Duct Design and Air Distribution Systems
Introduction

• The chief requirements of an air conditioning duct system are:
  – It should convey specified rates of air flow to prescribed locations
  – It should be economical in combined initial cost, fan operating cost and cost of building space
  – It should not transmit or generate objectionable noise
• Generally at the time of designing an air conditioning duct system, the required airflow rates are known from load calculations.

• The location of fans and air outlets are fixed initially. The duct layout is then made taking into account the space available and ease of construction.

• In principle, required amount of air can be conveyed through the air conditioning ducts by a number of combinations.

• However, for a given system, only one set results in the optimum design.

• Hence, it is essential to identify the relevant design parameters and then optimize the design.
General rules for duct design

- Air should be conveyed as directly as possible to save space, power and material.
- Sudden changes in directions should be avoided. When not possible to avoid sudden changes, turning vanes should be used to reduce pressure loss.
- Diverging sections should be gradual. Angle of divergence ≤ 20°.
- Aspect ratio should be as close to 1.0 as possible. Normally, it should not exceed 4.
- Air velocities should be within permissible limits to reduce noise and vibration.
- Duct material should be as smooth as possible to reduce frictional losses.
Classification of duct systems

• Low pressure systems: Velocity $\leq 10$ m/s, static pressure $\leq 5$ cm H2O (g)
• Medium pressure systems: Velocity $\leq 10$ m/s, static pressure $\leq 15$ cm H2O (g)
• High pressure systems: Velocity $> 10$ m/s, static pressure $15<p \leq 25$ cm H2O (g)
High velocities in the ducts results in:

- Smaller ducts and hence, lower initial cost and lower space requirement
- Higher pressure drop and hence larger fan power consumption
- Increased noise and hence a need for noise attenuation
- Recommended air velocities depend mainly on the application and the noise criteria. Typical recommended velocities are:
  - Residences: 3 m/s to 5 m/s
  - Theatres: 4 to 6.5 m/s
  - Restaurants: 7.5 m/s to 10 m/s

If nothing is specified, then a velocity of **5 to 8 m/s is used for main ducts and a velocity of 4 to 6 m/s is used for the branches. The allowable air velocities can be as high as 30 m/s in ships and aircrafts to reduce the space requirement.**
### TYPICAL AIR VELOCITIES FOR DUCTS

<table>
<thead>
<tr>
<th>Building</th>
<th>Air Velocity (m/s)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td><strong>Main Duct</strong></td>
<td><strong>Branch</strong></td>
</tr>
<tr>
<td>Domestic</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Auditoria</td>
<td>5</td>
<td>3-4</td>
</tr>
<tr>
<td>Hotel bedroom, Conference hall</td>
<td>5-6</td>
<td>3-4</td>
</tr>
<tr>
<td>Private office, Library, Hospital ward</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>General office, Restaurant, Dept. store</td>
<td>7.5</td>
<td>5</td>
</tr>
<tr>
<td>Cafeteria, Supermarket, Machine room</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Factory, Workshop</td>
<td>10-12</td>
<td>7.5</td>
</tr>
</tbody>
</table>
Purpose of Duct Design

• From load and psychrometric calculations the required supply airflow rates to each conditioned space are known.
• From the building layout and the location of the supply fan, the length of each duct run is known.
• The purpose of the duct design is to select suitable dimensions of duct for each run and then to select a fan, which can provide the required supply airflow rate to each conditioned zone.
Commonly used duct design methods

Most commonly used methods for simpler lay-outs

• Velocity method
• Equal Friction Method
• Static Regain method

The run with the highest pressure drop is called as the **index run**.
Velocity method

The various steps involved in this method are:

I. Select suitable velocities in the main and branch ducts

II. Find the diameters of main and branch ducts from airflow rates and velocities for circular ducts. For rectangular ducts, find the cross-sectional area from flow rate and velocity, and then by fixing the aspect ratio, find the two sides of the rectangular duct

III. From the velocities and duct dimensions obtained in the previous step, find the frictional pressure drop for main and branch ducts using friction chart or equation.
Continued...

IV. From the duct layout, dimensions and airflow rates, find the dynamic pressure losses for all the bends and fittings

V. Select a fan that can provide sufficient FTP for the index run

VI. Balancing dampers have to be installed in each run. The damper in the index run is left completely open, while the other dampers are throttled to reduce the flow rate to the required design values.
Continued...

- The velocity method is one of the simplest ways of designing the duct system for both supply and return air.
- However, the application of this method requires selection of suitable velocities in different duct runs, which requires experience.
- Wrong selection of velocities can lead to very large ducts, which, occupy large building space and increases the cost, or very small ducts which lead to large pressure drop and hence necessitates the selection of a large fan leading to higher fan cost and running cost.
- In addition, the method is not very efficient as it requires partial closing of all the dampers except the one in the index run, so that the total pressure drop in each run will be same.
Equal friction method

- In this method the frictional pressure drop per unit length in the main and branch ducts ($\Delta P_f/L$) are kept same, i.e.,

$$\left( \frac{\Delta P_f}{L} \right)_A = \left( \frac{\Delta P_f}{L} \right)_B = \left( \frac{\Delta P_f}{L} \right)_C = \left( \frac{\Delta P_f}{L} \right)_D = \ldots$$
Stepwise procedure for designing the duct system is as follows:

I. Select a suitable frictional pressure drop per unit length ($\Delta pf/L$) so that the combined initial and running costs are minimized.

II. Then the equivalent diameter of the main duct ($A$) is obtained from the selected value of ($\Delta pf/L$) and the airflow rate. Airflow rate in the main duct is equal to the sum total of airflow rates to all the conditioned zones, i.e.,

$$Q_A = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 = \sum_{i=1}^{N} Q_i$$
Continued...

From the airflow rate and \( \Delta pf/L \) the equivalent diameter of the main duct \( (D_{eq,A}) \) can be obtained either from the friction chart or using the frictional pressure drop equation, i.e.,

\[
D_{eq,A} = \left( \frac{0.022243 \dot{Q}_A^{1.852}}{\left( \frac{\Delta pf}{L} \right)_A} \right)^{\left( \frac{1}{4.973} \right)}
\]

III. Since the frictional pressure drop per unit length is same for all the duct runs, the equivalent diameters of the other duct runs, B to I are obtained from the equation:

\[
\left( \frac{\dot{Q}}{D_{eq}^{4.973}} \right)_A = \left( \frac{\dot{Q}}{D_{eq}^{4.973}} \right)_B = \left( \frac{\dot{Q}}{D_{eq}^{4.973}} \right)_C = \ldots
\]
Continued...

IV. If the ducts are rectangular, then the two sides of the rectangular duct of each run are obtained from the equivalent diameter of that run and by fixing aspect ratio as explained earlier. Thus the dimensions of all the duct runs can be obtained. The velocity of air through each duct is obtained from the volumetric flow rate and the cross-sectional area.

V. Next from the dimensions of the ducts in each run, the total frictional pressure drop of that run is obtained by multiplying the frictional pressure drop per unit length and the length, i.e.,

\[ \Delta P_{f,A} = \left( \frac{\Delta p_f}{L} \right)_A \cdot L_A ; \quad \Delta P_{f,B} = \left( \frac{\Delta p_f}{L} \right)_B \cdot L_B \ldots \]
Continued...

VI. Next the dynamic pressure losses in each duct run are obtained based on the type of bends or fittings used in that run.

VII. Next the total pressure drop in each duct run is obtained by summing up the frictional and dynamic losses of that run, i.e.,

\[ \Delta P_A = \Delta p_{f,A} + \Delta p_{d,A} ; \quad \Delta P_B = \Delta p_{f,B} + \Delta p_{d,B} \ldots \]

VIII. Next the fan is selected to suit the index run with the highest pressure loss. Dampers are installed in all the duct runs to balance the total pressure loss.
Reading Assignment

• Static Regain Method:
• Performance of duct systems:
• System balancing and optimization:
Example-1

The following figure shows a typical duct layout. Design the duct system using a) Velocity method, and b) Equal friction method. Take the velocity of air in the main duct (A) as 8 m/s for both the methods. Assume a dynamic loss coefficient of 0.3 for upstream to downstream and 0.8 for upstream to branch and for the elbow. The dynamic loss coefficients for the outlets may be taken as 1.0. Find the FTP required for each case and the amount of dampering required.
Continued...
a) Velocity method:

- Select a velocity of 5 m/s for the downstream and branches. Then the dimensions of various duct runs are obtained as shown below:
- Segment A: Flow rate, $Q_A = 4 \, \text{m}^3/\text{s}$ and velocity, $V_A = 8 \, \text{m/s}$
  \[ \Rightarrow \text{cross-sectional area } A_A = \frac{Q_A}{V_A} = \frac{4}{8} = 0.5 \, \text{m}^2 \Rightarrow D_{eq,A} = 0.798 \, \text{m} \]
- Segment B: Flow rate, $Q = 1 \, \text{m}^3/\text{s}$ and velocity, $V_B = 5 \, \text{m/s}$
  \[ \Rightarrow \text{cross-sectional area } A_B = \frac{Q_B}{V_B} = \frac{1}{5} = 0.2 \, \text{m}^2 \Rightarrow D_{eq,B} = 0.505 \, \text{m} \]
- Segment C: Flow rate, $Q_C = 3 \, \text{m}^3/\text{s}$ and velocity, $V_C = 5 \, \text{m/s}$
  \[ \Rightarrow \text{cross-sectional area } A_C = \frac{Q_C}{V_C} = \frac{3}{5} = 0.6 \, \text{m}^2 \Rightarrow D_{eq,C} = 0.874 \, \text{m} \]
• Segment D: Flow rate, $Q_D = 2 \text{ m}^3/\text{s}$ and velocity, $V_D = 5 \text{ m/s}$

$\Rightarrow$ cross-sectional area $A_D = Q_D/V_D = 2/5 = 0.4 \text{ m}^2 \Rightarrow D_{eq,D} = 0.714 \text{ m}$

• Segments E&F: Flow rate, $Q_{E,F} = 1 \text{ m}^3/\text{s}$ and velocity, $V_{E,F} = 5 \text{ m/s}$

$\Rightarrow$ cross-sectional area $A_{E,F} = Q_{E,F}/V_{E,F} = 1/5 = 0.2 \text{ m}^2 \Rightarrow D_{eq,EF} = 0.505 \text{ m}$
Calculation of pressure drop:

- **Section A-B:** \[ \Delta P_{A-B} = \Delta P_{A,f} + \Delta P_{b,f} + \Delta p_{u-b} + \Delta P_{exit} \]

  where \( \Delta P_{A,f} \) and \( \Delta P_{B,f} \) stand for frictional pressure drops in sections A and B, respectively, \( \Delta p_{u-b} \) is the dynamic pressure drop from upstream to branch and \( \Delta P_{exit} \) is the dynamic pressure loss at the exit 1.

The frictional pressure drop is calculated using the equation:

\[
\Delta p_{A,f} = \frac{0.022243 \dot{Q}_{air}^{1.852} L}{D^{4.973}} = \frac{0.022243 \times 4^{1.852} \times 15}{0.798^{4.973}} = 13.35 \text{ Pa}
\]

\[
\Delta p_{B,f} = \frac{0.022243 \dot{Q}_{air}^{1.852} L}{D^{4.973}} = \frac{0.022243 \times 1^{1.852} \times 6}{0.505^{4.973}} = 3.99 \text{ Pa}
\]
The dynamic pressure drop from upstream to branch is given by:

$$\Delta p_{u-b} = C_{u-b} \left( \frac{\rho V_d^2}{2} \right) = 0.8 \left( \frac{1.2 \times 5^2}{2} \right) = 12 \text{ Pa}$$

The dynamic pressure drop at the exit is given by:

$$\Delta p_{\text{exit,1}} = C_{\text{exit}} \left( \frac{\rho V_1^2}{2} \right) = 1.0 \left( \frac{1.2 \times 5^2}{2} \right) = 15 \text{ Pa}$$

Hence total pressure drop from the fan to the exit of 1 is given by:

$$\Delta P_{A-B} = \Delta P_{A,f} + \Delta P_{b,f} + \Delta P_{u-b} + \Delta P_{\text{exit}} = 13.35 + 3.99 + 12 + 15 = 44.34 \text{ Pa}$$
In a similar manner, the pressure drop from fan to 2 is obtained as:

\[ \Delta P_{A-C-D} = \Delta P_{A,f} + \Delta P_{C,f} + \Delta P_{D,f} + \Delta P_{u-b} + \Delta P_{u-d} + \Delta P_{exit} \]

\[ \Delta P_{A-C-D} = 13.35 + 3.99 + 2.57 + 12 + 4.5 + 15 = 51.41 \text{ Pa} \]

- Pressure drop from fan to exit 3 is obtained as:

\[ \Delta P_{A-C-E-F} = \Delta P_{A,f} + \Delta P_{C,f} + \Delta P_{E,f} + \Delta P_{F,f} + \Delta P_{u-d,c} + \Delta P_{u-d,E} + \Delta P_{elbow} + \Delta P_{exit} \]

\[ \Delta P_{A-C-E-F} = 13.35 + 3.99 + 11.97 + 3.99 + 4.5 + 4.5 + 12 + 15 = 69.3 \text{ Pa} \]

- Thus the run with maximum pressure drop is A-C-E-F is the index run. Hence the FTP required is: \( FTP = \Delta P_{A-C-E-F} = 69.3 \text{ Pa} \)

Amount of dampering required at 1 = \( FTP - \Delta P_{A-B} = 24.96 \text{ Pa} \)
Amount of dampering required at 2 = \( FTP - \Delta P_{A-C-D} = 17.89 \text{ Pa} \)
b) Equal Friction Method:

- The frictional pressure drop in segment A is given by:

  \[
  \Delta p_{f,A} = \frac{0.022243 Q_{\text{air}}^{1.852}}{D^{4.973}} = \frac{0.022243 \times 4^{1.852}}{0.798^{4.973}} = 0.89 \text{ (Pa/m)}
  \]

- The frictional pressure drops of B, C, D, E and F should be same as 0.89 Pa/m for Equal Friction Method. Hence, as discussed before:

  \[
  \begin{pmatrix}
  \frac{1.852}{D_{\text{eq}}^{4.973}} \\
  Q
  \end{pmatrix}_A = \begin{pmatrix}
  \frac{1.852}{D_{\text{eq}}^{4.973}} \\
  Q
  \end{pmatrix}_B = \begin{pmatrix}
  \frac{1.852}{D_{\text{eq}}^{4.973}} \\
  Q
  \end{pmatrix}_C = \ldots
  \]

  From this equation, we obtain:
Continued...

\[ D_{eq,B} = D_{eq,A} \left( \frac{Q_B}{Q_A} \right) \left( \frac{1.852}{4.973} \right) = 0.4762 \, m \]

\[ D_{eq,C} = D_{eq,A} \left( \frac{Q_C}{Q_A} \right) \left( \frac{1.852}{4.973} \right) = 0.717 \, m \]

\[ D_{eq,D} = D_{eq,A} \left( \frac{Q_D}{Q_A} \right) \left( \frac{1.852}{4.973} \right) = 0.6164 \, m \]

\[ D_{eq,E} = D_{eq,F} = D_{eq,A} \left( \frac{Q_E}{Q_A} \right) \left( \frac{1.852}{4.973} \right) = 0.4762 \, m \]
Calculation of total pressure drop:

From fan to 1:

$$\Delta P_{A-B} = \Delta P_{A,f} + \Delta P_{B,f} + \Delta P_{u-b} + \Delta P_{exit}$$

$$\Delta P_{A-B} = 13.35 + 5.34 + 15.1 + 18.9 = 52.69 \text{ Pa}$$

From fan to 2:

$$\Delta P_{A-C-D} = \Delta P_{A,f} + \Delta P_{C,f} + \Delta P_{D,f} + \Delta P_{u-d,c} + \Delta P_{u-b} + \Delta P_{exit}$$

$$\Delta P_{A-C-D} = 13.35 + 10.68 + 5.34 + 9.94 + 21.55 + 26.9 = 87.76 \text{ Pa}$$

From fan to exit 3:

$$\Delta P_{A-C-E-F} = \Delta P_{A,f} + \Delta P_{C,f} + \Delta P_{E,f} + \Delta P_{F,f} + \Delta P_{u-d,c} + \Delta P_{u-d,E} + \Delta P_{elbow} + \Delta P_{exit}$$

$$\Delta P_{A-C-E-F} = 13.35 + 10.68 + 16.02 + 5.34 + 9.94 + 5.67 + 15.1 + 18.9 = 95 \text{ Pa}$$
• As before, the Index run is from fan to exit 3. The required FTP is: $FTP = \Delta P_{A-C-E-F} = 95 \text{ Pa}$
• Amount of dampering required at 1 = $FTP \ - \ \Delta P_{A-B} = 42.31 \text{ Pa}$
• Amount of dampering required at 2 = $FTP \ - \ \Delta P_{A-C-D} = 7.24 \text{ Pa}$
• From the example, it is seen that the Velocity method results in larger duct diameters due to the velocities selected in branch and downstream.
• However, the required FTP is lower in case of velocity method due to larger ducts.
• Equal Friction method results in smaller duct diameters, but larger FTP.
• Compared to velocity method, the required dampering is more at outlet 1 and less at outlet 2 in case of equal friction method.
THE END!!!

GOOD LUCK....