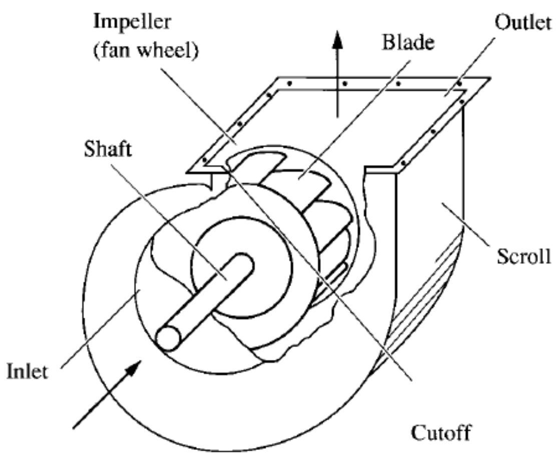
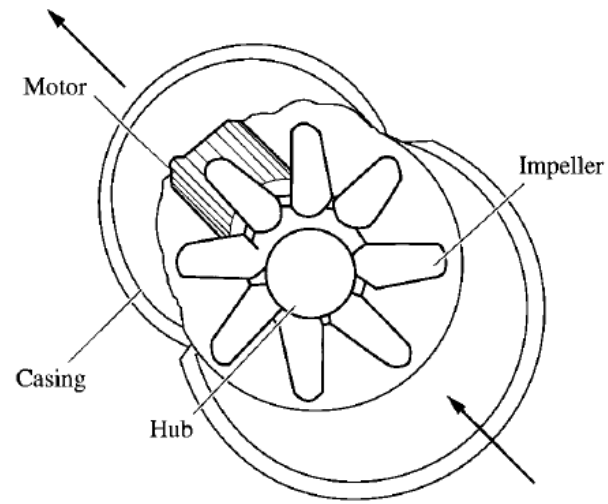
Fans & Fan laws

Basic fan types



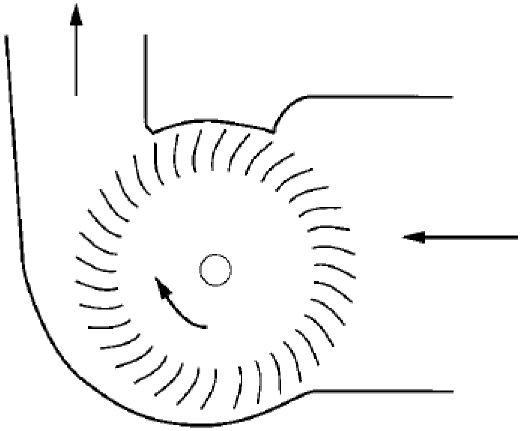
(a)

Centrifugal



(b)

Axial



(c)

Crossflow

Basic rotodynamic equations

Volumetric flow rate, Q is given by:

$$Q = \pi D_2 b_2 V_{m2} = \pi D_2 b_2 \phi u_2$$

D_2 = Outer diameter of the impeller

b_2= width of the impeller blade at outer tip

ϕ = Flow coefficient = V_{m2}/u_2

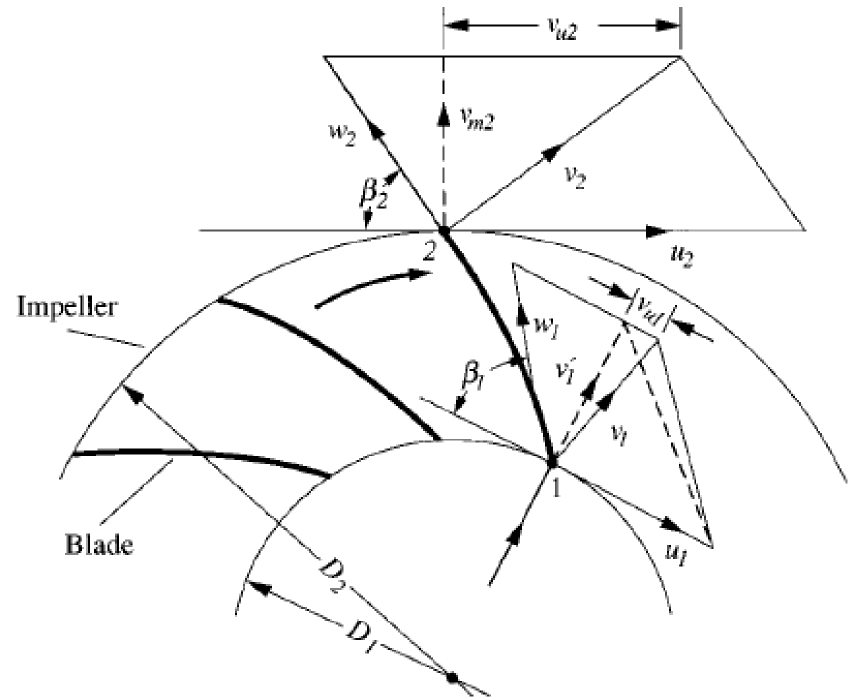


FIGURE 15.3 Velocity triangles at the blade inlet and outlet of a centrifugal fan.

Neglecting the radial velocity component at the inlet,

from **Euler's turbo-machinery equation**

$$Power\ input, P = \tau \times \omega = \dot{m} u_2 V_{u2} = \dot{m} u_2^2 \left(1 - \frac{V_{m2}}{u_2} cot(\beta_2)\right)$$

Theoretical performance

$$Also\ Power\ input, P = Q \times \Delta p_{total} = \dot{m} u_2^2 \left(1 - \frac{V_{m2}}{u_2} cot(\beta_2)\right)$$

$$\therefore \Delta p_{total} = \rho u_2^2 \left(1 - \frac{V_{m2}}{u_2} cot(\beta_2)\right) = \rho \left(u_2^2 - \frac{u_2 Q}{\pi D_2 b_2} cot(\beta_2)\right)$$

$$\therefore P = Q \times \Delta p_{total} = \rho \left(Q u_2^2 - \frac{u_2 Q^2}{\pi D_2 b_2} cot(\beta_2)\right)$$

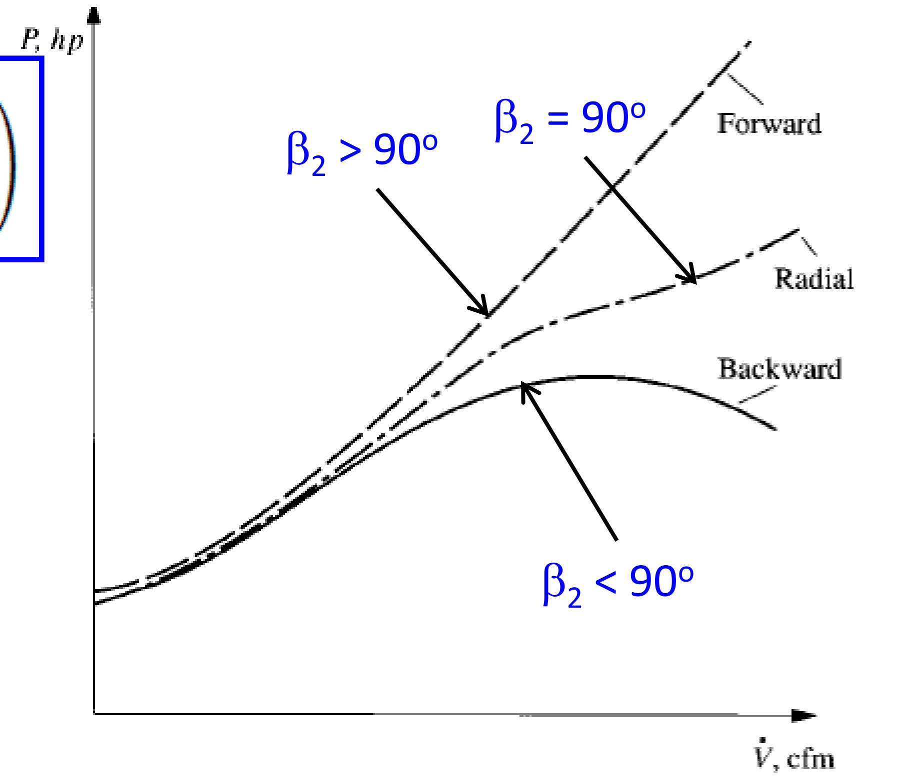


FIGURE 15.6 Power-volume P-$\dot{V}$ performance curves for centrifugal fans with impellers of same diameters.

Actual performance

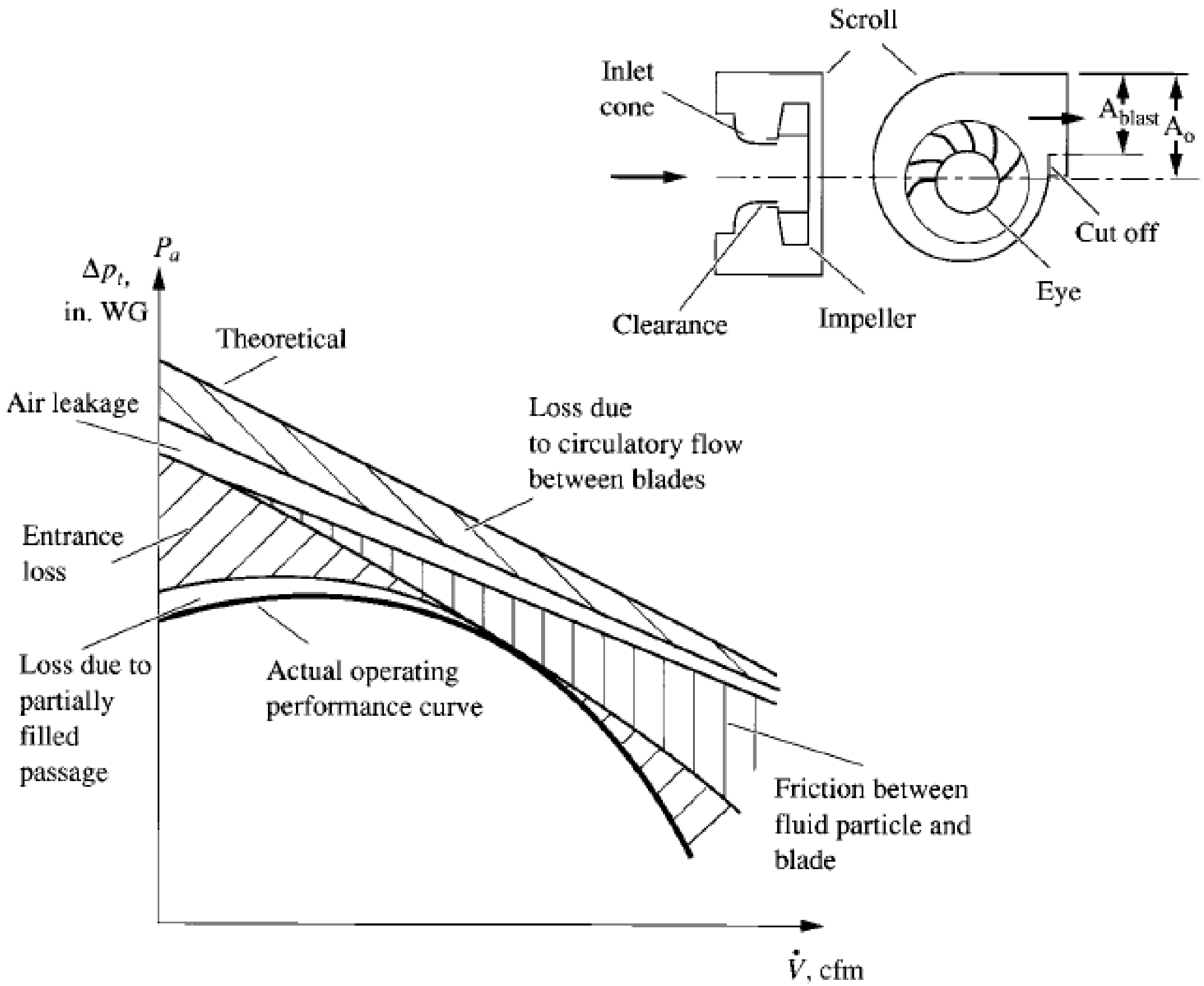


FIGURE 15.4 Operating characteristics for a backward-curved centrifugal fan.

Fan performance curves

Δp_{sf} = static head

Δp_{tf} = total head (static + velocity)

η_s = static efficiency

η_t = total efficiency

P_f = Power input

$$\eta_s = \frac{Q \times \Delta p_{sf}}{P_f}$$

$$\eta_t = \frac{Q \times \Delta p_{tf}}{P_f}$$

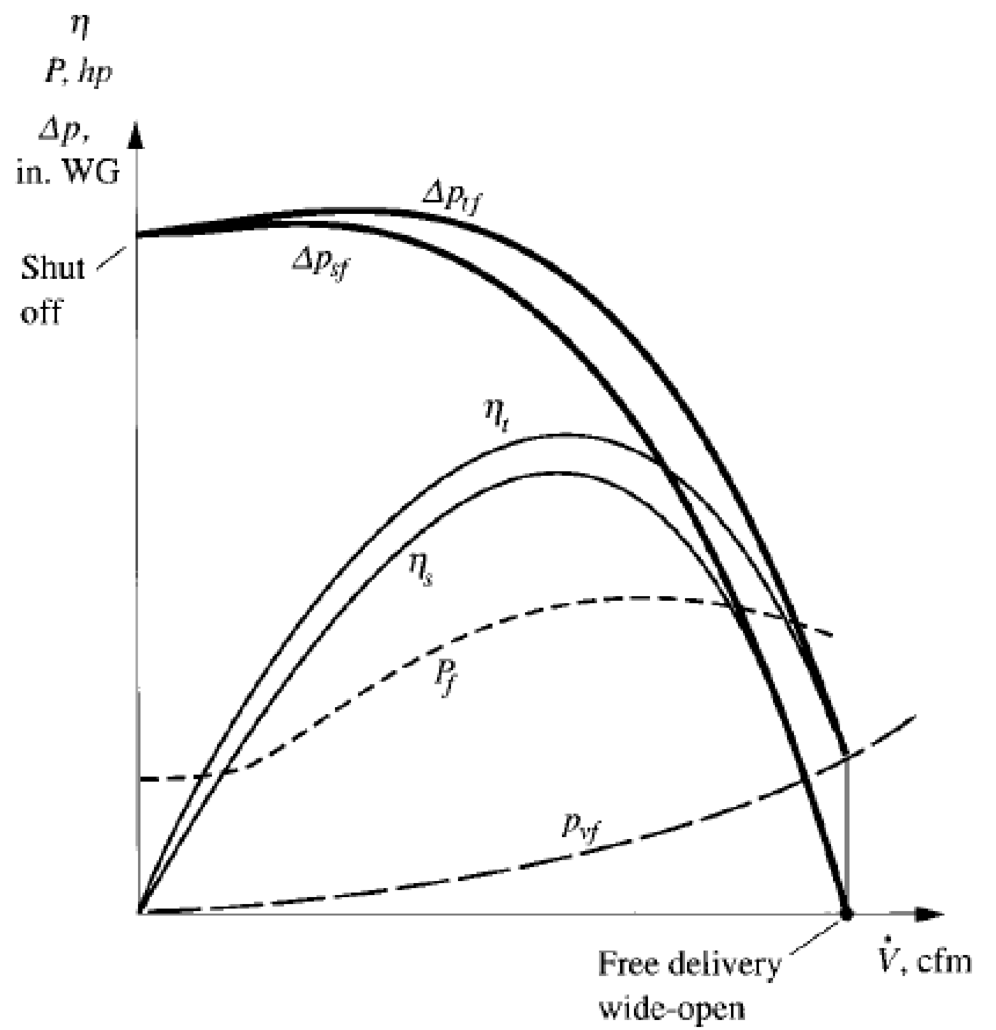


FIGURE 15.2 Fan performance curves.

Performance comparison

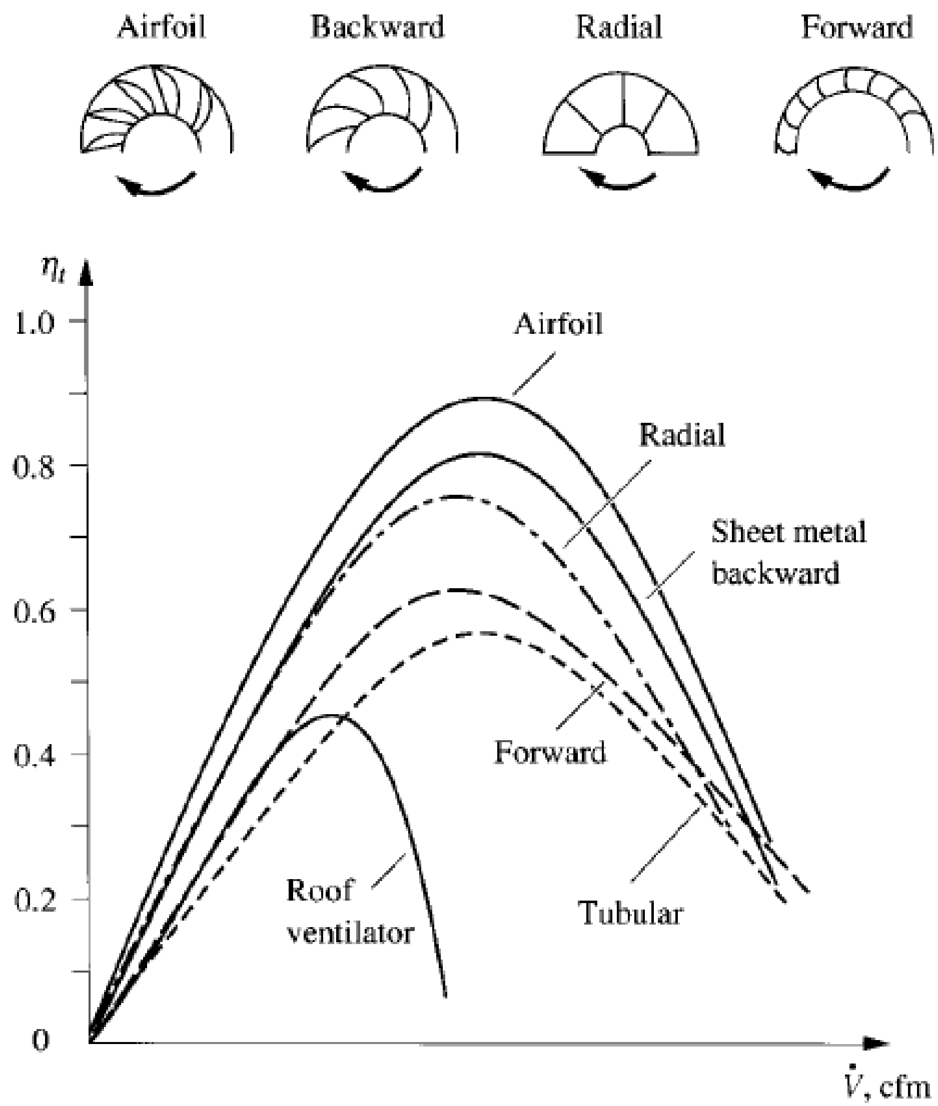
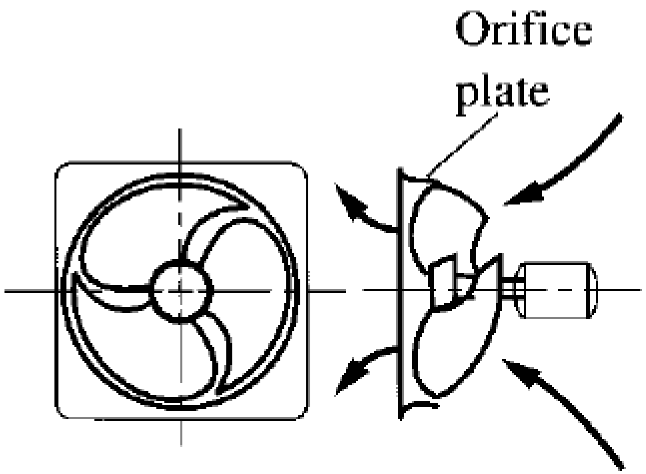
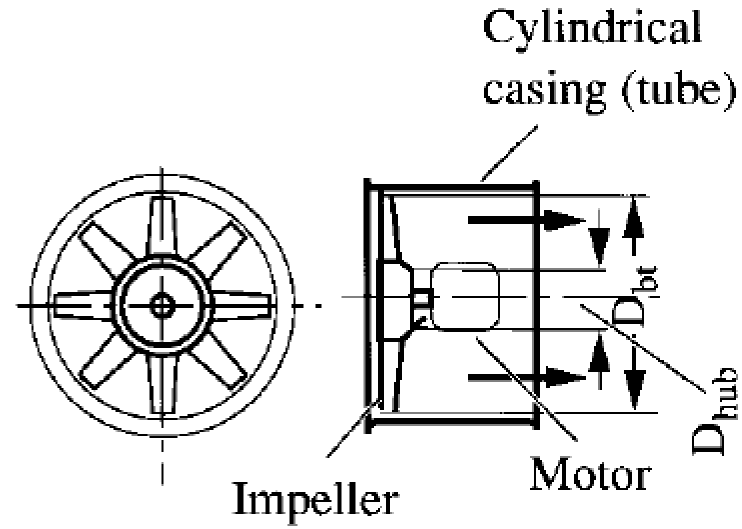


FIGURE 15.5 Total efficiency–volume η_t-$\dot{V}$ performance curves for centrifugal fans.

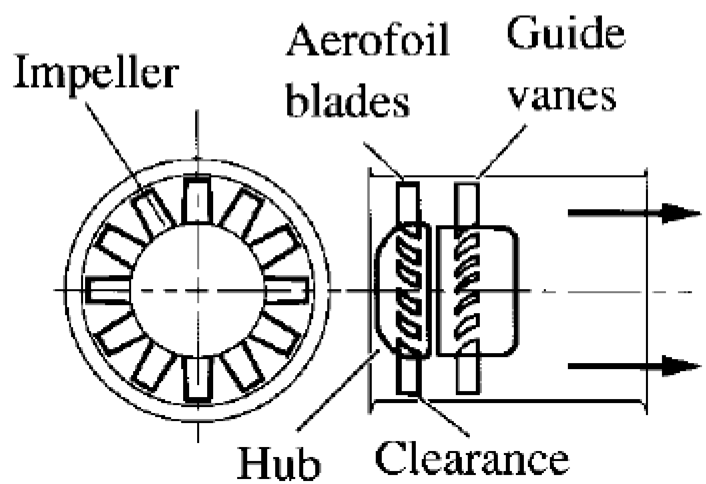
Axial fans



Propeller type



Tube axial type



Vane axial type

Performance of Axial fans

(For same impeller diameter)

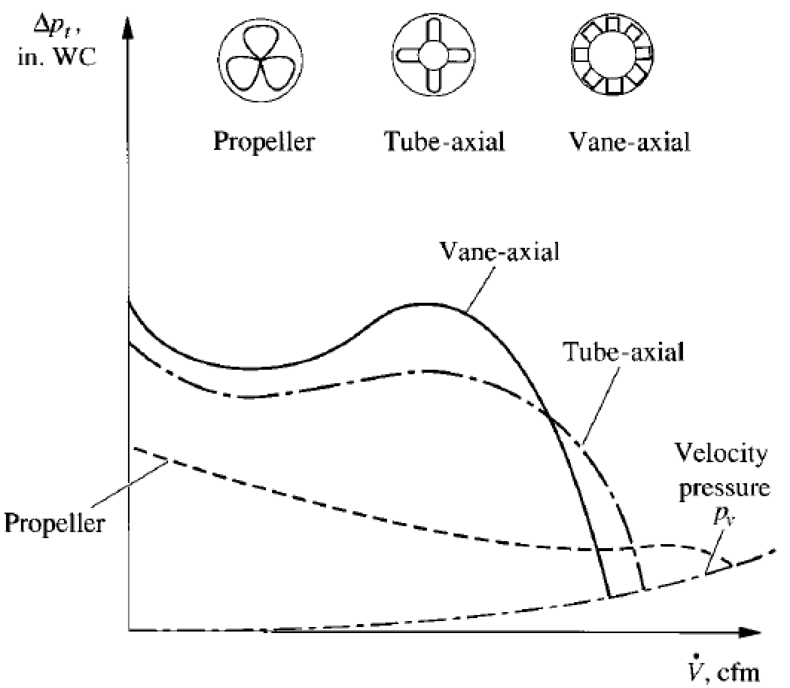


FIGURE 15.13 Pressure-volume Δp_t-$\dot{V}$ for axial fans with the same impeller diameter.

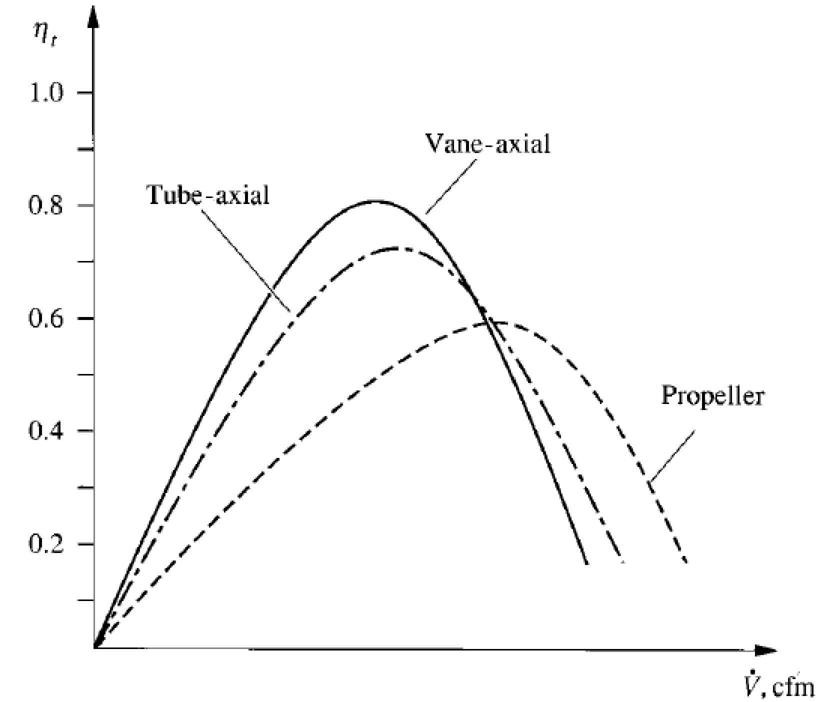
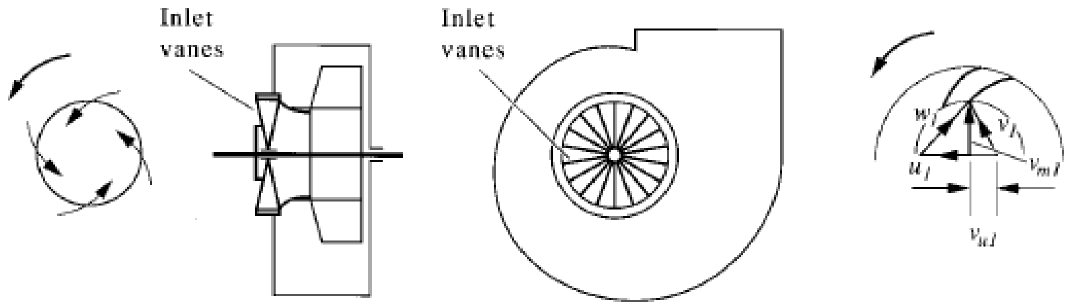


FIGURE 15.14 Total efficiency η_t-$\dot{V}$ curves for axial fans with the same impeller diameter.

Capacity modulation of fans through inlet guide vanes



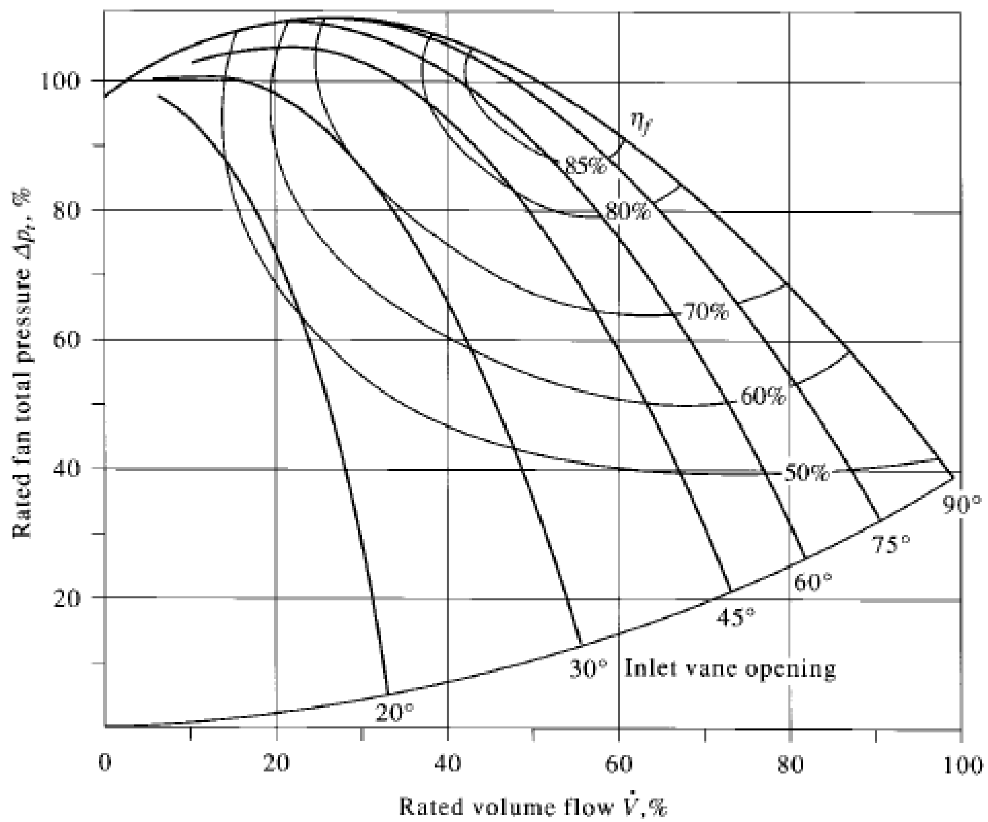
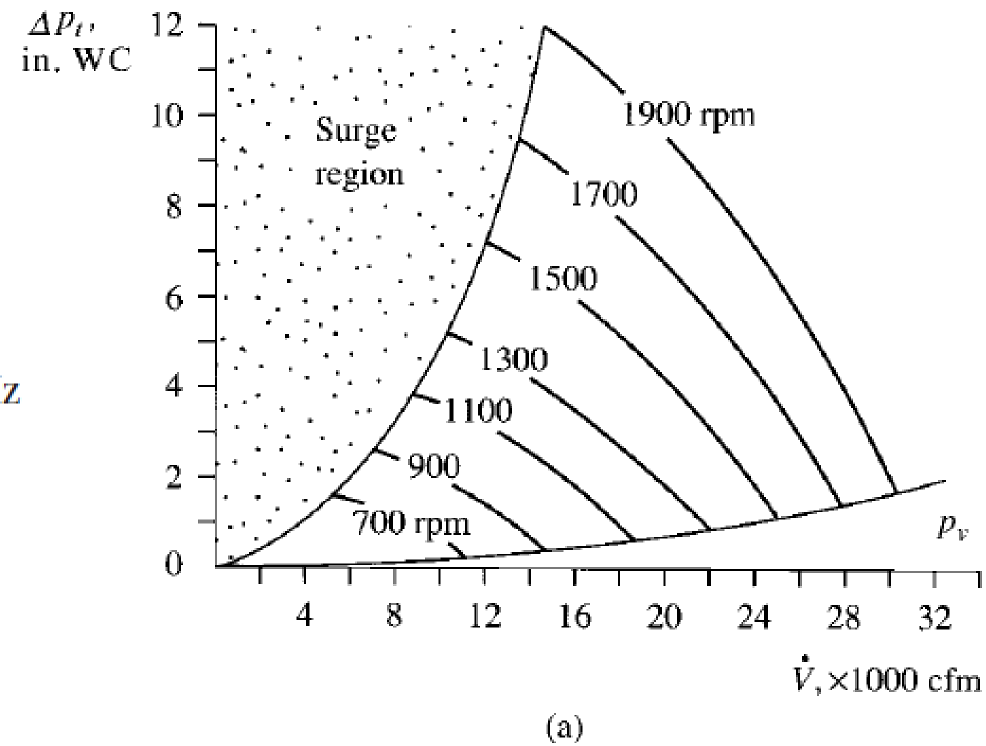


FIGURE 15.18 Inlet vane control of a backward-curved centrifugal fan.

Capacity modulation of fans through speed variation

$$n_m = \frac{120f}{N_p}$$

where f = frequency of applied power, Hz
N_p = number of poles



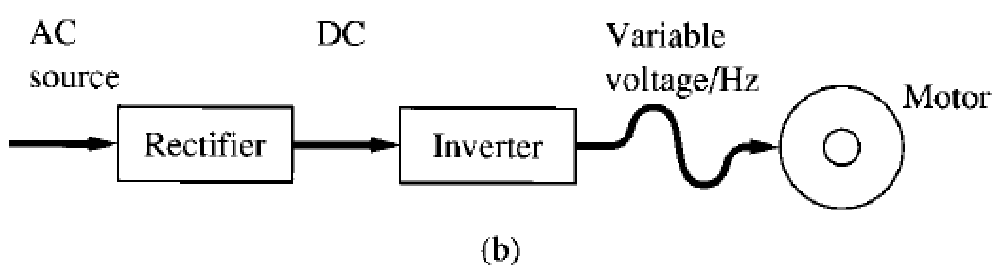


FIGURE 15.17 AC inverter and Δp_t-$\dot{V}$ curves of an airfoil fan at various speeds: (*a*) curves at various speeds; (*b*) ac inverter.

Comparison between different types of fans

TABLE 15.2 Comparison between Various Types of Fans

	Backward, airfoil centrifugal fan	Forward-curved centrifugal fan	Vane-axial	Propeller fan
Fan total pressure Δp_{tf}	Higher Δp_t	Comparatively lower Δp_t	Higher Δp_t	Low Δp_t
Flow rate	All flow rates	Larger flow rate	All flow rates	Larger flow rate
Fan power input	Nonoverloading	Overloading	Nonoverloading	Nonoverloading
Fan modulation	Inlet vanes AC inverter	Inlet vanes AC inverter	Controllable pitch AC inverter	
Fan total efficiency	0.7 to 0.86	0.6 to 0.75	0.7 to 0.88	0.45 to 0.6
Sound power level	Lower, higher L_w at low frequencies	Medium, higher L_w at low frequencies	Medium, difference of L_w values is small at various Hz	Higher, higher L_w at high frequencies
Airflow direction	90° turn	90° turn	Parallel to axle	Parallel to axle
Volume and weight	Greater	Less	Greater	Medium volume and lower weight
Initial cost	Higher	Medium	Higher	Low
Applications	Large HVAC&R systems	Lower pressure, small HVAC&R systems	Large HVAC&R systems	Low-pressure, high-volume flow exhaust systems

Fan laws

$$Flow\ rate, Q = AV \Rightarrow Q \propto D^3N, \because A \propto D^2 \ \&\ V \propto ND$$

$$Pressure\ rise, P = \rho u_2^2 \Rightarrow P \propto \rho D^2N^2, \because u_2^2 \propto ND$$

$$Power\ input, W = PQ \Rightarrow W \propto \rho D^5N^3$$

Fan Law: Set 1 Independent variables: ***ρ, D & N*** Dependent variables: ***P, Q & W***	Fan Law: Set 2 Independent variables: ***ρ, D & P*** Dependent variables: ***N, Q & W***	Fan Law: Set 3 Independent variables: ***ρ, D & Q*** Dependent variables: ***N, P & W***
$Q_1 = Q_2\left(\frac{D_1}{D_2}\right)^3\left(\frac{N_1}{N_2}\right)$ $P_1 = P_2\left(\frac{D_1}{D_2}\right)^2\left(\frac{N_1}{N_2}\right)^2\left(\frac{\rho_1}{\rho_2}\right)$ $W_1 = W_2\left(\frac{D_1}{D_2}\right)^5\left(\frac{N_1}{N_2}\right)^3\left(\frac{\rho_1}{\rho_2}\right)$	$Q_1 = Q_2\left(\frac{D_1}{D_2}\right)^2\left(\frac{P_1}{P_2}\right)^{(1/2)}\left(\frac{\rho_2}{\rho_1}\right)^{(1/2)}$ $N_1 = N_2\left(\frac{D_2}{D_1}\right)\left(\frac{P_1}{P_2}\right)^{(1/2)}\left(\frac{\rho_2}{\rho_1}\right)^{(1/2)}$ $W_1 = W_2\left(\frac{D_1}{D_2}\right)^2\left(\frac{P_1}{P_2}\right)^{(3/2)}\left(\frac{\rho_2}{\rho_1}\right)^{(1/2)}$	$N_1 = N_2\left(\frac{D_2}{D_1}\right)^3\left(\frac{Q_1}{Q_2}\right)$ $P_1 = P_2\left(\frac{D_2}{D_1}\right)^4\left(\frac{Q_1}{Q_2}\right)^2\left(\frac{\rho_1}{\rho_2}\right)$ $W_1 = W_2\left(\frac{D_2}{D_1}\right)^4\left(\frac{Q_1}{Q_2}\right)^3\left(\frac{\rho_1}{\rho_2}\right)$

Fan and duct interactions