Today, we will:

- Discuss **Exhaust Duct System Design** [Section 6.10]
- Briefly discuss some additional considerations beyond ME 320 material
- Show how to estimate major and minor head losses in ducts

Recall, **major loss** = long straight section of duct

**minor loss** = anything else (elbows, damper, drop-out box, etc.)

"Minor losses somehow > major losses"

"**Beyond ME 320**":

- Drop-out box — remove partially
- Particles can settle on bottom of duct — blockage & excess weight
(1) can clog the duct — more loss
(2) weight can cause structural problems (collapse!)

- Vapors usually hot
  - ducts are cool
  - condensation
  - corrosion

- Explosions — particles + vapors if exceed LEL

  We don’t monitor PEL in duct (PPM)

END OF EXAM 2 MATERIAL
Equations for flow through ducts and pipes:
Here is the head form of the steady-state, steady-flow (SSSF) energy equation for a control volume from an inlet (1) to an outlet (2) (from ME 320):

\[
\frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} + z_1 + h_{\text{pump,u}} = \frac{P_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g} + z_2 + h_{\text{turbine,e}} + h_L
\]

- \(P\) = pressure
- \(V\) = avg. speed through the duct
- \(z\) = up always
- \(\alpha\) = kinetic energy correction factor
- For turb duct, \(\alpha = 1.05\)

\(h_{\text{turbine,e}} = 0\) → CC book

\(h_{\text{pump,u}} = \) useful head delivered (ad) to the fluid by a pump

"pump" = pump, fan, blower

\(h_{\text{fan,u}}\) → HC book

\(h_{\text{fan,u}} = \frac{n_{\text{fan}} W_s}{\rho Q g}\)

\(Q = \) volumetric flow rate

We never have turbines in HVAC, hoops etc

Actual

Model

\(V_{av}\)

\(\frac{\rho Q g}{\text{HC}}\)
\( \{ \dot{W}_s \} = \left\langle \frac{\text{Force} \cdot \text{Length}}{\text{Time}} \right\rangle = \left\langle \frac{mL}{t^2} \cdot \frac{L}{t} \right\rangle \)

\( \left\langle h_{\text{fan,u}} \right\rangle = \left\langle \frac{(1) \cdot \frac{mL^2}{t^3}}{\frac{m}{L^3} \cdot \left( \frac{L^3}{t} \right) \cdot \left( \frac{L}{t^2} \right)} \right\rangle = \left\langle \frac{1}{L} \right\rangle \)

\( \dot{W}_{s,\text{fan}} = \dot{W}_{\text{motor}} \cdot \eta_{\text{motor}} \)

\( h_i = \text{irreversible head loss} \)
Irreversible head losses:

\[ h_L = \sum h_{L,\text{major}} + \sum h_{L,\text{minor}} = \sum \left( \frac{L V^2}{D 2g} \right) + \sum \left( \frac{K_L V^2}{2g} \right) \]

\[ \text{Darcy friction factor} \]

\[ h_{L,\text{major}} = f_L \frac{L V^2}{D 2g} \]
\[ h_{L,\text{minor}} = K_L \frac{V^2}{2g} \]

\[ K_L = C_0 \]

Always use the large V if there is a change of V to define the minor loss (convention)

E.g., expansion

\[ V_A \quad \rightarrow \quad V_B \]

\[ V_A \quad \rightarrow \quad \text{we} \]

\[ V_B \]

See Fig. 6.29-31 for minor loss coeff. we

ALSO ASHRAE Fundamentals Handbook

ACGIH has more
Minor Loss Coefficients for various entrances, elbows, and expansions:

**Note:** We use $K_L$ as the minor loss coefficient in fluids class, but in HVAC we use $C_0$. $K_L = C_0$.

### Table: Loss Coefficient $C_0$ for Round Duct Mounted in Wall

<table>
<thead>
<tr>
<th>$t/D$</th>
<th>0.00</th>
<th>0.01</th>
<th>0.05</th>
<th>0.10</th>
<th>0.20</th>
<th>0.30</th>
<th>0.50</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.50</td>
<td>0.68</td>
<td>0.80</td>
<td>0.86</td>
<td>0.92</td>
<td>0.97</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.02</td>
<td>0.50</td>
<td>0.52</td>
<td>0.55</td>
<td>0.60</td>
<td>0.66</td>
<td>0.69</td>
<td>0.72</td>
<td>0.72</td>
</tr>
<tr>
<td>0.05</td>
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<td>0.50</td>
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<td>0.50</td>
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<tr>
<td>10.0</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

(a)

### Figure 6.29

Fitting loss coefficients: (a) duct mounted in a wall (also called a re-entrant inlet); (b) round 90-degree elbows: 5 gore, $r/D = 1.5$ and 7 gore, $r/D = 2.5$ (abstracted from ASHRAE Fundamentals Handbook, 1997).

### Table: Loss Coefficients $C_0$

<table>
<thead>
<tr>
<th>$D$ (mm)</th>
<th>75</th>
<th>150</th>
<th>230</th>
<th>300</th>
<th>380</th>
<th>450</th>
<th>530</th>
<th>600</th>
<th>690</th>
<th>750</th>
<th>1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_0$, CD3-9</td>
<td>0.51</td>
<td>0.28</td>
<td>0.21</td>
<td>0.18</td>
<td>0.16</td>
<td>0.15</td>
<td>0.14</td>
<td>0.13</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>$C_0$, CD3-10</td>
<td>0.16</td>
<td>0.12</td>
<td>0.10</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
<td>-</td>
<td>-</td>
<td>0.05</td>
<td>-</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Figure 6.30 Fitting loss coefficients for an ED2-1 conical diffuser (abstracted from ASHRAE Fundamentals Handbook, 1997).
Major loss — friction in long straight section of pipe

For round pipe (duct) — use \( D = \text{diameter} \)

- Moody chart
- Empirical eqn — Colebrook eqn
  or Churchill eqn

\[
f = \text{Darcy friction factor} = f_h \left( \frac{Re}{E/0} \right)
\]

\[
\left( \nu = \frac{M}{\rho} \right)
\]

\[
Re = \frac{VD}{\nu} = \left( \frac{E^2}{m} \right)
\]

Hydraulic Diameter — used for non-round duct

\[
D_h = \text{equivalent diameter (pretend it is round with \( d_h = D \))}
\]

\[
D_h = 4 \frac{A_c}{P}
\]

E.g., rectangular duct

\[
D_h = 4 \frac{A_c}{P} = \frac{4 \left( W \cdot H \right)}{2W + 2H} = \frac{2WH}{W+H} = D_h
\]
Friction factor for major losses (losses in long straight sections of pipe or duct):

**Graphical estimate – the Moody Chart:** [Figure from Cengel and Cimbala, Fluid Mechanics: Fundamentals and Applications, Ed. 4.]

![Moody Chart](image)

**Empirical equation – the Churchill Equation:**

\[
f = 8 \left[ \left( \frac{8}{Re} \right)^{12} + (A + B)^{-1.5} \right]^{1/12},
\]

where

\[
A = \left\{ -2.457 \cdot \ln \left[ \left( \frac{7}{Re} \right)^{0.9} + 0.27 \frac{\varepsilon}{D} \right] \right\}^{16},
\]

\[
B = \left( \frac{37530}{Re} \right)^{16},
\]

and \( f \) is the **Darcy friction factor**, \( h_{L,\text{major}} = f \frac{L V^2}{D 2g} \), where \( A_c \) is the cross-sectional area of the duct and \( p \) is the wetted perimeter (always the entire perimeter for air flows).

For non-circular ducts, use **hydraulic diameter**, \( D_h = \frac{4 A_c}{p} \).