Today, we will:

- Continue to discuss **Exhaust Duct System Design** in **Section 6.10**
- Continue to discuss **Fan Performance and Selection** in **Section 6.11**
- Do some example problems – duct design and selection of a fan
- Do Candy Questions for Candy Friday

equivalent column height of the fluid (air)

From last lecture, here is the head form of the steady-state, steady-flow energy equation for a control volume from an inlet (1) to an outlet (2) (from ME 33):

$$\left(\frac{P_1}{\rho g}+\alpha_1\frac{V_1^2}{2g}+z_1\right)_{inlet}+h_{fan}=\left(\frac{P_2}{\rho g}+\alpha_2\frac{V_2^2}{2g}+z_2\right)_{outlet}+h_{turbine}+\sum h_{losses}$$

Usually use 1

[I like to use 1.05 for turbulent flow – just for better accuracy]

no turbines in exhaust ducts

Notation:

ΔP_{fan} = pressure rise across the fan

$$\Delta P_{fan} = \rho g h_{fan}$$

air density

Manufacturer lit ΔP_{fan} in inches of water

$\sum h_{losses} = h_{LT}$ = total head loss

$$h_{LT} = \sum_{major} h_{Lf} + \sum_{minor} h_{LM}$$

Also, we use V instead of V (avg. velocity in the duct)

★ Write the eq. in terms of pressure rather than head

★
$$\left(P_1+\tfrac{1}{2}\rho V_1^2+\rho g z_1\right)+\Delta P_{fan}=\left(P_2+\tfrac{1}{2}\rho V_2^2+\rho g z_2\right)+\rho g h_{LT}$$

(α_1 under $\tfrac{1}{2}\rho V_1^2$, α_2 under $\tfrac{1}{2}\rho V_2^2$)

Eq. (2)

Head losses:

major: $h_{Lf} = f \frac{L}{D} \frac{V^2}{2g}$ for each section of straight duct

minor $h_{Lm} = C_0 \frac{V_0^2}{2g}$ for each minor loss component

same as K_L in fluids book
some people use F
} C_0 = minor loss coeff.

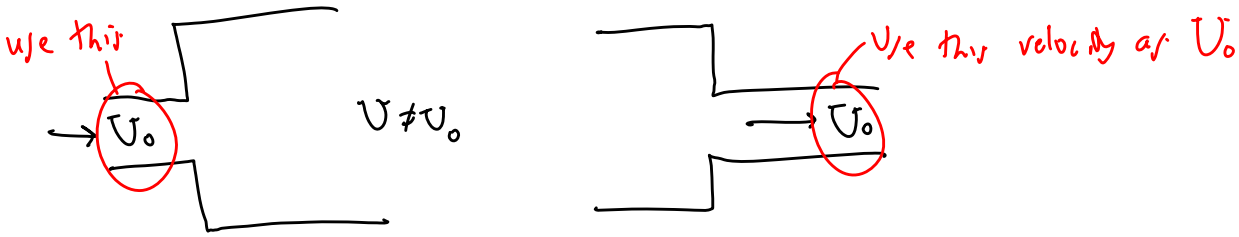
Can re-write $h_{Lm} = C_0 \left(\frac{1}{2}\rho V_0^2\right) \frac{1}{\rho g}$

VP = Dynamic pressure = "velocity pressure"

So, in terms of $VP = \frac{1}{2}\rho V_0^2$

$$h_{Lm} = C_0 \frac{(VP)_0}{\rho g} \qquad h_{Lf} = \frac{f\left(\frac{L}{D}\right)(VP)_0}{\rho g}$$

Always use the larger velocity as the ref. value (V_0)



Values of C_0 → obtained experimentally See ASHRAE Handbook
ACGIH ventilation manual
etc.

Rewrite Eq. (2):

A

$$\Delta P_{fan} = \left[P_2 - P_1\right] + \left\{(VP)_2 - (VP)_1\right\} + \rho g\left(z_2 - z_1\right) + \rho g h_{LT}$$

(1) (2) (3) (4)

This is $\Delta P_{fan\_required}$ (see plot below)

The fan must do 4 things:

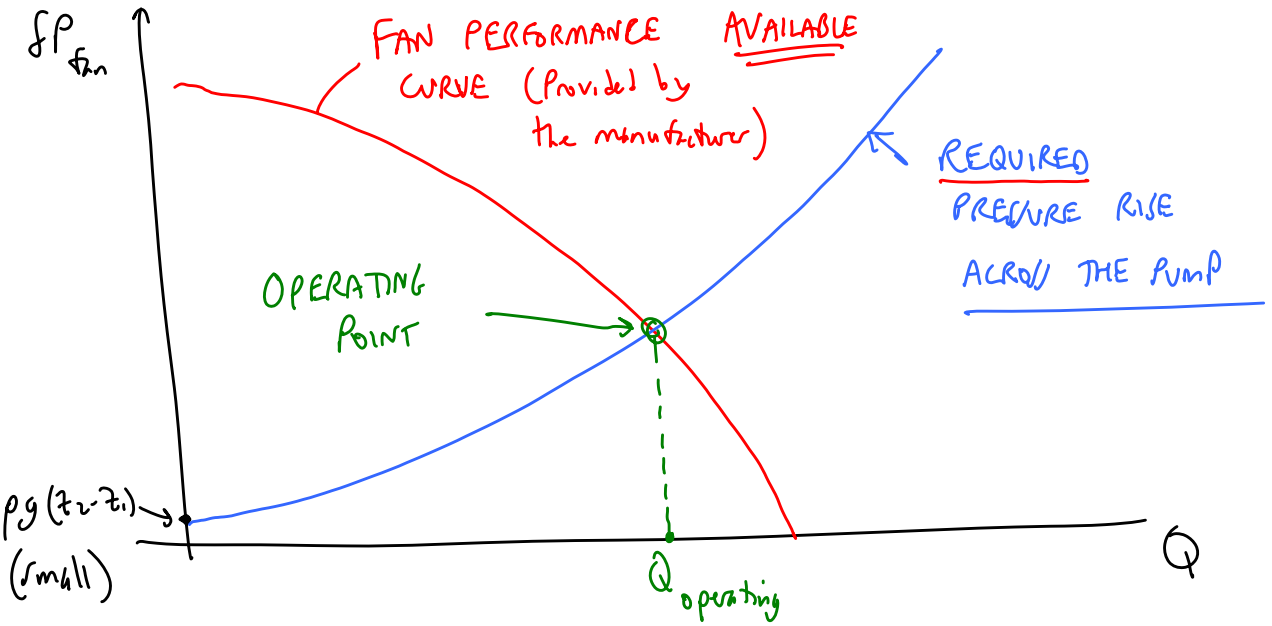
(1) raises the static pressure — Can be ⊕ or ⊖

(2) increases the velocity pressure (kinetic energy) — Can be ⊕ or ⊖

(3) increases the elevation pressure (potential energy) — Can be ⊕ or ⊖ — USUALLY NEGLIGIBLE FOR AIR FLOW

(4) overcomes irreversible losses (friction, turbulent mixing, etc.) → ALWAYS ⊕

Plot ΔP_{fan} vs Q (volume flow rate)

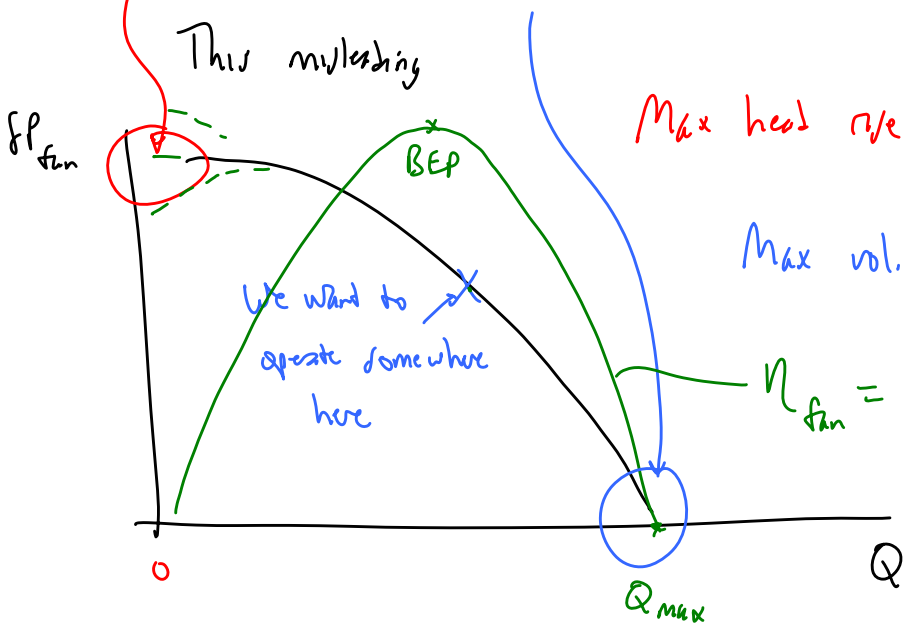


Sec. 6.11 → Fan Performance → Read first part of this — type of fans is blowers.

Caution: Fan manufacturers advertise like this:

Max pressure rise = ~~~

Max volume flow rate = ~~~



Max head rise @ no flow!

Max vol. flow @ no head!

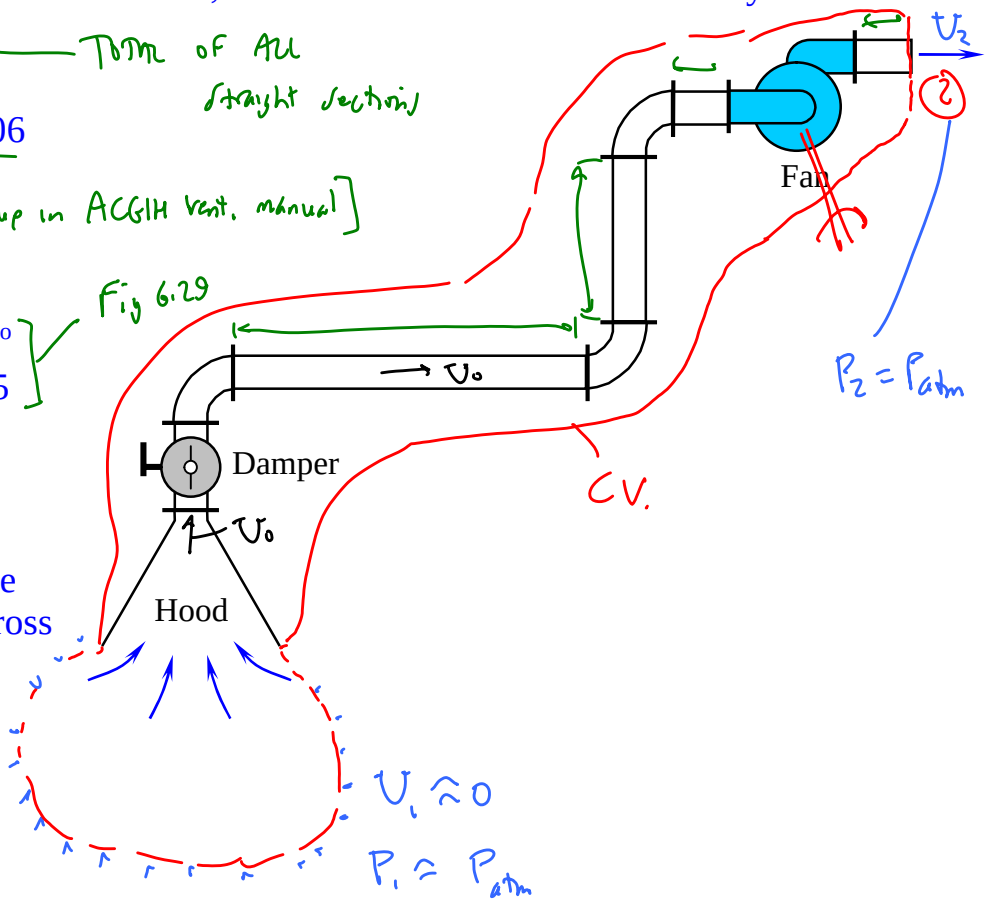
η_{fan} = efficiency

BEP = best efficiency point

Example

Given: Air is drawn into a 45° tapered hood, and then goes through a damper, several long sections of pipe, and three elbows, as sketched. The air is exhausted by a fan.

- duct length = 100 ft — Total of ALL straight sections
- duct dia. = 6 in
- duct roughness = 0.006 in
- $C_{o,\,hood} = 0.15$ (look up in ACGIH vent. manual)
- $C_{o,\,damper} = 0.50$ when fully open
- elbows are 5-gore, 90° CD3-9 with $R/D = 1.5$ — Fig 6.29
- $\rho_{air} = 1.2$ kg/m^3
- $\nu_{air} = 1.5 \times 10^{-5}$ m^2/s
- $Q = 1200$ CFM



(a) To do: Calculate the required pressure rise across the fan

Solution:

- Pick a CV wisely

- Convert to SI → $D = 0.1524$ m $= 152.4$ mm
  $L = 30.48$ m

  roughness ratio $\varepsilon/D = \dfrac{0.006''}{6''} = 0.001$

  $Q = 1200\ ft^3/min = 0.5663\ m^3/s$

- Fig 6.29 → $C_{o\ elbow} = 0.28$ @ $D = 150$ mm

Apply fan eq.

$$\Delta p_{fan,\,required} = \underbrace{[p_2 - p_1]}_{\text{cancel}} + [\alpha_2 (VP)_2 - \alpha_1 (VP)_1] + \underbrace{\rho g (z_2 - z_1)}_{\text{ignore for air}} + \rho g\, h_{LT}$$

$V_1 \approx 0$

$$(\delta P_{fan})_{req.} = \alpha_2 (VP)_2 + \rho g h_{LT}$$

$$= \alpha_2 (VP)_2 + \sum \delta P_{L,\,major} + \sum \delta P_{L,\,minor}$$

$$U = \frac{Q}{A} = \frac{4Q}{\pi D^2} = 31.2 \ m/s$$

$$Re = \frac{UD}{\nu} = 3.16 \times 10^5$$

@ this Re if $\varepsilon/D = 0.001$, Colebrook eq (Moody Chart)

$$f = 0.0206$$

$$(VP)_2 = VP \text{ in duct}$$

$$= \frac{1}{2} \rho U^2 = \underline{583.8 \ Pa}$$

$$\delta P_{L,\,major} = f \frac{L}{D} (VP) = 2413 \ Pa$$

$$\delta P_{L\,minor} = \sum C_0 (VP)$$

$$= \left(0.15 + 0.50 + 3(0.28) \right) (583.8 \ Pa)$$

(hood) (damper) 3 elbows

$$= \underline{869.8 \ Pa}$$

$$(\delta P)_{fan,\,required} = \alpha_2 (VP)_2 + \delta P_{L\,major} + \delta P_{L\,minor}$$

$$\left((1.05)(583.8) + 2413 + 869.8 \right) Pa$$

$$(\delta P_{fan})_{req} = 3900 \ Pa \quad (2 \text{ digits})$$