# Fans and Pumps II

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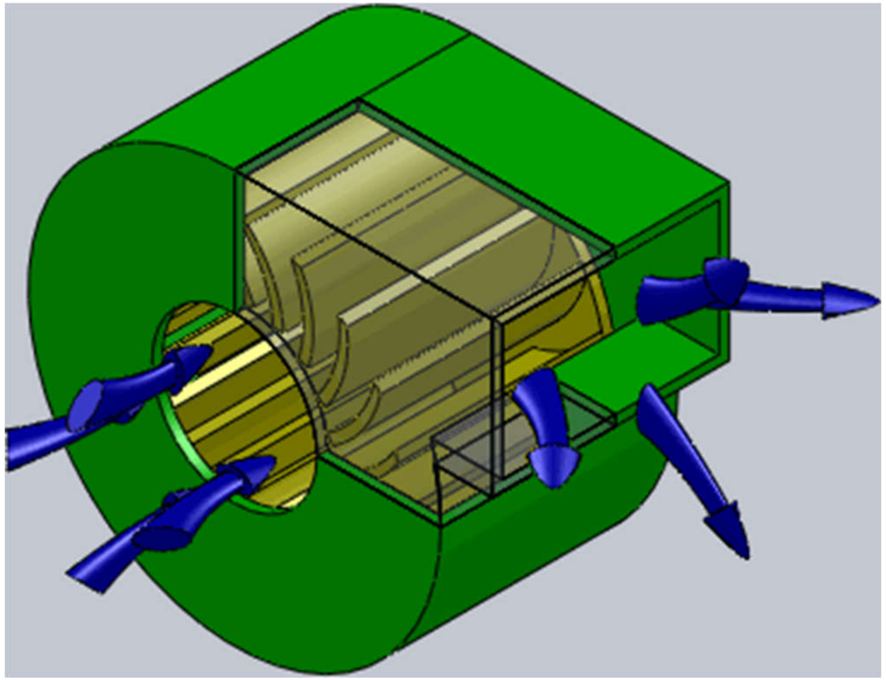
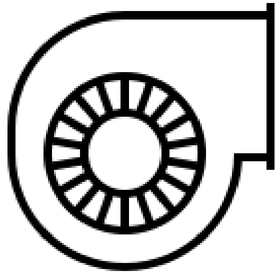
# Contents

- Fan Design
- Fan Performance
- Fan-duct Systems
- Duct Construction
- Air Duct Design



# Fan Design

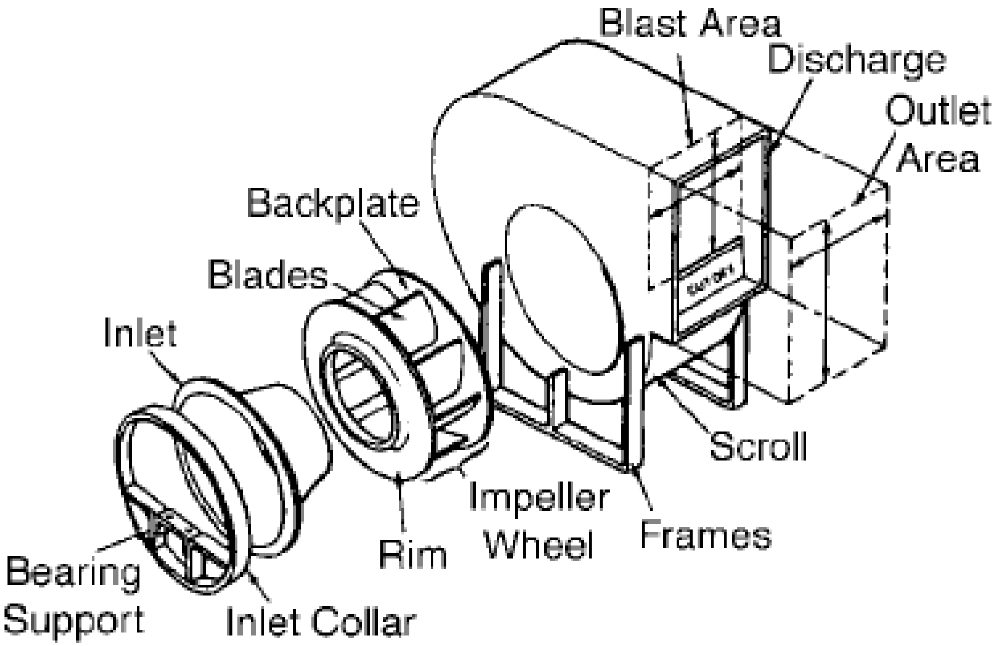



- Common types of fans
  - **Centrifugal fans**: radial, forward curved, air foil (backward curved), backward inclined, tubular, roof ventilator
  - **Axial fans**: propeller, tube-axial, vane-axial
- Fan arrangements
  - Motor location, air discharge orientation, drive train type (direct drive or pulley drive)
  - Centrifugal: single width single inlet (SWSI), double width double inlet (DWDI)

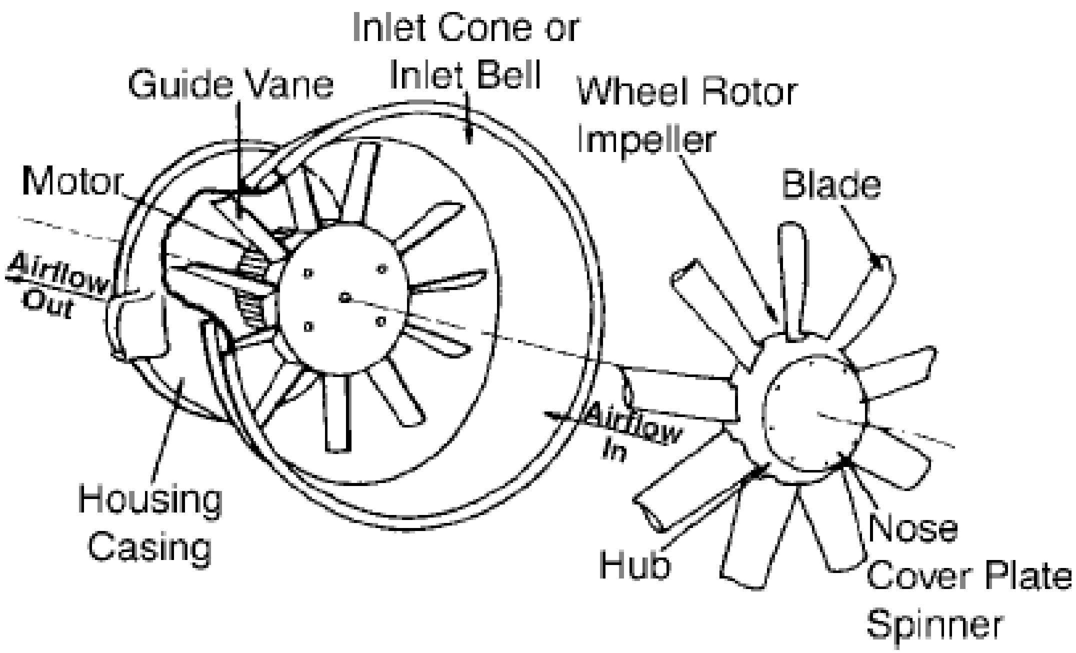
(See also: Centrifugal fan http://en.wikipedia.org/wiki/Centrifugal_fan)

# Centrifugal and axial fan components

## CENTRIFUGAL FANS

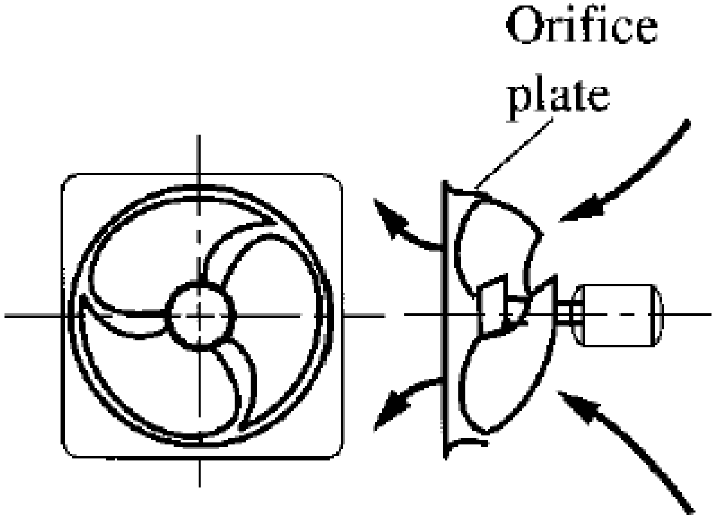



## AXIAL FANS

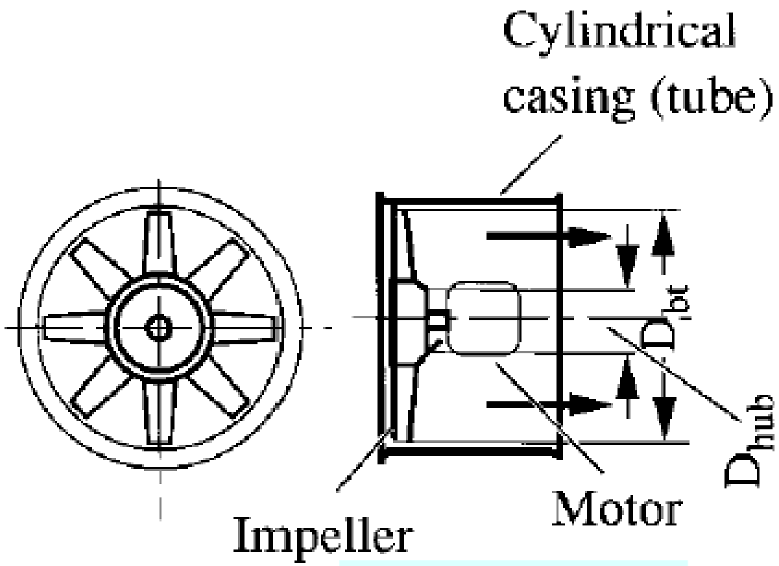



[Source: Kreider, K. F. (ed.), 2001. *Handbook of Heating, Ventilation, and Air Conditioning*, CRC Press, Boca Raton, FL.]

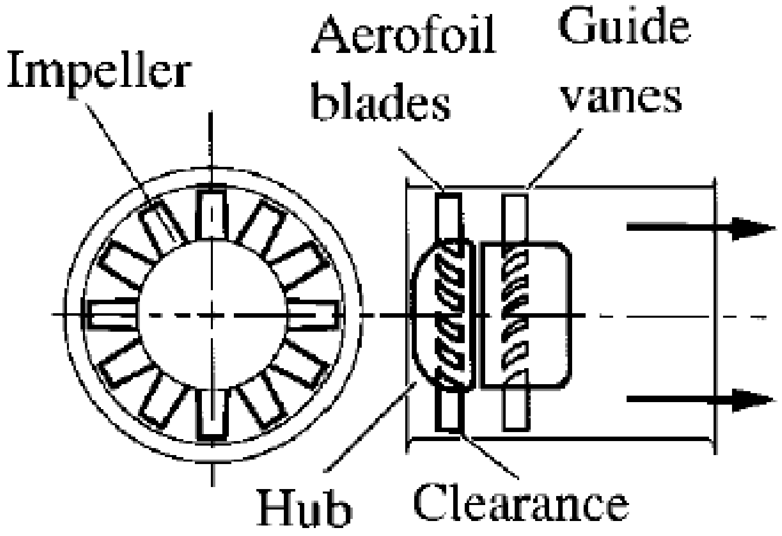
# Axial fans




Propeller



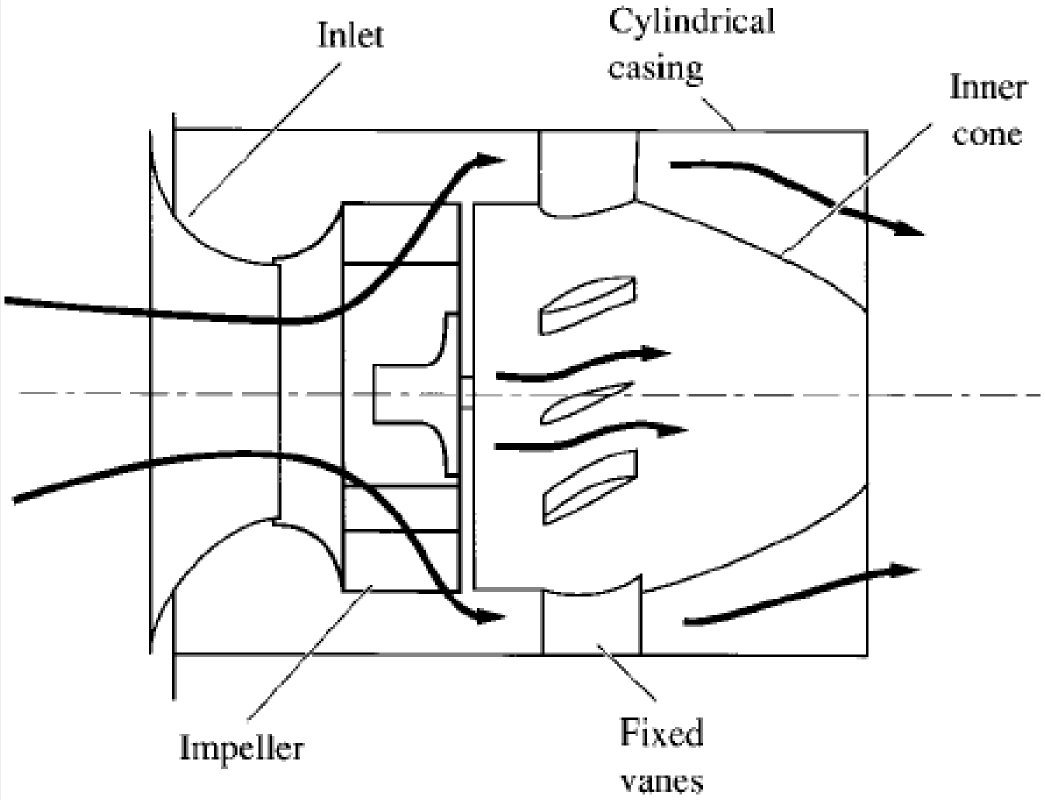

Tube-axial



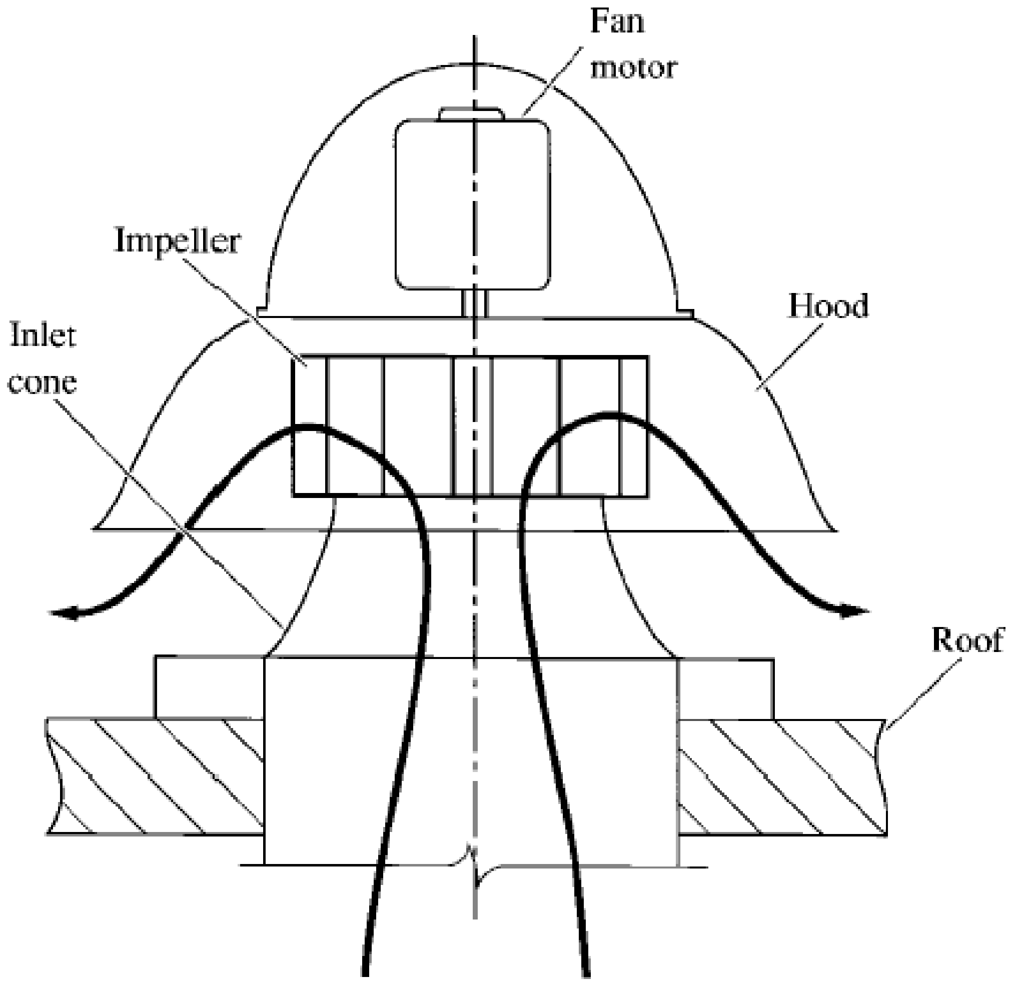

Tube-vane

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Centrifugal fans




Tubular centrifugal fan

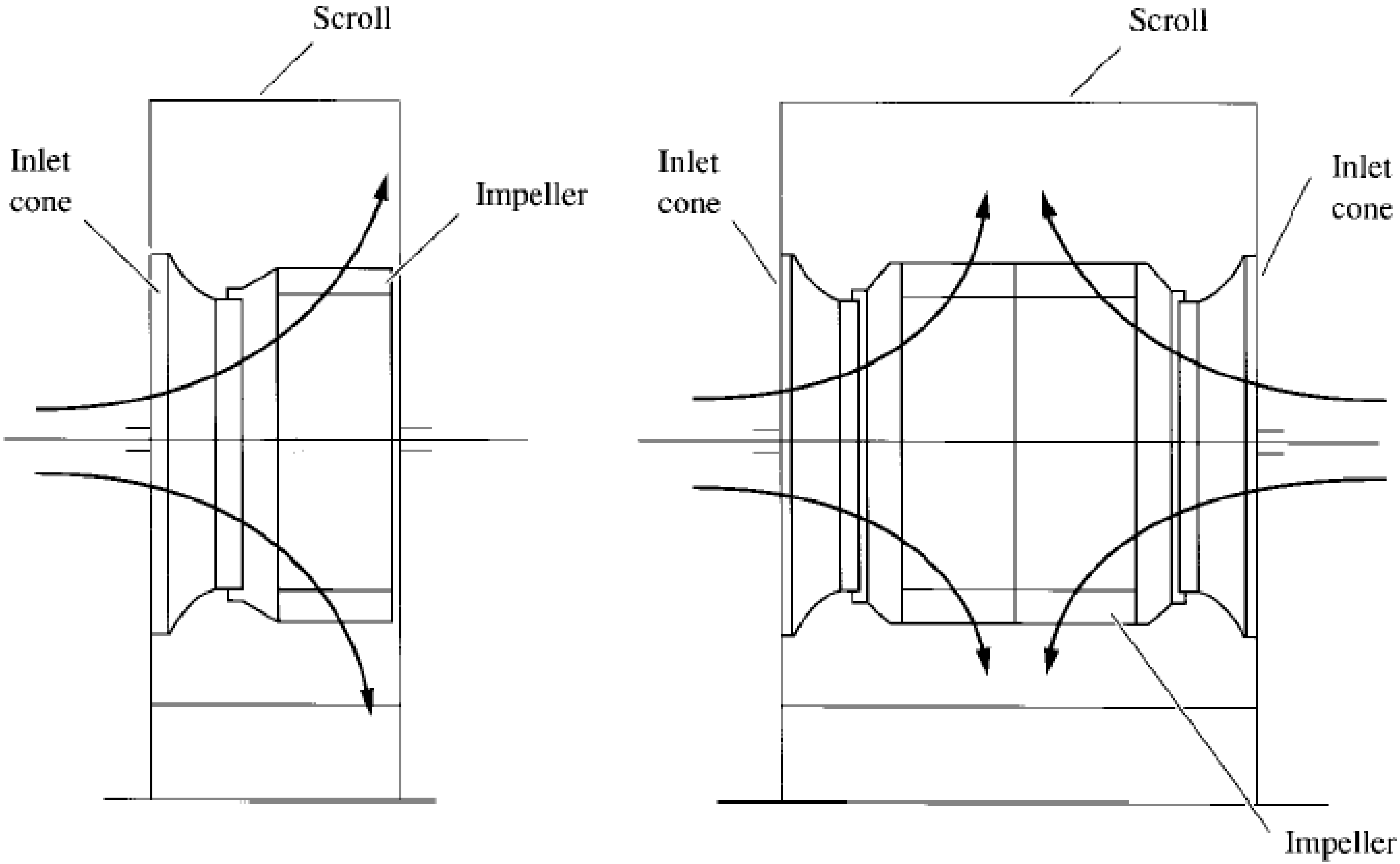



Centrifugal roof ventilator

(* Note the airflow paths and impeller design.)

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

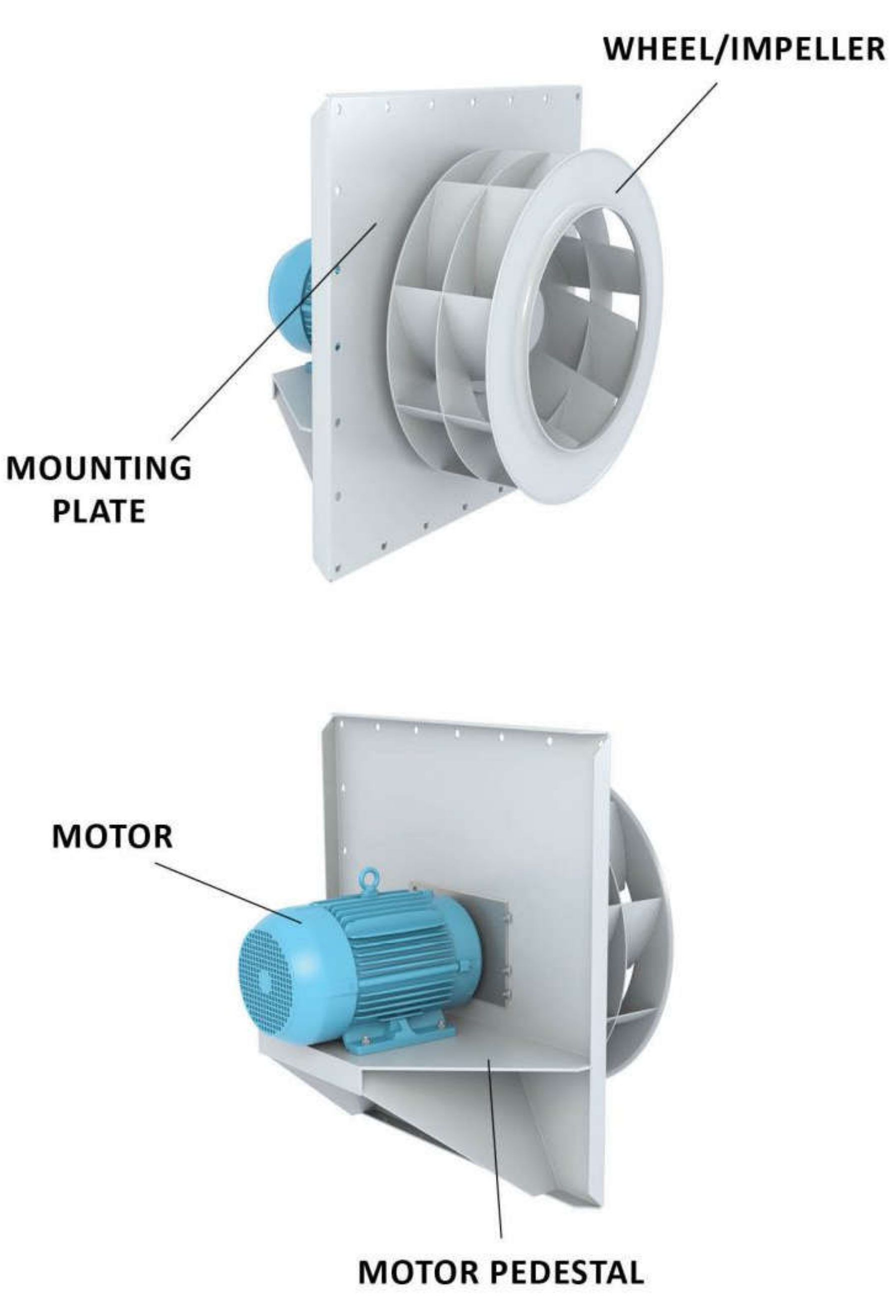
# Single- and double-width centrifugal fans



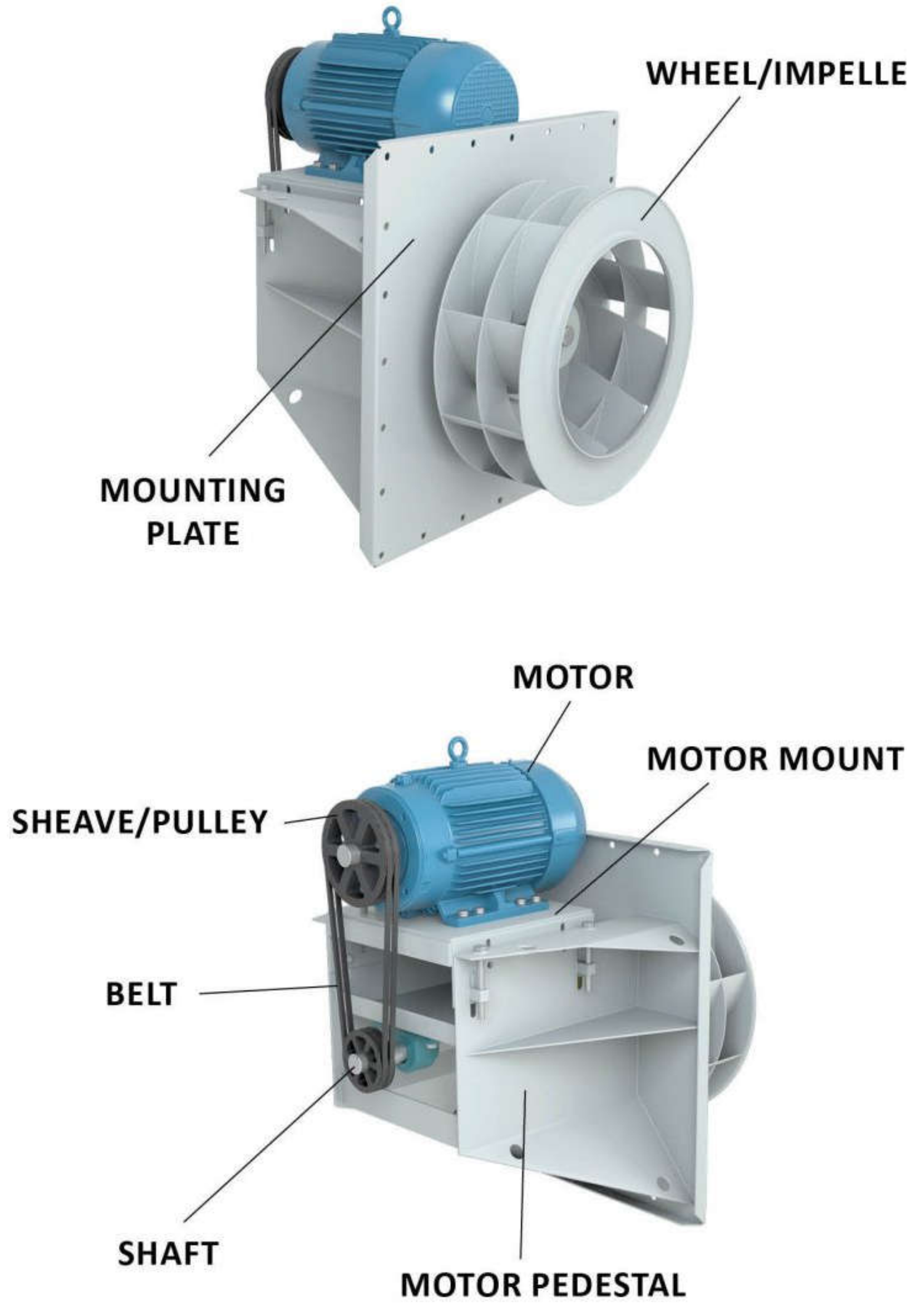

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Plug fans (also known as plenum or unhoused centrifugal fans)

## DIRECT DRIVE PLUG FANS

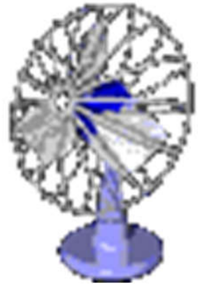



## BELT DRIVEN PLUG FANS



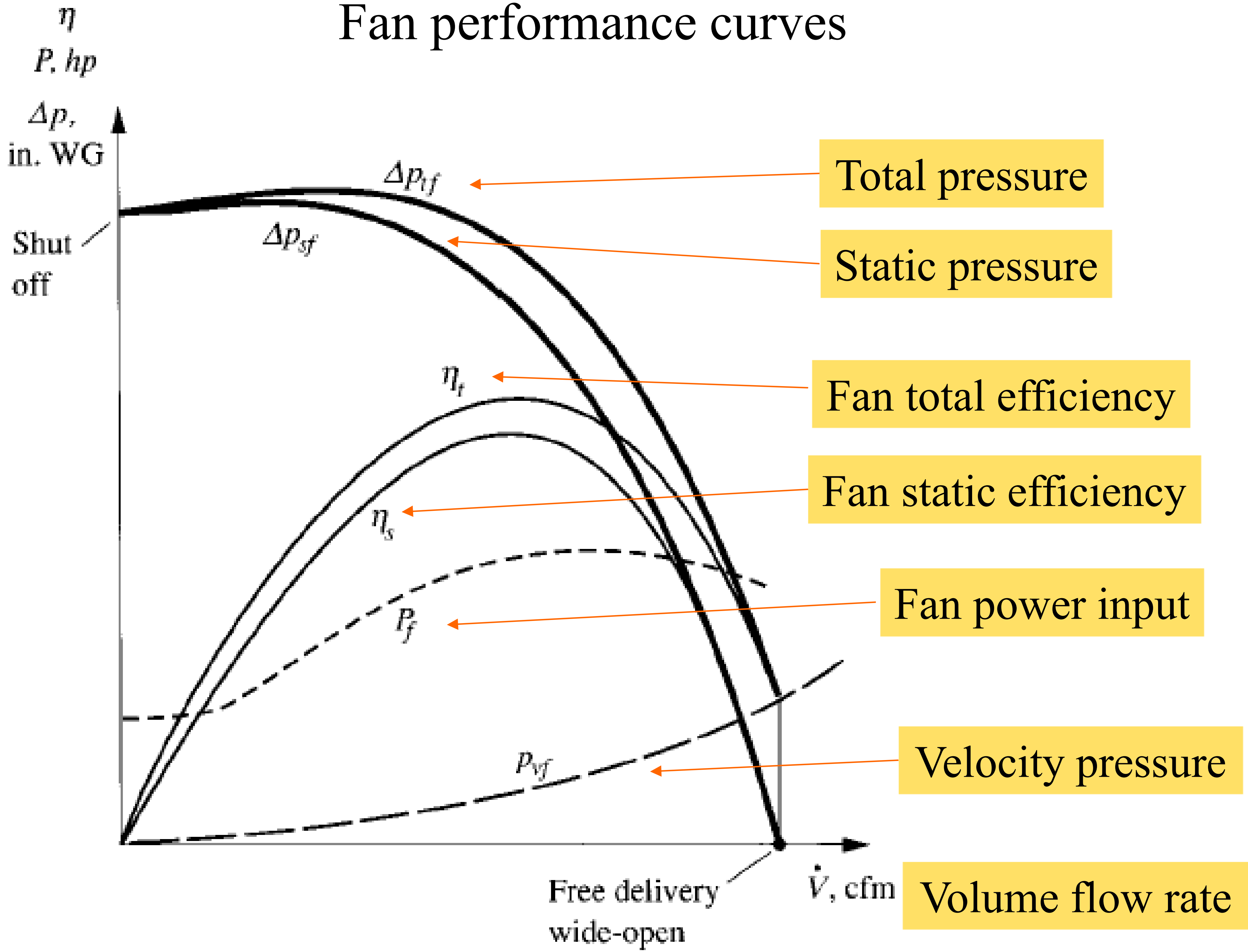

(Source: Plug fans https://www.tcf.com/products/plug/)

# Fan Performance



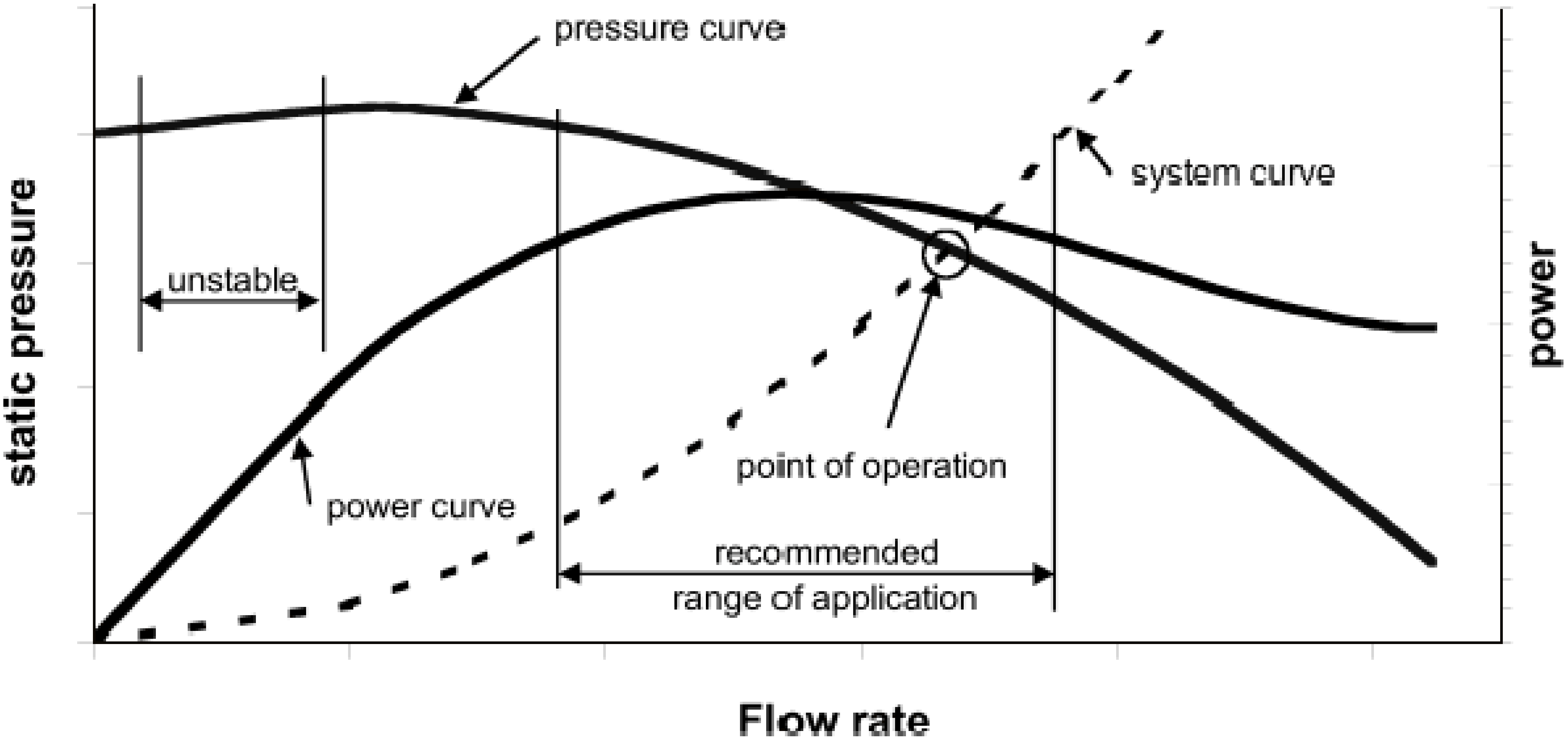
- Major parameters
  - Fan volume flow rate ($m^3/s$ or l/s), $V_f$
  - Fan total pressure $\Delta p_{tf}$, fan velocity pressure $p_{vf}$ & fan static pressure $\Delta p_{sf}$ (Pa)
  - Fan power & efficiency
    - Fan power or air power (W) = $\Delta p_{tf} \times V_f$
    - Fan power input on the fan shaft (brake horsepower), $P_f$
    - Fan total efficiency: $\eta_t = \Delta p_{tf} \times V_f / P_f$
      - Combined aerodynamic, volumetric & mechanical efficiencies
    - Fan static efficiency: $\eta_s = \Delta p_{sf} \times V_f / P_f$
    - Air temp. increase through fan, $\Delta T_f = \Delta p_{tf} / (\rho c_{pa} \eta_t)$

# Fan performance curves



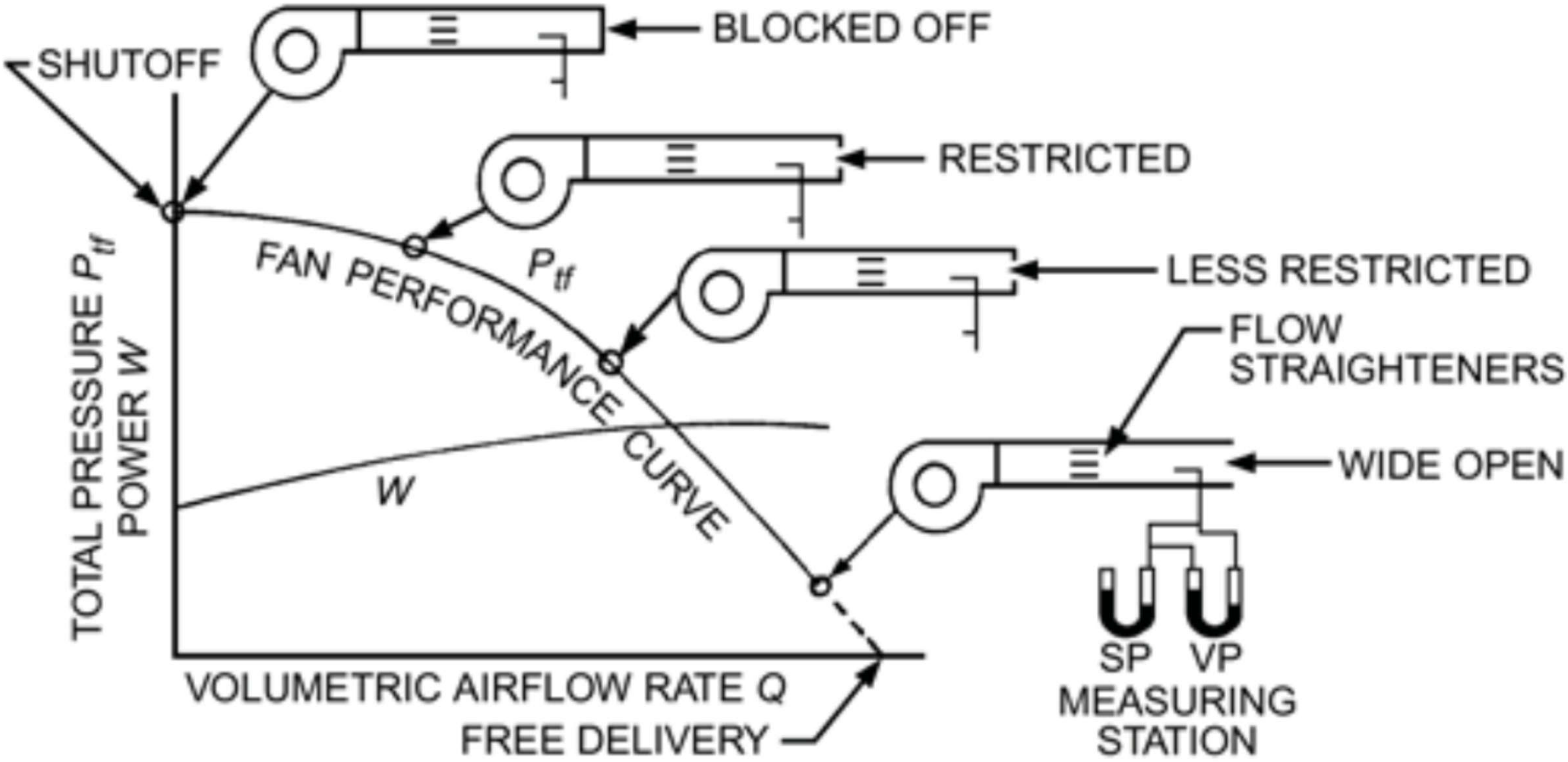

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# System and fan operating point



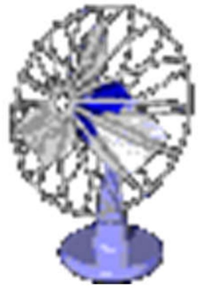

[Source: Kreider, K. F. (ed.), 2001. *Handbook of Heating, Ventilation, and Air Conditioning*, CRC Press, Boca Raton, FL.]

# Method of obtaining fan performance curves




(Source: *ASHRAE Handbook HVAC Systems & Equipment 2016*, Chp. 21)

# Fan Performance



- **Fan Laws**
  - Speed ($n$)
  - Volume flow ($V$)
  - Total pressure loss ($\Delta p$ )
  - Air density ($\rho$)
  - For air systems that are geometrically & dynamically similar: (D = impeller diameter)
- c.f.: pump laws

$$\mathring{V}_2 / \mathring{V}_1 = n_2 / n_1$$

$$\Delta p_{t2} / \Delta p_{t1} = \left(n_2 / n_1\right)^2 \left(\rho_2 / \rho_1\right)$$

$$P_2 / P_1 = \left(n_2 / n_1\right)^3 \left(\rho_2 / \rho_1\right)$$

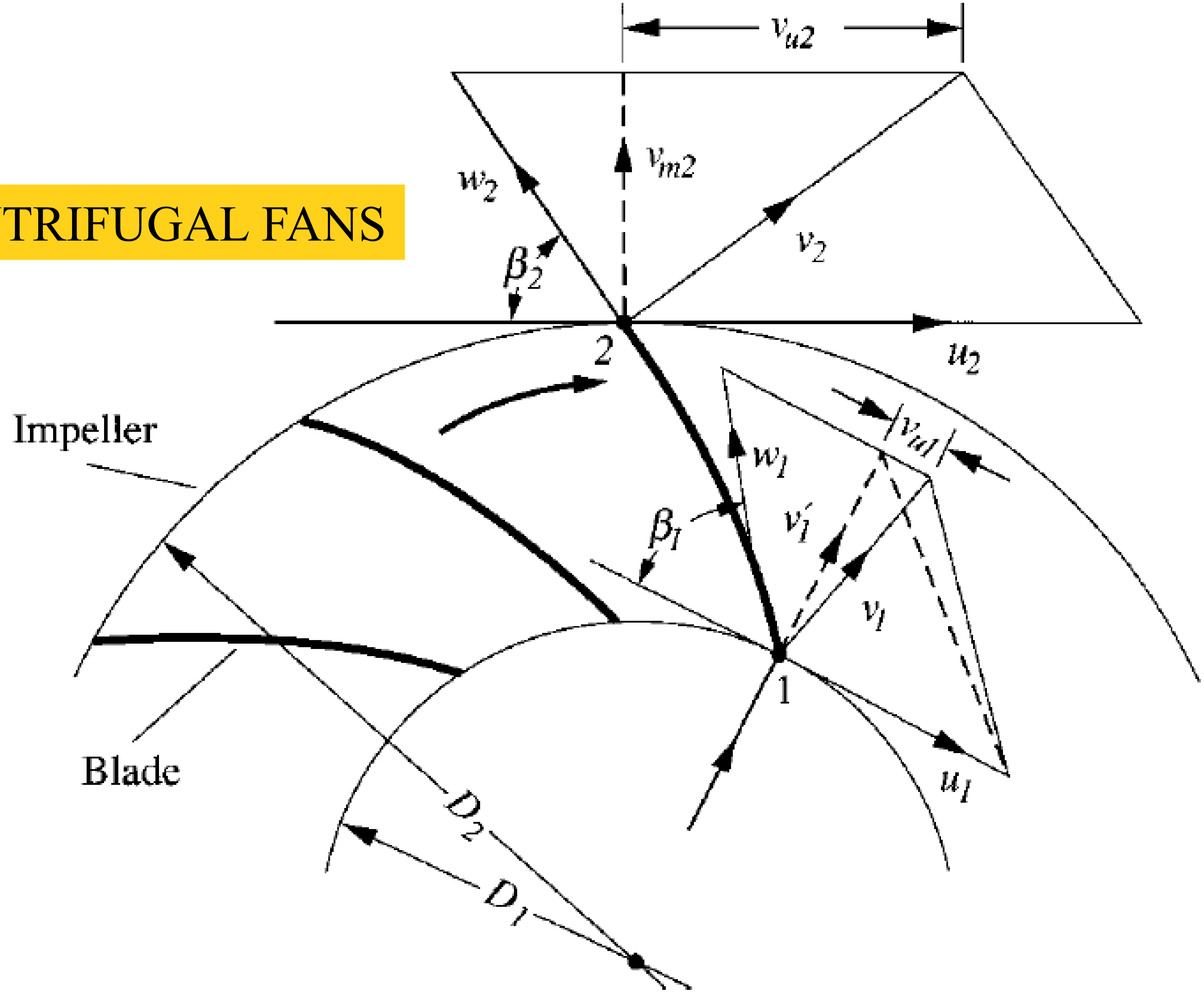
$$\mathring{V}_2 / \mathring{V}_1 = \left(D_2 / D_1\right)^3 \left(n_2 / n_1\right)$$

$$\Delta p_{t2} / \Delta p_{t1} = \left(D_2 / D_1\right)^2 \left(n_2 / n_1\right)^2 \left(\rho_2 / \rho_1\right)$$

$$P_2 / P_1 = \left(D_2 / D_1\right)^5 \left(n_2 / n_1\right)^3 \left(\rho_2 / \rho_1\right)$$

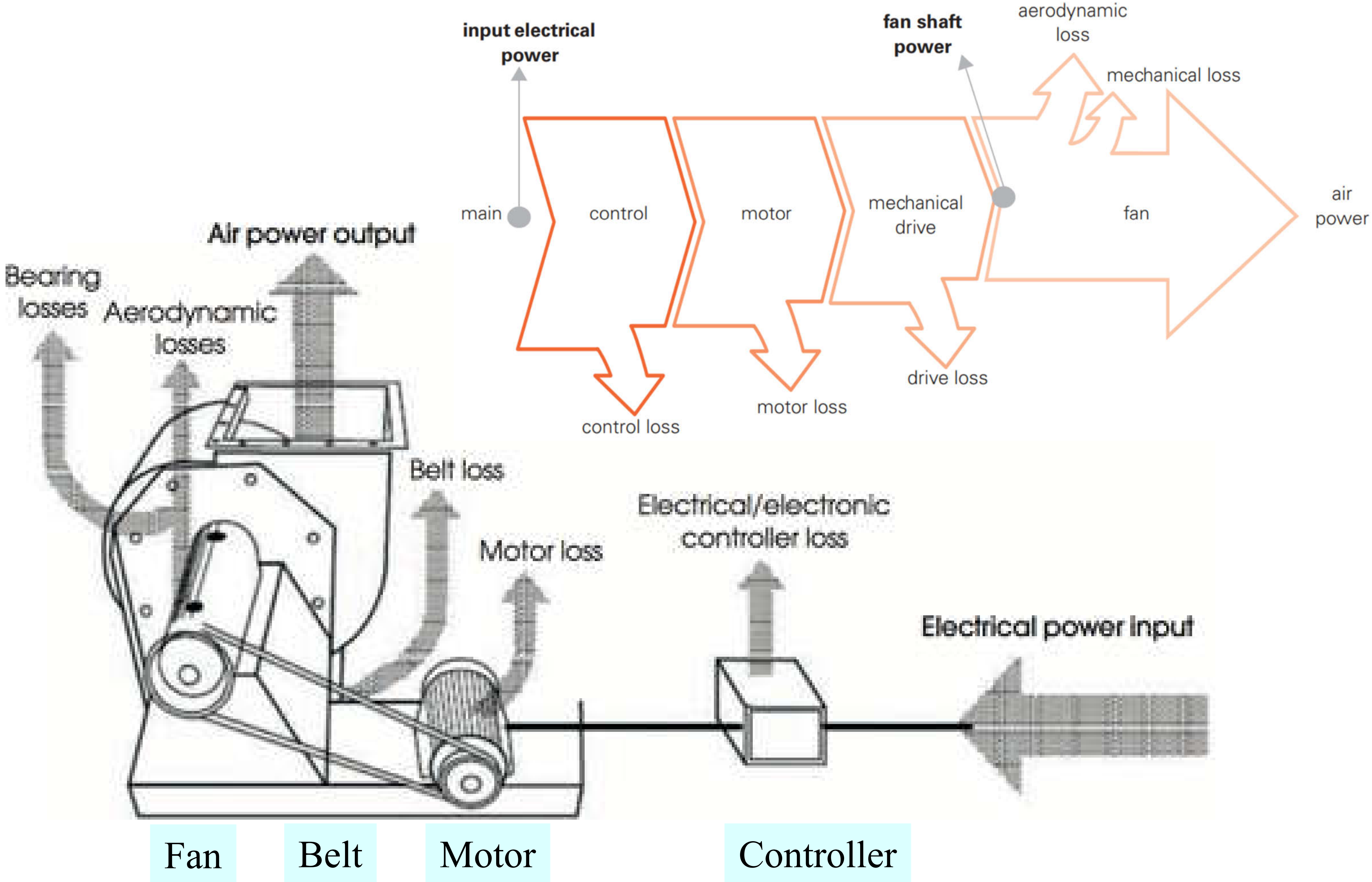
# Velocity triangle at the blade inlet and outlet of a centrifugal fan

CENTRIFUGAL FANS



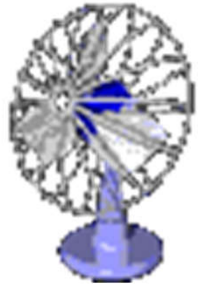

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Losses from the whole fan subsystem and overall fan efficiency



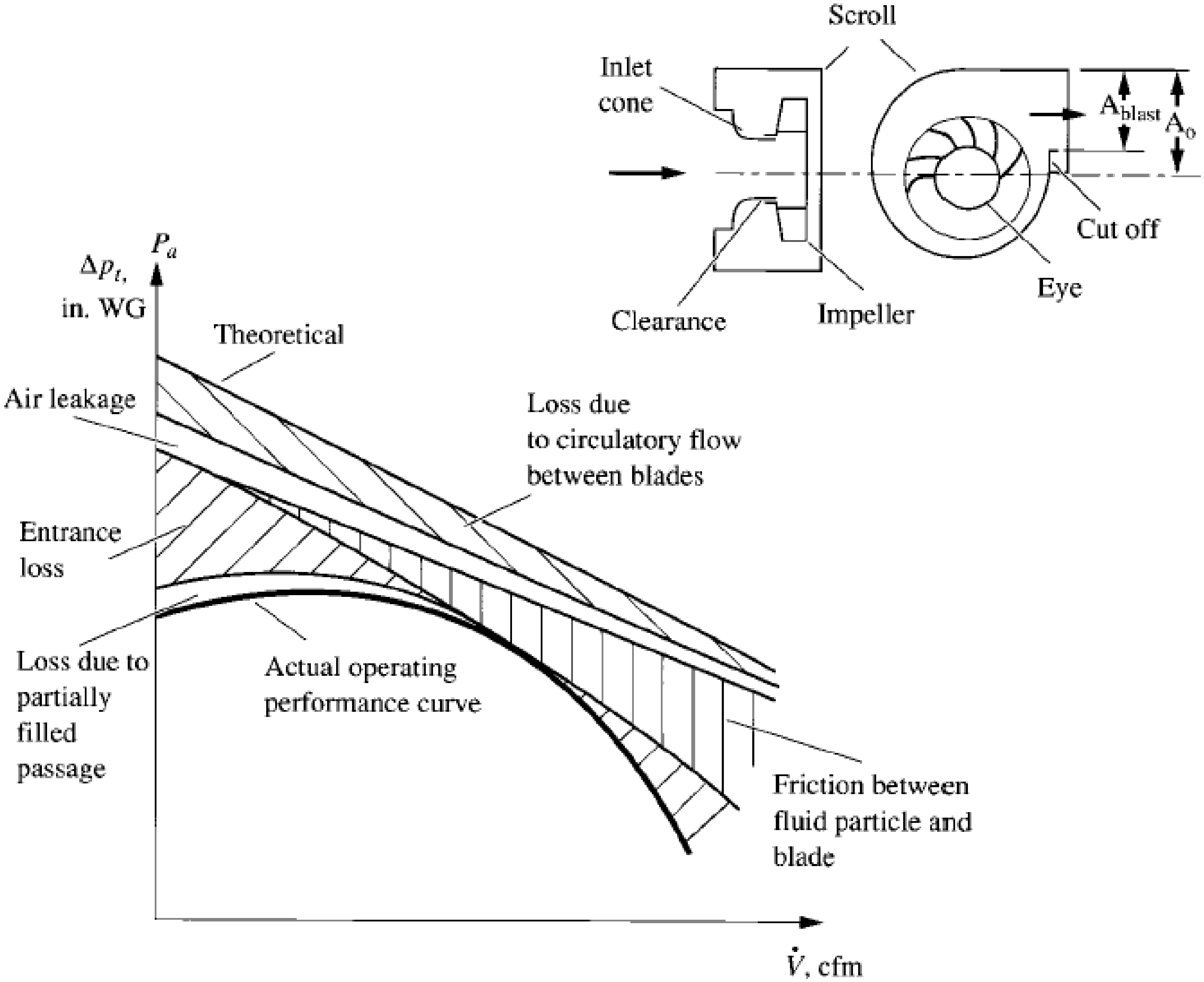

(Source: https://www.cibsejournal.com/cpd/modules/2011-11/; FANtastic! A Closer Look At Fan Efficiency Metrics (Trane Engineers Newsletter volume 43 –3) [PDF])

# Fan Performance



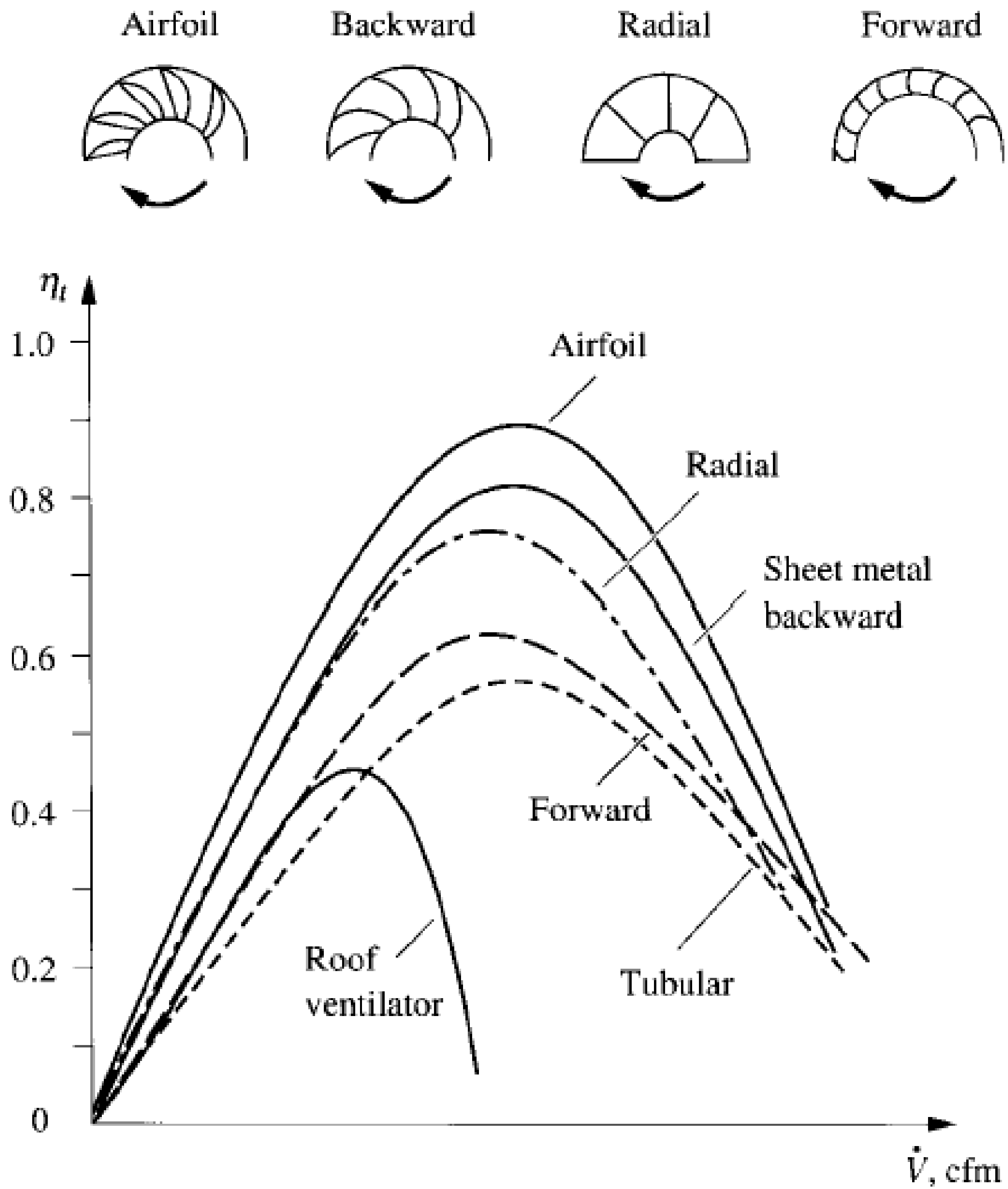
- Major issues causing energy losses to a centrifugal fan:
  - Circulatory flow between the blades
  - Air leakage at the inlet
  - Friction between fluid particles and the blade
  - Energy loss at the entrance
  - Partially filled passage

# Operating characteristics for a backward-curved centrifugal fan



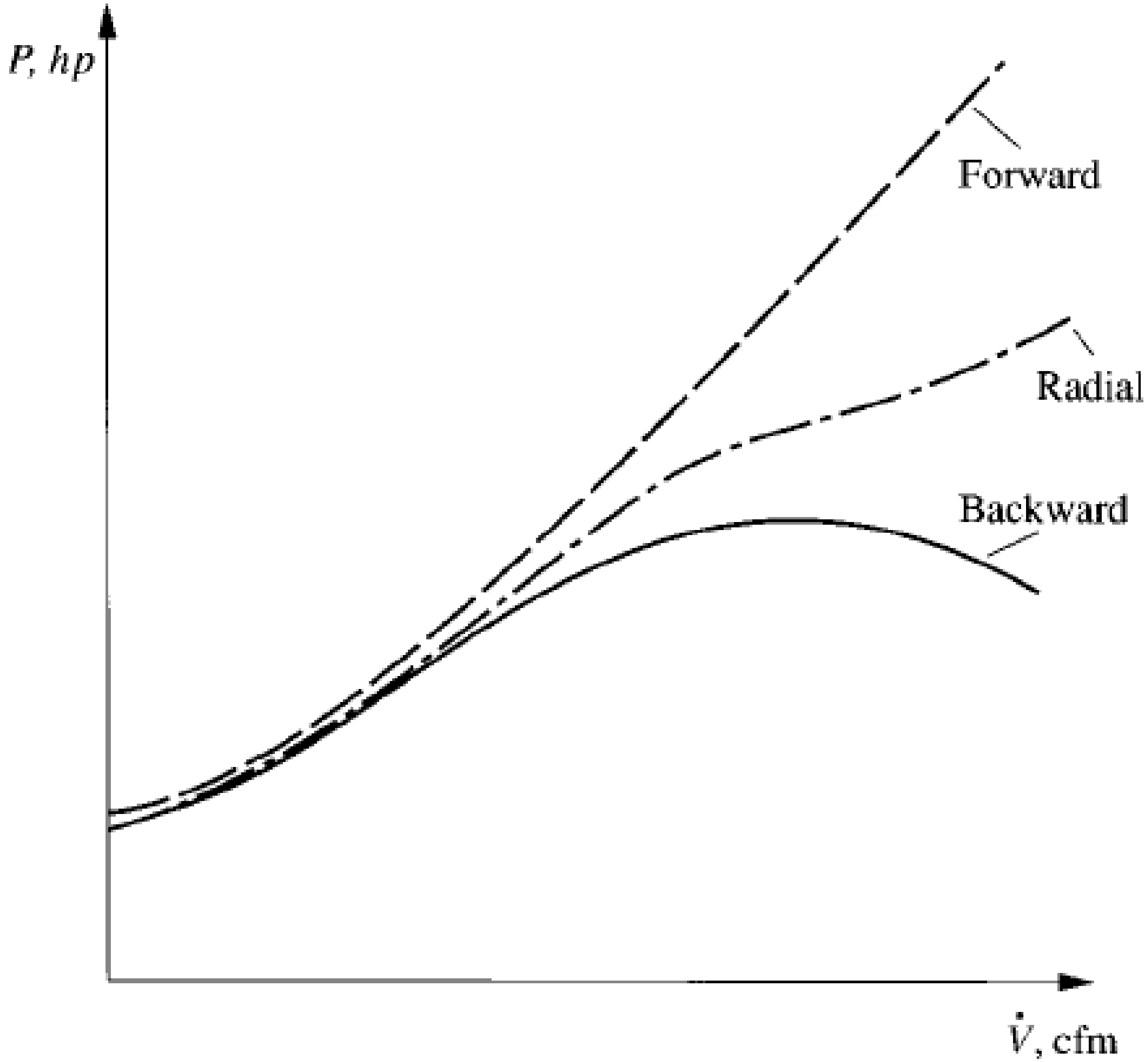

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Total efficiency curves for centrifugal fans



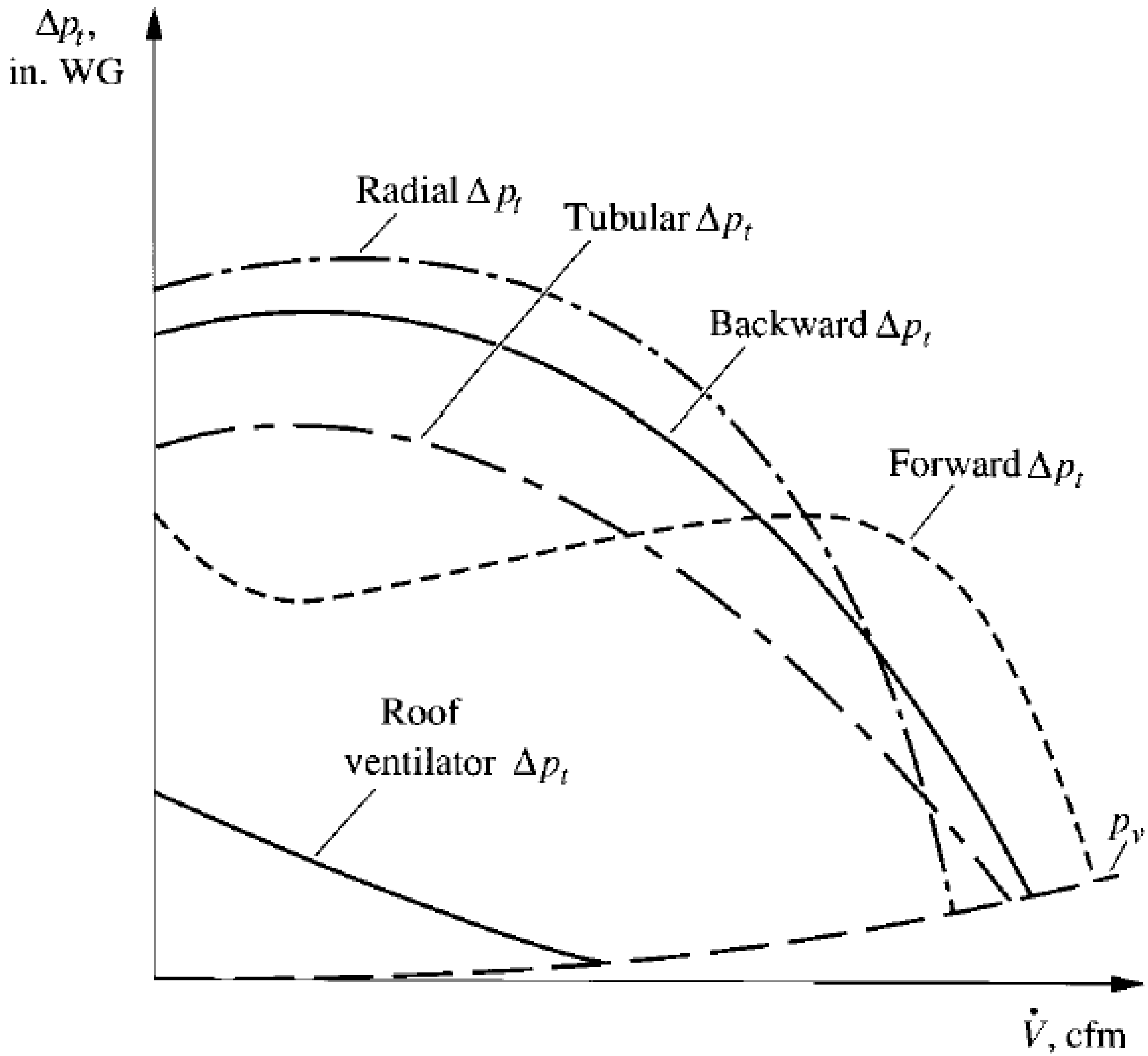

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan power curves for centrifugal fans with same impeller diameter




(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

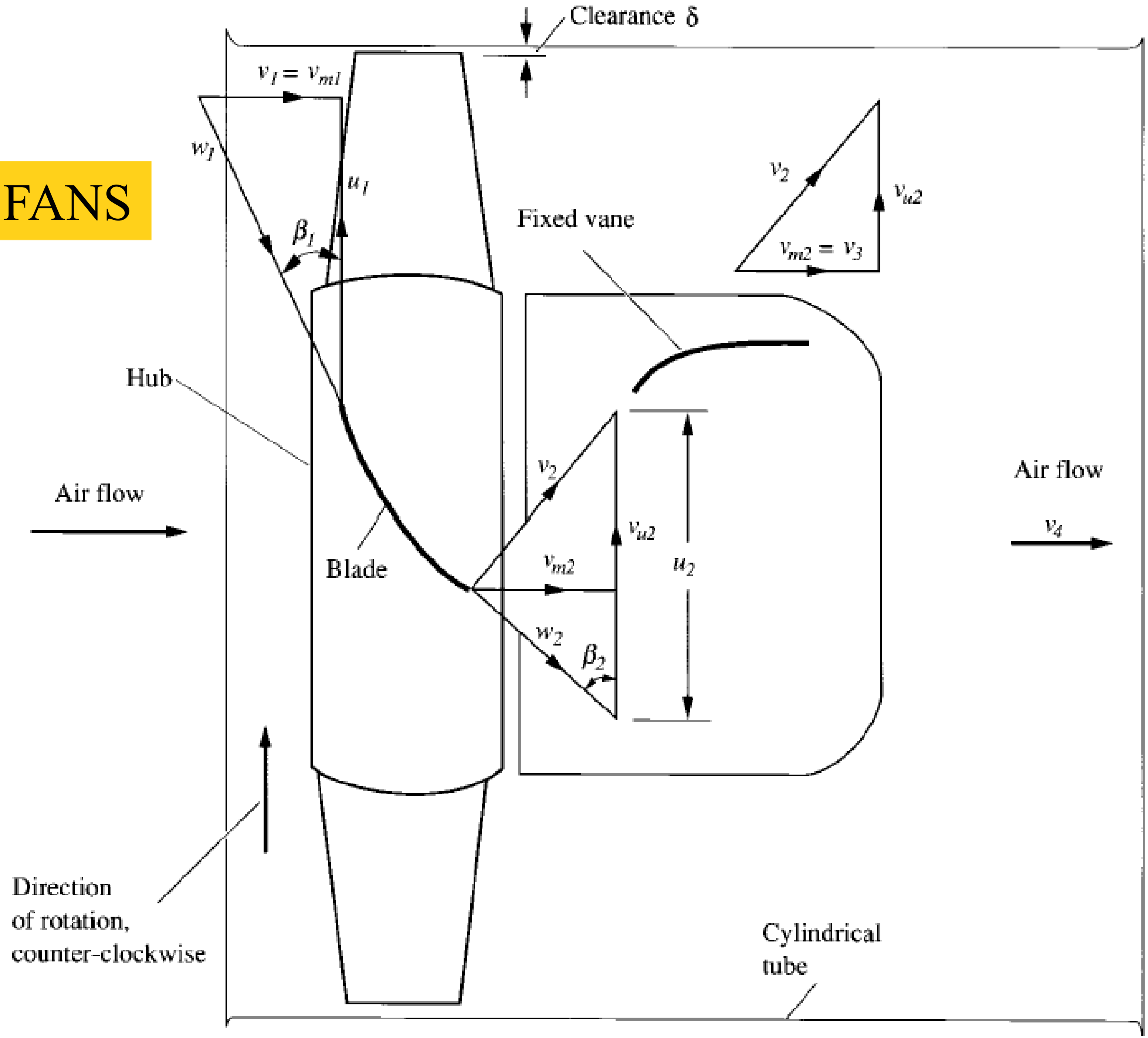
# Fan pressure curves for centrifugal fans with same impeller diameter




(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

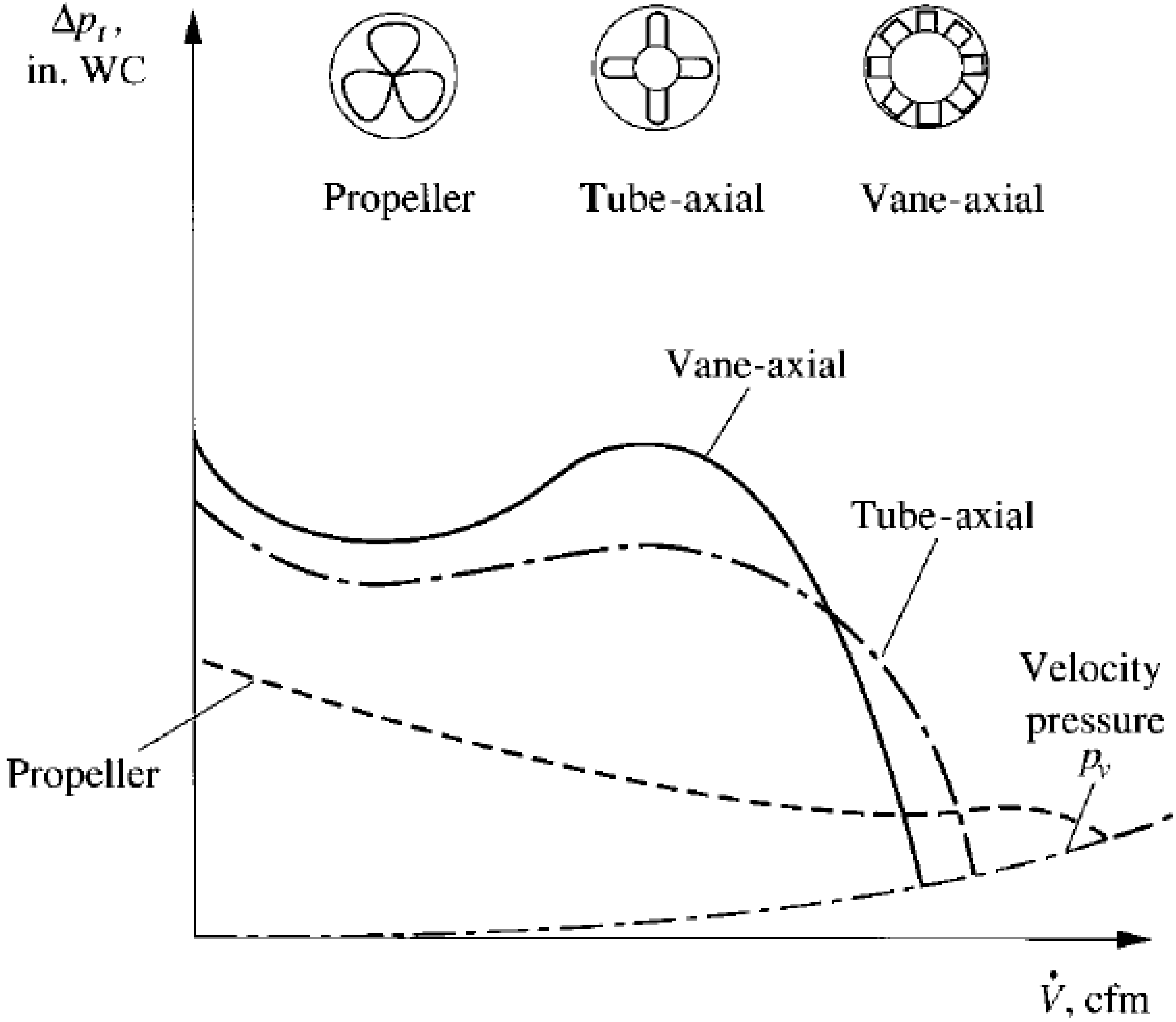
# Velocity triangles for a vane-axial fan

AXIAL FANS



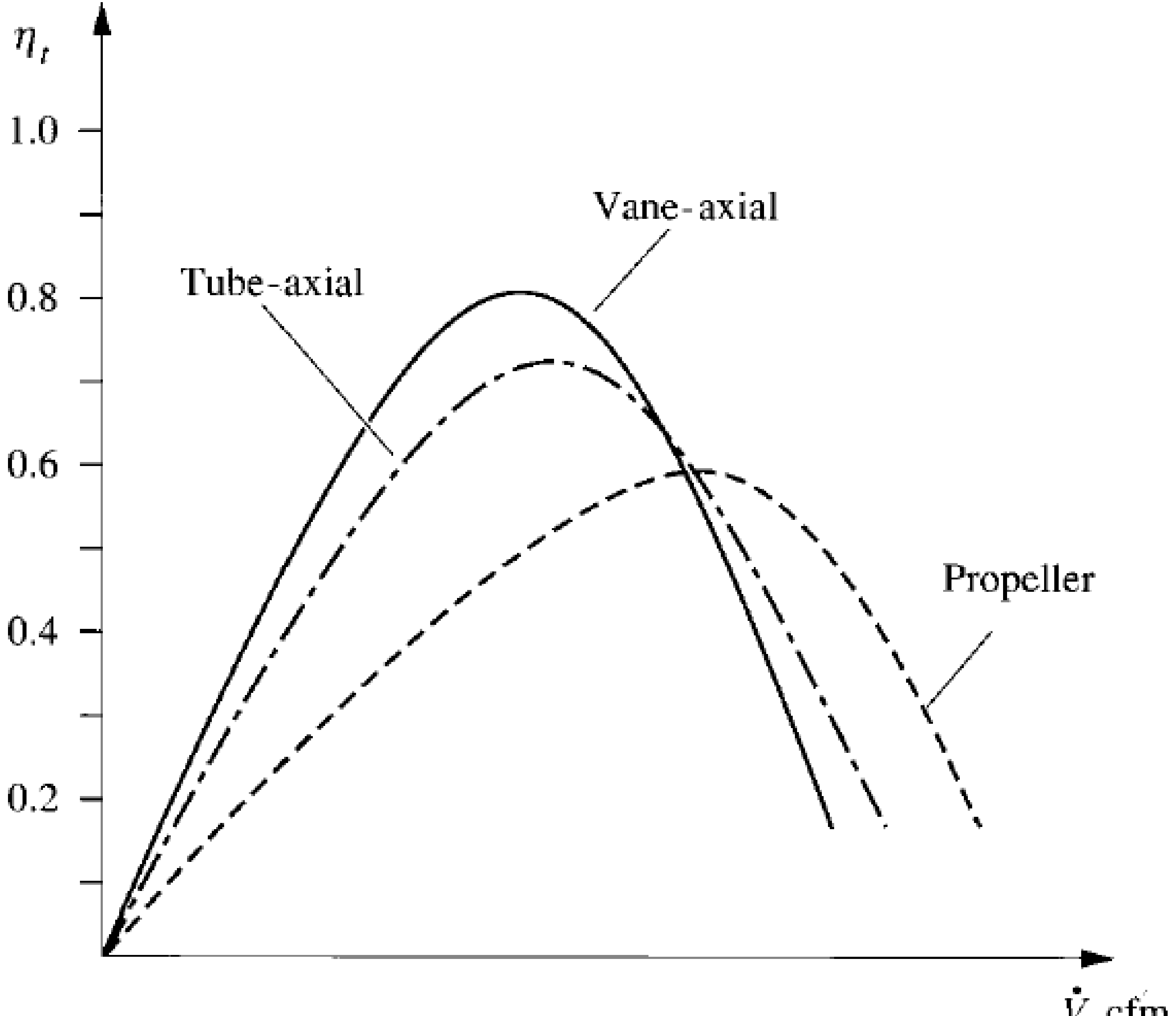

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan pressure curves for axial fans with same impeller diameter



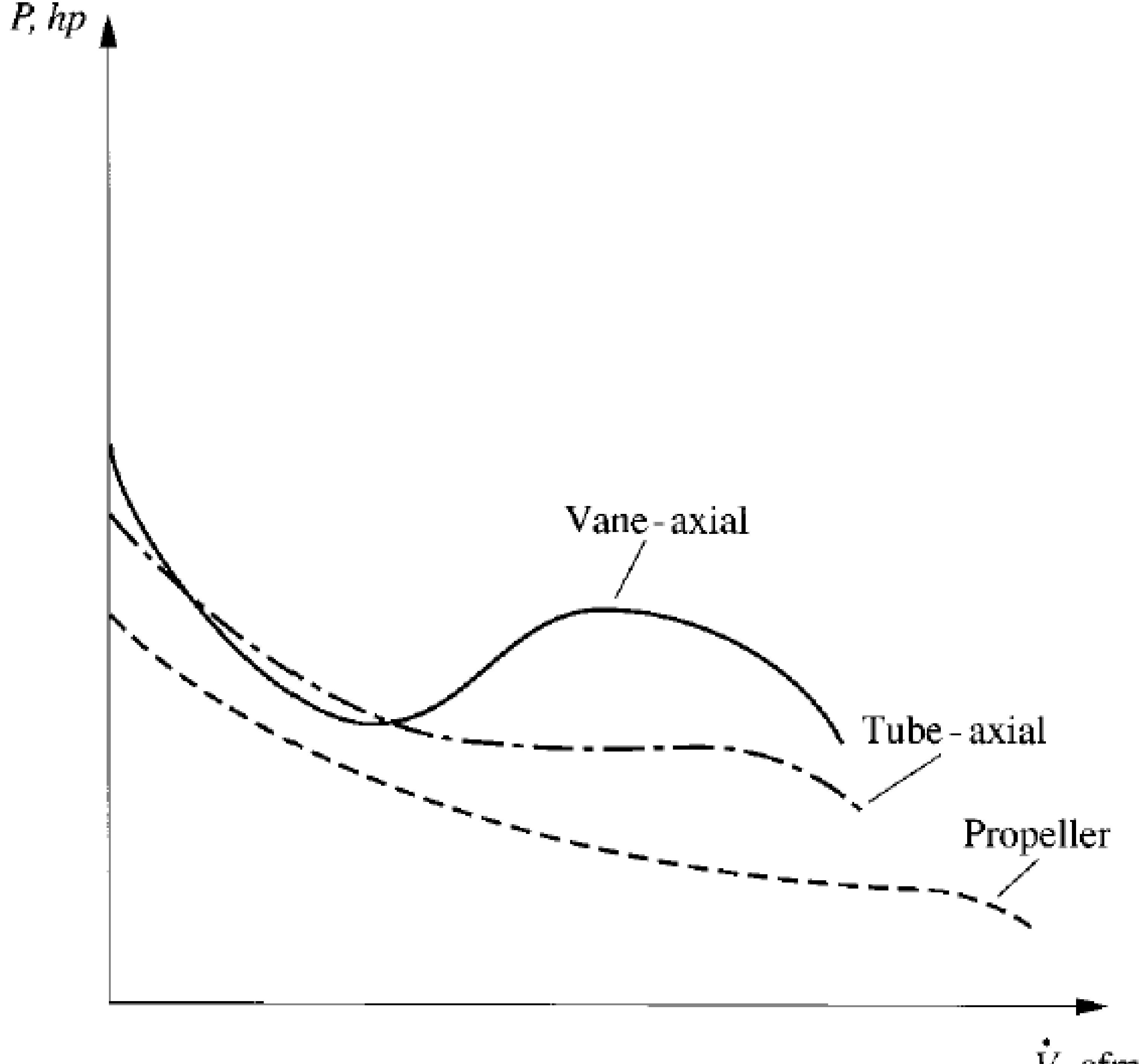

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan efficiency curves for axial fans with same impeller diameter



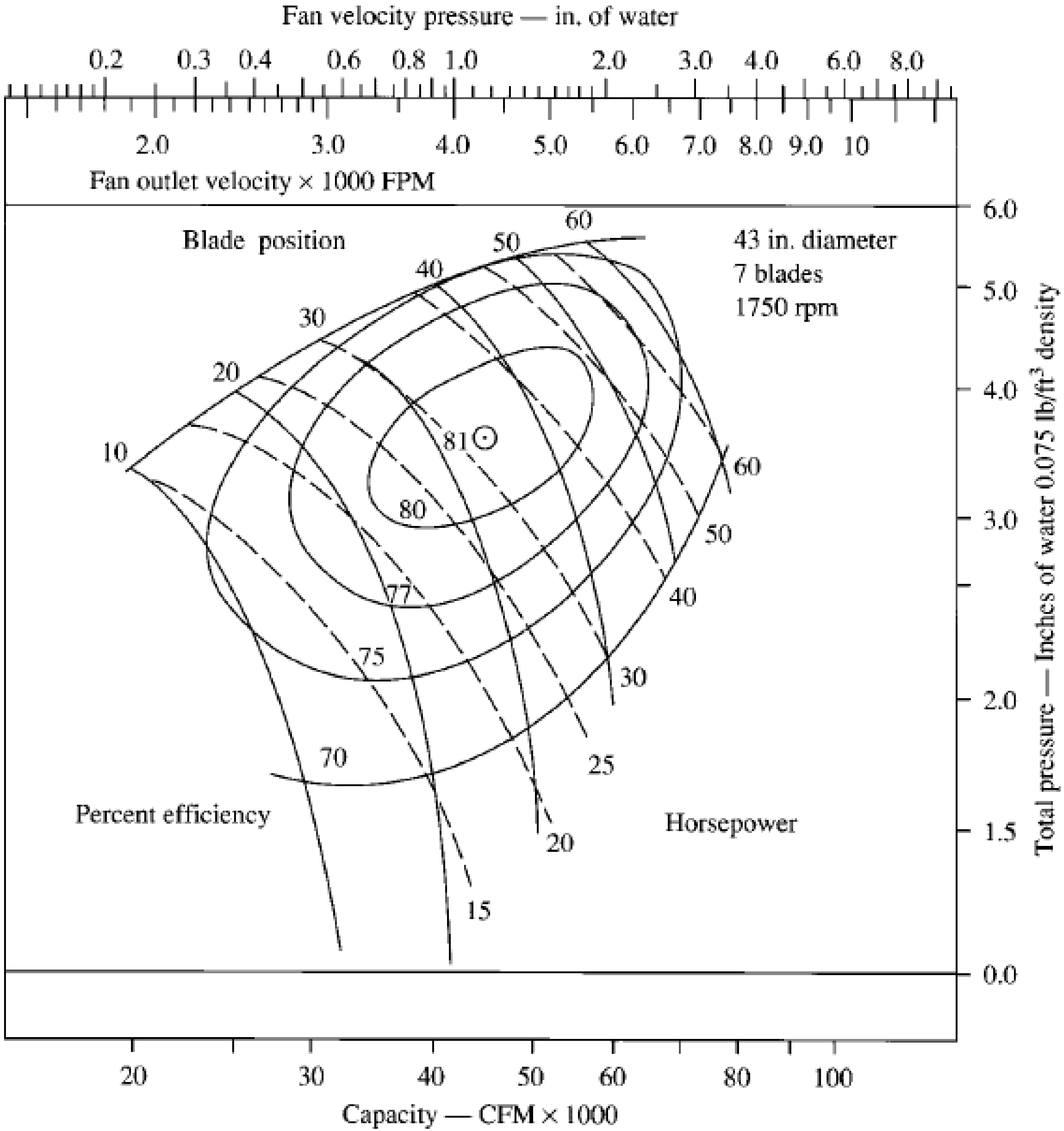

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan power curves for axial fans with same impeller diameter




(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

Performance curves for controllable-pitch vane-axial fans

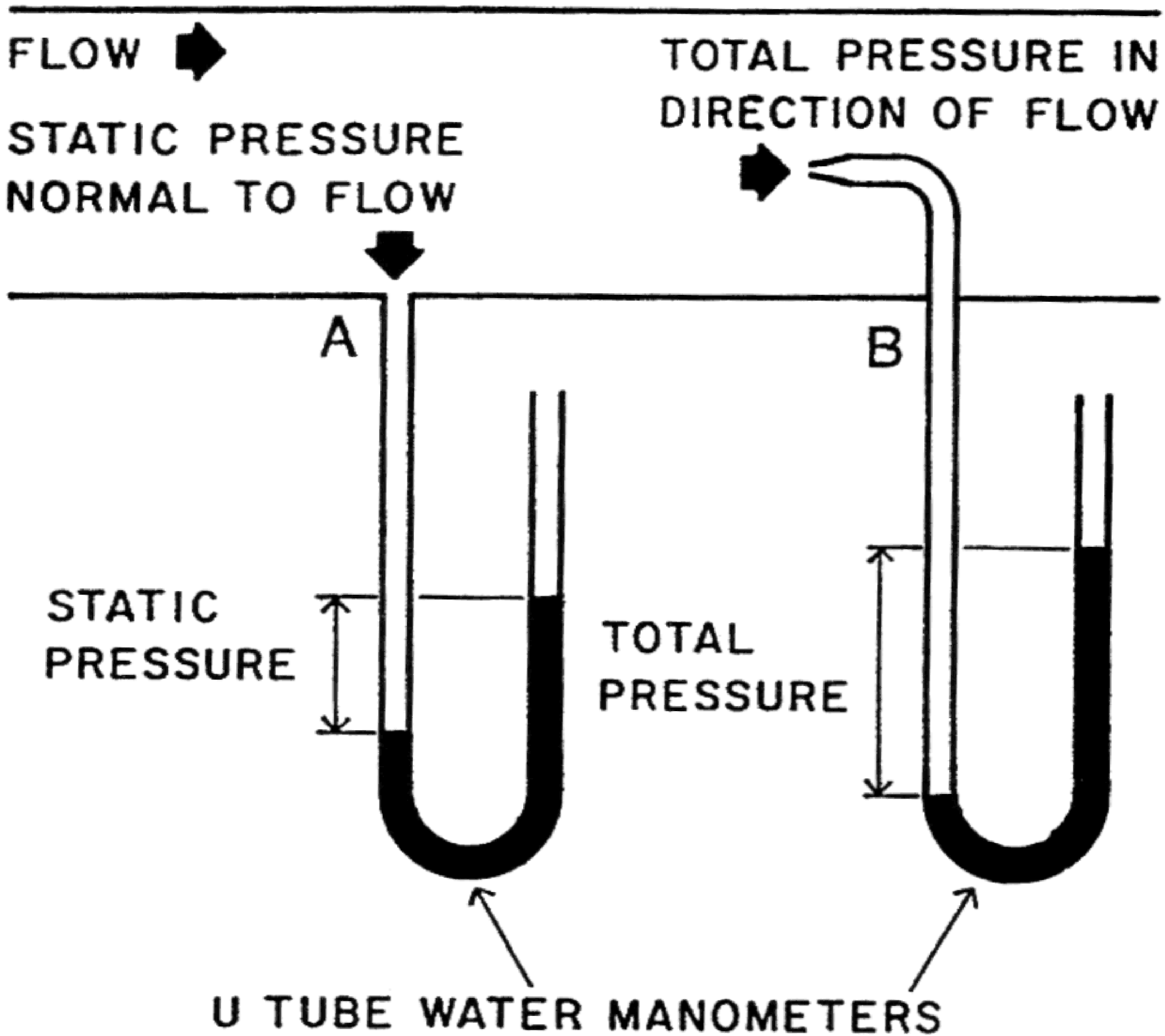



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

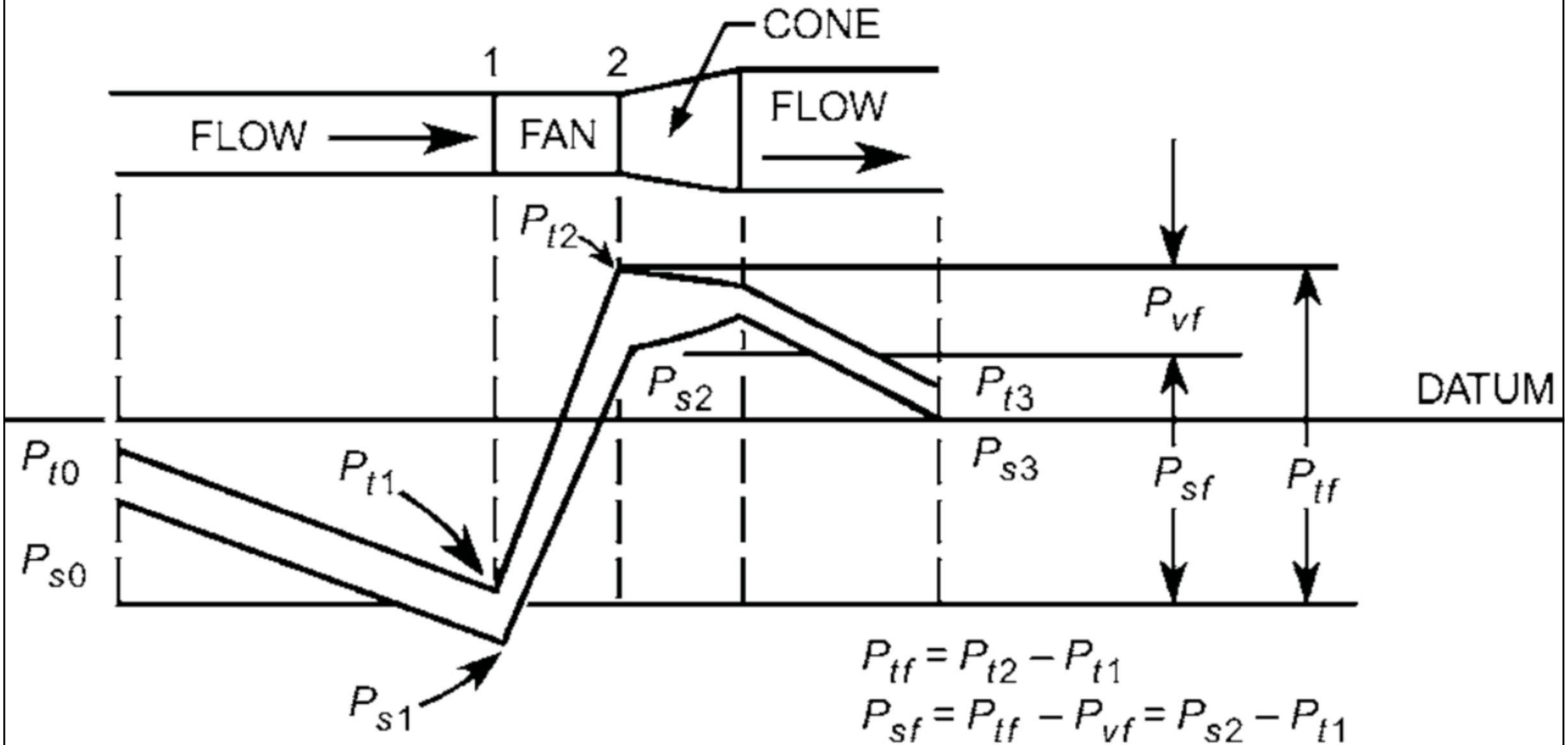
# Fan-duct Systems

- Duct pressure changes (c.f. atm pressure)
  - Static pressure (SP)
  - Velocity pressure (VP) = $\rho V^2 / 2\,g$
  - Total pressure (TP) = SP + VP
- Fan: a pumping device
  - Fan (total) pressure = pressure difference between fan inlet and fan discharge
  - At fan suction/inlet, SP = negative (c.f. atmospheric); at discharge, SP = positive

## STATIC AND TOTAL PRESSURE

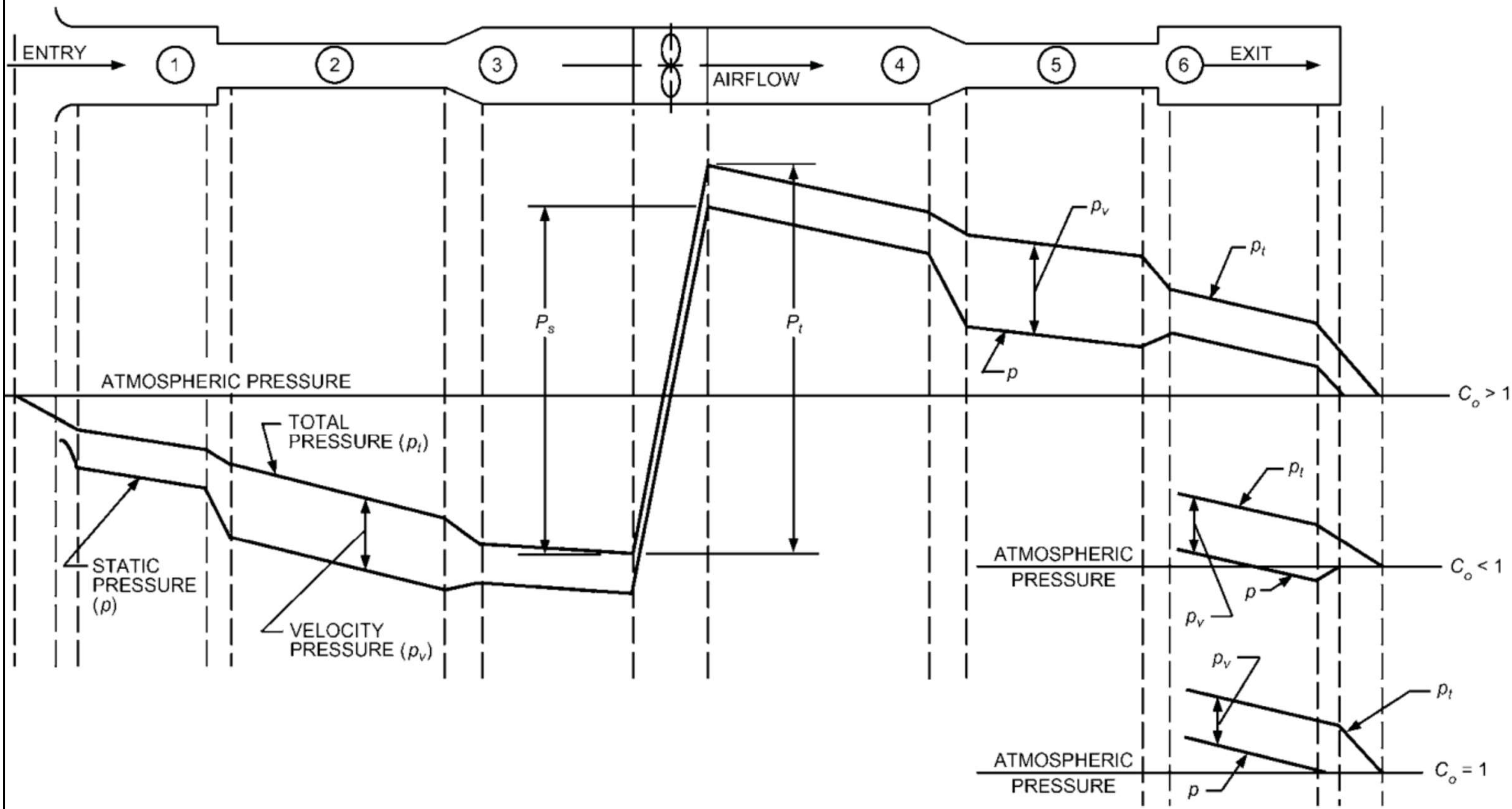


# Pressure relationships of fan with diverging cone outlet




(Source: *ASHRAE Handbook HVAC Systems & Equipment 2016*, Chp. 21)

# Pressure changes during flow in ducts



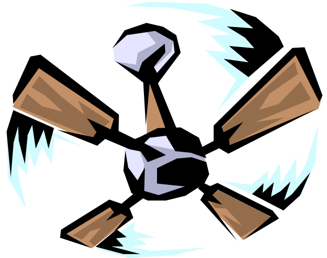

$C_o$ = Exit loss coefficient

(Source: *ASHRAE Handbook Fundamentals 2017*, Chp. 21)

# Fan-duct Systems

- Pressure characteristics
  - SP and VP are mutually convertible (↑or↓)
  - TP always decreases in the direction of airflow
  - For constant-area straight duct sections
    - Velocity and VP are constant
    - TP change = SP change
  - When duct cross-sectional areas are reduced
    - Velocity and VP increase
    - Absolute value of both TP and SP decrease
    - Dynamic losses from elbow, dampers, etc.

# Fan-duct Systems



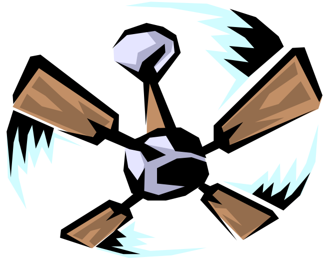
- Fan-duct systems
  - Flow resistance $R$, pressure drop $\Delta p$ and volume flow rate $\dot{V}$

$$\Delta p = R \cdot \dot{V}^2$$

  - Duct sections in series: $R_s = R_1 + R_2 + \ldots + R_n$
  - Duct sections in parallel:

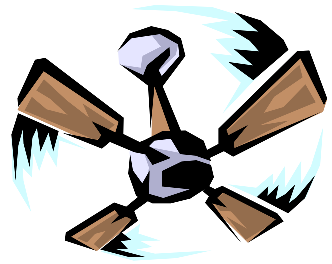
$$\frac{1}{\sqrt{R_p}} = \frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \ldots + \frac{1}{\sqrt{R_n}}$$

# Fan-duct Systems



- Fan-duct systems
  - Terminology
    - Primary air (conditioned air or makeup air)
    - Secondary air (induced space air, plenum air, or recirculating air)
    - Transfer air (indoor air that moves from an adjacent area)
  - System curve: volume flow vs pressure loss
  - System operating point

# Fan-duct Systems

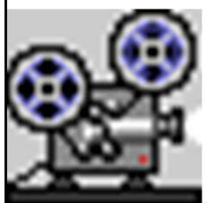


- System effect $\Delta p_{ts}$
  - Its additional total pressure loss caused by uneven or non-uniform velocity profile at the fan inlet, or at duct fittings after fan outlet
  - Due to the actual inlet and outlet connections as compared with the total pressure loss of the fan test unit during laboratory ratings

$$\Delta p_{\mathrm{ts}} = \Delta p_{\mathrm{sy}} + \Delta p_{\mathrm{se}} = \Delta p_{\mathrm{sy}} + \Delta p_{\mathrm{s.i}} + \Delta p_{\mathrm{s.o}}$$

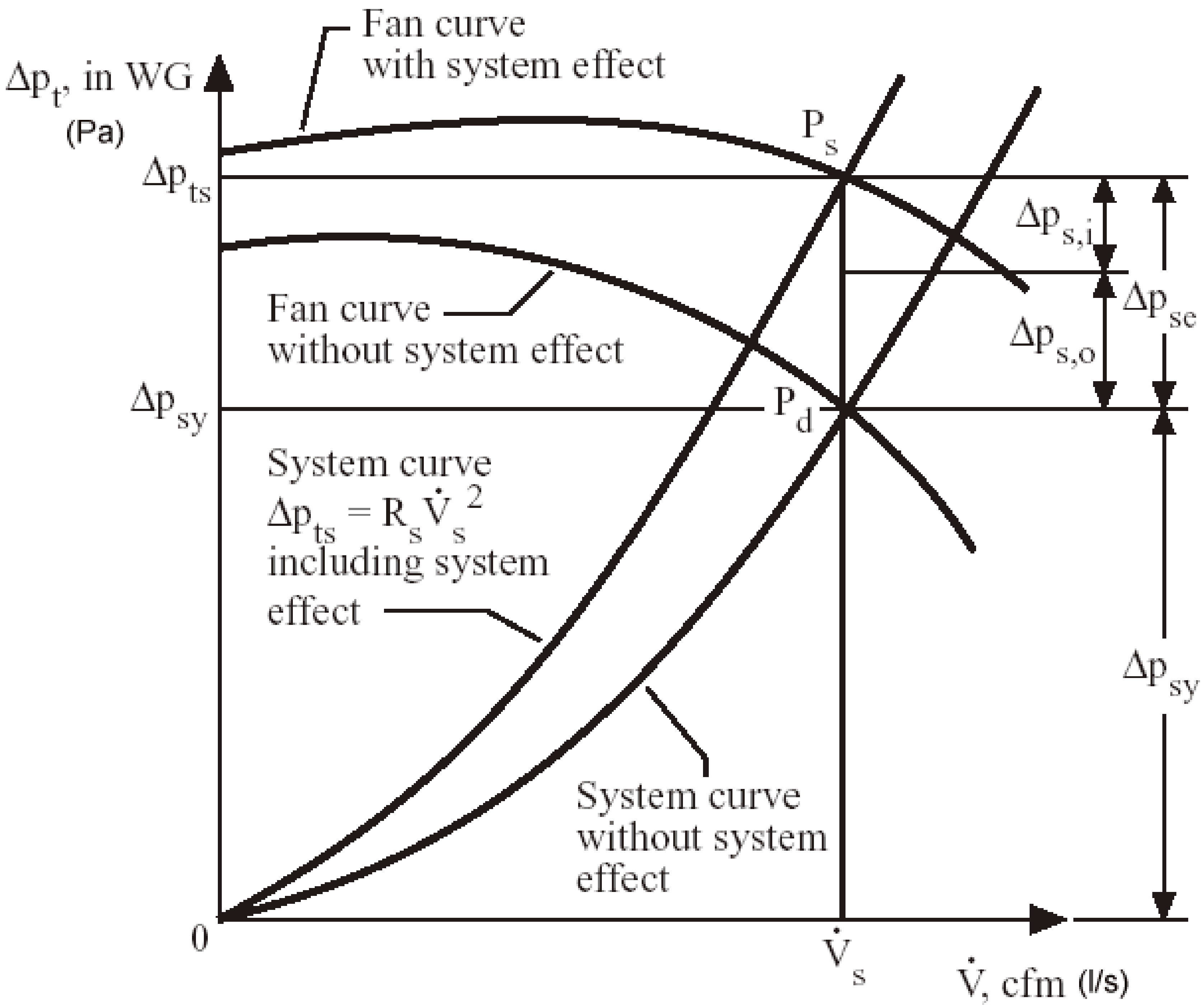
$$= \Delta p_{\mathrm{sy}} + C_{\mathrm{s.i}}\left(v_{\mathrm{fi}}/4005\right)^2 + C_{\mathrm{s.o}}\left(v_{\mathrm{fo}}/4005\right)^2$$

Inlet Outlet



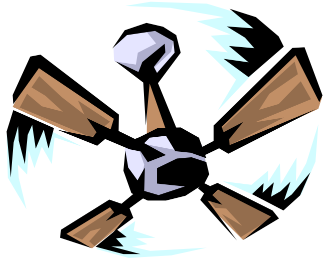
(Video: AMCA System Effects and Design Fans and Blowers (9:50) https://youtu.be/wQGbVefdHzQ)

# Fan system operating point & system effect



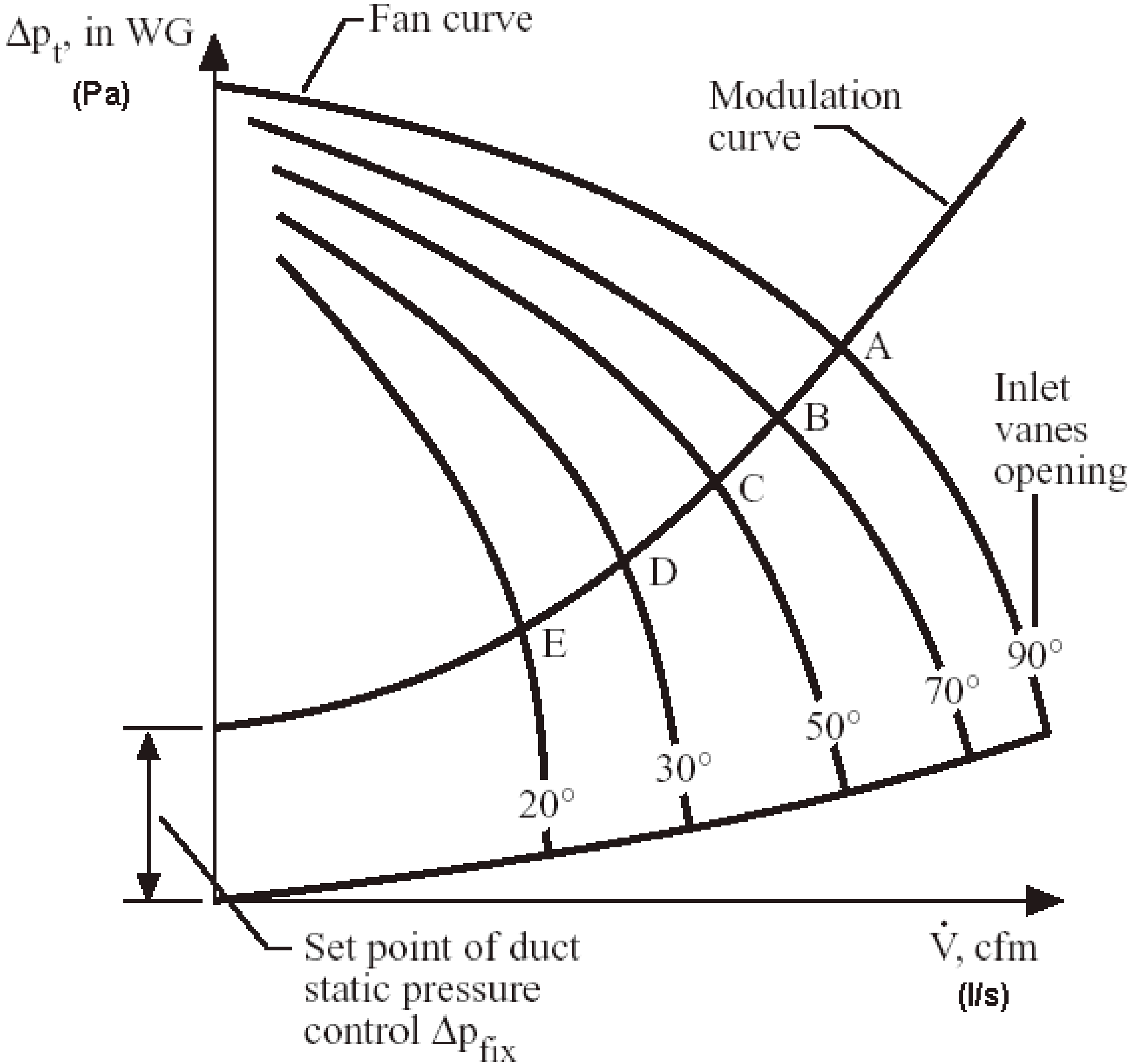

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan-duct Systems



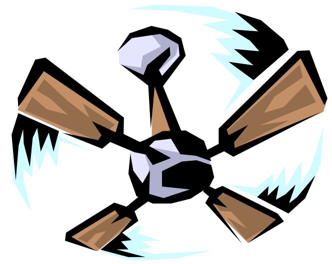
- Modulation of air systems
  - Constant volume system
    - Volume flow rate remains constant
    - Supply temperature is raised during part load
  - Variable-air-volume (VAV) system
    - Volume flow rate is reduced to match part load operation
    - Modulation curve

# Fan modulation curve



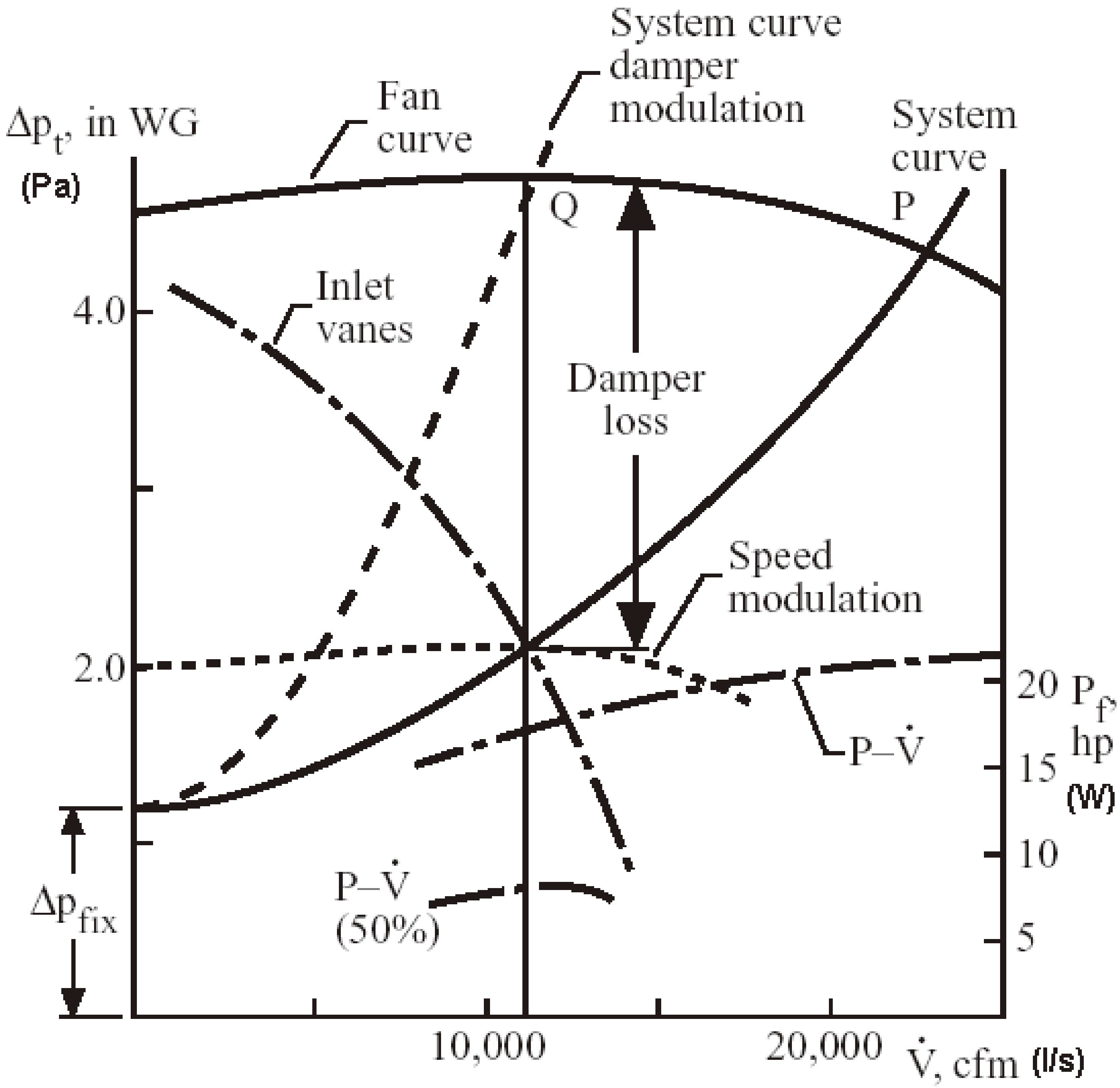

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan-duct Systems



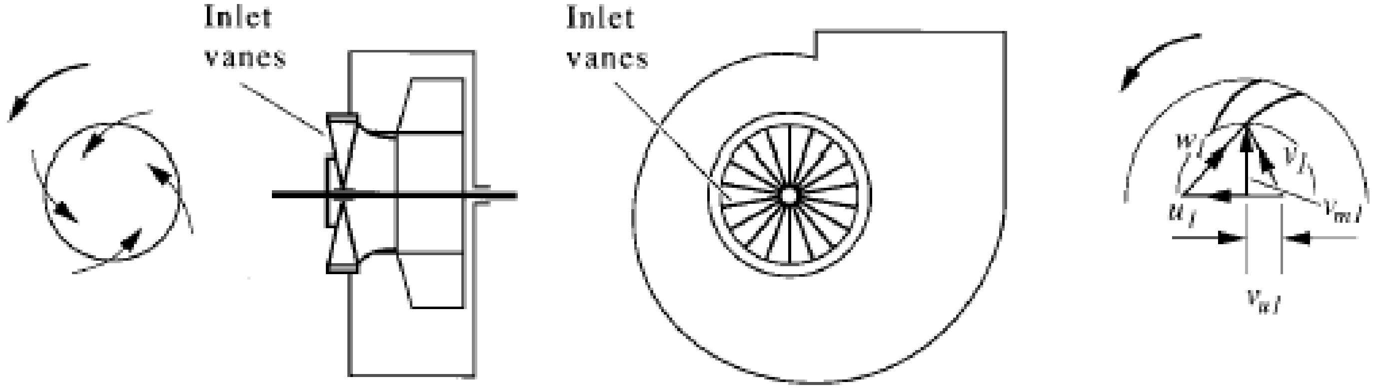
- Fan modulation methods
  - Damper (vary the opening of the air flow passage)
    - Waste energy
  - Inlet vanes (opening & angle of inlet vanes)
    - Low cost; less efficient than following types
  - Inlet cone (peripheral area of fan impeller)
    - Inexpensive; for backward curved centrifugal fan
  - Blade pitch (blade angle of axial fan)
  - Fan speed (using adjustable frequency drives)
    - Most energy-efficient; but usually cost more

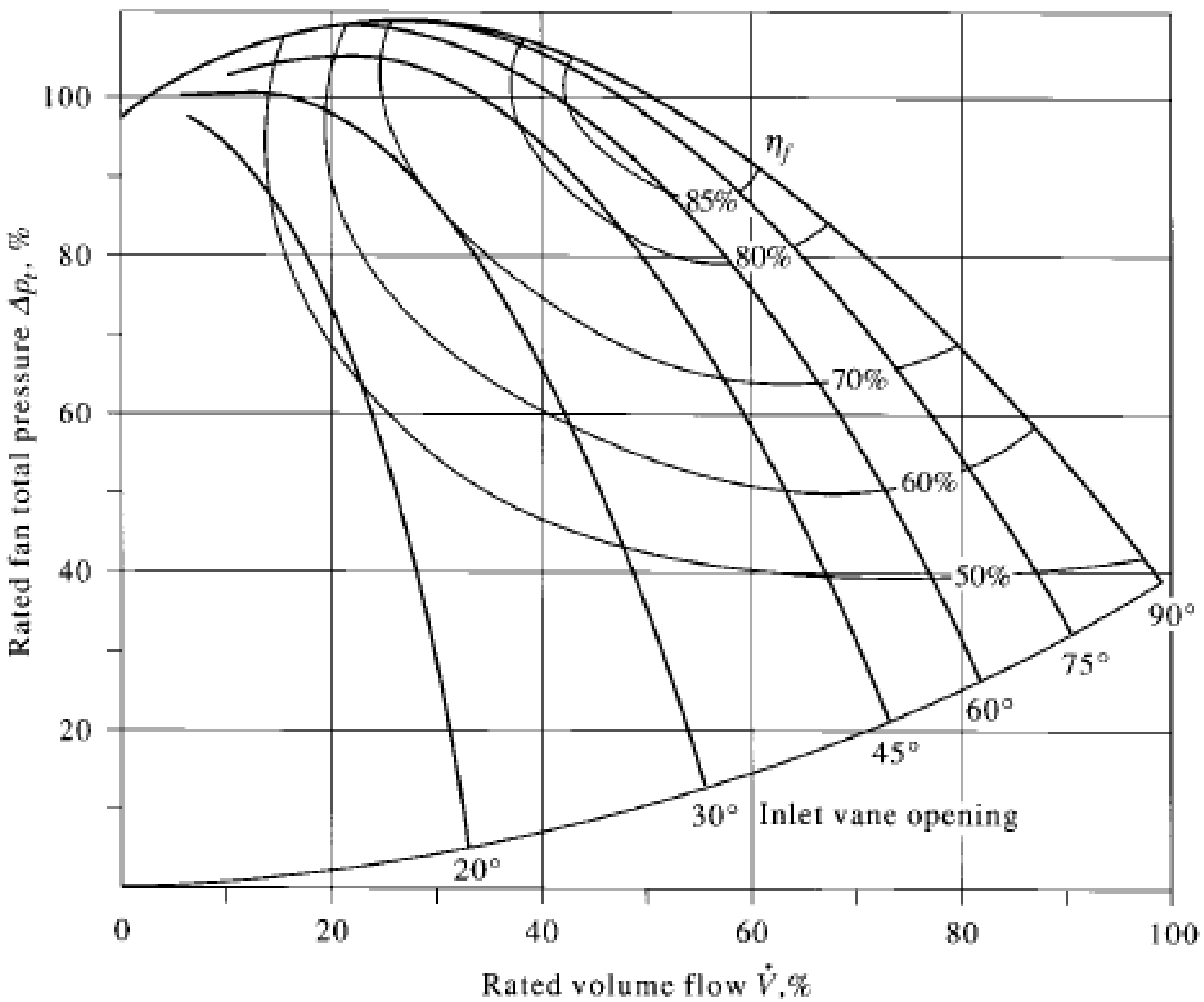
# Damper, inlet vanes & fan speed modulation



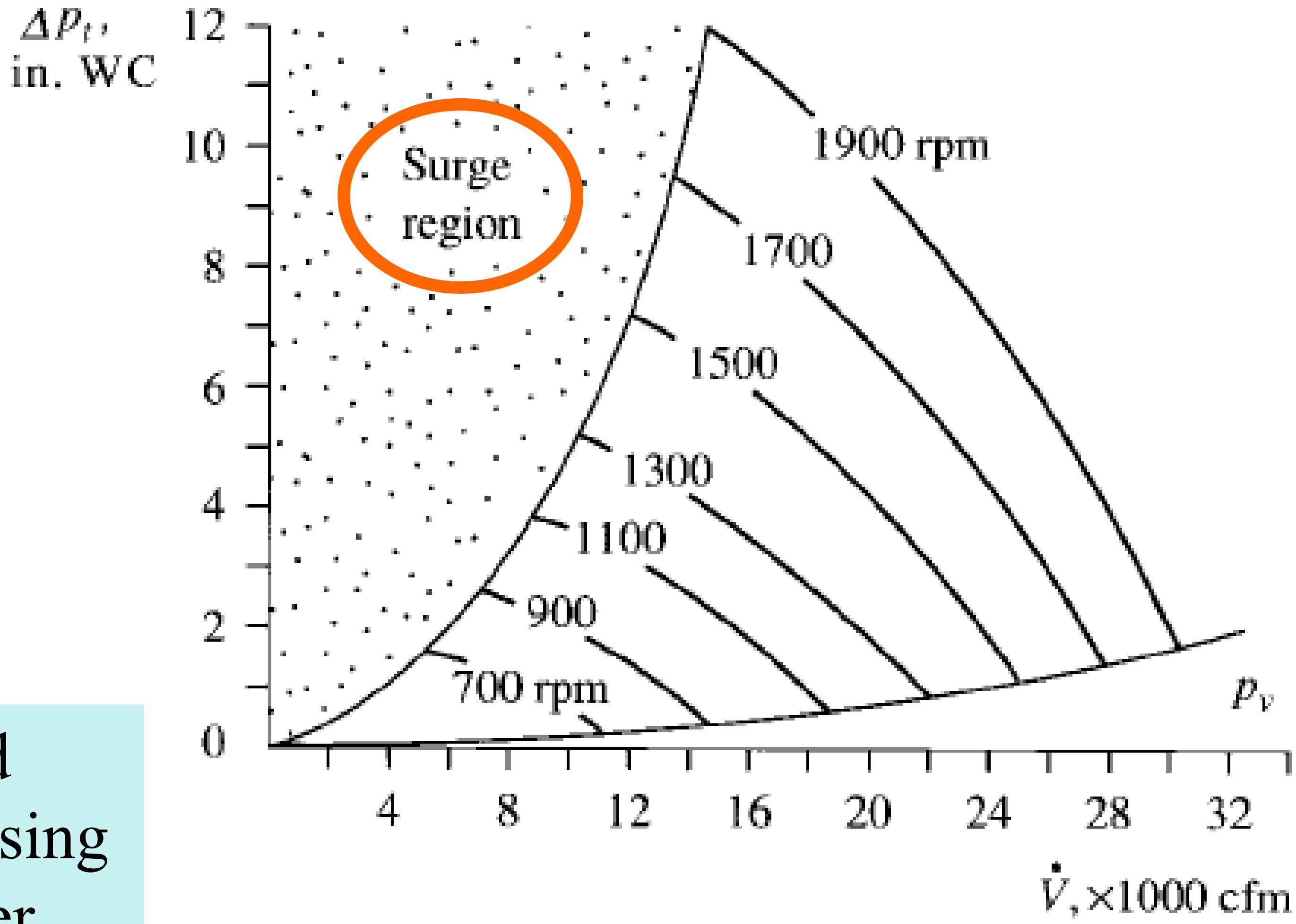

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Inlet vane modulation

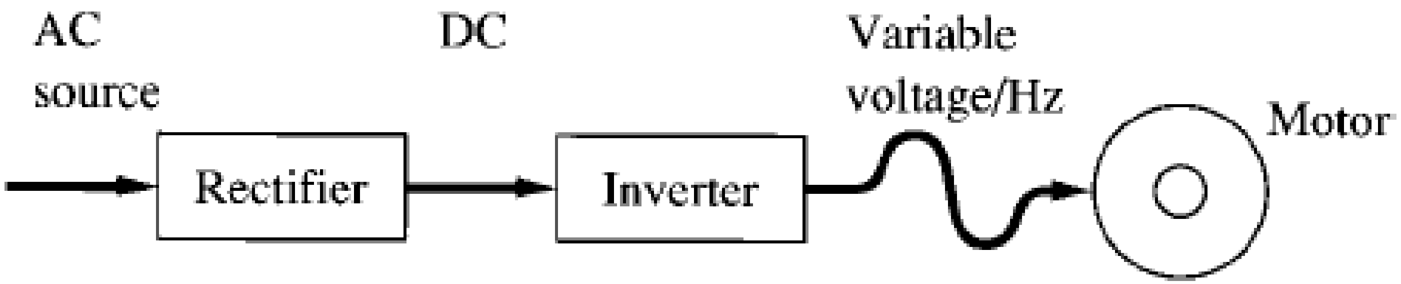



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

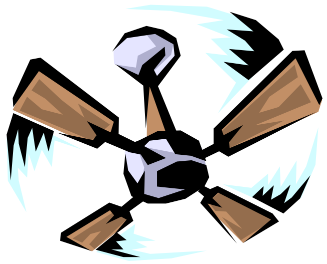



Fan speed modulation using AC inverter



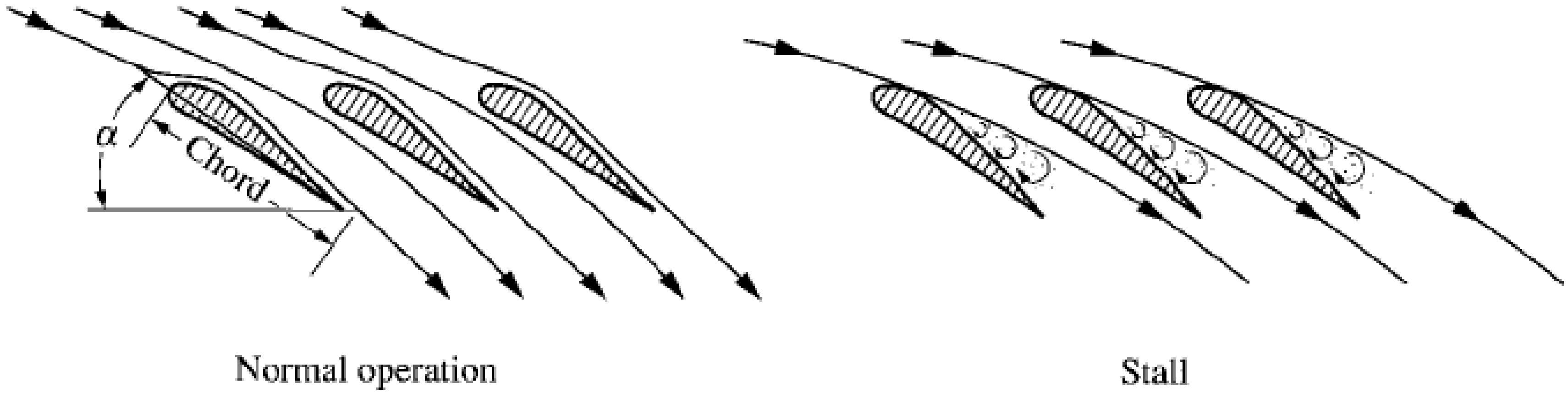

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

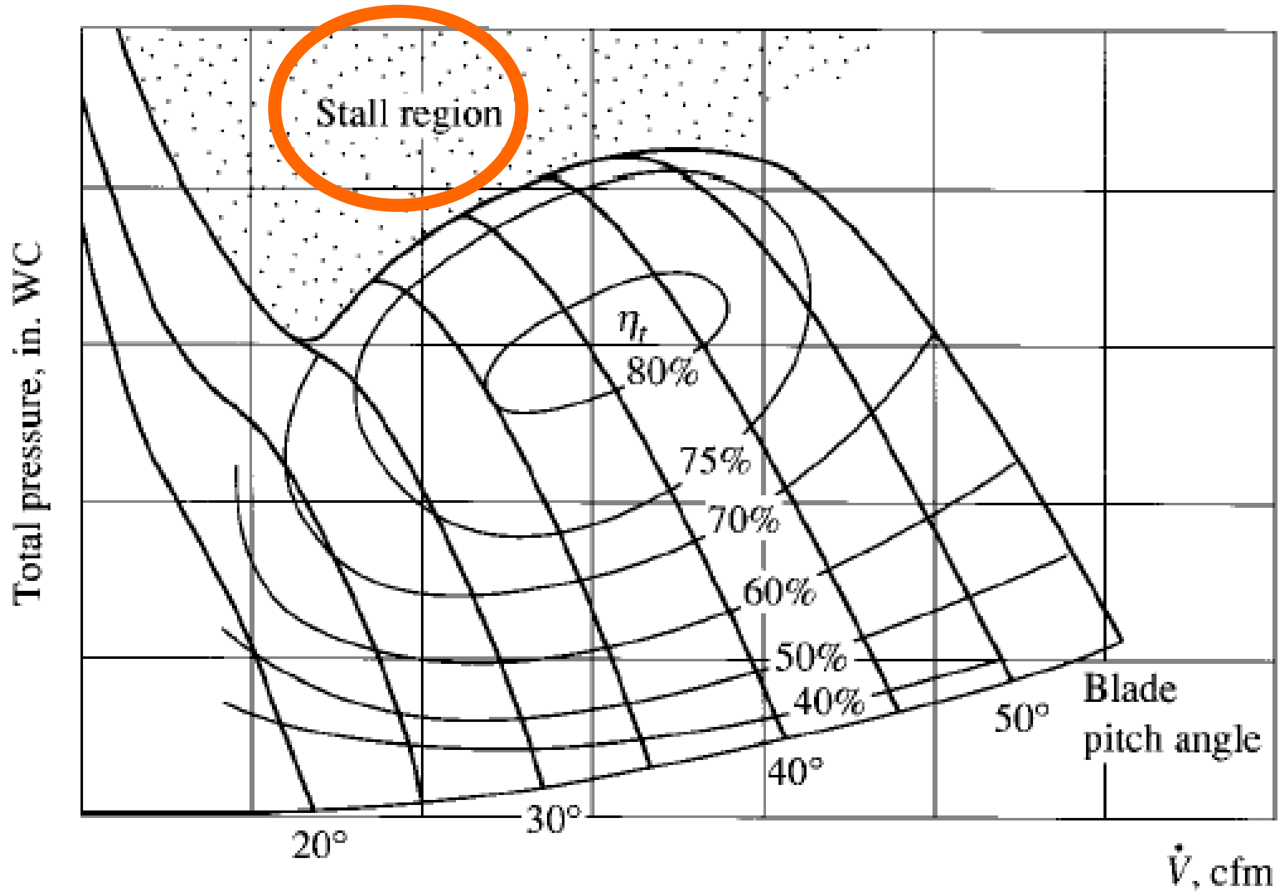
# Fan-duct Systems



- **Fan surge** (in centrifugal fan)
  - Occurs when air volume flow is not sufficient to sustain the static pressure difference between discharge & suction
    - Discharge pressure is reduced momentarily
    - Volume flow & pressure fluctuations
    - Create noise & vibration
  - Surge region: shall avoid operation in it
- **Fan stall** (in axial fans)
  - When smooth air flow suddenly breaks & pressure difference across the blades decreases
  - The fan loses pressure capability drastically

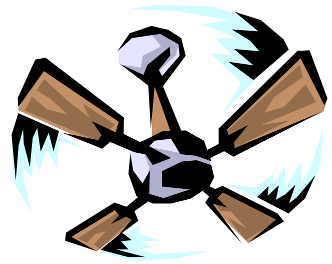
# Stall and stall region of an axial fan




(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Fan-duct Systems



- Fan selection
  - Select fan type + determine fan size
  - Important factors:
    - Pressure-volume flow operating characteristics
    - Fan capacity modulation
    - Fan efficiency
    - Sound power level
    - Airflow direction
    - Initial cost

# Various types of fans

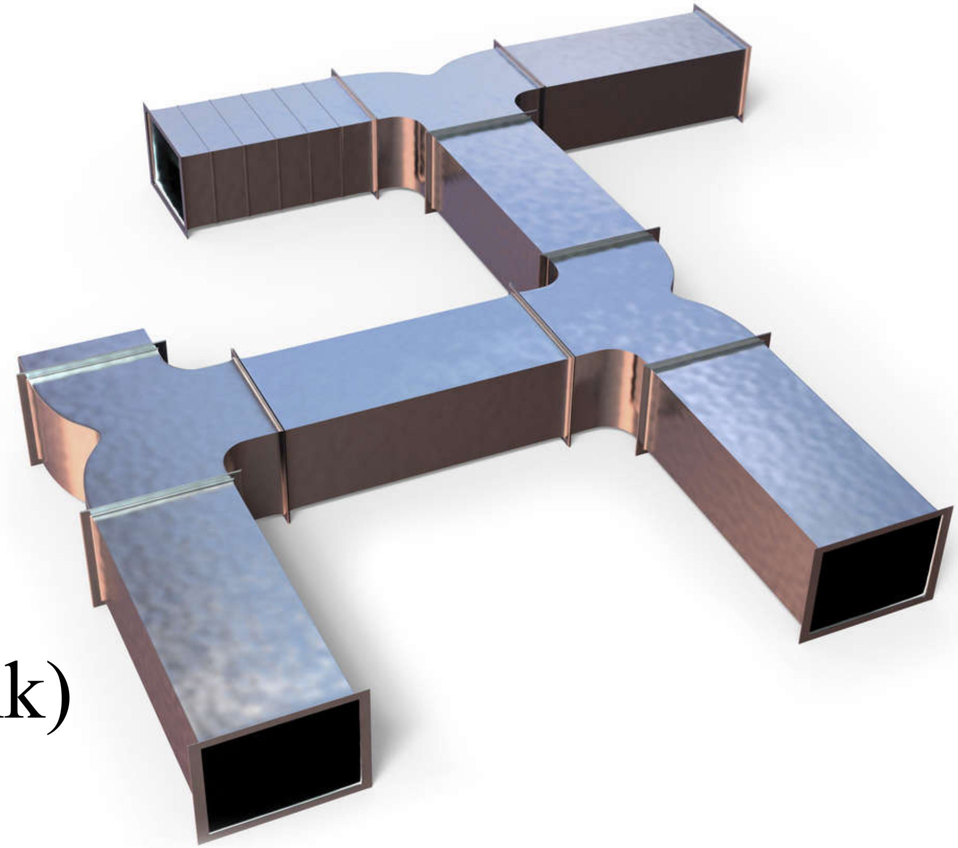
**TABLE 15.2** Comparison between Various Types of Fans

| | Backward, airfoil centrifugal fan | Forward-curved centrifugal fan | Vane-axial | Propeller fan |
|---|---|---|---|---|
| Fan total pressure $\Delta p_{tf}$ | Higher $\Delta p_t$ | Comparatively lower $\Delta p_t$ | Higher $\Delta p_t$ | Low $\Delta p_t$ |
| 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 |

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Duct Construction

- Types of air duct
  - Supply air duct
  - Return air duct
  - Outdoor air duct
  - Exhaust air
- Duct sections
  - Header or main duct (trunk)
  - Branch duct or runout



# Duct Construction

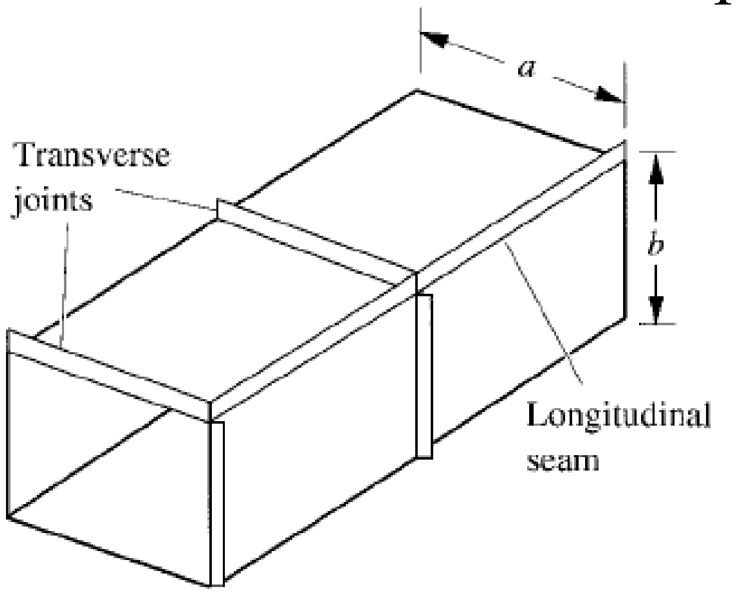
- Duct systems
  - Max. pressure difference (between air inside the duct and the ambient air)
    - 125, 250, 500, 750, 1000, 1500, 2500 Pa
  - Commercial buildings
    - Low-pressure duct system: ≤ 500 Pa, max 12 m/s
    - Medium-pressure system: 500-1500 Pa, max 17.5 m/s
  - Residential buildings: 125 Pa or 250 Pa
  - Industrial duct system: $\Delta P$ can be higher

# Duct Construction

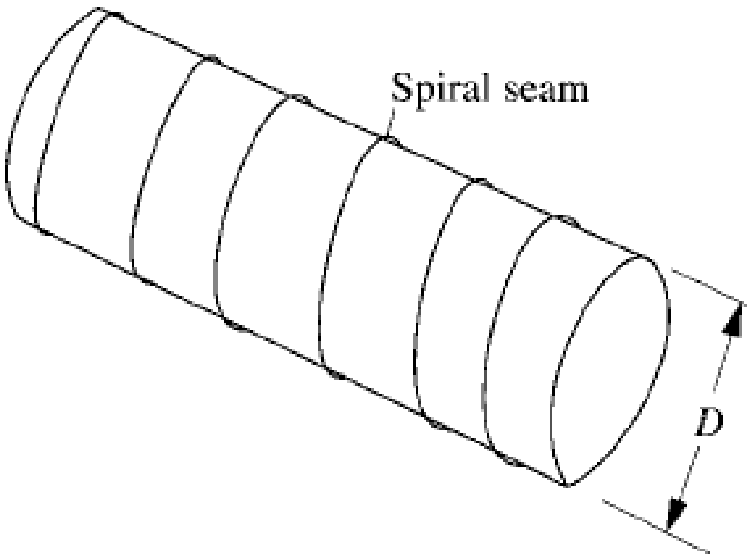
- Shapes of air duct
  - Rectangular
    - More easily fabricated on site, air leakage
  - Round
    - Less fluid resistance, better rigidity/strength
  - Flat oval
  - Flexible
    - Multiple-ply polyester film w/ metal wire or strips
- SMACNA (Sheet Metal and Air Conditioning Contractors' National Association) standards*

(* Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) http://www.smacna.org/)

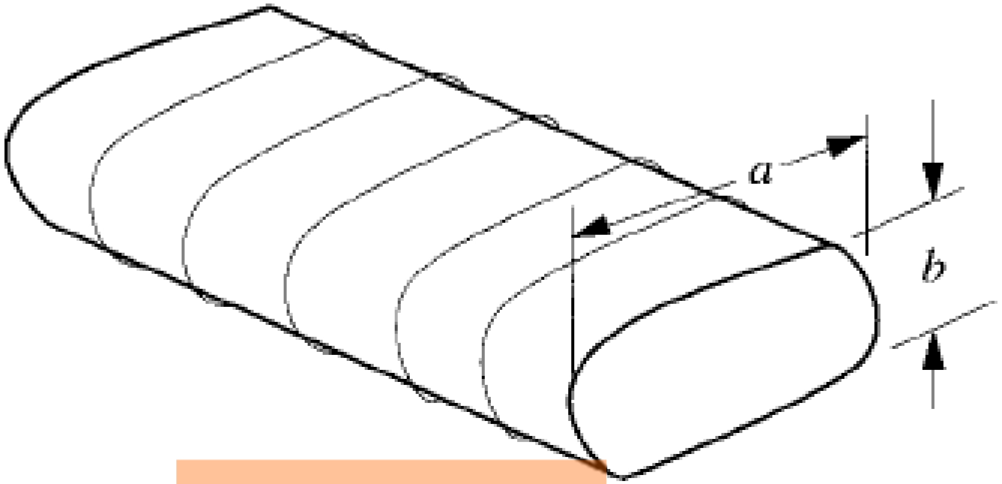
# Different shapes/types of air ducts



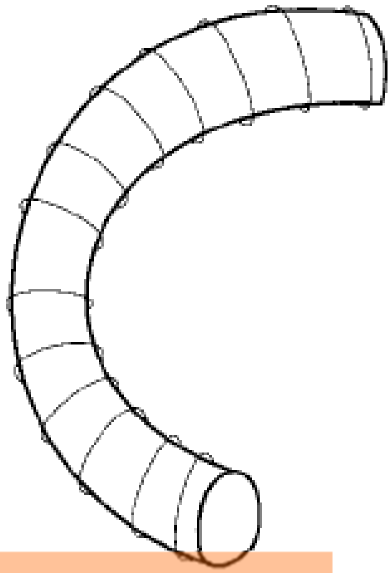

Rectangular duct




Round duct w/ spiral seam




Flat oval duct



Flexible duct

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Duct Construction

- Duct specification
  - Sheet gauge and thickness of duct material
  - Traverse joints & longitudinal seam reinforcements
  - Duct hangers & their spacing
  - Tapes & adhesive closures
  - Fire spread and smoke developed
  - Site-fabricated or factory-/pre-fabricated
  - Duct leakage classification: ANSI, SMACNA, ASHRAE standards

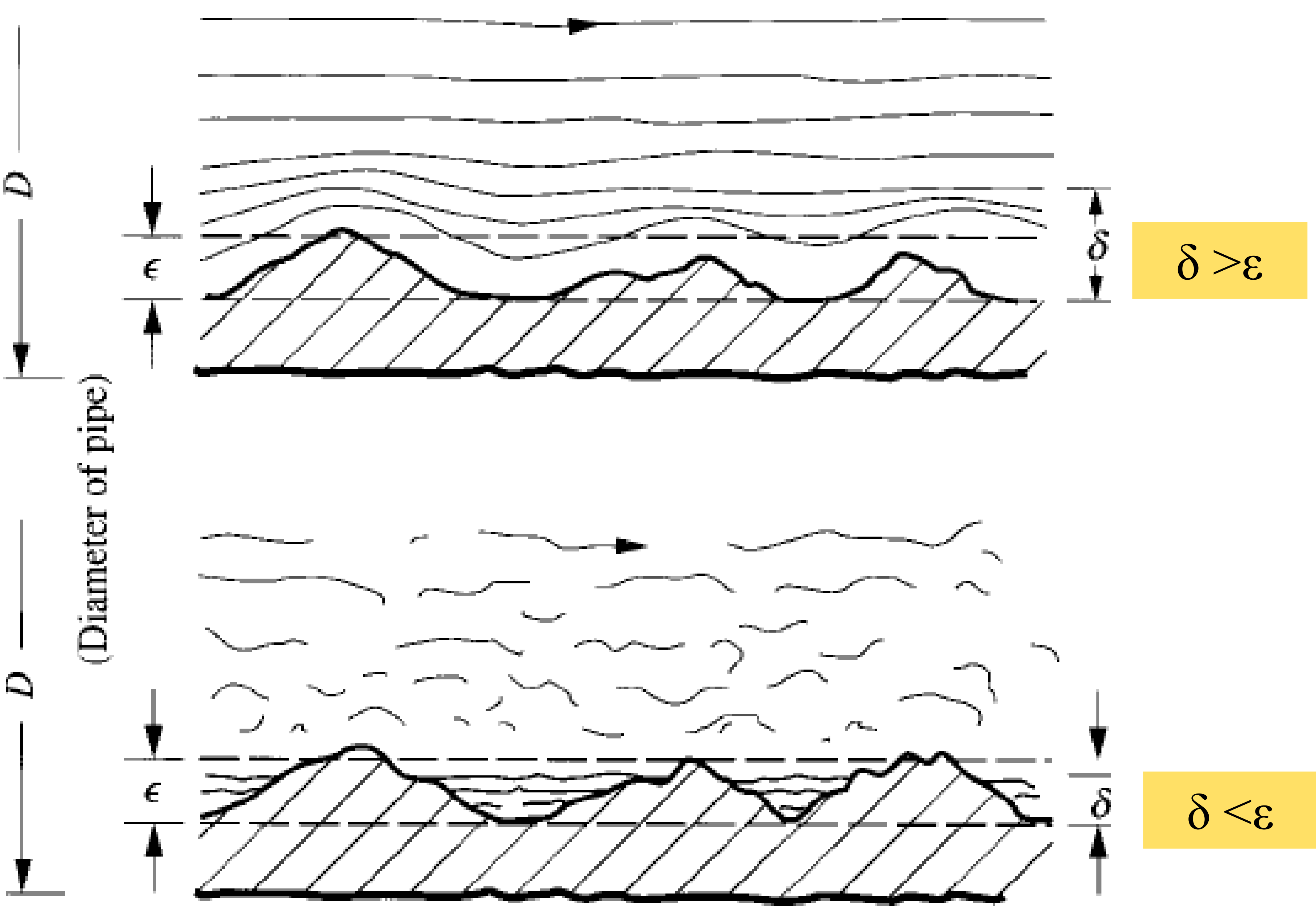
# Duct Construction

- Frictional losses
  - Darcey-Weisbach Equation
    - $H_f$ = friction head loss, or $\Delta p_f$ = pressure loss

$$H_f = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right) \qquad \Delta p_f = f\left(\frac{L}{D}\right)\left(\frac{\rho v^2}{2g_c}\right)$$

    - $f$ = friction factor (dimensionless)
    - $L$ = length of duct or pipe (m)
    - $D$ = diameter of duct or pipe (m)
    - $v$ = mean air velocity in duct (m/s)

# Mode of airflow when air passes over and around surface protuberances of the duct wall

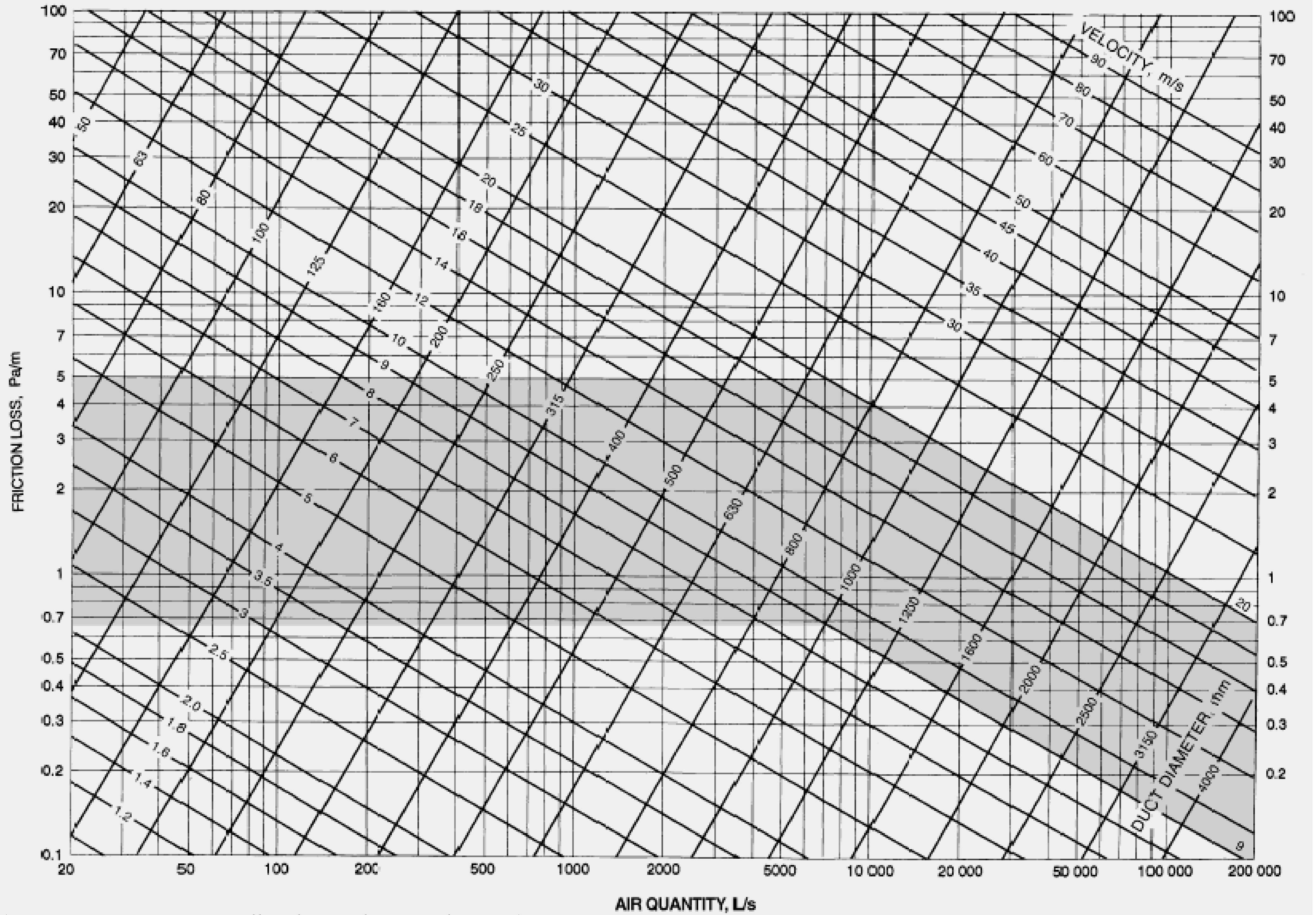



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Duct Construction

- Duct friction chart
  - Colebrook formula $$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}_D\sqrt{f}}\right)$$
- Roughness & temperature corrections
  - $\Delta p_f = K_{sr} K_T K_{el} \Delta p_{f,c}$
    - $K_{sr}$ = correction factor for surface roughness
    - $K_T$ = correction factor for air temperature
    - $K_{el}$ = correction factor for elevation

# Friction chart for round duct




(Source: *ASHRAE Handbook Fundamentals 2001*)

# Duct Construction

- Circular equivalent
  - Hydraulic diameter, $D_h = 4\,A\,/\,P$
    - $A$ = area ($mm^2$); $P$ = perimeter (mm)
  - Rectangular duct:

$$D_e = \frac{1.30(ab)^{0.625}}{(a+b)^{0.25}}$$

  - Flat oval duct:

$$D_e = \frac{1.55A^{0.625}}{P^{0.25}}$$

$$A = \frac{\pi b^2}{4} + b(a-b)$$

$$P = \pi b + 2(a+b)$$

# Duct Construction

- Dynamic losses
  - Result from flow disturbances caused by duct-mounted equipment and fittings
    - Change airflow path's direction and/or area
    - Flow separation & eddies/disturbances
  - In dynamic similarity (same Reynolds number & geometrically similar duct fittings), dynamic loss is proportional to their velocity pressure

# Duct Construction

- Local or dynamic loss coefficient
  - Ratio of total pressure loss to velocity pressure

$$C = \frac{\Delta p_j}{(\rho V^2/2)} = \frac{\Delta p_j}{p_v}$$

*where*

$C$ = local loss coefficient, dimensionless
$\Delta p_j$ = total pressure loss, Pa
$\rho$ = density, kg/m$^3$
$V$ = velocity, m/s
$p_v$ = velocity pressure, Pa

# FITTING LOSS COEFFICIENTS

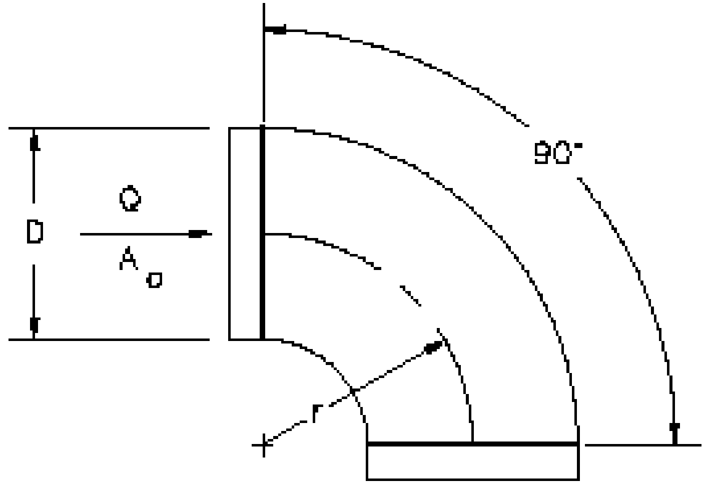
Fittings to support Examples 8 and 9 and some of the more common fittings are reprinted here.

**For the complete fitting database see the *Duct Fitting Database* (ASHRAE 1994).**

## ROUND FITTINGS

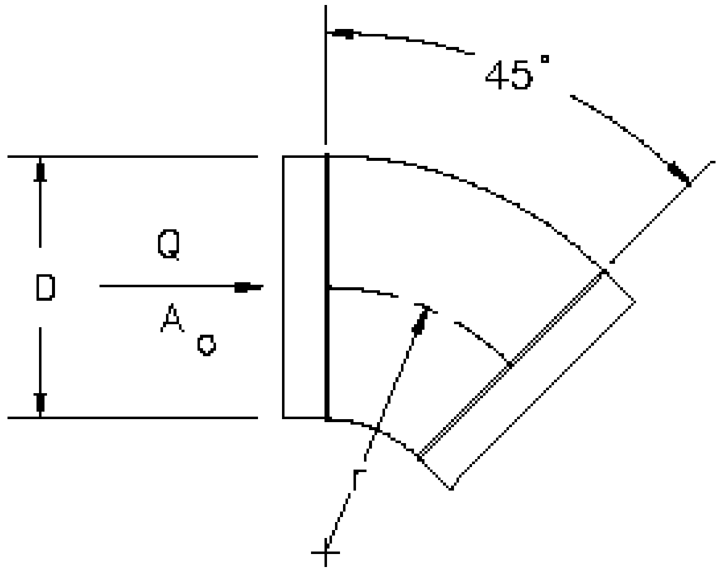
**CD3-1 Elbow, Die Stamped, 90 Degree, $r/D$ = 1.5**

| $D$, mm | 75 | 100 | 125 | 150 | 180 | 200 | 230 | 250 |
|---|---|---|---|---|---|---|---|---|
| $C_o$ | 0.30 | 0.21 | 0.16 | 0.14 | 0.12 | 0.11 | 0.11 | 0.11 |



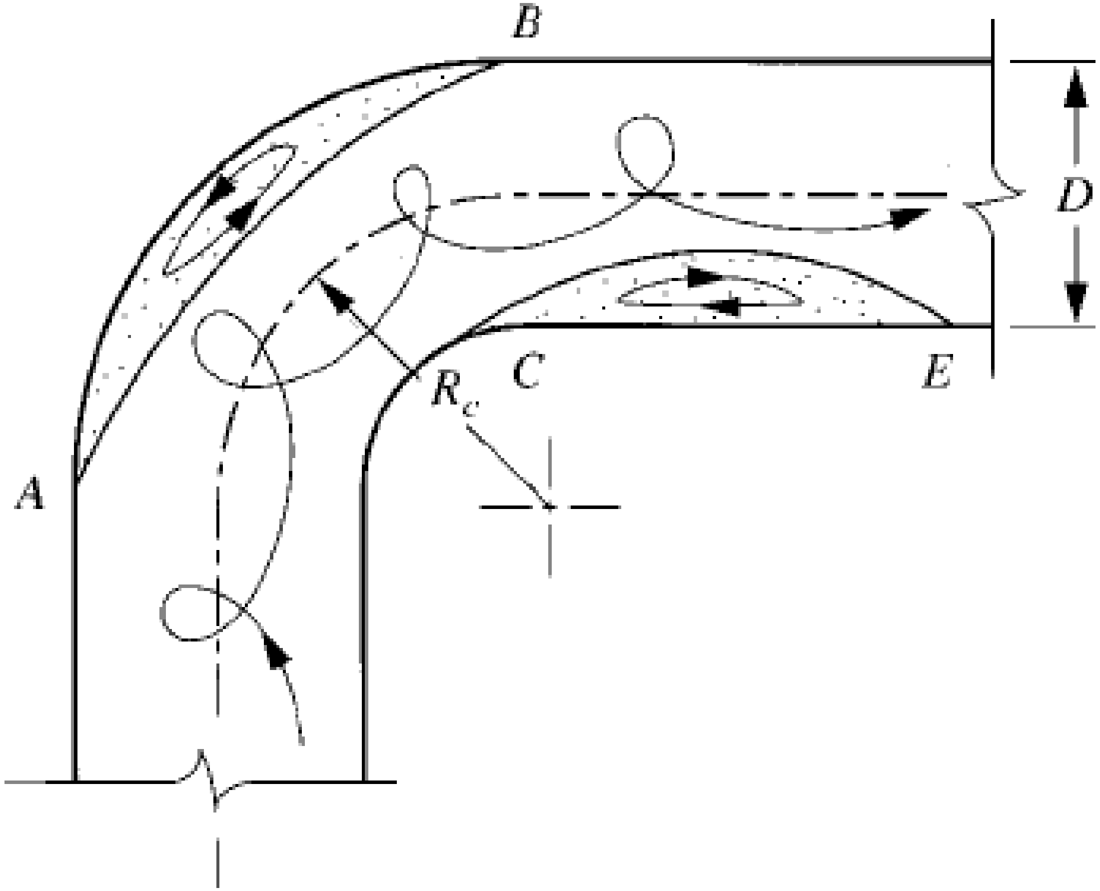

**CD3-3 Elbow, Die Stamped, 45 Degree, $r/D$ = 1.5**

| $D$, mm | 75 | 100 | 125 | 150 | 180 | 200 | 230 | 250 |
|---|---|---|---|---|---|---|---|---|
| $C_o$ | 0.18 | 0.13 | 0.10 | 0.08 | 0.07 | 0.07 | 0.07 | 0.07 |

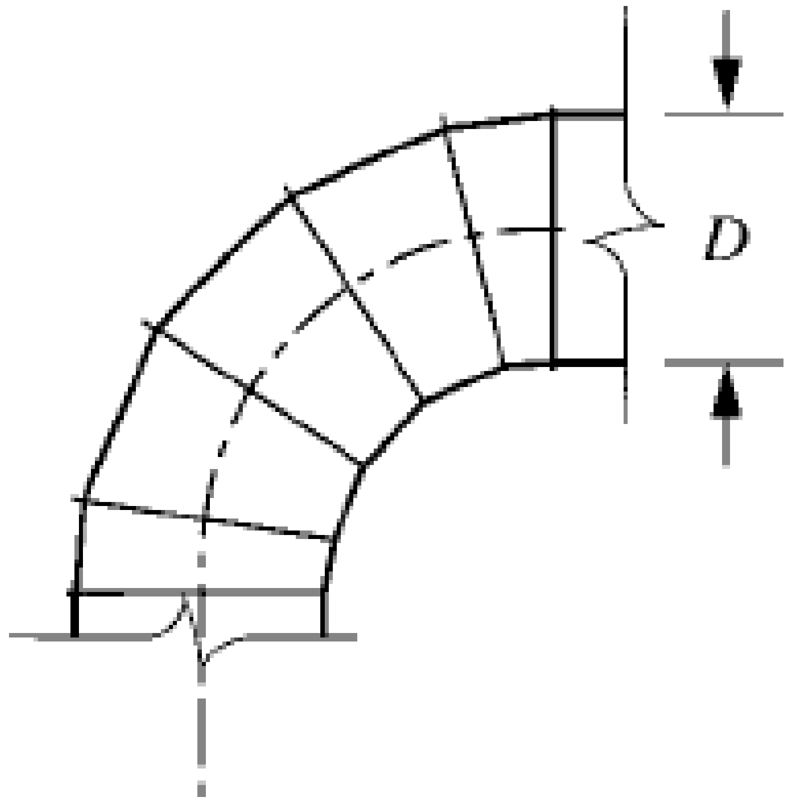



(Source: *ASHRAE Handbook Fundamentals 2001*)

# Round elbow

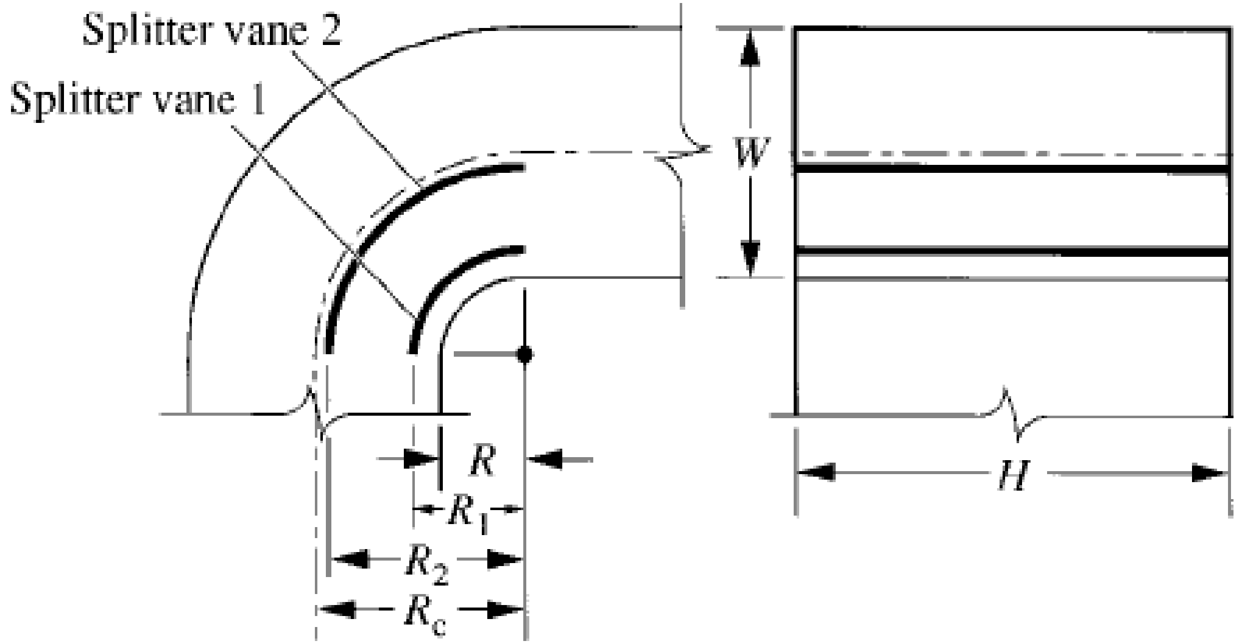



Region of eddies and turbulences in a round elbow

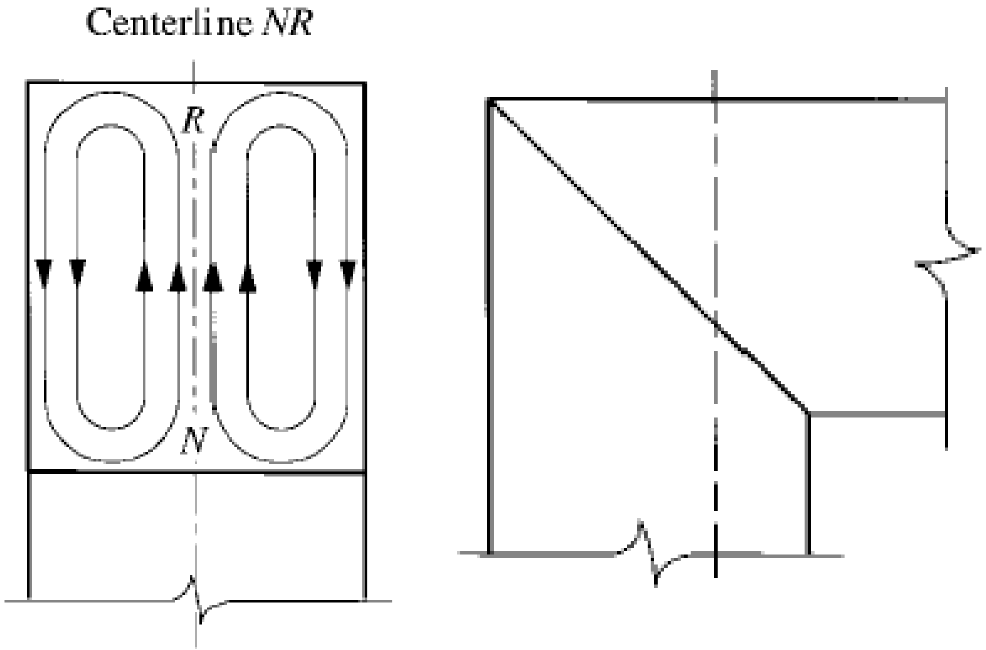


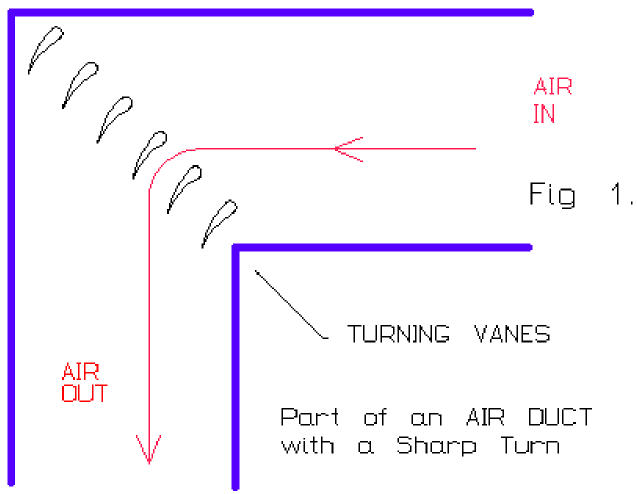

5-piece 90$^o$ round elbow

(Source: *ASHRAE Handbook Fundamentals 2001*)



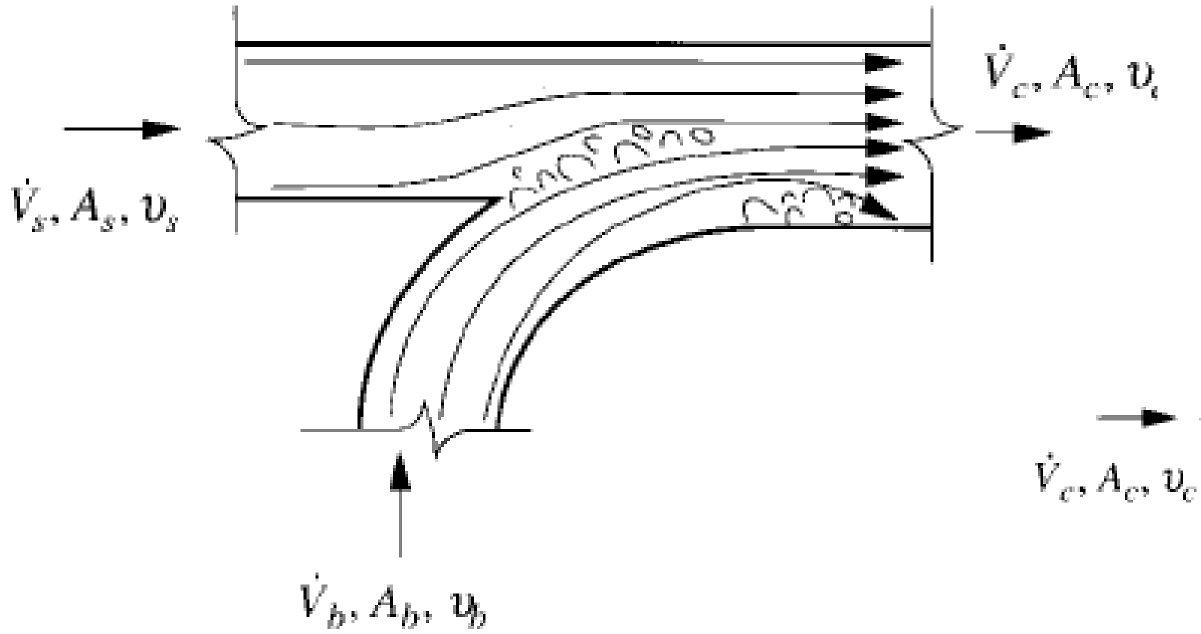

Rectangular elbow, smooth radius, 2 splitter vanes

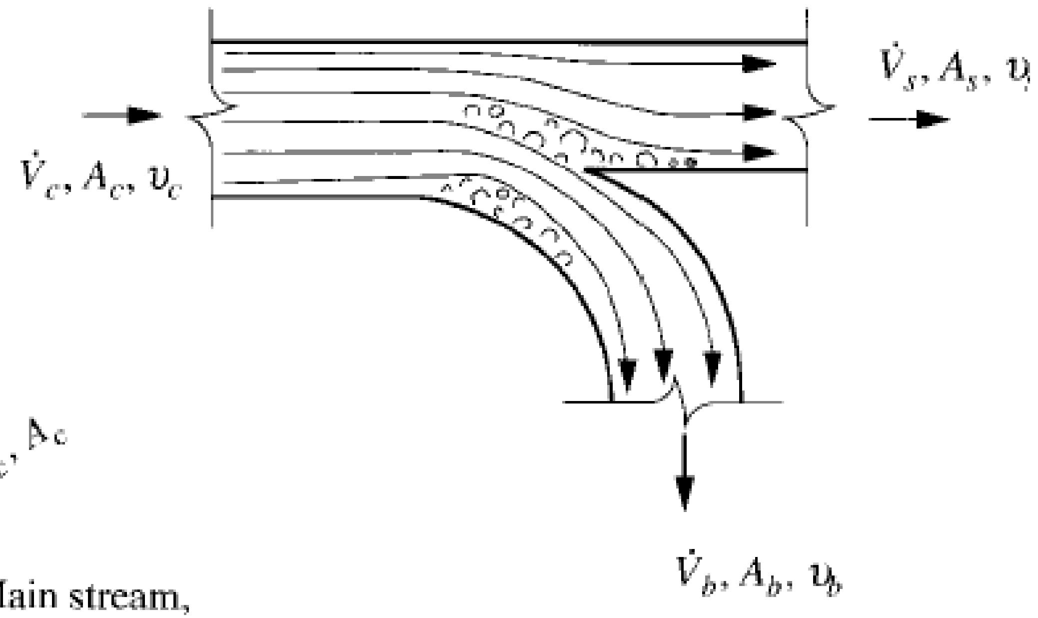


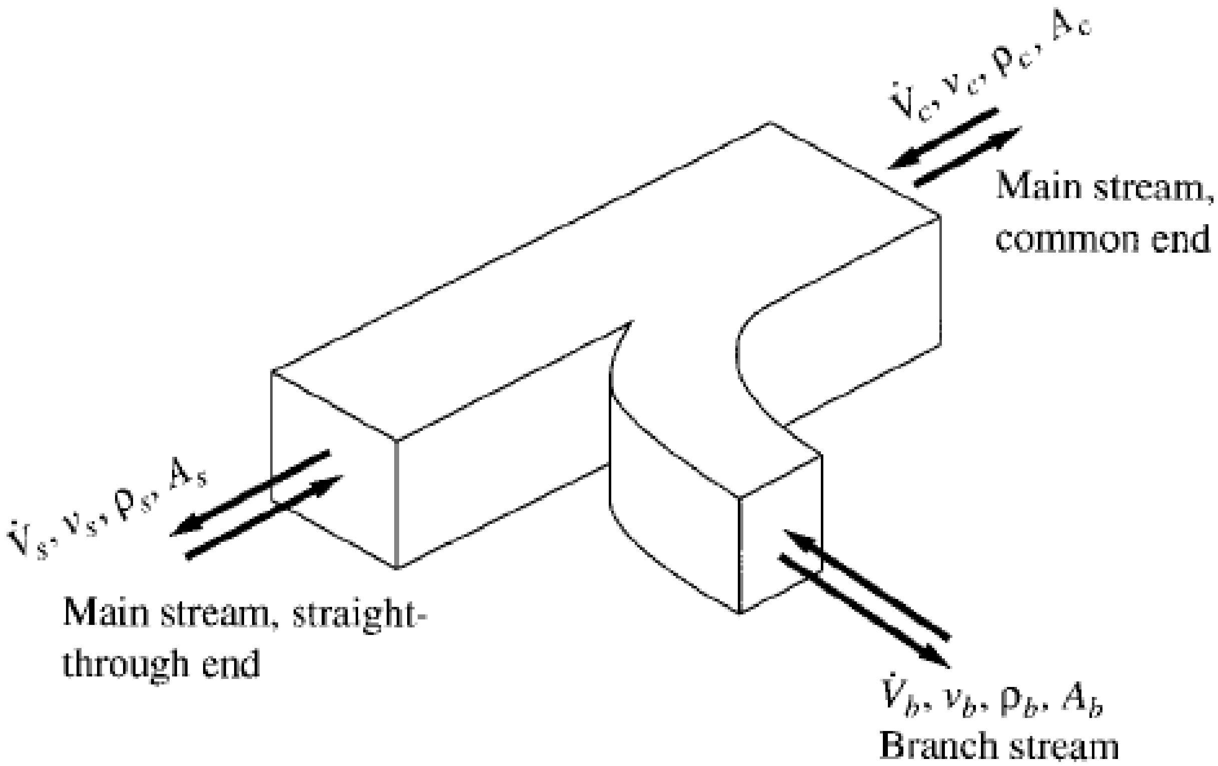




Mitered elbow and its secondary flow

(Source: *ASHRAE Handbook Fundamentals 2001*)



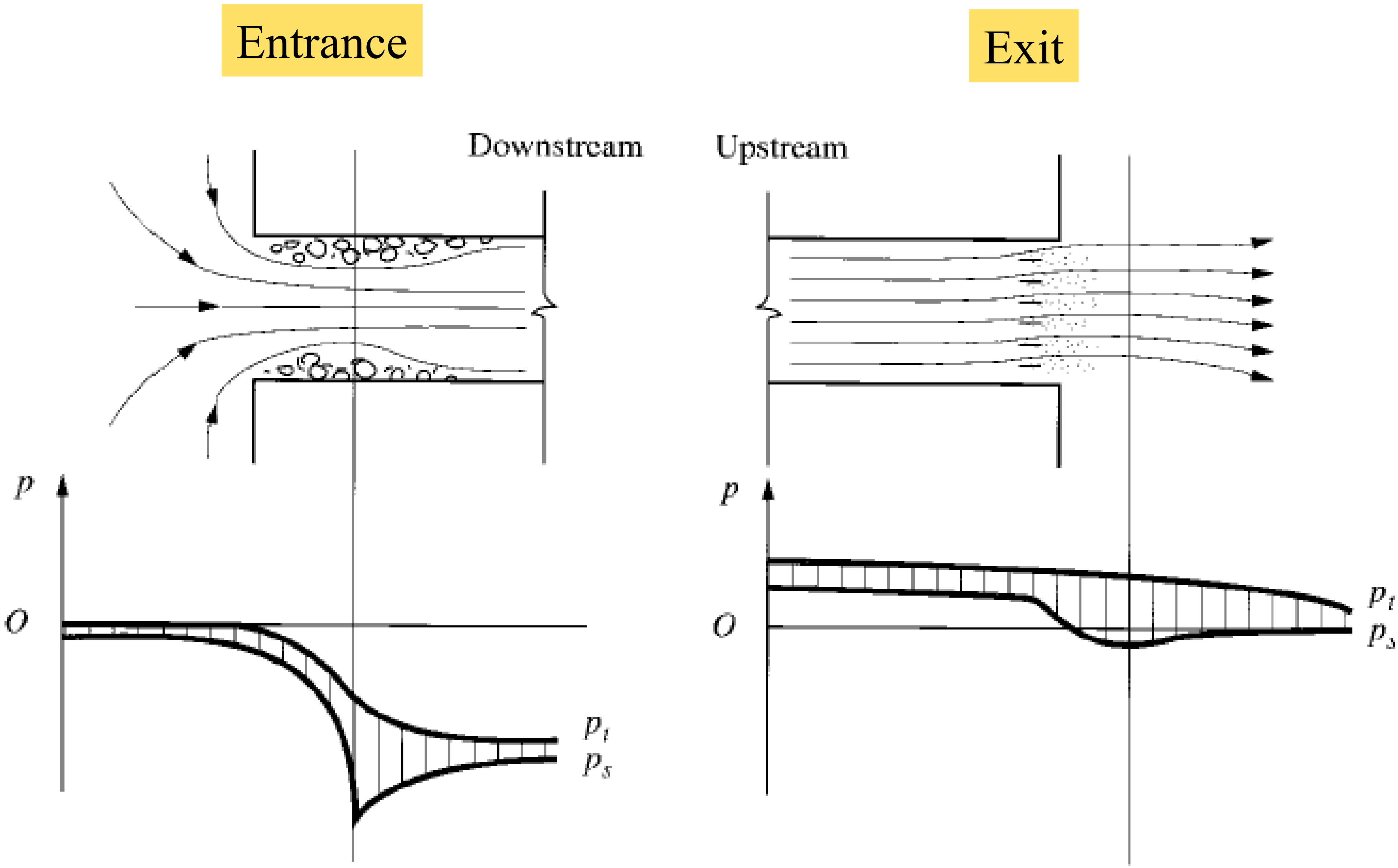




Airflow through a rectangular converging or diverging wye

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Entrance and exit

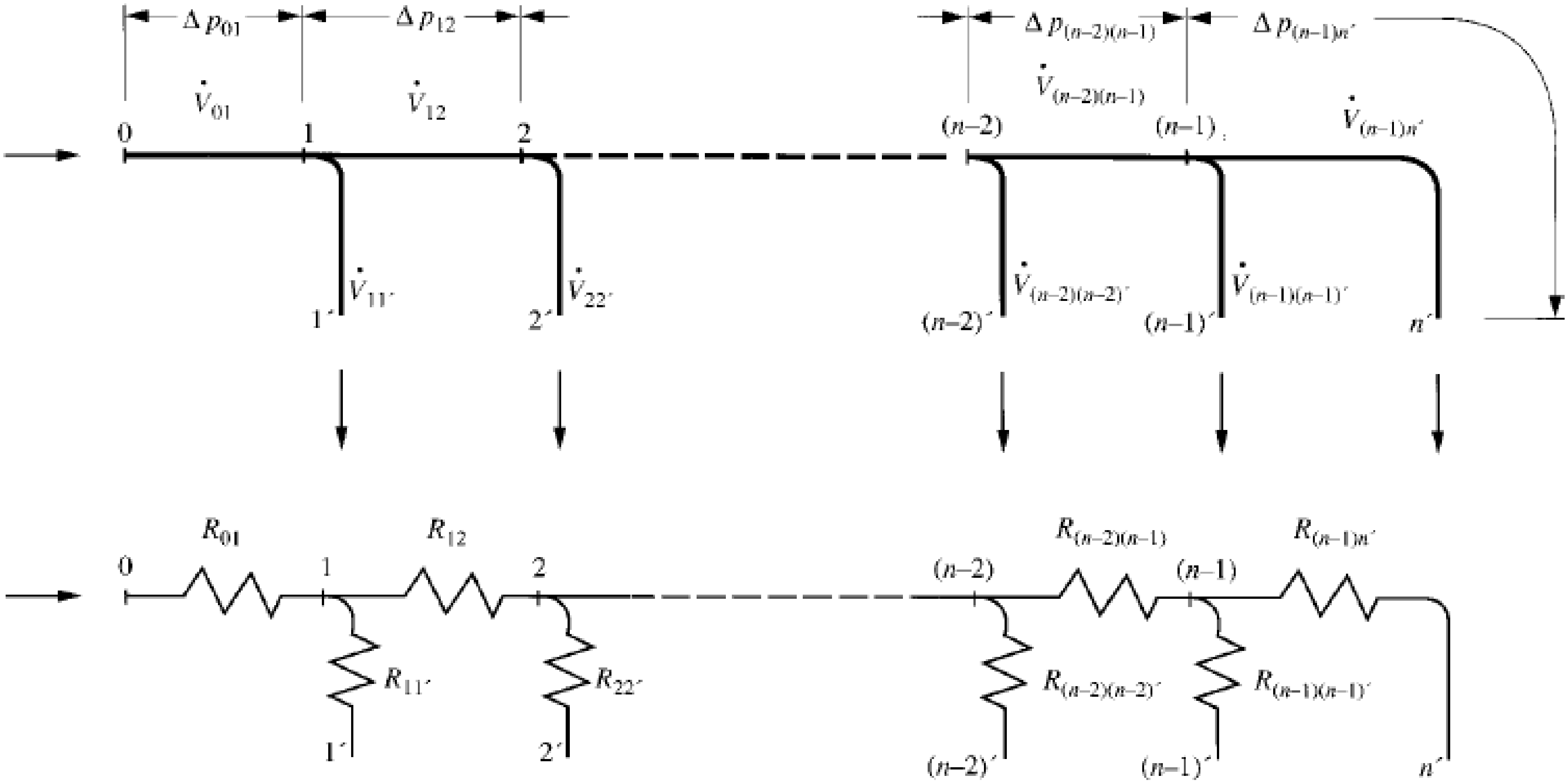



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Air Duct Design

- Optimal air duct design
  - Optimal duct system layout, space available
  - Satisfactory system balance
  - Acceptable sound level
  - Optimum energy loss and initial cost
  - Install only necessary balancing devices (dampers)
  - Fire codes, duct construction & insulation
- Require comprehensive analysis & care for different transport functions

# Flow characteristics of a supply duct system



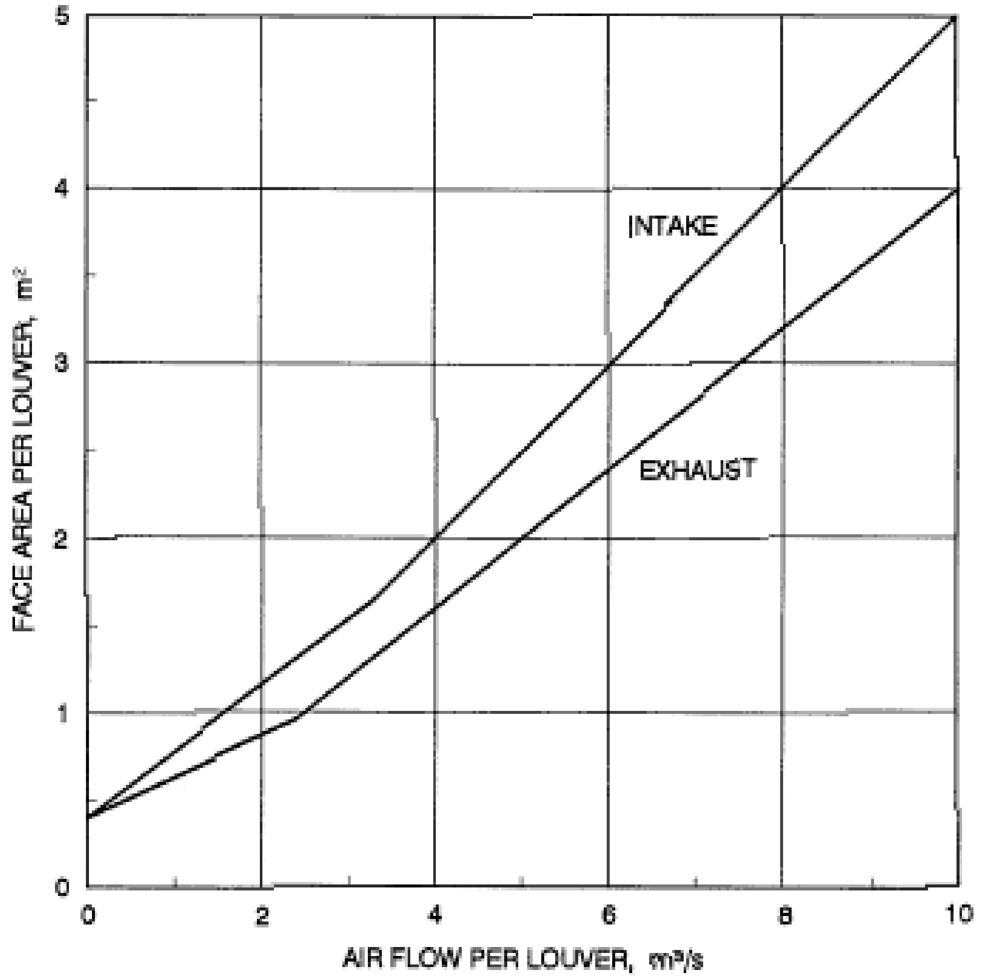

(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Air Duct Design

- Design velocity
  - Constraints: space available, beam depth
  - Typical guidelines:
    - Main ducts: air flow usually $\leq$ 15 m/s; air flow noise must be checked
    - With more demanding noise criteria (e.g. hotels), max. air velocity: main duct $\leq$ 10-12.5 m/s, return main duct $\leq$ 8 m/s, branch ducts $\leq$ 6 m/s
  - Face velocities for air-handling system components

**Table 10 Typical Design Velocities for HVAC Components**

| Duct Element | Face Velocity, m/s |
|---|---|
| LOUVERS[a] | |
| Intake | |
| 3300 L/s and greater | 2 |
| Less than 3300 L/s | See Figure 15 |
| Exhaust | |
| 2400 L/s and greater | 2.5 |
| Less than 2400 L/s | See Figure 15 |
| FILTERS[b] | |
| Panel filters | |
| Viscous impingement | 1 to 4 |
| Dry-type, extended-surface | |
| Flat (low efficiency) | Duct velocity |
| Pleated media (intermediate efficiency) | Up to 3.8 |
| HEPA | 1.3 |
| Renewable media filters | |
| Moving-curtain viscous impingement | 2.5 |
| Moving-curtain dry media | 1 |
| Electronic air cleaners | |
| Ionizing type | 0.8 to 1.8 |
| HEATING COILS[c] | |
| Steam and hot water | 2.5 to 5<br>1 min., 8 max. |
| Electric | |
| Open wire | Refer to mfg. data |
| Finned tubular | Refer to mfg. data |
| DEHUMIDIFYING COILS[d] | 2 to 3 |
| AIR WASHERS[e] | |
| Spray type | 1.5 to 3.0 |
| Cell type | Refer to mfg. data |
| High-velocity spray type | 6 to 9 |




| Parameters Used to Establish Figure | Intake Louver | Exhaust Louver |
|---|---|---|
| Minimum free area (1220 mm square test section), % | 45 | 45 |
| Water penetration, μL/(m²·s) | Negligible (less than 0.6) | na |
| Maximum static pressure drop, Pa | 35 | 60 |

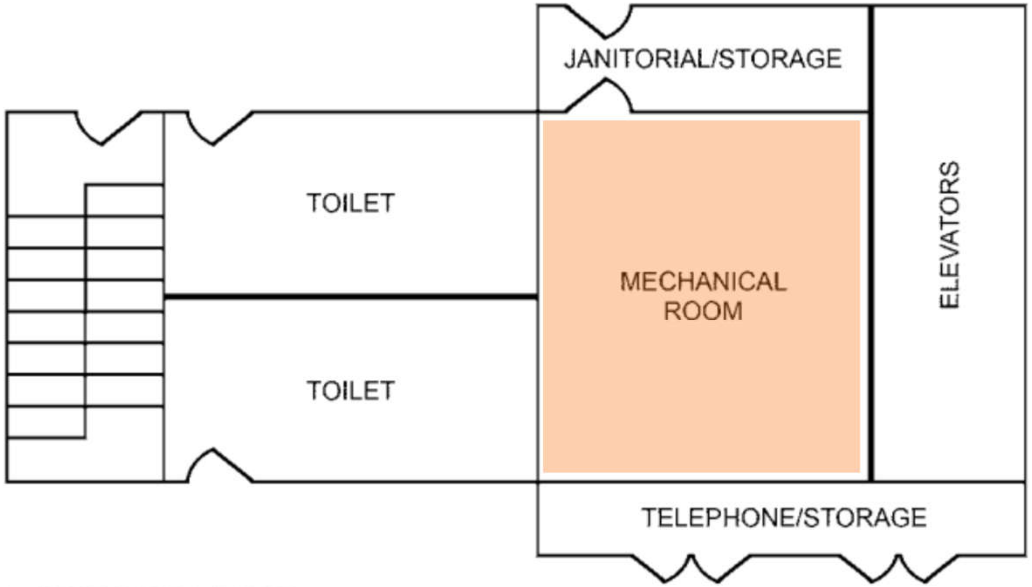
**Fig. 15 Criteria for Louver Sizing**

(Source: *ASHRAE Handbook Fundamentals 2001*)

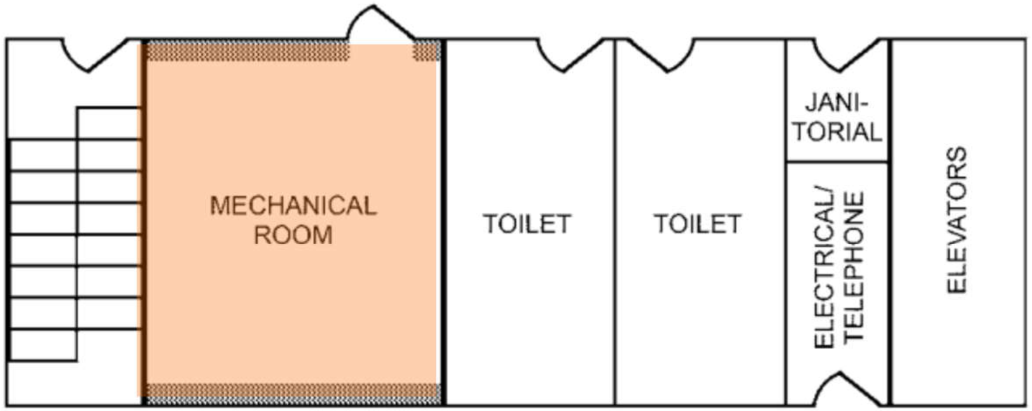
# Air Duct Design

- Reduce dynamic losses of the critical path
  - Maintain optimum air velocity through duct fittings
  - Emphasize reduction of dynamic losses nearer to the fan outlet or inlet (high air velocity)
  - Proper use of splitter vanes
  - Set 2 duct fittings as far apart as possible
- Equipment room locations & core layout
  - Mechanical room (AHU): maintenance & operation issues, space requirements
  - Noise-sensitive areas & surrounded by buffer zones (toilets, storage rooms, lifts, stairs, duct shafts)

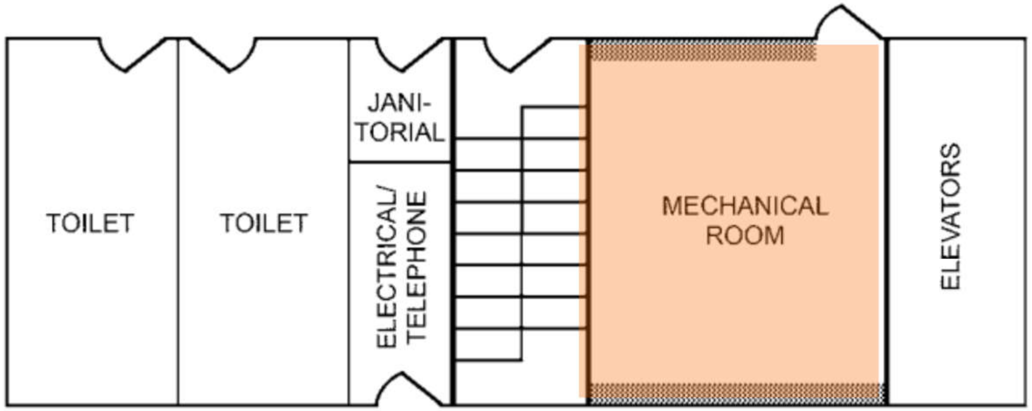
# Comparison of various mechanical equipment room locations



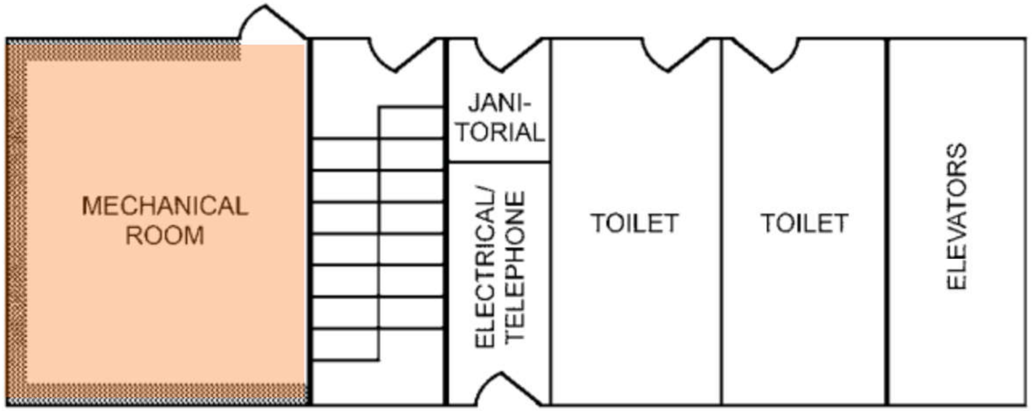

A. BEST CORE LAYOUT
No mechanical room walls exposed to tenant space. No supply and return air openings need be next to tenant space. Ceiling over toilets can be used for supply air ducts or return air path.




B. BETTER CORE LAYOUT
Exposes 2 mechanical room walls to tenant space. Ceiling over toilets can be used for supply ducts or return air path.



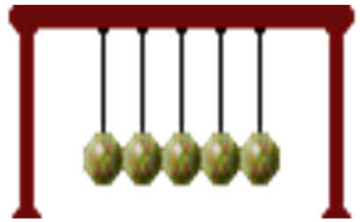

C. FAIR CORE LAYOUT
Exposes 2 mechanical room walls to tenant space. Impenetrable mechanical room partition to elevators and stairs results in supply and return air wall openings next to tenant space.




D. POOR CORE LAYOUT
Exposes 3 mechanical room walls to surrounding tenant space. Impenetrable partition between mechanical room and exit stairs results in supply and return air wall openings next to tenant space.

(Source: *ASHRAE Handbook Fundamentals 2017*, Chp. 21)

# Air Duct Design



- Fire protection
  - Duct material selection
  - Vertical ducts (using masonry, concrete or clay)
  - When ducts pass through floors & walls
  - Use of fire dampers
  - Filling the gaps between ducts & bldg structure
  - Duct systems for industrial applications
- Any other fire precautions?

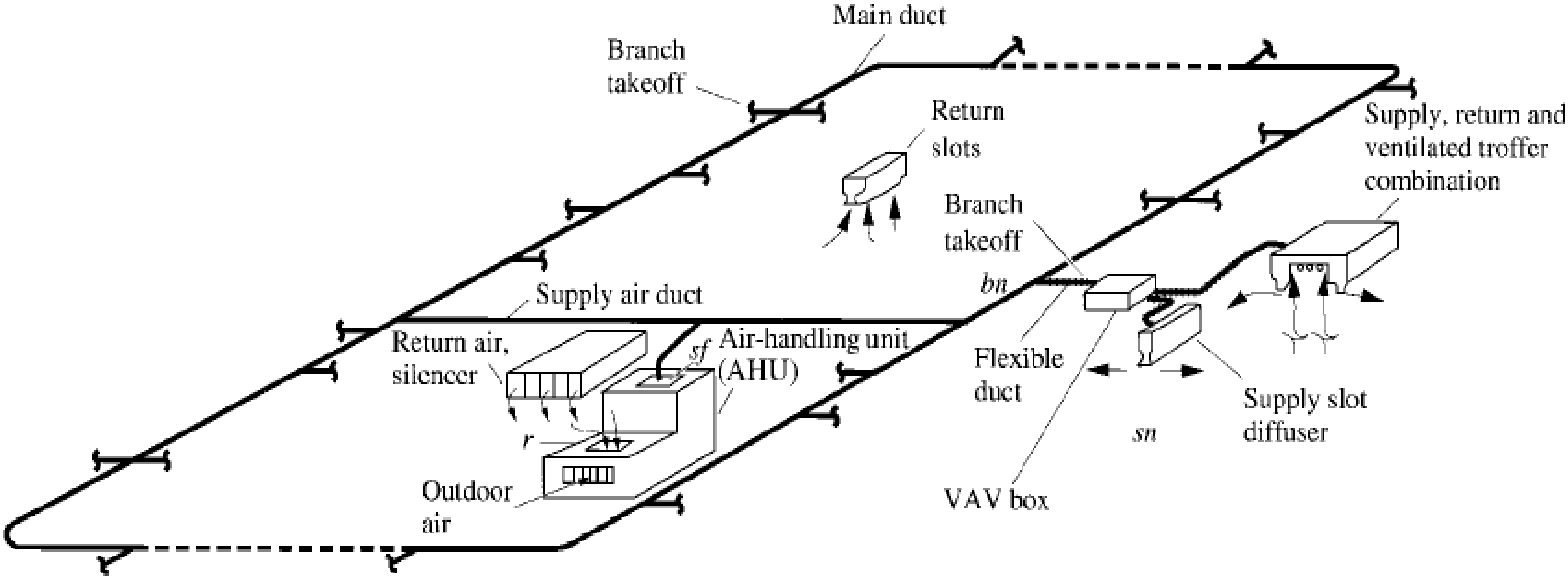
# Air Duct Design

- Design procedure (computer-aided or manual)
  - Verify local codes & material availability
  - Preliminary duct layout
  - Divide into consecutive duct sections
  - Minimise local loss coefficients of duct fittings
  - Select duct sizing methods
  - Critical total pressure loss of tentative critical path
  - Size branch ducts & balance total pressure at junctions
  - Adjust supply flow rates according to duct heat gain
  - Resize duct sections, recalculate & balance parallel paths
  - Check sound level & add necessary attenuation

# Air Duct Design

- Duct layout
  - Symmetric layout is easier to balance
    - Smaller main duct & shorter design path
  - For VAV systems, duct looping allows feed from opposite direction
    - Optimise transporting capacity (balance points often follow the sun’s position)
    - Result in smaller main duct
  - Compare alternative layouts & reduce fittings
  - For exposed ducts, appearance & integration with the structure is important

# Typical supply duct system with symmetric layout & looping




(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Air Duct Design

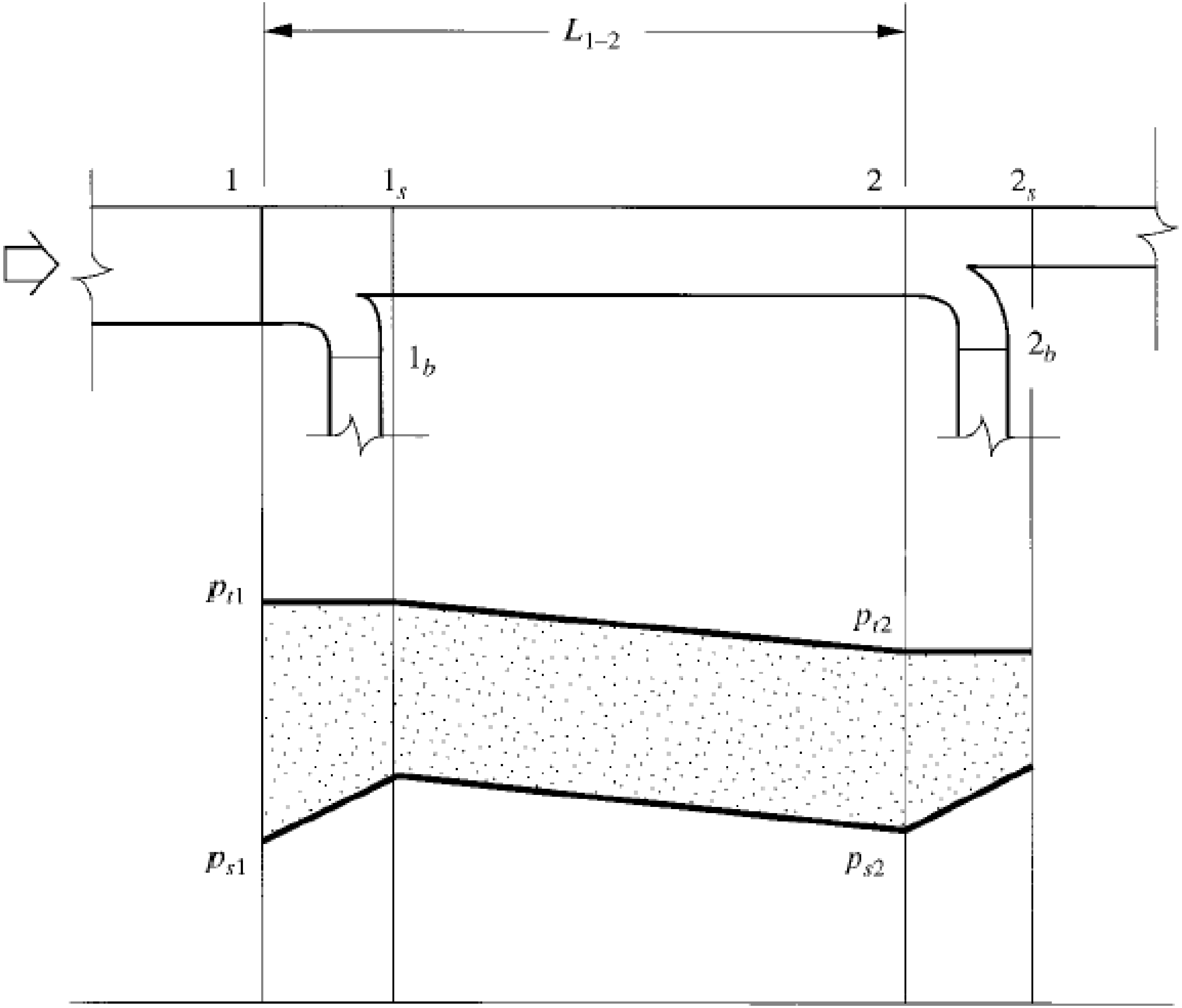
- Duct sizing methods
  - Equal-friction method with maximum velocity
    - Duct friction loss per unit length remains constant
    - Most widely used in normal HVAC applications
  - Constant-velocity method
    - Often for exhaust ventilation system
    - Minimum velocity to carry dust is important
    - Limit velocity to reduce noise

(Video: Ductwork sizing, calculation and design for efficiency - HVAC Basics + full worked example (17:38) https://youtu.be/5y_VBiTiuAY)

# Air Duct Design

- Duct sizing methods
  - Static regain method
    - Normally used with a computer package for high velocity systems (e.g. in main duct)
    - Size air duct so that ↑static pressure nearly offset the pressure loss of succeeding duct section along main duct
  - T method
    - Optimising procedure by minimising life-cycle cost
      - System condensing (into a single imaginary duct)
      - Fan selection (optimum system pressure loss)
      - System expansion (back to original duct system)

# Concept of static regain method

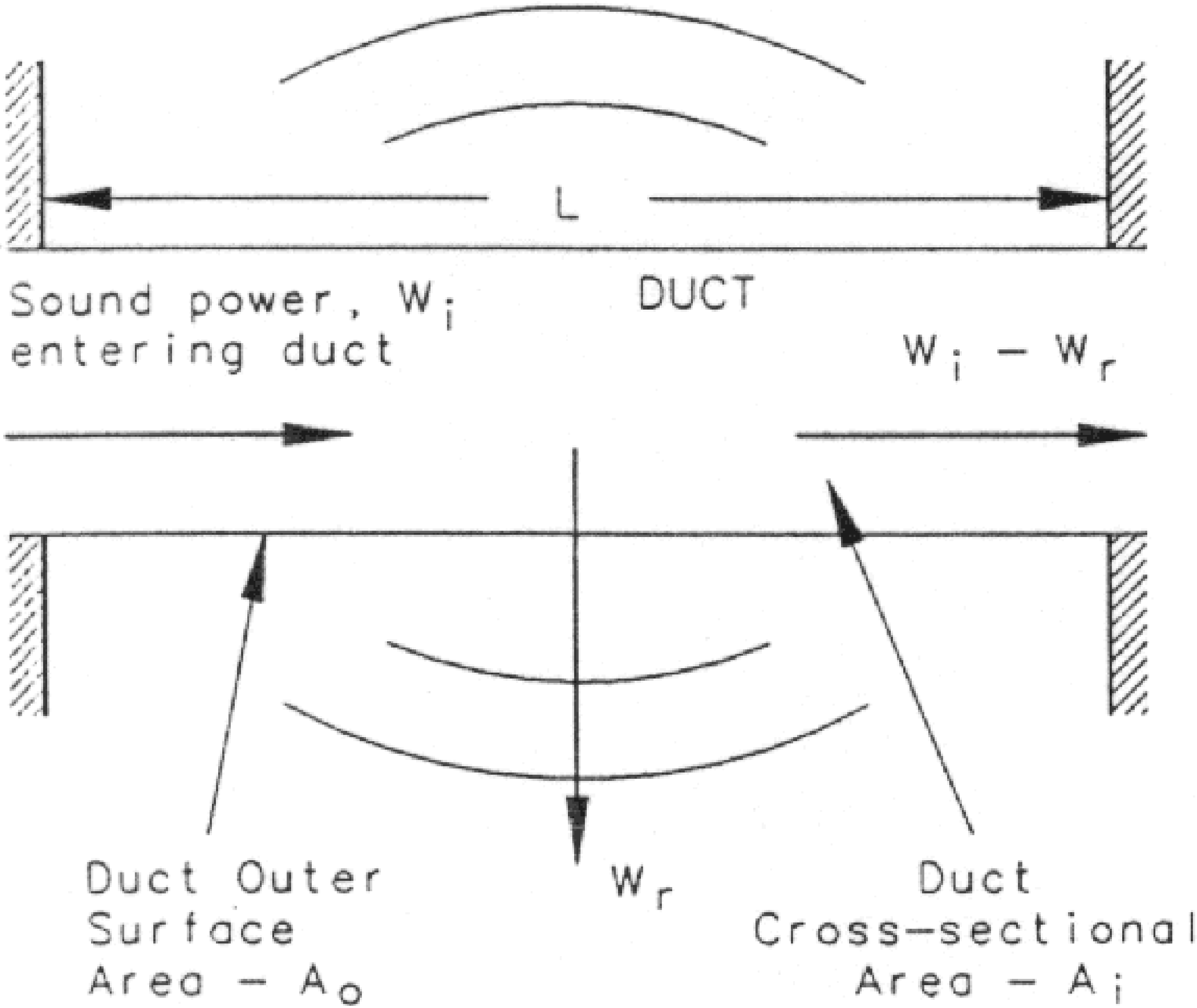



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Air Duct Design

- Duct liner
  - Lined internally on inner surface of duct wall
  - Mainly used for noise attenuation & insulation
  - Fiberglass blanket or boards
- Duct cleaning
  - Prevent accumulation of dirt & debris
  - Agitation device to loosen the dirt & debris
  - Duct vacuum to extract loosened debris
  - Sealing of access openings

# Duct breakout noise




(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

# Further Reading


- ASHRAE, 2020. *ASHRAE Systems and Equipment Handbook 2020*, SI edition, Chp. 21 - Fans, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
- CIBSE Journal CPD http://www.cibsejournal.com/cpd/
  - Module 31: Airflow pressure drop in HVAC ductwork https://www.cibsejournal.com/cpd/modules/2011-08/
  - Module 33: Designing ducted air system pressure drops for low carbon operation https://www.cibsejournal.com/cpd/modules/2011-10/
  - Module 34: Matching the fan to the ventilation system https://www.cibsejournal.com/cpd/modules/2011-11/
  - Module 35: Fans for ducted ventilation systems https://www.cibsejournal.com/cpd/modules/2011-12/
  - Module 37: The performance of fans in ducted air systems https://www.cibsejournal.com/cpd/modules/2012-02/
- FANtastic! A Closer Look At Fan Efficiency Metrics (Trane Engineers Newsletter volume 43 –3) [PDF]

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- Pennycook, K., Churcher, D. and Bleicher, D., 2007. *A Guide to HVAC Building Services Calculations*, 2nd ed., Building Services Research and Information Association, Bracknell, Berkshire, England.
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