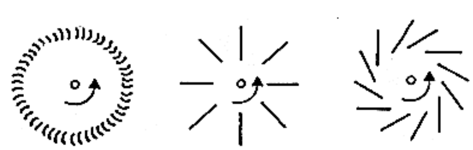
Centrifugal Fans



Source: ASHRAE Handbook

Centrifugal Fan Operation

- Fans cause a pressure increase through two methods
  - Centrifugal force is created by the rotation of the column of air trapped between two blades.
  - Kinetic energy is supplied to the air through the impeller
  - Total pressure = velocity head + static pressure
- Blades are airfoil-type, backward-curved, forward-curved, or radial (straight)
  - Airfoil-types are complex and expensive but very efficient; they're used for large systems where the cost is justified.



a) forward curved b) straight c) backward curved

Backward-Curved Fan Blades

- Have a self-limiting power characteristic, so if sized correctly the motor won't overheat or burn out even if conditions change.
- High efficiency and stable operation make this blade type popular.
- Choose the operating point to be just to the right of the peak pressure flow rate to achieve both high efficiency and a stable flow rate.
- This type of fan operates stably because the pressure difference provided by the fan drops if the flow rate goes up. If the opposite were true, increased an increased flow rate would cause increase fan power, which is unstable.

Fan Curve, Backward-Curved Centrifugal Blade

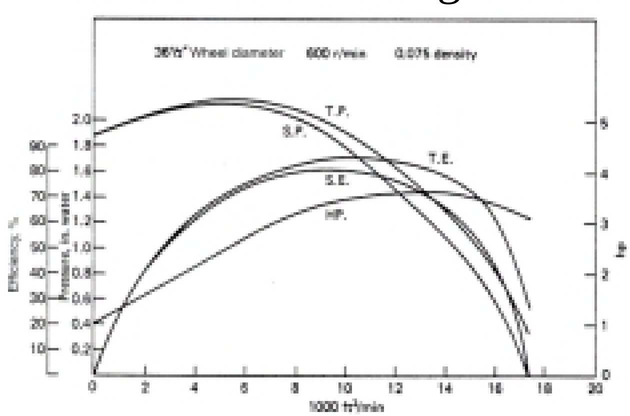


Figure 2-56 Characteristics of a typical backward-curved blade centrifugal fan (Bovay, 1981, p. 14-10, Fig. 14-14. Printed by permission).

Source: Burmeister

TP=total pressure
SP=static pressure
TE=total efficiency=$Q\Delta P_{total}/W_{shaft}$
SE=static efficiency
HP=horsepower

Radial Blades

- Similar performance to a backward-curved except that it's easier to overheat because as flow rate goes up, so does power.
- Easier to maintain, so it's used in dirty situations (easy to clean straight blades, and they don't collect as much)
- Blades are stronger than other types.

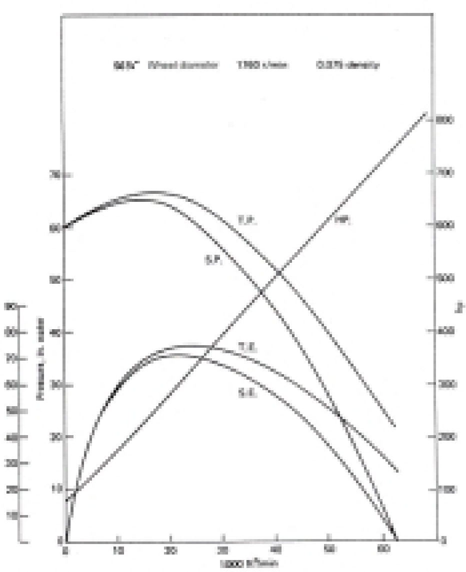
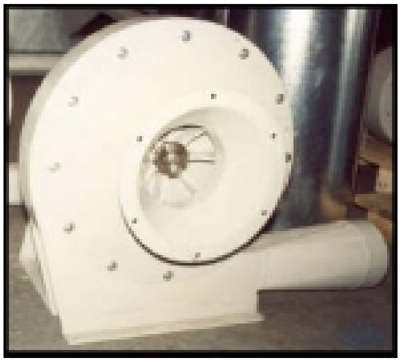


Figure 2-37 Characteristics of a typical radial-blade centrifugal fan (Barsy, 1981, p. 14-13, Fig. 14-20. Printed by permission).

Source: Burmeister



Forward-Curved Blades

- Have problems with instability because a specified pressure rise can fit three different flow rates.

- Burnout can also be a problem because fan power increases with flow rate.
- Quieter than other fans; used for most furnace blowers

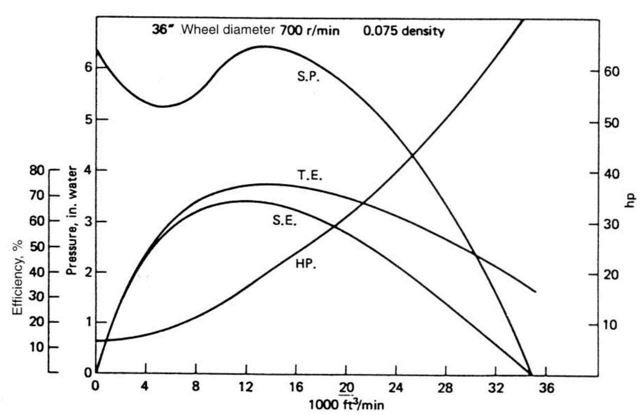


Figure 2-58 Characteristics of a typical forward-curved blade centrifugal fan (Bovay, 1981, p. 14-12, Fig. 14-17. Printed by permission).

Source: Burmeister

Axial Flow Fans

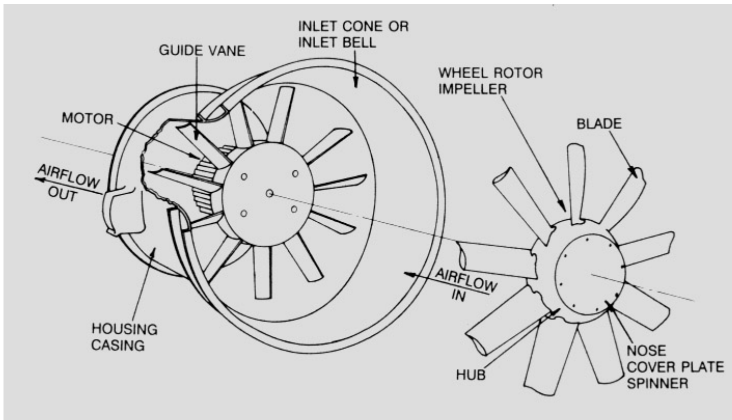
- Common types: propeller, tubeaxial, vaneaxial
- Tubeaxial: impeller is inside a tube to guide airflow and improve performance
- Vaneaxial: like a tubeaxial except vanes either up or downstream of the impeller are used to reduce swirl and improve performance
- Used to deliver large flow rates but small increase in pressure
- Examples include fans used for ventilation without ductwork, mobile room fans, and fans used to cool computers

Tubeaxial fan for computer cooling

Tubeaxial fan for ventilation

Vaneaxial fan for high air resistance electronics cooling
Straightening vanes are located inside tube

Vaneaxial Flow Fan



Source: ASHRAE Handbook

System Pressure Effects

- Fan curves are typically given in terms of total pressure vs. volumetric flow rate
- A typical fan running at a fixed speed can provide a greater volumetric flow rate for systems with smaller total pressure drops (if we're to the right of the peak in the fan curve).
- Total pressure loss=static pressure loss+dynamic pressure loss

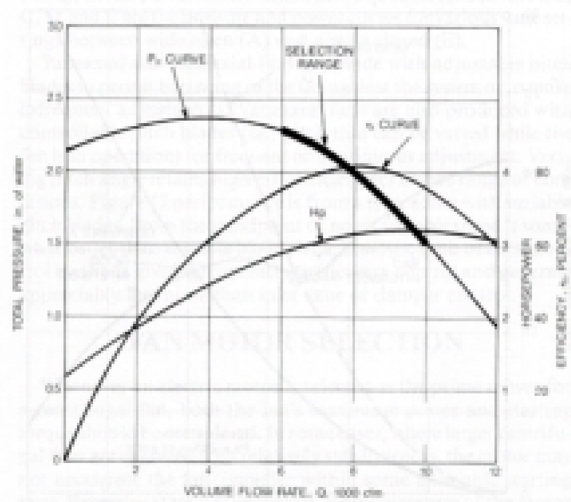
$$\Delta P_{total} = \left(P_{in,static} - P_{out,static}\right) + \frac{1}{2}\rho\left(V_{in}^2 - V_{out}^2\right)$$

- If exit and inlet area of a duct are about the same, the dynamic pressure loss (or gain) may be minimal.

Fan Curves

- Manufacturer will provide a fan curve for each fan he or she produces.
- The fan curves predict the pressure-flow rate performance of each fan.
- Choose a fan that gives you the volumetric flow rate you need for your system pressure drop.
- Choose a fan that has its peak efficiency at or near your operating point.
- Sometimes will provide data in a table rather than in a graph.

Fan Curves



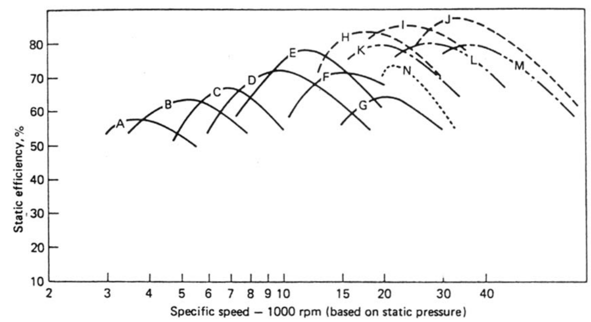
(Curve shows performance of a fixed fan size running at a fixed speed)

Fig. 13 Conventional Fan Performance Curve Used by Most Manufacturers

Source: ASHRAE Handbook

Generalized Fan Curves

- These kinds of curves can be used to help choose a fan.



Type	Relative width	Usual duty	Type	Relative width	Usual duty
Radial blades			Airfoil blades		
A	Narrow	Pressure blower	H	Narrow	Mechanical draft
B		Pressure blower	I	Medium	Mechanical draft
C		Pressure blower	J	Wide	Ventilating
D	Medium	Pressure blower	Backward curved		
E		Pressure blower	K	Narrow	Mechanical draft
F		Pressure blower	L	Medium	Mechanical draft
G	Wide	Industrial exhauster	M	Wide	Ventilating
			Forward curved		
			N	Medium	Mechanical draft

Source: Burmeister

Fan Laws

Fan data for geometrically similar fans can be collapsed onto a single curve using dimensionless numbers

dimensionless flow rate $\Pi_1 = \dfrac{Q}{D^3 N}$

dimensionless pressure rise $\Pi_2 = \dfrac{\Delta P}{\rho D^2 N^2}$

dimensionless power $\Pi_3 = \dfrac{W}{\rho D^5 N^3}$

Q=volumetric flow rate

D=fan diameter

N=fan rotational speed

W=fan power

ρ=fluid density

ΔP=fan pressure rise

Fan Laws

- The laws only apply to aerodynamically similar fans at the same point of rating on the performance curve.
- Under these conditions, the dimensionless parameters will be constants. For example, if fan operation moves from point 1 to point 2, the values of the dimensionless parameters will not change and thus can be used to estimate system effects.
- Be careful about using the fan laws to determine the effect of fan speed change – you may move to a very different spot on the performance curve, which will invalidate your results.

Fan Laws

- It may be easier to see how these work in a different form:

Source: ASHRAE Handbook

Table 2 Fan Laws

No.	Dependent Variables		Independent Variables
1a	$Q_1 = Q_2$	$\times$	$(D_1/D_2)^3\ (N_1/N_2)$
1b	$p_1 = p_2$	$\times$	$(D_1/D_2)^2\ (N_1/N_2)^2\ \rho_1/\rho_2$
1c	$W_1 = W_2$	$\times$	$(D_1/D_2)^5\ (N_1/N_2)^3\ \rho_1/\rho_2$
2a	$Q_1 = Q_2$	$\times$	$(D_1/D_2)^2\ (p_1/p_2)^{1/2}\ (\rho_2/\rho_1)^{1/2}$
2b	$N_1 = N_2$	$\times$	$(D_2/D_1)\ (p_1/p_2)^{1/2}\ (\rho_2/\rho_1)^{1/2}$
2c	$W_1 = W_2$	$\times$	$(D_1/D_2)^2\ (p_1/p_2)^{3/2}\ (\rho_2/\rho_1)^{1/2}$
3a	$N_1 = N_2$	$\times$	$(D_2/D_1)^3\ (Q_1/Q_2)$
3b	$p_1 = p_2$	$\times$	$(D_2/D_1)^4\ (Q_1/Q_2)^2\ \rho_1/\rho_2$
3c	$W_1 = W_2$	$\times$	$(D_2/D_1)^4\ (Q_1/Q_2)^3\ \rho_1/\rho_2$

Notes:
1. Subscript 1 denotes the variable for the fan under consideration. Subscript 2 denotes the variable for the tested fan.
2. For all fans laws $(\eta_t)_1 = (\eta_t)_2$ and (Point of rating)$_1$ = (Point of rating)$_2$.
3. p equals either p_{tf} or p_{sf}.

Fan Laws

- Law 1 – relates to effect of changing size, speed, or density on volume flow, pressure, and power level
- Law 2 – relates to effect of changing size, pressure, or density on volume flow rate, speed, and power
- Law 3 – shows effect of changing size, volume flow, or density on speed, pressure, and power

Fan Law Example

This example applies the fan laws to a case where the fan speed N is changed from 600 to 650 RPM for a fan of a given size.

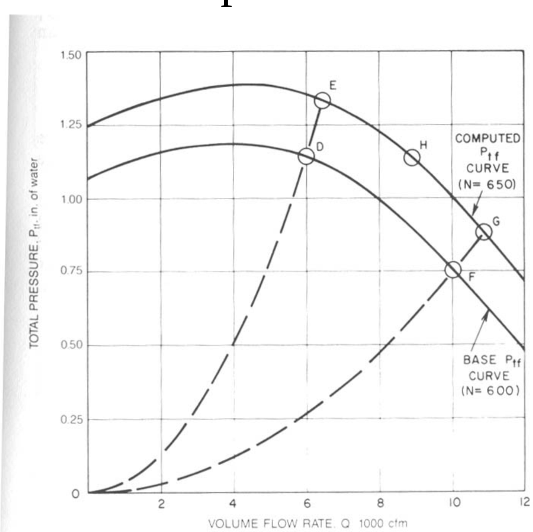


Fig. 4 Example Application of Fan Laws

Source: ASHRAE Handbook

Fan Law Example

- At point D Q_2=6000 cfm and P_{t2}=1.13 in of water
- From Fan Law 1a, at point E

  Q_1=6000x650/600=6500 cfm
- From Fan Law 1b, at point E

  P_{t1}=1.13x(650/600)^2=1.33 in of water

Two Fans in Parallel or Series

- For two identical fans in parallel, you can make your own fan curve by taking the original fan curve and doubling the volumetric flow rate for a given pressure.
- For two identical fans in series, you can make your own fan curve by doubling the pressure drop for a given volumetric flow rate.
- Which would be better for cooling computer chasses?

Fans in Series and Parallel