SMACNA Technical Service

Presented By:
Patrick J Brooks, P.E. - Senior Project Manager
Duct Design Fundamentals

Learning Objectives
- Basic Air Flow
- Pressure
- Pressure Losses - Friction
- Pressure Losses – Dynamic
  - Fitting Efficiencies
- Duct Design Overview
- Duct Design – Equal Friction
- Duct Design – Static Regain
- Acoustics
- Commissioning
Duct Design Fundamentals

Basics of AirFlow
Mass Flow and Continuity Equations

Mass flow into a section = mass flow out of a section

\[ \dot{m} = \rho A_d V = \text{constant} \]

If air density is constant, we get the Continuity Equation

\[ \frac{\dot{m}}{\rho} = Q = A_d V = \text{constant} \]
Duct Areas

Round: \( A_d = \frac{\pi D^2}{4} \)

Rectangular: \( A_d = WH \)

Flat Oval: \( A_d = \left(\frac{\pi a^2}{4}\right) + a(A-a) \)
Velocity

If \( Q \) and \( A \) are known, the duct velocity, \( V \) can be calculated.

\[
V = \frac{Q}{A_d}
\]

Example 1: If the volume flow rate in a 22 in. duct is, \( Q = 5000 \) cfm, what is the average velocity of air in the duct.

\[
D = 22 \text{ inch (1.83 ft)}
\]

\[
A_d = \frac{\pi (1.83)^2}{4} = 2.64 \text{ ft}^2
\]

\[
V = \frac{5000}{2.64} = 1894 \text{ fpm}
\]
Calculate Duct Size for a Given Velocity

\[ V = \frac{Q}{A_d} \Rightarrow A_d = \frac{Q}{V} \]

Example 2: If the design volume flow rate and velocity is 13,000 cfm and 4000 fpm respectively, what is the H dimension in a rectangular duct if the W dimension is 14 inches

\[ A_d = \frac{Q}{V} = \frac{13,000}{4000} = 3.25 \text{ ft}^2 \ (\text{Multiply by 144 to get in}^2) \]

\[ = 468 \text{ in}^2 \]

\[ A_d = WH \Rightarrow H = \frac{A_d}{W} \]

\[ H = \frac{468}{14} = 33.4 \text{ inches} \]
Diverging Flow

According to the law of conservation of mass, the volume flow rate before flow divergence is equal to the sum of the flows after divergence.

\[ Q_c = Q_b + Q_s \]

Where:
- \( Q_c \) = common (upstream) volume flow rate, cfm
- \( Q_b \) = branch volume flow rate, cfm
- \( Q_s \) = straight-through volume flow rate, cfm
Converging Flow

According to the law of conservation of mass, the volume flow rate after flow convergence is equal to the sum of the flows before convergence

\[ Q_c = Q_b + Q_s \]

Where:
- \( Q_c \) = common (downstream) volume flow rate, cfm
- \( Q_b \) = branch volume flow rate, cfm
- \( Q_s \) = straight-through volume flow rate, cfm
Duct Design Fundamentals

Pressure
CONSERVATION OF ENERGY

\[ p_t = p_s + p_v \]

Where:

- \( p_t \) = total pressure, in. of water
- \( p_s \) = static pressure, in. of water
- \( p_v \) = velocity pressure, in. of water
Duct Design Fundamentals
Pressure

The inch of water is defined as the pressure exerted at the base of a column of fluid exactly 1 inch (in) high.

- 27.7 inch of water per 1 psi (lb/in²)
- 1 inch of water is 5.2 psf (lb/ft²)
- 1 inch of water is 0.036 psi
Duct Design Fundamentals

Static Pressure ($p_s$)

- Measure of the static energy of air flowing
- Air which fills a balloon is a good example of static pressure
- Equally exerted in all directions
- The atmospheric pressure of air is a static pressure = 14.696 psi at sea level. One psi ~ 27.7 in. of water, so 1 atm ~ 407 in. of water.
- Air always flows from an area of higher pressure to an area of lower pressure.
- Because the static pressure is above atmospheric pressure at a fan outlet, air will flow from the fan through any connecting ductwork until it reaches atmospheric pressure at the discharge.
- Because the static pressure is below atmospheric at a fan inlet, air will flow from the higher atmospheric pressure through an intake and any connecting ductwork until it reaches the area of lowest static pressure at the fan inlet.
Velocity Pressure \((p_v)\)

- Measure of the kinetic energy of the air flowing in a duct system
- Proportional to the square of the velocity

\[
p_v = \rho \left(\frac{V}{1097}\right)^2
\]

Where:
- \(p_v\) = velocity pressure, in. of water
- \(V\) = velocity, ft/min
- \(\rho\) = density, lbm/ft\(^3\)

\[
p_v = \left(\frac{V}{4005}\right)^2
\]
Velocity Pressure \( (p_v) \)

- **Velocity pressure** \( (p_v) \) is always a positive number in the direction of flow.
- Will increase if duct cross-section area decreases.
- Will decrease if duct cross-sectional area increases.
- When velocity pressure increases, static pressure must decrease.
- When velocity pressure decreases, there can be a gain in static pressure, commonly called **STATIC REGAIN**.
CONSERVATION OF ENERGY

Change in total pressure between any two points of a system is equal to the sum of the change in static pressure and the change in velocity pressure.

\[ \Delta p_t = \Delta p_s + \Delta p_v \]

Derived from the Bernoulli Equation:

\[ p_s + \frac{\rho_1 V_1^2}{2 g_c} + \frac{g}{g_c} \rho_1 z_1 = p_s + \frac{\rho_2 V_2^2}{2 g_c} + \frac{g}{g_c} \rho_2 z_2 + \Delta p_{t,1-2} \]
Duct Design Fundamentals
Pressure Changes During Flow in Ducts

• **Total pressure** \((p_t)\) represents the energy of the air flowing in a duct system.
• Energy cannot be created or increased except by adding work or heat.
• Energy and thus total pressure must always decrease in the direction of flow once the fan is turned on **except at the fan**.
• Total pressure losses represent the irreversible conversion of static and kinetic energy to internal energy in the form of heat.
• These losses are classified as either friction losses or dynamic losses.
Duct Design Fundamentals
Pressure Changes During Flow in Ducts – Graphically
Duct Design Fundamentals
Pressure Losses in Duct Systems

Two Types of Losses

Friction Losses
Produced whenever moving air flows in contact with a fixed boundary

Dynamic Losses
Result of turbulence or changes in size, shape, direction, or volume flow rate
Duct Design Fundamentals

Pressure Losses

Darcy-Weisbach Equation

\[ \Delta p_t = \left( \frac{f}{D_h} \frac{L}{p_v} \right) + \Sigma(C) \cdot p_v \]
Duct Design Fundamentals

Darcy-Weisbach Equation

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

which is known as **Hydraulic Diameter**.

\[ A_d = \frac{\pi D^2}{4}, \quad P = \pi D \quad \text{Round} \]

\[ A_d = WH, \quad P = 2(W + H) \quad \text{Rectangular} \]

\[ A_d = \frac{\pi \alpha^2}{4} + \alpha(A - \alpha), \quad P = \pi \alpha + 2(A - \alpha) \quad \text{Flat Oval} \]
The left-hand side of the Darcy-Weisbach Equation, which is the Darcy Equation, calculates the friction loss.

\[ \Delta p_f = \left( \frac{f}{D_h} \right) \left( \frac{L}{p_v} \right) \]
The Colebrook equation was developed to calculate the friction factor, $f$, requires you to also know the Reynolds Number, $Re$ and the absolute roughness, $\varepsilon$, which is determined experimentally. Values of $\varepsilon$ are available in the SMACNA HVAC SYSTEMS DUCT DESIGN MANUAL, FOURTH EDITION – DECEMBER 2006, Table A-1, pg A.4. A common value to remember is 0.0003 ft for standard galvanized material which is what the friction chart is based on. The Colebrook equation value of $f$ must be solved for iteratively.
### Table A-1 Duct Material Roughness Factors

<table>
<thead>
<tr>
<th>Duct Material</th>
<th>Roughness Category</th>
<th>( \frac{\varepsilon}{D_h} )</th>
<th>( \frac{2.51}{\sqrt{Re}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoated carbon steel, clean (Moody 1944) (0.00015 ft) (0.05 mm)</td>
<td>Smooth</td>
<td>0.0001</td>
<td>0.03</td>
</tr>
<tr>
<td>PVC plastic pipe (Swim 1982) (0.0003 to 0.00015 ft) (0.01 to 0.05 mm)</td>
<td>Smooth</td>
<td>0.0001</td>
<td>0.03</td>
</tr>
<tr>
<td>Aluminum (Hutchinson 1953) (0.00015 to 0.0002 ft) (0.04 to 0.06 mm)</td>
<td>Smooth</td>
<td>0.0001</td>
<td>0.03</td>
</tr>
<tr>
<td>Galvanized steel, longitudinal seams, 4 ft (1200 mm) joints (Griggs 1987) (0.00016 to 0.00032 ft) (0.05 to 0.1 mm)</td>
<td>Medium Smooth</td>
<td>0.0003</td>
<td>0.09</td>
</tr>
<tr>
<td>Galvanized steel, spiral seam with 1, 2, and 3 ribs, 12 ft (3600 mm) joints (Jones 1979, Griggs 1987) (0.00018 to 0.00038 ft) (0.05 to 0.12 mm)</td>
<td>(New Duct Friction Loss Chart)</td>
<td>0.0005</td>
<td>0.15</td>
</tr>
<tr>
<td>Hot-dipped galvanized steel, longitudinal seams, 2.5 ft (760 mm) joints (Wright 1945) (0.0005 ft) (0.15 mm)</td>
<td>Old Average</td>
<td>0.0005</td>
<td>0.15</td>
</tr>
<tr>
<td>Fibrous glass duct, rigid</td>
<td>Medium Rough</td>
<td>0.0003</td>
<td>0.9</td>
</tr>
<tr>
<td>Fibrous glass duct liner, air side with facing material (Swim 1978) (0.005 ft) (1.5 mm)</td>
<td>Medium Rough</td>
<td>0.0003</td>
<td>0.9</td>
</tr>
<tr>
<td>Fibrous glass duct liner, air side spray coated (Swim 1978) (0.015 ft) (4.5 mm)</td>
<td>Rough</td>
<td>0.01</td>
<td>3.0</td>
</tr>
<tr>
<td>Flexible duct, metallic, (0.004 to 0.007 ft) (1.2 to 2.1 mm) when fully extended)</td>
<td>Rough</td>
<td>0.01</td>
<td>3.0</td>
</tr>
<tr>
<td>Flexible duct, all types of fabric and wire (0.0035 to 0.015 ft) (1.0 to 4.6 mm) when fully extended)</td>
<td>Rough</td>
<td>0.01</td>
<td>3.0</td>
</tr>
<tr>
<td>Concrete (Moody 1944) (0.001 to 0.01 ft) (0.3 to 3.0 mm)</td>
<td>Rough</td>
<td>0.01</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Duct Design Fundamentals

Pressure Losses – Friction

Reynolds Number

The Reynolds Number, Re is the ratio of the inertia force to the viscous force caused by changes in velocity.

The Reynolds Number is calculated from:

\[ Re = \frac{\rho D_h V}{\mu} \]

Air density (\( \rho \)) and dynamic viscosity (\( \mu \)) are obtained from a Handbook or by using a calculator with psychometric routines.

At standard air Conditions:

\[ Re = 8.56D_h V \]
Duct Design Fundamentals
Pressure Losses – Friction

Comparison of Different Velocities and Materials

Example: Calculate the Friction Loss in 100 ft of rectangular duct 24” x 32” at 1000 fpm, 2000 fpm, 3000 fpm and 4000 fpm for standard galvanized metal (\(\varepsilon = 0.0003\) ft) and lined duct (\(\varepsilon = 0.003\) ft)

\[
\frac{1}{\sqrt{f}} = -2 \log \left( \frac{\varepsilon}{3.7D_h} + \frac{2.51}{\text{Re} \sqrt{f}} \right)
\]
Pressure Losses – Friction

\[
\frac{\varepsilon}{3.7 D_h} + \frac{2.51}{\text{Re} \sqrt{f}} \leq 1
\]

Table A-1 Duct Material Roughness Factors

<table>
<thead>
<tr>
<th>Duct Material</th>
<th>Roughness Category</th>
<th>Absolute Roughness ε₁</th>
<th>Roughness (ft)</th>
<th>Roughness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoated carbon steel, clean (Moody 1944) (0.00015 ft) (0.05 mm)</td>
<td>Smooth</td>
<td>0.0001</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>PVC plastic pipe (Swim 1982) (0.0003 to 0.00015 ft) (0.01 to 0.05 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum (Hutchinson 1953) (0.00015 to 0.0002 ft) (0.04 to 0.06 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galvanized steel, longitudinal seams, 4 ft (1200 mm) joints (Griggs 1987)</td>
<td>Medium Smooth</td>
<td>0.0003</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>(0.00016 to 0.00032 ft) (0.05 to 0.1 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galvanized steel, spiral seam with 1, 2, and 3 ribs, 12 ft (3600 mm) joints</td>
<td>(New Duct Friction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jones 1979, Griggs 1987) (0.00018 to 0.00038 ft) (0.05 to 0.12 mm)</td>
<td>Loss Chart)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot-dipped galvanized steel, longitudinal seams, 2.5 ft (760 mm) joints</td>
<td>Old Average</td>
<td>0.0005</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>(Wright 1945) (0.0005 ft) (0.15 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibrous glass duct, rigid</td>
<td>Medium Rough</td>
<td>0.003</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Fibrous glass duct liner, air side with facing material (Swim 1978)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.005 ft) (1.5 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibrous glass duct liner, air side spray coated (Swim 1978)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.015 ft) (4.5 mm)</td>
<td>Rough</td>
<td>0.01</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Flexible duct, metallic, (0.004 to 0.007 ft (1.2 to 2.1 mm) when fully</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>extended)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible duct, all types of fabric and wire (0.0035 to 0.015 ft (1.0 to 4.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mm) when fully extended)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete (Moody 1944) (0.001 to 0.01 ft) (0.3 to 3.0 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Duct Design Fundamentals
Pressure Losses – Friction
Comparison of Different Velocities and Materials

\[
\Delta p_f = \left( \frac{f}{D_h} \right) \frac{L}{\rho_v}
\]

<table>
<thead>
<tr>
<th>Solution</th>
<th>100 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area =</td>
<td>5.33 ft²</td>
</tr>
<tr>
<td>(P =)</td>
<td>9.33 ft</td>
</tr>
<tr>
<td>(D_h =)</td>
<td>2.29 ft</td>
</tr>
<tr>
<td>(\rho = 0.075 \text{ lb} / \text{ft}^3)</td>
<td>Standard Conditions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Velocity (fpm)</th>
<th>Velocity Pressure (p_v) (inch water)</th>
<th>(Q = AV) Flow Rate (cfm)</th>
<th>Friction Factor, (f)</th>
<th>(\Delta p_f) Friction Loss (inch water)</th>
<th>Friction Factor, (f)</th>
<th>(\Delta p_f) Friction Loss (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.06</td>
<td>5333</td>
<td>0.0163</td>
<td>0.04</td>
<td>0.0220</td>
<td>0.05</td>
</tr>
<tr>
<td>2000</td>
<td>0.25</td>
<td>10667</td>
<td>0.0148</td>
<td>0.16</td>
<td>0.0215</td>
<td>0.23</td>
</tr>
<tr>
<td>3000</td>
<td>0.56</td>
<td>16000</td>
<td>0.0142</td>
<td>0.35</td>
<td>0.0213</td>
<td>0.52</td>
</tr>
<tr>
<td>4000</td>
<td>0.99</td>
<td>21333</td>
<td>0.0139</td>
<td>0.60</td>
<td>0.0212</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Duct Design Fundamentals
Pressure Losses – Friction
Comparison of Different Velocities and Roughness

Observations:
• Factor of ~15 increasing pressure loss from 1000 – 4000 fpm
  • 0.04 to 0.60 inch water

• Factor of ~ 1.5 increasing ε by a factor of 10
  • 0.02 to 0.32 inch of water increase
Duct Design Fundamentals
Using a Friction Loss Chart

Example: 1000 cfm in 10” Dia

Result: 0.40 in wg/100 ft
Most duct systems are originally sized with round ducts. For many reasons (head room, available equipment), the designer or engineer may want to use an equivalent rectangular or flat oval size.

The following equations calculate the round duct diameter that will give the same friction loss as the rectangular or flat oval duct, at the same volume flow rate (cfm).

Most of the time however, the round size is known, and the designer wants to determine one of the dimensions of the rectangular or flat oval section. (For example, the ceiling area may only allow a 12-inch minor axis).
Pressure Losses – Friction

Equivalent Duct Sizes for Same Friction Loss

Rectangular:

\[ D_e = 1.55 \frac{A^{0.625}}{P^{0.25}} = 1.30 \frac{(WH)^{0.625}}{(W+H)^{0.25}} \]

Flat Oval:

\[ D_e = 1.55 \frac{A^{0.625}}{P^{0.25}} = 1.55 \frac{\left[ \frac{\pi a}{4} + a(A-a)^{0.625} \right]}{\left[ \pi a + 2(A-a) \right]^{0.25}} \]

Because of the power relationships these must also be solved iteratively to get the original equivalent round size. Fortunately tables, ductulators, spreadsheets and other programs have been created to calculate the equations. See Appendix A, Tables A-2 and A-3 of the SMACNA HVAC SYSTEMS DUCT DESIGN manual – FOURTH EDITION – DECEMBER 2006
Example: 12 x 7 Rectangular, 1000 cfm
Solution: From Table A-2, the Equivalent Round Size is 9.9 inches. Use the friction chart at 1000 cfm in 9.9 inch Diameter to, friction loss is 0.4 in water/100 ft
Duct Design Fundamentals
Using a Friction Loss Chart

Example: 1000 cfm in 10” Dia

Result: 0.40 in wg/100 ft
Table A–3 Spiral Flat-Oval Duct (Nominal Sizes)
(Diameter of the round duct which will have the capacity and friction equivalent to the actual duct size)

Example: 12 x 7 Flat Oval 1000 cfm
Solution: From Table A-3, the Equivalent Round Size is 9.4 inches. Use the friction chart at 1000 cfm in 9.4-inch Diameter to, friction loss is 0.5 in water/100 ft
Duct Design Fundamentals

Using a Friction Loss Chart

Example: 1000 cfm in 10” Dia

Result: 0.50 in wg/100 ft
Duct Design Fundamentals
Pressure Losses in Duct Systems

Two Types of Losses

Friction Losses
Produced whenever moving air flows in contact with a fixed boundary

Dynamic Losses
Result of turbulence or changes in size, shape, direction, or volume flow rate
Duct Design Fundamentals

Pressure Losses

Darcy-Weisbach Equation

\[ \Delta p_t = \left( \frac{f}{D_h} \right) \frac{L}{p_v} + \sum (C) \times p_v \]
Duct Design Fundamentals

Pressure Losses – Dynamic

The right-hand side of the Darcey-Weisbach Equation, which is the Weisbach Equation, calculates the dynamic loss.

\[ \Delta p_{t,\text{fittings}} = \sum (C) \times p_v \]
Duct Design Fundamentals

Pressure Losses – Dynamic

• Experimentally determined loss coefficients are generally used to calculate total pressure dynamic losses for fittings or components.
• Loss coefficients are a function of velocity pressure, $p_v$
• If the section velocity pressure is used, all loss coefficients can be added and multiplied by the sections velocity pressure to determine the dynamic losses for the section

$$\Delta p_{t, fittings} = \sum (C) \times p_v$$

• If the common velocity pressure is used, then the individual losses must be totaled.

$$\Delta p_{t, fittings} = \sum [C \times p_v]$$
Duct Design Fundamentals

Pressure Losses – How Loss Coefficients are Determined

\[ \Delta p_{t,fitting} = C \times pv \]

\[ C = \frac{\Delta p_{t,fitting}}{p_v} \]

Every fitting has associated loss coefficients, which can be determined experimentally by measuring the total pressure loss through the fitting for varying flow conditions. Often the pressure loss is regressed vs the velocity pressure and the slope of the regression is the loss coefficient.
\[ \Delta p_{t,1-2} = \Delta p_{s,7-8} + (p_{v7} - p_{v8}) - (L_{7-1} \Delta p_{f,7-1} + L_{2-8} \Delta p_{f,2-8}) \]

\[ C = \frac{\Delta p_{t,1-2}}{p_{v8}} \]

L_{7-1} \text{ is the measured length from the upstream static pressure measurement plane to the center point of the fitting, and }
L_{2-8} \text{ is the measured length from the center point of the fitting to the downstream static pressure measurement plane.}
Main: \( \Delta p_{t,1-2} = \Delta p_{s,7-8} + (p_{v7} - p_{v8}) - (L_{7-1} \Delta p_{f,7-1} + L_{2-8} \Delta p_{f,2-8}) \)

Branch: \( \Delta p_{t,1-3} = \Delta p_{s,7-9} + (p_{v7} - p_{v9}) - (L_{7-1} \Delta p_{f,7-1} + L_{3-9} \Delta p_{f,3-9}) \)

\( C_s = \frac{\Delta p_{t,1-2}}{p_{v8}} \)

\( C_b = \frac{\Delta p_{t,1-3}}{p_{v7}} \)

\( L_{7-1}, L_{2-8} \) and \( L_{3-9} \) are measured to the centerline of the fitting.
Duct Design Fundamentals

Pressure Losses – How Loss Coefficients Branch Fittings are Determined when Referenced to the Common Section

For diverging flow, if the loss coefficient is referenced to the upstream velocity pressure,

\[ \Delta p_{t,u-d} = C_{u-d} \cdot p_{vu} \]

Since the total pressure loss has to be the same, then:

\[ \Delta p_{t,1-2} = C_{\text{section}} \cdot p_{v,\text{section}} \]

\[ C_{\text{section}} \cdot p_{v,\text{section}} = C_{u-d} \cdot p_{vu} \]

or

\[ C_{\text{section}} = C_{u-d} \cdot \frac{p_{vu}}{p_{v,\text{section}}} \]
Main: $\Delta p_{t,1-2} = \Delta p_{x,7-8} + (p_{v7} - p_{v8}) - (L_{7-1}\Delta p_{f,7-1} + L_{2-8}\Delta p_{f,2-8})$

Branch: $\Delta p_{t,3-2} = \Delta p_{x,9-8} + (p_{v9} - p_{v8}) - (L_{9-3}\Delta p_{f,9-3} + L_{2-8}\Delta p_{f,2-8})$

$C_s = \frac{\Delta p_{t,1-2}}{p_{v7}}$

$C_b = \frac{\Delta p_{t,3-2}}{p_{v9}}$

$L_{7-1}$, $L_{2-8}$ and $L_{9-3}$ are measured to the centerline of the fitting.
Duct Design Fundamentals

Pressure Losses – How Loss Coefficients Branch Fittings are Determined when Referenced to the Common Section

For converging flow, if the loss coefficient is referenced to the downstream velocity pressure

Since the total pressure loss has to be the same, then:

\[
\Delta p_{t,u-d} = C \cdot u \cdot d \cdot p_{vd}
\]

\[
\Delta p_{t,1-2} = C_{section} \cdot p_{v,section}
\]

\[
C_{section} \cdot p_{v,section} = C \cdot u \cdot d \cdot p_{vd}
\]

or

\[
C_{section} = C \cdot u \cdot d \frac{p_{vd}}{p_{v,section}}
\]
Duct Design Fundamentals

Loss Coefficient Tables

• Loss coefficients are often published in table form or equations. See tables A-7 to A-15 in the HVAC SYSTEMS DUCT DESIGN manual.

• If a branched fitting, check to see what referenced velocity pressure is used.

• If non-standard conditions are encountered, use the density correction factors from Figure A-4

Example: 10” Dia, 90° Smooth Radius Elbow, R/D = 1.5. Airflow is 1000 acfm. Elevation is 5000 ft.
Solution: Area = $\left(\pi \times 10^2/4\right)/144 = 0.55$ ft$^2$
Velocity = $1000/0.55 = 1833$ fpm
Velocity pressure at standard conditions, $p_v = \left(1833/4005\right)^2 = 0.21$ inch of water
$C = 0.15$ from Table A-7A, $K_e$ from Figure A-4, A.14 (elevation correction factor for density) = 0.83
Duct Design Fundamentals
Loss Coefficient Tables

FIGURE A-4 AIR DENSITY FRICTION CHART
CORRECTION FACTORS
Δ\(\rho_t\) = 0.15 \times 0.21 \times 0.83 = 0.03\) inch of water
Example: Diverging Tee 45° Rectangular Main and Branch. Main is 10” x 10”, Branch is 7” x 7”. Airflow Main is 1000 cfm. AirFlow Branch is 500 cfm. Standard air.
### N. TEE, 45° RECTANGULAR MAIN AND BRANCH

<table>
<thead>
<tr>
<th>( V_b/V_c )</th>
<th>( Q_b/Q_c )</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td></td>
<td>0.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td></td>
<td>0.81</td>
<td>0.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td>0.77</td>
<td>0.72</td>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td>0.78</td>
<td>0.73</td>
<td>0.69</td>
<td>0.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td>0.78</td>
<td>0.98</td>
<td>0.85</td>
<td>0.79</td>
<td>0.74</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td>0.90</td>
<td>1.11</td>
<td>1.16</td>
<td>1.23</td>
<td>1.03</td>
<td>0.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td></td>
<td>1.19</td>
<td>1.22</td>
<td>1.26</td>
<td>1.29</td>
<td>1.54</td>
<td>1.25</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td></td>
<td>1.35</td>
<td>1.42</td>
<td>1.55</td>
<td>1.59</td>
<td>1.63</td>
<td>1.50</td>
<td>1.31</td>
<td>1.09</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td></td>
<td>1.44</td>
<td>1.50</td>
<td>1.75</td>
<td>1.74</td>
<td>1.72</td>
<td>2.24</td>
<td>1.63</td>
<td>1.40</td>
<td>1.17</td>
</tr>
</tbody>
</table>

**Note 8:** A = Area (sq. in.), \( Q \) = airflow (cfm), \( V \) = Velocity (fpm).

Use the velocity pressure \( (V_p) \) of the upstream section. Fitting loss \( TP = C \times V_p \)

\[ V_p = p_{vc} \]

Table A-11 Loss Coefficients, Diverging Junctions (Tees, Wyes) (Continued)
Solution:  Area Main, $A_c = (10 \times 10) / 144 = 0.69$ ft$^2$
Area Branch, $A_b = (7 \times 7) / 144 = 0.34$ ft$^2$
Velocity, $V_c = 1000/0.69 = 1440$ fpm
Velocity, $V_b = 500/0.34 = 1469$ fpm
Velocity pressure $p_{vc} = (1440/4005)^2 = 0.13$ in H$_2$O
Velocity pressure $p_{vb} = (1469/4005)^2 = 0.13$ in H$_2$O
Velocity Ratio, $V_b / V_c = 1469/1440 = 1.02$
Flow Rate Ratio, $Q_b / Q_c = 500/1000 = 0.50$
When the downstream section of the main stays the same diameter, the loss coefficient is approximately 0.00 and $\Delta p_{t,c-s} = 0.00$ inch of water.

Table A-11N, $C_b = 0.74$

$\Delta p_{t,c-b} = 0.74 \times 0.13 = 0.10$ inch water
Duct Design Fundamentals
Loss Coefficient Tables

Example: Converging Tee 90° Round Main and Branch. Main is 10”, Branch is 7”. Airflow Main is 1000 cfm. AirFlow Branch is 500 cfm. Standard air.

Table A-10, Page A.25

Note 8: A = Area (sq. in.). Q= airflow (cfm). V= Velocity (fpm)
Use the velocity pressure ($p_v$) of the downstream section. Fitting loss $TP = C \cdot p_v$

![Diagram of Converging Tee](image)

<table>
<thead>
<tr>
<th>$Q_b/Q_c$</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_b/A_c$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.40</td>
<td>-0.37</td>
<td>-0.51</td>
<td>-0.46</td>
<td>-0.50</td>
<td>-0.51</td>
<td>-0.52</td>
</tr>
<tr>
<td>0.2</td>
<td>0.38</td>
<td>0.72</td>
<td>0.17</td>
<td>-0.02</td>
<td>-0.14</td>
<td>-0.18</td>
<td>-0.24</td>
</tr>
<tr>
<td>0.3</td>
<td>0.23</td>
<td>2.3</td>
<td>1.0</td>
<td>0.44</td>
<td>0.21</td>
<td>0.11</td>
<td>-0.08</td>
</tr>
<tr>
<td>0.4</td>
<td>0.16</td>
<td>4.3</td>
<td>2.1</td>
<td>0.94</td>
<td>0.54</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>0.5</td>
<td>0.05</td>
<td>6.8</td>
<td>3.2</td>
<td>1.1</td>
<td>0.66</td>
<td>0.49</td>
<td>0.42</td>
</tr>
<tr>
<td>0.6</td>
<td>0.06</td>
<td>9.7</td>
<td>4.7</td>
<td>1.6</td>
<td>0.92</td>
<td>0.69</td>
<td>0.57</td>
</tr>
<tr>
<td>0.7</td>
<td>0.07</td>
<td>13</td>
<td>6.3</td>
<td>2.1</td>
<td>1.2</td>
<td>0.88</td>
<td>0.72</td>
</tr>
<tr>
<td>0.8</td>
<td>0.08</td>
<td>17</td>
<td>7.9</td>
<td>2.7</td>
<td>1.5</td>
<td>1.1</td>
<td>0.86</td>
</tr>
<tr>
<td>0.9</td>
<td>0.09</td>
<td>21</td>
<td>9.7</td>
<td>3.4</td>
<td>1.8</td>
<td>1.2</td>
<td>0.99</td>
</tr>
<tr>
<td>1.0</td>
<td>0.10</td>
<td>26</td>
<td>12</td>
<td>4.0</td>
<td>2.1</td>
<td>1.4</td>
<td>1.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$Q_b/Q_c$</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C$</td>
<td>0.16</td>
<td>0.27</td>
<td>0.38</td>
<td>0.46</td>
<td>0.53</td>
<td>0.57</td>
<td>0.59</td>
<td>0.60</td>
<td>0.59</td>
<td>0.55</td>
</tr>
</tbody>
</table>

![Table A-10](image)
Solution: Area Main, $A_c = \frac{\pi 10^2}{4} / 144 = 0.55 \text{ ft}^2$
Area Branch, $A_b = \frac{\pi 7^2}{4} / 144 = 0.24 \text{ ft}^2$
Velocity, $V_c = \frac{1000}{0.55} = 1818 \text{ fpm}$
Velocity, $V_b = \frac{500}{0.24} = 2083 \text{ fpm}$
Velocity pressure $p_{vc} = \left(\frac{1818}{4005}\right)^2 = 0.21 \text{ in water}$
Velocity pressure $p_{vb} = \left(\frac{2083}{4005}\right)^2 = 0.27 \text{ in water}$
Flow Rate Ratio, $Q_b / Q_c = 500/1000 = 0.50$
Area Rate Ratio, $A_b / A_c = 0.24/0.55 = 0.44$

Table A-10, Page A.25
Example: Converging Tee 90° Round Main and Branch. Main is 10”, Branch is 7”. Airflow Main is 1000 cfm. AirFlow Branch is 500 cfm. Standard air.

Table A-10, Page A.25

Note 8: A = Area (sq. in.). Q= airflow (cfm). V= Velocity (fpm)
Use the velocity pressure ($p_{vc}$) of the downstream section. Fitting loss TP = C · $p_{vc}$

$C_b = 1.0$
Solution: \( C_b = 1.0, \ C_s = 0.53 \)

\[ \Delta p_{t,b-c} = 1.0 \times 0.21 = 0.21 \text{ inch water} \]

\[ \Delta p_{t,s-c} = 0.53 \times 0.21 = 0.11 \text{ inch water} \]

Table A-10, Page A.25
# Duct Design Fundamentals

## Fitting Efficiency – Round Elbows

### Comparison of Round Elbow Losses

- **D**: 12 inch
- **Area**: 0.79 ft²
- **ρ**: 0.075 lbm/ft³

### Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

<table>
<thead>
<tr>
<th>Velocity (fpm)</th>
<th>Velocity Pressure (psi, in water)</th>
<th>Q = AV Flow Rate (cfm)</th>
<th>Loss Coefficient C</th>
<th>Δp, (inch water)</th>
<th>Loss Coefficient C</th>
<th>Δp, (inch water)</th>
<th>Loss Coefficient C</th>
<th>Δp, (inch water)</th>
<th>Loss Coefficient C</th>
<th>Δp, (inch water)</th>
<th>Loss Coefficient C</th>
<th>Δp, (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.06</td>
<td>785</td>
<td>0.15</td>
<td>0.01</td>
<td>0.71</td>
<td>0.04</td>
<td>0.24</td>
<td>0.01</td>
<td>0.34</td>
<td>0.02</td>
<td>0.45</td>
<td>0.03</td>
</tr>
<tr>
<td>2000</td>
<td>0.25</td>
<td>1571</td>
<td>0.15</td>
<td>0.04</td>
<td>0.71</td>
<td>0.18</td>
<td>0.24</td>
<td>0.06</td>
<td>0.34</td>
<td>0.09</td>
<td>0.45</td>
<td>0.11</td>
</tr>
<tr>
<td>3000</td>
<td>0.56</td>
<td>2356</td>
<td>0.15</td>
<td>0.08</td>
<td>0.71</td>
<td>0.40</td>
<td>0.24</td>
<td>0.13</td>
<td>0.34</td>
<td>0.19</td>
<td>0.45</td>
<td>0.25</td>
</tr>
<tr>
<td>4000</td>
<td>0.99</td>
<td>3142</td>
<td>0.15</td>
<td>0.15</td>
<td>0.71</td>
<td>0.70</td>
<td>0.24</td>
<td>0.24</td>
<td>0.34</td>
<td>0.34</td>
<td>0.45</td>
<td>0.45</td>
</tr>
</tbody>
</table>

### Notes:
- **Best**
- **Better**
- **Good**

**Standard Conditions**
## Duct Design Fundamentals

### Fitting Efficiency – Rectangular Elbows

**Comparison of Round Elbow Losses**

<table>
<thead>
<tr>
<th>W x H</th>
<th>12 x 12 inches</th>
<th>H/W = 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>1.00 ft²</td>
<td></td>
</tr>
<tr>
<td>ρ</td>
<td>0.075 lb/ft³</td>
<td>Standard Conditions</td>
</tr>
</tbody>
</table>

Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

![Diagram of various rectangular elbows]

<table>
<thead>
<tr>
<th>Velocity (fpm)</th>
<th>Velocity Pressure (inch water)</th>
<th>Q = AV (cfm)</th>
<th>Loss Coefficient</th>
<th>Δp1 (inch water)</th>
<th>Loss Coefficient</th>
<th>Δp1 (inch water)</th>
<th>Loss Coefficient</th>
<th>Δp1 (inch water)</th>
<th>Loss Coefficient</th>
<th>Δp1 (inch water)</th>
<th>Loss Coefficient</th>
<th>Δp1 (inch water)</th>
<th>Loss Coefficient</th>
<th>Δp1 (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.06</td>
<td>1000</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
<td>0.00</td>
<td>0.21</td>
<td>0.01</td>
<td>0.17</td>
<td>0.01</td>
<td>1.2</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>0.25</td>
<td>2000</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
<td>0.00</td>
<td>0.21</td>
<td>0.01</td>
<td>0.17</td>
<td>0.04</td>
<td>1.2</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>0.56</td>
<td>3000</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
<td>0.03</td>
<td>0.21</td>
<td>0.12</td>
<td>0.17</td>
<td>0.10</td>
<td>1.2</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>0.99</td>
<td>4000</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
<td>0.05</td>
<td>0.21</td>
<td>0.21</td>
<td>0.17</td>
<td>0.17</td>
<td>1.2</td>
<td>1.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Best**

**Better**

**Good**
# Duct Design Fundamentals

## Fitting Efficiency – Rectangular Elbows

<table>
<thead>
<tr>
<th>Comparison of Round Elbow Losses</th>
<th>Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A</th>
</tr>
</thead>
<tbody>
<tr>
<td>W x H</td>
<td>Loss Coefficients C</td>
</tr>
<tr>
<td>12 x 12 inches, H/W = 1.0</td>
<td>C</td>
</tr>
<tr>
<td>Area = 1.00 ft²</td>
<td>0.26</td>
</tr>
<tr>
<td>ρ = 0.075 lb/ft³</td>
<td>0.27</td>
</tr>
</tbody>
</table>

### Standard Conditions

**Single Thickness**

- Single Thickness, Mitered w/ Turbine Vanes, R=2.0, s=1.5 (Table A-7I)
- Single Thickness, Mitered w/ Turbine Vanes, R=4.5, s=3.25 (Table A-7I)

**Double Thickness**

- Double Thickness, Mitered w/ Turbine Vanes, R=2.0, s=1.5 (Table A-7I)
- Double Thickness, Mitered w/ Turbine Vanes, R=4.5, s=3.25 (Table A-7I)

**Mitered without Vanes** (Table A-7D)

### Table

<table>
<thead>
<tr>
<th>Velocity (fpm)</th>
<th>Velocity Pressure, p (inch water)</th>
<th>Q = AV Flow Rate, (cfm)</th>
<th>Loss Coefficient C</th>
<th>ΔP, (inch water)</th>
<th>Loss Coefficient C</th>
<th>ΔP, (inch water)</th>
<th>Loss Coefficient C</th>
<th>ΔP, (inch water)</th>
<th>Loss Coefficient C</th>
<th>ΔP, (inch water)</th>
<th>Loss Coefficient C</th>
<th>ΔP, (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.68</td>
<td>1000</td>
<td>0.24</td>
<td>0.01</td>
<td>0.26</td>
<td>0.02</td>
<td>0.27</td>
<td>0.02</td>
<td>0.43</td>
<td>0.03</td>
<td>0.53</td>
<td>0.03</td>
</tr>
<tr>
<td>1500</td>
<td>0.14</td>
<td>1500</td>
<td>0.23</td>
<td>0.03</td>
<td>0.24</td>
<td>0.03</td>
<td>0.25</td>
<td>0.04</td>
<td>0.42</td>
<td>0.06</td>
<td>0.53</td>
<td>0.07</td>
</tr>
<tr>
<td>2000</td>
<td>0.25</td>
<td>2000</td>
<td>0.22</td>
<td>0.03</td>
<td>0.23</td>
<td>0.06</td>
<td>0.24</td>
<td>0.06</td>
<td>0.41</td>
<td>0.10</td>
<td>0.50</td>
<td>0.12</td>
</tr>
<tr>
<td>2500</td>
<td>0.39</td>
<td>2500</td>
<td>0.20</td>
<td>0.08</td>
<td>0.22</td>
<td>0.09</td>
<td>0.23</td>
<td>0.09</td>
<td>0.40</td>
<td>0.16</td>
<td>0.49</td>
<td>0.19</td>
</tr>
</tbody>
</table>

**Notes:**

1. Vanes with trailing edges have higher loss coefficients than standard construction.
2. Removing every other vane will double the pressure loss.
3. Turbine vanes are 90°. If used in non-90° elbows, the pressure loss will increase.
4. Other elbow without turning vane configurations can reduce the elbow loss coefficient, including:
   - a 45° throat, 90° heel; radius throat, 90° heel and a 45° throat, radius heel.
## Duct Design Fundamentals

### Fitting Efficiency – Diverging Flow Branches

<table>
<thead>
<tr>
<th>Comparison of Round Diverging Flow Fittings</th>
<th>Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1 = 12$ inch $A_1 = 0.79$ ft$^2$ $Q_1 = 1000$ cfm $V_1 = 1273$ fpm $P_{v1} = 0.10$ inch water</td>
<td></td>
</tr>
<tr>
<td>$D_2 = 8.5$ inch $A_2 = 0.39$ ft$^2$ $Q_2 = 500$ cfm $V_2 = 1269$ fpm $P_{v2} = 0.10$ inch water</td>
<td></td>
</tr>
<tr>
<td>$A_1/A_2 = 0.50$ $Q_1/Q_2 = 0.50$ $V_1/V_2 = 1.00$</td>
<td></td>
</tr>
</tbody>
</table>

### Note 8:
- $A =$ Area (sq. in.). $Q =$ airflow (cfm). $V =$ Velocity (fps).
- Use the velocity pressure ($V_p$) of the upstream section. Fitting loss $TP = C \times V_p$.

### Table A-11 Loss Coefficients, Diverging Junctions (Tees, Wyes), A

### Standard Conditions

<table>
<thead>
<tr>
<th>Velocity $V_u = V_e$ (fps)</th>
<th>Velocity Pressure $p_v$ (inch water)</th>
<th>Loss Coefficient $C$</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1273$</td>
<td>$0.10$</td>
<td>$0.18$</td>
<td>$0.02$</td>
<td>$0.40$</td>
<td>$0.04$</td>
<td>$0.68$</td>
<td>$0.07$</td>
<td>$1.4$</td>
<td>$0.14$</td>
<td>$0.17$</td>
</tr>
</tbody>
</table>

### Wye, 30°

### Wye, 45°

### Wye, 60°

### Wye, 90°

### Conical Wye

### Conical Tee

### 45° Entry Tee

<table>
<thead>
<tr>
<th>Velocity $V_u = V_e$ (fps)</th>
<th>Velocity Pressure $p_v$ (inch water)</th>
<th>Loss Coefficient $C$</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
<th>$\Delta p$ (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1273$</td>
<td>$0.10$</td>
<td>$0.18$</td>
<td>$0.02$</td>
<td>$0.40$</td>
<td>$0.04$</td>
<td>$0.68$</td>
<td>$0.07$</td>
<td>$1.4$</td>
<td>$0.14$</td>
</tr>
</tbody>
</table>

- Best
- Better
- Good
- Poor

Of 90° taps
### Duct Design Fundamentals

#### Fitting Efficiency – Diverging Flow Branches

#### Comparison of Rectangular Diverging Flow Fittings

<table>
<thead>
<tr>
<th>$W_x H_x$</th>
<th>$W_x H_y$</th>
<th>$A_x$</th>
<th>$Q_x$</th>
<th>$V_x$</th>
<th>$V_y$</th>
<th>$V_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$12 \times 12$ inch</td>
<td>$12 \times 7$ inch</td>
<td>$1.00 \text{ ft}^2$</td>
<td>$1000 \text{ cfm}$</td>
<td>$1000 \text{ fpm}$</td>
<td>$1469 \text{ fpm}$</td>
<td>$0.06 \text{ inch water}$</td>
</tr>
<tr>
<td>$7 \times 7$ inch</td>
<td>$7 \times 7$ inch</td>
<td>$0.34 \text{ ft}^2$</td>
<td>$500 \text{ cfm}$</td>
<td>$500 \text{ fpm}$</td>
<td>$1469 \text{ fpm}$</td>
<td>$0.02 \text{ inch water}$</td>
</tr>
</tbody>
</table>

Note: $A = \text{Area (sq. in.)}, Q = \text{Airflow (cfm)}, V = \text{Velocity (fpm)}$

Use the velocity pressure ($V_p$) of the upstream section. Fitting loss $TP = C \times V_p$

#### Table A-11 Loss Coefficients, Diverging Junctions (Tees, Wyes)

<table>
<thead>
<tr>
<th>Fitting</th>
<th>Loss Coefficient $C$</th>
<th>$\Delta P_1$ (Inch water)</th>
<th>$\Delta P_2$ (Inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. Tee, 45° Main to Branch</td>
<td>1.59</td>
<td>0.10</td>
<td>1.62</td>
</tr>
<tr>
<td>O. Tee, 45° Main to Branch w Damper</td>
<td>1.88</td>
<td>0.12</td>
<td>2.01</td>
</tr>
<tr>
<td>P. Tee, 90° Main to Branch</td>
<td>2.01</td>
<td>0.12</td>
<td>2.09</td>
</tr>
<tr>
<td>Q. Tee, 90° Main to Branch w Extracots</td>
<td>2.09</td>
<td>0.13</td>
<td>2.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Velocity $V_u - V_c$ (fpm)</th>
<th>Best</th>
<th>Better, but will increase Loss in Main</th>
<th>Good</th>
<th>Good, but will increase Loss in Main</th>
<th>Increases Loss in Main, not recommend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\rho = 0.075 \text{ lbm/ft}^3$

Standard Conditions
# Duct Design Fundamentals

## Fitting Efficiency – Diverging Flow Branches

### Comparison of Round Diverging Flow Fittings

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Area</th>
<th>Loss Coefficient</th>
<th>Velocity</th>
<th>Pressure Drop</th>
<th>Loss Coefficient</th>
<th>Pressure Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 inch</td>
<td>0.79 ft²</td>
<td>1269 fpm</td>
<td>0.10 inch water</td>
<td>0.02</td>
<td>1000 cfm</td>
<td>0.39 ft³</td>
</tr>
<tr>
<td>8.5 inch</td>
<td>0.39 ft³</td>
<td>1269 fpm</td>
<td>0.10 inch water</td>
<td>0.04</td>
<td>500 cfm</td>
<td>0.39 ft³</td>
</tr>
<tr>
<td>8.5 inch</td>
<td>0.39 ft³</td>
<td>1269 fpm</td>
<td>0.10 inch water</td>
<td>0.04</td>
<td>500 cfm</td>
<td>0.39 ft³</td>
</tr>
</tbody>
</table>

### Loss Coefficients from ASHRAE DFD8

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Pressure Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1269 fpm</td>
<td>0.10</td>
</tr>
</tbody>
</table>

### Standard Conditions

- \( \rho = 0.075 \text{ lb/ft}^3 \)
- Loss Coefficients are based on section velocity pressure

### Diagrams

- Symmetrical Wye, SDS-22
- Bullhead Tee with Vanes, SDS-19
- Bullhead Tee without Vanes, SDS-18
- Capped Cross, SDS-20
Duct Design Fundamentals

Fitting Efficiency – Diverging Flow Branches

Table 1.3
Loss Coefficient Comparisons for Diverging Flow Fittings

<table>
<thead>
<tr>
<th>Fitting</th>
<th>Loss Coefficient ($C_L$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-branch plus 45° Elbows</td>
<td>0.22</td>
</tr>
<tr>
<td>Vee Fitting</td>
<td>0.30</td>
</tr>
<tr>
<td>Tee with Turning Vanes plus Branch Reducers (Ballhead Tee with Vanes)</td>
<td>0.45</td>
</tr>
<tr>
<td>Tee plus Branch Reducers</td>
<td>1.08</td>
</tr>
<tr>
<td>Capped Cross with Straight Branches</td>
<td>4.45</td>
</tr>
<tr>
<td>Capped Cross with Conical Branches</td>
<td>4.45</td>
</tr>
<tr>
<td>Capped Cross with 1½° Cushion Head</td>
<td>5.4</td>
</tr>
<tr>
<td>Capped Cross with 2½° Cushion Head</td>
<td>6.0</td>
</tr>
<tr>
<td>Capped Cross with 3½° Cushion Head</td>
<td>6.4</td>
</tr>
</tbody>
</table>

The loss coefficient, $C_L$, is for a 1/2:1 ratio of approximately 1.0.
### Duct Design Fundamentals

**Fitting Efficiency – Converging Flow Branches**

#### Comparison of Converging Flow Fittings

<table>
<thead>
<tr>
<th>D2 (Inch)</th>
<th>A2 (ft²)</th>
<th>Q2 (cfm)</th>
<th>V2 (fpm)</th>
<th>P2 (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.79</td>
<td>1000</td>
<td>1273</td>
<td>0.10</td>
</tr>
<tr>
<td>8.5</td>
<td>0.39</td>
<td>500</td>
<td>1269</td>
<td>0.10</td>
</tr>
<tr>
<td>8.5</td>
<td>0.39</td>
<td>500</td>
<td>1269</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A2/A1</th>
<th>Q2/Q1</th>
<th>V2/V1</th>
<th>P2/P1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Note: A = Area (sq. in.), Q = Airflow (cfm), V = Velocity (fpm)

Use the velocity pressure (Vp) of the downstream section. Fitting loss TP = C x Vp

\[ p = 0.075 \text{ lb} / \text{ft}^2 \]

### Table A-10 Loss Coefficients, Converging Junctions (Tees, Wyes)

#### Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

<table>
<thead>
<tr>
<th>Branch</th>
<th>Velocity Vp (fpm)</th>
<th>Velocity Pressure p (inch water)</th>
<th>Loss Coefficient C</th>
<th>ΔpL (inch water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main</td>
<td>1273</td>
<td>0.10</td>
<td>0.49</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.10</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Best Not Recommended Good
A “SYSTEM EFFECT FACTOR” IS A PRESSURE LOSS TO THE FAN CAPACITY – CAUSED BY FAN INLET AND/OR OUTLET RESTRICTIONS TO THE FLOW OF AIR OR OTHER CONDITIONS INFLUENCING THE FAN PERFORMANCE WHEN THE FAN IS INSTALLED IN A HVAC SYSTEM.
Duct Design Fundamentals
System Effect

FIGURE 5-53 EFFECTS OF SYSTEM EFFECT
FIGURE 5-52 ESTABLISHMENT OF A UNIFORM VELOCITY PROFILE
Duct Design Fundamentals
Fan Outlet Effects

- For 100 percent energy recovery, the duct and an acceptable transition usually must be as long as the "full effective duct length" before a duct fitting is used.

- Any changes in the discharge duct within the effective duct length, which differ from the duct configuration used when the fan was tested and rated, may cause the fan to perform less efficiently.

- Where uniform flow conditions do not exist, the fan's performance will be reduced.
To Calculate 100 Percent Effective Duct Length, Assume a Minimum of 2-1/2 Hydraulic Duct Diameters for 2500 FPM or Less. Add 1 Duct Diameter for Each Additional 1000 FPM.

Example: 5000 FPM = 5D_h

D_h = 4A/P

For Rectangular, D_h = 4 x (a x b)/(2 x (a + b))
## Duct Design Fundamentals

### Fan Outlet Effects

<table>
<thead>
<tr>
<th>Pressure Recovery</th>
<th>No Duct</th>
<th>12% Effective Duct</th>
<th>25% Effective Duct</th>
<th>50% Effective Duct</th>
<th>100% Effective Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>50%</td>
<td>80%</td>
<td>90%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Blast Area Outlet Area</th>
<th>No Duct</th>
<th>12% Effective Duct</th>
<th>25% Effective Duct</th>
<th>50% Effective Duct</th>
<th>100% Effective Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>P</td>
<td>R-S</td>
<td>U</td>
<td>W</td>
<td>–</td>
</tr>
<tr>
<td>0.5</td>
<td>P</td>
<td>R-S</td>
<td>U</td>
<td>W</td>
<td>–</td>
</tr>
<tr>
<td>0.6</td>
<td>R-S</td>
<td>S-T</td>
<td>U-V</td>
<td>W-X</td>
<td>–</td>
</tr>
<tr>
<td>0.7</td>
<td>S</td>
<td>U</td>
<td>W-X</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>0.8</td>
<td>T-U</td>
<td>V-W</td>
<td>X</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>0.9</td>
<td>V-W</td>
<td>W-X</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

**Table 6-1 System Effect Curves for Outlet Ducts**
Duct Design Fundamentals
System Effect Curves

See page 6.2 of the HVAC Systems Duct Design Manual
## Duct Design Fundamentals

### Fan Outlet Effects

<table>
<thead>
<tr>
<th>Blast Area Outlet Area</th>
<th>Pressure Recovery</th>
<th>No Duct</th>
<th>12% Effective Duct</th>
<th>25% Effective Duct</th>
<th>50% Effective Duct</th>
<th>100% Effective Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>P</td>
<td>R-S</td>
<td>U</td>
<td>W</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>P</td>
<td>R-S</td>
<td>U</td>
<td>W</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>R-S</td>
<td>S-T</td>
<td>U-V</td>
<td>W-X</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td><strong>0.7</strong></td>
<td><strong>S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>T-U</td>
<td>V-W</td>
<td>X</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>V-W</td>
<td>W-X</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Effect Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
</tr>
<tr>
<td>R-S</td>
</tr>
<tr>
<td>S-T</td>
</tr>
<tr>
<td>U-V</td>
</tr>
<tr>
<td>W-X</td>
</tr>
</tbody>
</table>

Table 6-1 System Effect Curves for Outlet Ducts
Duct Design Fundamentals

System Effect Curves

**Figure 6-1 System Effect Curves**

- **AIR VELOCITY**—FPM in Hundreds (m/s)
- **Air Density** = 0.075 lb per cu ft (1.204 kg/m³)
If the outlet velocity is 3000 fpm, the System Effect is 0.40 inch of water.
Duct Design Fundamentals

Fan Outlet Effects – Specifically for Elbows
### Duct Design Fundamentals

**Fan Outlet Effects – Specifically for Elbows**

<table>
<thead>
<tr>
<th>Blast Area Outlet Area</th>
<th>Outlet Elbow Position</th>
<th>No Outlet Duct</th>
<th>12% Effective Duct</th>
<th>25% Effective Duct</th>
<th>50% Effective Duct</th>
<th>100% Effective Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>A</td>
<td>N</td>
<td>O</td>
<td>P-Q</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>M</td>
<td>M-N</td>
<td>O</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>L-M</td>
<td>M</td>
<td>N</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>L-M</td>
<td>M</td>
<td>N</td>
<td>Q</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>P</td>
<td>Q</td>
<td>R</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>N-O</td>
<td>O-P</td>
<td>P-Q</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>M-N</td>
<td>N-O</td>
<td>O-P</td>
<td>R-S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>M-N</td>
<td>N-O</td>
<td>O-P</td>
<td>R-S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>Q</td>
<td>Q-R</td>
<td>R-S</td>
<td>U</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>P</td>
<td>Q</td>
<td>R</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>N-O</td>
<td>O-P</td>
<td>P-Q</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>O</td>
<td>P</td>
<td>Q-R</td>
<td>S-T</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>A</td>
<td>S-T</td>
<td>T</td>
<td>U</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>R-S</td>
<td>S</td>
<td>T</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Q-R</td>
<td>R</td>
<td>S</td>
<td>U-V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>R</td>
<td>R-S</td>
<td>S-T</td>
<td>U-V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>S</td>
<td>S-T</td>
<td>T-U</td>
<td>V-W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>R</td>
<td>R-S</td>
<td>S-T</td>
<td>U-V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Q</td>
<td>Q-R</td>
<td>R-S</td>
<td>U</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Q-R</td>
<td>R</td>
<td>S</td>
<td>U-V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>S-T</td>
<td>T</td>
<td>U</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>R-S</td>
<td>S</td>
<td>T</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>R</td>
<td>R-S</td>
<td>S-T</td>
<td>U-V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>R-S</td>
<td>S</td>
<td>T</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>A</td>
<td>R-S</td>
<td>S</td>
<td>T</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>S-T</td>
<td>T</td>
<td>U</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>R-S</td>
<td>S</td>
<td>T</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>R-S</td>
<td>S</td>
<td>T</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

Table 6-2 System Effect Factor Curves for Outlet Elbows
Duct Design Fundamentals

Fan Inlet Effects

- HVAC centrifugal and axial flow fans are tested without any inlet obstructions or duct connections.

- For rated performance, the air must enter the fan uniformly over the inlet area in an axial direction without pre-rotation.

- Non-uniform flow into the inlet is the most common cause of reduced fan performance.

- A poor inlet condition results in an entirely new fan performance.
Many other inlet situations are identified in Chapter 6 of the SMACNA HVAC SYSTEMS DUCT DESIGN manual.

Uses Chart from Figure 6-1
Duct Design Fundamentals
General Fan Connection System Effects

Conditions Include:

- 6.2.1 Fan Outlet Ducts
- 6.2.2 Fan Outlet Diffusers
- 6.2.3 Fan Outlet Duct Elbows
- 6.2.4 Turning Vanes
- 6.2.5 Fan Volume Control Dampers
- 6.2.6 Duct Branches
- 6.3.1 Inlet Ducts
- 6.3.2 Inlet Elbows
- 6.3.3 Inlet Vortex
- 6.3.4 Inlet Duct Vanes
- 6.3.5 Straighteners
- 6.3.6 Enclosures
- 6.3.7 Obstructed Inlets
ASHRAE developed an Online Duct Fitting Database (DFDB). The database enables the user to select from over 200 fittings, enter information such as airflow and size, and the database outputs velocity, velocity pressure, loss coefficient and pressure loss.

<table>
<thead>
<tr>
<th>Fitting Function</th>
<th>Geometry</th>
<th>Category</th>
<th>Sequential Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>S: Supply</td>
<td>D: Round</td>
<td>1: Entries</td>
<td>1, 2, 3 … n</td>
</tr>
<tr>
<td>E: Exhaust/Return</td>
<td>R: Rectangular</td>
<td>2: Exits</td>
<td></td>
</tr>
<tr>
<td>C: Common</td>
<td>F: Flat oval</td>
<td>3: Elbows</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4: Transitions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5: Junctions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6: Obstructions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7: Fan and System Interactions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8: Duct-Mounted Equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9: Dampers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10: Hoods</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11: Straight Duct</td>
<td></td>
</tr>
</tbody>
</table>
### Setting Air Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>IP</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature</td>
<td>70°F</td>
<td>20°C</td>
</tr>
<tr>
<td>Elevation</td>
<td>0 ft</td>
<td>0 m</td>
</tr>
<tr>
<td>Barometric Pressure</td>
<td>14.696 psia</td>
<td>101.325 kPa</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>0 percent</td>
<td>0 percent</td>
</tr>
<tr>
<td>Density</td>
<td>0.075 lbm/ft³</td>
<td>1.204 kg/m³</td>
</tr>
<tr>
<td>Viscosity</td>
<td>0.00073350 lbm/ft-min</td>
<td>0.00001818 N-s/m²</td>
</tr>
</tbody>
</table>
Duct Design Fundamentals
ASHRAE Duct Fitting Data Base (DFDB)

CD11-1 Straight Duct, Round (Colebrook 1939)

**INPUT**
- Diameter (D)  in.  21.0
- Length (L)  ft  100
- Absolute Roughness (er)  ft  0.00040
- Flow Rate (Q)  cfm  5,000
- Density (RHO)  lbm/ft^3  0.075

**OUTPUT**
- Velocity (V)  fpm  2,079
- Velocity Pressure (Pv)  in. wg  0.27
- Reynolds Number (Re)  369,485
- Friction Factor (f)  0.0161
- Pressure Loss (Po)  in. wg  0.25
Duct Design Fundamentals
ASHRAE Duct Fitting Data Base (DFDB)

SDS-10 Tee, Conical Branch Tapered into Body, Diverging
(UMC 1986, Report SRF386)

**INPUT**
- Diameter (Dc) in. 12.0
- Diameter (Db) in. 6.0
- Diameter (Da) in. 10.0
- Flow Rate (Qc) cfm 1,500
- Flow Rate (Qb) cfm 300
- Density (RHO) lbm/ft²·s 0.075

**OUTPUT**

**BRANCH**
- Velocity (Vb) fpm 1,528
- Vel Pres at Vb (Pvb) in. wg 0.14
- Loss Coefficient (Cb) 1.11
- Branch Pressure Loss (Pob) in. wg 0.16

**MAIN**
- Velocity (Vs) fpm 2,200
- Velocity (Vc) fpm 1,910
- Vel Pres at Vs (Pvs) in. wg 0.30
- Vel Pres at Vc (Pvc) in. wg 0.23
- Loss Coefficient (Cv) 0.15
- Main Pressure Loss (Pom) in. wg 0.04
Duct Design Fundamentals

Duct Design Overview
Goals of a High Performance Air System - Duct Design

- Design energy efficient HVAC systems that deliver the proper amount of air to specific areas of the building
- Design balanced systems
- Minimize fan energy use
- Minimize first cost
- Minimize the maintenance cost
- Keep noise levels within the required NC/RC levels
- Provide a comprehensive design to the owner per the Owner’s Project Requirements (OPRS)
Step 1: Determine air volume requirements. Include an allowance for leakage.
Step 2: Locate duct runs. Avoid unnecessary directional changes.
Step 3: Locate balancing dampers if necessary.
Step 4: Determine the allowable noise (NC) levels.
Step 5: Select design method.
Step 6: Select the initial duct size.
Step 7: Determine duct sizes based on the design methodology. Use efficient fittings.
Step 8: Keep aspect ratios as close to 1 as possible.
Step 9: Determine system pressure requirements. Include total pressure losses of components.
Step 10: Analyze the design to improve balancing and reduce material cost.
Step 11: Select fan according to proper guidelines.
Step 12: Analyze the design to make sure it meets the acoustical requirements.
Step 13: Select materials that minimize cost and meet SMACNA Duct Construction Standards.
Step 14: Analyze the life-cycle cost of the design.
Step 15: Commission the design to make sure it meets the OPR.
## Duct Design Fundamentals

### Designing the Duct System - Select the Design Method

<table>
<thead>
<tr>
<th>Design Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Friction</td>
<td>Easier to Use</td>
<td>Does not account for varying lengths, uses same friction loss rate to size 1 ft. length or 100 ft. for example.</td>
</tr>
<tr>
<td></td>
<td>Can Use a Ductulator to Determine Sizes</td>
<td>Fittings don’t affect the design only the analysis. The design or size is a function of the friction rate used. Fittings losses must be included in the analysis.</td>
</tr>
<tr>
<td></td>
<td>Good for quickly designing small systems.</td>
<td>The system will not be balanced without additional work or use of dampers.</td>
</tr>
<tr>
<td></td>
<td>Can design return/exhaust or supply systems.</td>
<td>Optimum friction rate is not known. Choosing a friction rate is from experience by rule of thumb.</td>
</tr>
<tr>
<td>Static Regain</td>
<td>Larger duct sizes may be used, but offset by smaller sizes in non-critical paths.</td>
<td>Sizing ducts is cumbersome and may require many iterations which are best suited by the use of a computerized duct design program.</td>
</tr>
<tr>
<td></td>
<td>System will be more balanced than equal friction, depending on the available duct sizes allow.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Often can use smaller sizes or less efficient and lower cost types of fittings in the non-design legs.</td>
<td>Can only be used on Supply systems.</td>
</tr>
<tr>
<td></td>
<td>Must choose an initial velocity based on guidelines.</td>
<td></td>
</tr>
</tbody>
</table>
Duct Design Fundamentals
Designing the Duct System - The Critical Path

- Critical paths are the duct sections from a fan outlet to the terminal device with the largest total pressure drop for supply systems or from the entrance to the fan inlet with the highest total pressure drop for return or exhaust systems.

- The difference between the critical path and other paths will be excess total pressure. If the path has excess total pressure, it can be used with smaller sections, less efficient fittings, dampers, or the VAV box.

[SMALLER SECTIONS IS THE PREFERRED METHOD; BALANCES AND LOWERS COST]

- In all systems there will be an imbalance because we don’t use an infinite amount of duct sizes. It is always recommended to provide designed balanced systems.
**Duct Design Fundamentals**

Determine the Duct System Method – Sample Equal Friction Design

---

### Example Equal Friction Loss

![Diagram of duct system with labels and measurements](image)

1. **SD5-1, 45° Entry Branch**
2. **100 ft**
3. **5 ft**
4. **10 ft**
5. **1000 cfm**

---

**For \( \frac{p_1}{100} = 0.10 \text{ inch water} \)**

<table>
<thead>
<tr>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_1 = ) 2000 cfm</td>
<td>( Q_2 = ) 1000 cfm</td>
<td>( Q_3 = ) 1000 cfm</td>
</tr>
<tr>
<td>( D_1 = ) 18 inch</td>
<td>( D_2 = ) 14 inch</td>
<td>( D_3 = ) 14 inch</td>
</tr>
<tr>
<td>( V_1 = ) 1132 fpm</td>
<td>( V_2 = ) 935 fpm</td>
<td>( V_3 = ) 935 fpm</td>
</tr>
<tr>
<td>( p_{e,1} = ) 0.08 inch water</td>
<td>( p_{e,2} = ) 0.05 inch water</td>
<td>( p_{e,3} = ) 0.05 inch water</td>
</tr>
<tr>
<td>( p_1 = ) 0.09 inch water /100 ft</td>
<td>( p_2 = ) 0.09 inch water /100 ft</td>
<td>( p_3 = ) 0.09 inch water /100 ft</td>
</tr>
<tr>
<td>( \Delta p_{e,1} = ) 0.01 inch water</td>
<td>( \Delta p_{e,2} = ) 0.01 inch water</td>
<td>( \Delta p_{e,3} = ) 0.01 inch water</td>
</tr>
<tr>
<td>Outlet Loss ( = ) 0.05 inch water</td>
<td>Outlet Loss ( = ) 0.05 inch water</td>
<td>Outlet Loss ( = ) 0.05 inch water</td>
</tr>
</tbody>
</table>

- **Path 1 - 2 \( \Delta p = \) 0.16 inch water**
- **Path 1 - 3 \( \Delta p = \) 0.07 inch water**

**Total Pressure** = 0.16 inch water  For Path 1 - 2

**Excess Pressure** = 0.09 inch water  For Path 1 - 3
Duct Design Fundamentals

Determine the Duct System Method

Recommend Using Equal Friction for Smaller System with slower velocity.

For HPAS designs, recommend Static Regain w additional Balancing using even smaller ducts and/or less efficient fittings

DESIGN BALANCED SYSTEMS
Duct Design Fundamentals

Designing the Duct System - Select the initial duct size

Method 1 - Use Grey Shaded Area

For Air Quantity greater than 20,000 cfm, maximum suggested velocity is 4000 fpm
Duct Design Fundamentals
Designing the Duct System - Select the initial duct size

<table>
<thead>
<tr>
<th>Duct Location</th>
<th>RC or NC Rating in Adjacent Occupancy</th>
<th>Maximum Airflow Velocity, Fpm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rectangular Duct</td>
<td>Round Duct</td>
</tr>
<tr>
<td>In shaft or above drywall ceiling</td>
<td>45</td>
<td>3500</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>1700</td>
</tr>
<tr>
<td>Above suspended acoustic ceiling</td>
<td>45</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1750</td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>1200</td>
</tr>
<tr>
<td>Duct located within occupied space</td>
<td>45</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1450</td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>950</td>
</tr>
</tbody>
</table>

Method 2 - Use Table 8 from Chapter 48 of the ASHRAE – HVAC Application, Noise and Vibration Control.

¹Table 4-1 [Schaffer 2005 (2011)] [Table 8 from ASHRAE 2015 – HVAC Applications Chapter 48, Noise and Vibration Control]
Duct Design Fundamentals
Designing the Duct System - Select the initial duct size

Method 3 - Use an initial friction rate (inch water / 100 ft), based on the economics of the area

- **Prevailing Energy Cost is High or Installation Labor Cost is Low**: 0.08 to 0.15 in. water per 100 ft

- **Prevailing Energy Cost is Low or Installation Labor Cost High**: 0.30 to 0.60 in. water per 100 ft
Duct Design Fundamentals

Duct Design Methods!

Duct Design – Equal Friction
Duct Design Fundamentals

Equal Friction Rate Design Steps

- Layout a single-line drawing of the system, and assign section numbers.
- Locate balancing dampers for Constant Volume systems, not needed for VAV system.
- Determine leakage in each section of ductwork, and add to the air quantity required per the load calculations and system diversity. A good average is include an allowance for about 5% system leakage.
- Determine terminal total pressure requirements for constant volume diffusers, or VAV terminal units.
- Size all main and branch duct at a constant friction rate/maximum duct velocity.
- Calculate the total pressure loss for each section, both supply and return ductwork. Use the “Equal Friction” spreadsheet. For each main and branch of a junction be sure to account for the straight-through and branch loss coefficients.
- Tabulate the total pressure required for each path from the fan to each supply and return terminal.
- Determine the maximum operating pressure; then calculate the excess total pressure at each terminal.
- If excess pressure is greater than 0.1 in. of water, consider using a higher friction rate in non design legs to use smaller sections.
- Less Efficient / less costly elbows might also be used in non-design legs.
- Perform an acoustical analysis of the system. Add insulation or silencers as necessary.
Sample Problem: Size the system shown by the equal friction method. The design air temperature is 69°F, located in Denver. Density (ρ) is 0.061 lbm/ft³, zero duct air leakage. Ducts are round spiral galvanized steel. The diffuser and distribution ductwork downstream of the VAV box has a pressure loss of 0.05 in. of water. The VAV terminal units have loss coefficients according to the following Table Size:

<table>
<thead>
<tr>
<th>Section</th>
<th>Box Inlet Size (in.)</th>
<th>Airflow (cfm)</th>
<th>Loss Coefficient (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 &amp; 5</td>
<td>10</td>
<td>1000</td>
<td>2.58</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>800</td>
<td>2.31</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>8</td>
<td>600</td>
<td>2.49</td>
</tr>
<tr>
<td>13 &amp; 14</td>
<td>14</td>
<td>2000</td>
<td>2.56</td>
</tr>
<tr>
<td>17 &amp; 18</td>
<td>12</td>
<td>1400</td>
<td>2.65</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
<td>600</td>
<td>2.49</td>
</tr>
</tbody>
</table>
Assume the first section is located above a suspended acoustical ceiling with an RC requirement of 35 maximum.

Solution: Using the Acoustical Table below, the maximum velocity is 3500 fpm.

<table>
<thead>
<tr>
<th>Duct Location</th>
<th>RC or NC Rating in Adjacent Occupancy</th>
<th>Maximum Airflow Velocity, Fpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>In shaft or above drywall ceiling</td>
<td>45</td>
<td>3500</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>1700</td>
</tr>
<tr>
<td>Above suspended acoustic ceiling</td>
<td>45</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1750</td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>1200</td>
</tr>
<tr>
<td>Duct located within occupied space</td>
<td>45</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1450</td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>950</td>
</tr>
</tbody>
</table>

1Table 4-1 (Schaffer 2005 (2011)) [Table 8 from ASHRAE 2015 – HVAC Applications Chapter 48, Noise and Vibration Control]
Solution: The total fan airflow is 11,400 CFM. Sizing the first section for the maximum velocity results in a diameter size of 25 inches.

That has a friction loss rate of 0.41 inch water /100 ft. That rate will be used to size the other sections. This is actually Section 2 as Section 1 will be the fan transition. We must also account for the other fitting losses, so a spreadsheet is used to calculate the data for each section.
# Duct Design Fundamentals

**DUCT DESIGN BY THE EQUAL FRICTION METHOD**

## Equal Friction Example Problem (DDG)

<table>
<thead>
<tr>
<th>Upstream Section</th>
<th>Section</th>
<th>Fitting</th>
<th>ASHRAE Fitting Code</th>
<th>Air Quantity (cfm)</th>
<th>Duct Size (in.)</th>
<th>Velocity (fpm)</th>
<th>Duct Length (ft)</th>
<th>Velocity Pressure, $p_v$ (in. wg)</th>
<th>Loss Coefficient, $C$</th>
<th>Total Pressure Loss (in. wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Duct</td>
<td>CD11-4/CD11-1</td>
<td>11400</td>
<td>11</td>
<td>3344</td>
<td>26</td>
<td>0.13</td>
<td>0.01</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Elbow, 90°</td>
<td>CD4-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Transition: $H_1=27.0$, $W_1=20.0$, $L=24$ (Theta1=5°, Theta2=12°)</td>
<td>SD4-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Duct</td>
<td>CD11-1</td>
<td>7400</td>
<td>21</td>
<td>3077</td>
<td>11</td>
<td>0.14</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tee, 45° Entry, Main</td>
<td>SD5-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sized at Maximum Velocity of 3500 fpm**

Total Pressure Loss: 0.19 in. wg
## Duct Design Fundamentals

### Duct Design by the Equal Friction Method

#### Equal Friction Example Problem (DDG)

<table>
<thead>
<tr>
<th>Upstream Section</th>
<th>Section</th>
<th>Fitting</th>
<th>ASHRAE Fitting Code</th>
<th>Air Quantity (cfm)</th>
<th>Duct Size (in.)</th>
<th>Velocity (fpm)</th>
<th>Duct Length (ft)</th>
<th>Velocity Pressure, p, (in. wg)</th>
<th>Loss Coefficient, C</th>
<th>Total Pressure Loss (in. wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>Duct</td>
<td>CD11-1/CD11-1</td>
<td>11400</td>
<td>25</td>
<td>3344</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elbow, 90°</td>
<td>CD4-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transition: H1=27.0&quot;, W1=20.0&quot;, L=24&quot; (Theta1=5°, Theta2=12°)</td>
<td>SD4-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Duct</td>
<td>CD11-1</td>
<td>7400</td>
<td>21</td>
<td>3077</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tee, 45° Entry, Main</td>
<td>SD5-12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Dc=25, Ds=21, Db=17)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Temperature, °F</th>
<th>69</th>
<th>Relative Humidity, %</th>
<th>0</th>
<th>Elevation, ft</th>
<th>5430</th>
<th>Air Density (ρ), lbm/ft³</th>
<th>0.061</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric Pressure, psia</td>
<td>12.032</td>
<td>Viscosity (μ), lbm/(ft-min)</td>
<td>0.00073245</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Duct Design Fundamentals

DUCT DESIGN BY THE EQUAL FRICTION METHOD,
Section 15, 19 and 20
## Duct Design Fundamentals

### DUCT DESIGN BY THE EQUAL FRICTION METHOD

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct Description</th>
<th>D</th>
<th>F</th>
<th>Loss-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Wye, 45° &lt;br&gt;(Dc=21, Ds=16, Db=17)</td>
<td>CD11-1</td>
<td>3400</td>
<td>16</td>
</tr>
<tr>
<td>15</td>
<td>Tee, 45° Entry, Main &lt;br&gt;(Dc=16, Ds=8, Db=15)</td>
<td>SD5-12</td>
<td>600</td>
<td>8</td>
</tr>
<tr>
<td>19</td>
<td>Flexible Duct (36.5 inches long, 38 inches fully extended, 4% compression) &lt;br&gt;Transition Round to Round &lt;br&gt;Do=8, D1=8 &lt;br&gt;VALV Box &lt;br&gt;Distribution and Diffuser</td>
<td>CD11-2, SD4-1, CD8-11</td>
<td>600</td>
<td>8</td>
</tr>
</tbody>
</table>

**Section Total**

<table>
<thead>
<tr>
<th>D</th>
<th>F</th>
<th>Loss-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.14</td>
<td>0.04</td>
</tr>
<tr>
<td>0.15</td>
<td>0.46</td>
<td>0.07</td>
</tr>
<tr>
<td>0.15</td>
<td>2.49</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Duct Design Fundamentals

DUCT DESIGN BY THE EQUAL FRICTION METHOD,
Section 3, 6 and 8
### Duct Design Fundamentals

**DUCT DESIGN BY THE EQUAL FRICTION METHOD**

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>CD11-1</th>
<th>31</th>
<th>0.12</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Tee, 45° Entry, Branch</td>
<td>SD5-12</td>
<td>4000</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Elbow 90°</td>
<td>CD4-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Section Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Coss, 45° Entry, Main</td>
<td>SD5-26</td>
<td>2000</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(Dc=17, Ds=13, Db1=Db2=10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Section Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Wye, 45° Branch with 45° Elbow, Branch 90° to Main</td>
<td>SD5-4</td>
<td>1200</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>(Dc=13, Ds=11, Db=8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Section Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DUCT DESIGN BY THE EQUAL FRICTION METHOD, Section 4/5, 9/10 and 7
# Duct Design Fundamentals

## DUCT DESIGN BY THE EQUAL FRICTION METHOD

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct Description</th>
<th>A</th>
<th>L</th>
<th>Dn</th>
<th>φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 &amp; 9</td>
<td>Bullhead Tee w/ Vanes, Branch</td>
<td>600</td>
<td>8</td>
<td>1719</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>CD11-1</td>
<td></td>
<td></td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>SDS-19</td>
<td></td>
<td></td>
<td></td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>CD8-11</td>
<td></td>
<td></td>
<td></td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>Distribution and Diffuser</td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.52</td>
</tr>
<tr>
<td>3 &amp; 4 &amp; 5</td>
<td>Duct (sized to match VAV terminal unit inlet)</td>
<td>1000</td>
<td>10</td>
<td>1000</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Cross 45° Entry, Branch</td>
<td></td>
<td></td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>CD11-1</td>
<td></td>
<td></td>
<td></td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>SDS-26</td>
<td></td>
<td></td>
<td></td>
<td>2.58</td>
</tr>
<tr>
<td></td>
<td>CD8-11</td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Distribution and Diffuser</td>
<td></td>
<td></td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.67</td>
</tr>
<tr>
<td>6 &amp; 7</td>
<td>Wye, 45° Branch with 45° Elbow, Branch 90° to Main</td>
<td>800</td>
<td>9</td>
<td>1811</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>CD11-1</td>
<td></td>
<td></td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>SDS-4</td>
<td></td>
<td></td>
<td></td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>CD8-11</td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Distribution and Diffuser</td>
<td></td>
<td></td>
<td></td>
<td>0.57</td>
</tr>
</tbody>
</table>

**Section Total:**

- 0.52
- 0.60
- 0.57
Duct Design Fundamentals

DUCT DESIGN BY THE EQUAL FRICTION METHOD,
Section 12, 16 and 13/14
## Duct Design Fundamentals

### DUCT DESIGN BY THE EQUAL FRICTION METHOD

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>Friction</th>
<th>Diameter</th>
<th>Length</th>
<th>Friction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-12</td>
<td>Duct</td>
<td>CD11-1</td>
<td>4000</td>
<td>17</td>
<td>2538</td>
</tr>
<tr>
<td></td>
<td>Wye 45°</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>(Dc=21, Ds=16, Db=17)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elbow 45°</td>
<td>CD4-14</td>
<td></td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>15-16</td>
<td>Duct</td>
<td>CD11-1</td>
<td>2800</td>
<td>15</td>
<td>2282</td>
</tr>
<tr>
<td></td>
<td>Tee 45° Entry, Branch</td>
<td>SD5-12</td>
<td></td>
<td></td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>(Dc=16, Ds=8, Db=15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>12-13, 14</td>
<td>Duct (sized to match VAV terminal unit inlet)</td>
<td>CD11-1</td>
<td>2000</td>
<td>14</td>
<td>1871</td>
</tr>
<tr>
<td></td>
<td>Symmetrical Wye w/45° Elbows</td>
<td>SD5-22</td>
<td></td>
<td></td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>(Dc=17, Db1=14, Db2=14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VAV terminal unit</td>
<td>CD8-11</td>
<td></td>
<td></td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>Distribution and Diffuser</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.61</td>
</tr>
</tbody>
</table>
Duct Design Fundamentals

DUCT DESIGN BY THE EQUAL FRICTION METHOD,
Section 17, 18
### Duct Design Fundamentals

**DUCT DESIGN BY THE EQUAL FRICTION METHOD**

<table>
<thead>
<tr>
<th></th>
<th>Duct (sized to match VAV terminal unit inlet)</th>
<th>CD11-1</th>
<th>1400</th>
<th>12</th>
<th>1783</th>
<th>5</th>
<th>0.02</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Bullhead Tee with Vanes, Branch</td>
<td>SD5-19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td>17</td>
<td>(Dc=15, Db1=12, Db2=12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>VAV terminal unit</td>
<td>CD8-11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>Distribution and Diffuser</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Section Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.54</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.61</strong></td>
</tr>
</tbody>
</table>
# Duct Design Fundamentals

## Duct Design by the Equal Friction Method

### Summary of Example

<table>
<thead>
<tr>
<th>Section</th>
<th>Pressure Drop (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
</tr>
<tr>
<td>4 &amp; 5</td>
<td>0.67</td>
</tr>
<tr>
<td>6</td>
<td>0.09</td>
</tr>
<tr>
<td>7</td>
<td>0.57</td>
</tr>
<tr>
<td>8</td>
<td>0.08</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>0.52</td>
</tr>
<tr>
<td>11</td>
<td>0.12</td>
</tr>
<tr>
<td>12</td>
<td>0.33</td>
</tr>
<tr>
<td>13 &amp; 14</td>
<td>0.61</td>
</tr>
<tr>
<td>15</td>
<td>0.13</td>
</tr>
<tr>
<td>16</td>
<td>0.15</td>
</tr>
<tr>
<td>17 &amp; 18</td>
<td>0.61</td>
</tr>
<tr>
<td>19</td>
<td>0.25</td>
</tr>
<tr>
<td>20</td>
<td>0.46</td>
</tr>
</tbody>
</table>

### Path A/B:

<table>
<thead>
<tr>
<th>Section</th>
<th>TP (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
</tr>
<tr>
<td>4/5</td>
<td>0.67</td>
</tr>
<tr>
<td>Total</td>
<td>1.28</td>
</tr>
</tbody>
</table>

### Path C:

<table>
<thead>
<tr>
<th>Section</th>
<th>TP (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
</tr>
<tr>
<td>6</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>0.57</td>
</tr>
</tbody>
</table>

### Path D/E:

<table>
<thead>
<tr>
<th>Section</th>
<th>TP (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.42</td>
</tr>
<tr>
<td>6</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>0.80</td>
</tr>
</tbody>
</table>

### Path F/G:

<table>
<thead>
<tr>
<th>Section</th>
<th>TP (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>11</td>
<td>0.12</td>
</tr>
<tr>
<td>12</td>
<td>0.33</td>
</tr>
<tr>
<td>Total</td>
<td>1.64</td>
</tr>
</tbody>
</table>

### Path H/I:

<table>
<thead>
<tr>
<th>Section</th>
<th>TP (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>11</td>
<td>0.12</td>
</tr>
<tr>
<td>15</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>0.44</td>
</tr>
</tbody>
</table>

### Path J:

<table>
<thead>
<tr>
<th>Section</th>
<th>TP (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.19</td>
</tr>
<tr>
<td>11</td>
<td>0.12</td>
</tr>
<tr>
<td>15</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>0.44</td>
</tr>
</tbody>
</table>

### Equal Friction Method:

- Calculate the pressure drop for each section.
- Ensure the total pressure drop is equal for all paths.
- Adjust the sections as necessary to achieve equal friction.
Duct Design Fundamentals
DUCT DESIGN BY THE EQUAL FRICTION METHOD
UN-BALANCE

<table>
<thead>
<tr>
<th>Path</th>
<th>TP (in. wg)</th>
<th>Excess Pressure (in. wg)</th>
<th>% Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B (4/5)</td>
<td>1.28</td>
<td>0.02</td>
<td>1.3</td>
</tr>
<tr>
<td>C (7)</td>
<td>1.27</td>
<td>0.03</td>
<td>2.1</td>
</tr>
<tr>
<td>D/E (9/10)</td>
<td>1.30</td>
<td>0.00</td>
<td>0.0</td>
</tr>
<tr>
<td>F/G (13/14)</td>
<td>1.26</td>
<td>0.04</td>
<td>3.1</td>
</tr>
<tr>
<td>H/I (17/18)</td>
<td>1.20</td>
<td>0.09</td>
<td>7.1</td>
</tr>
<tr>
<td>J (20)</td>
<td>1.15</td>
<td>0.14</td>
<td>11.1</td>
</tr>
</tbody>
</table>
Duct Design Fundamentals
Duct Design – Static Regain

\[ \Delta p_{t,1-2} = \Delta p_{s,1-2} + \Delta p_{v,1-2} \]
\[ \Delta p_{s,1-2} = \Delta p_{t,1-2} - \Delta p_{v,1-2} \]
\[ \Delta p_{s,1-2} = 0 \]
\[ \Delta p_{t,1-2} = \Delta p_{v,1-2} \]

Satisfied When:
\[ \Delta p_{v,1-2} \cdot \Delta p_{t,1-2} = 0 \]
or
\[ p_{v1} \cdot p_{v2} \cdot \Delta p_{t,1-2} = 0 \]
Duct Design Fundamentals
Duct Design – Static Regain

- Layout a single-line drawing of the system, and assign section numbers.
- Locate balancing dampers for Constant Volume systems, not needed for VAV system.
- Determine leakage in each section of ductwork, and add to the air quantity required per the load calculations and system diversity. A good average is include an allowance for about 5% system leakage.
- Determine terminal total pressure requirements for constant volume diffusers, or VAV terminal units.
- Size fan discharge duct (first supply air section after the fan) at the maximum recommended initial duct velocity.
- Size the straight-through sections first using $p_{v1} - p_{v2} - \Delta p_{t,1-2}$. Use the “static regain” spreadsheet.
- Size the branches using the same method up to VAV terminal units, if any. Use the junction upstream velocity to determine $p_{v1}$.
- Size ductwork downstream of VAV terminal units by the equal friction method.
- Tabulate the total pressure required for each path from the fan to each supply terminal, and calculate the excess total pressure at each terminal.
- Design should be reasonably in balance. If not, adjust the appropriate branch by decreasing duct size or use less efficient fittings. Unbalance of 0.1 in. of water is acceptable (well within the accuracy of the fitting loss coefficients).
- Perform an acoustical analysis of the system (consult Chapter 10). Provide lined duct or sound attenuators where necessary.
Sample Problem: Size the system shown by the static regain method. The design air temperature is 69 °F, located in Denver. Density (ρ) is 0.061 lbm/ft³, zero duct air leakage. Ducts are round spiral galvanized steel. The diffuser and distribution ductwork downstream of the VAV box has a pressure loss of 0.05 in. of water. The VAV terminal units have loss coefficients according to the following Table Size:

<table>
<thead>
<tr>
<th>Section</th>
<th>Box Inlet Size (in.)</th>
<th>Airflow (cfm)</th>
<th>Loss Coefficient (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 &amp; 5</td>
<td>10</td>
<td>1000</td>
<td>2.58</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>800</td>
<td>2.31</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>8</td>
<td>600</td>
<td>2.49</td>
</tr>
<tr>
<td>13 &amp; 14</td>
<td>14</td>
<td>2000</td>
<td>2.56</td>
</tr>
<tr>
<td>17 &amp; 18</td>
<td>12</td>
<td>1400</td>
<td>2.65</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
<td>600</td>
<td>2.49</td>
</tr>
</tbody>
</table>
Assume the first section is located above a suspended acoustical ceiling with an RC requirement of 35 maximum.

Solution: Using the Acoustical Table below, the maximum velocity is 3500 fpm.

<table>
<thead>
<tr>
<th>Duct Location</th>
<th>RC or NC Rating in Adjacent Occupancy</th>
<th>Maximum Airflow Velocity, Fpm</th>
<th>Rectangular Duct</th>
<th>Round Duct</th>
</tr>
</thead>
<tbody>
<tr>
<td>In shaft or above drywall ceiling</td>
<td>45</td>
<td>3500</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>2500</td>
<td>3500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>1700</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td>Above suspended acoustic ceiling</td>
<td>45</td>
<td>2500</td>
<td>4500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1750</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>1200</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Duct located within occupied space</td>
<td>45</td>
<td>2000</td>
<td>3900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1450</td>
<td>2600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 or less</td>
<td>950</td>
<td>1700</td>
<td></td>
</tr>
</tbody>
</table>

1Table 4-1 [Schaffer 2005 (2011)] [Table 8 from ASHRAE 2015 – HVAC Applications Chapter 48, Noise and Vibration Control]
Solution: The total fan airflow is 11,400 CFM. Sizing the first section for the maximum velocity results in a size of 25 inches.

This is actually Section 2 as Section 1 will be the fan transition. We must also account for the other fitting losses, so a spreadsheet is used to calculate the data for each section.
## Duct Design Fundamentals

### DUCT DESIGN BY THE STATIC REGAIN METHOD

<table>
<thead>
<tr>
<th>Air Temperature, °F</th>
<th>69</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Humidity, %</td>
<td>0</td>
</tr>
<tr>
<td>Elevation, ft</td>
<td>5430</td>
</tr>
<tr>
<td>Air Density, lbm/ft³</td>
<td>0.061</td>
</tr>
<tr>
<td>Barometric Pressures, psia</td>
<td>12.03</td>
</tr>
<tr>
<td>Viscosity (μ), lbm/(ft·min)</td>
<td>0.00073245</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Upstream Section</th>
<th>Section</th>
<th>Fitting</th>
<th>ASHRAE Fitting Code</th>
<th>Air Quantity (cfm)</th>
<th>Duct Size (in.)</th>
<th>Duct Length (ft)</th>
<th>Velocity Pressur e, p_v (in. wg)</th>
<th>Loss Coefficient, C</th>
<th>Total Pressur e Loss (in. wg)</th>
<th>Regain (in. wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Drawings</td>
<td>DFDB</td>
<td>Drawings</td>
<td>Iteration</td>
<td>DFD B</td>
<td>Drawing</td>
<td>DFDB</td>
<td>DFDB</td>
<td>Σ</td>
<td>Static Regain Calc</td>
</tr>
<tr>
<td>1</td>
<td>2&quot;</td>
<td>Duct</td>
<td>CD11-1</td>
<td>11400</td>
<td>25</td>
<td>3334</td>
<td>26</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>CD3-9</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition: H1= 20&quot;, W1= 27&quot;, L=24&quot; (Theta1=17°, Theta2=0°)</td>
<td>SD4-2</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sized at Maximum Velocity of 3500 fpm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.57</td>
<td>0.14</td>
<td>0.08</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11a</td>
<td>Duct</td>
<td>CD11-1</td>
<td>24</td>
<td>25</td>
<td>2171</td>
<td>11</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tee, 45° Entry, Main:</td>
<td>SD5-1</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=25, Ds=25, Db=25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.24</td>
<td>0.15</td>
<td>0.04</td>
<td>(0.57 - 0.24) - 0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{Regain (in. wg)} = (p_v - p_o) - \Delta p
\]
Duct Design Fundamentals

DUCT DESIGN BY THE Static Regain METHOD, Section 11
### Static Regain Spreadsheet

<table>
<thead>
<tr>
<th>Air Temperature, °F</th>
<th>69</th>
<th>Relative Humidity, %</th>
<th>0</th>
<th>Elevation, ft</th>
<th>5430</th>
<th>Air Density, lbm/ft³</th>
<th>0.061</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barometric Pressures, psia</td>
<td>12.03</td>
<td>2</td>
<td>Viscosity (μ), lbm/(ft·min)</td>
<td>0.00073245</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Upstream Section</th>
<th>Section</th>
<th>Fitting</th>
<th>ASHRAE Fitting Code</th>
<th>Air Quantity (cfm)</th>
<th>Duct Size (in.)</th>
<th>Velocity (fpm)</th>
<th>Duct Length (ft)</th>
<th>Velocity Pressure, p, (in. wg)</th>
<th>Loss Coefficient, C</th>
<th>Total Pressure Loss (in. wg)</th>
<th>Regain (In. wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawings</td>
<td>DFDB</td>
<td>Drawings</td>
<td>Iteration</td>
<td>DFDB</td>
<td>Drawings</td>
<td>DFDB</td>
<td>DFDB</td>
<td>Σ</td>
<td>Static Regain Calc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2&quot;</td>
<td>Duct</td>
<td>CD11-1</td>
<td>11400</td>
<td>25</td>
<td>3334</td>
<td>26</td>
<td>0.13</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>CD3-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition: H1= 20&quot;, W1= 27&quot;, L=24&quot;, (Theta1=17°, Theta2=0°)</td>
<td>SD4-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sized at Maximum Velocity of 3500 fpm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Section Total

| 2 | 11a | Duct | CD11-1 | 24 | 25 | 2171 | 11 | 0.15 |
| Tee, 45° Entry, Main: | | | | | | | | |
| Dc=25, Ds=25, Db=25 | | | | | | | | |

<p>| 0.24 | 0.15 | 0.04 | (0.57 - 0.24) - 0.08 | 0.06 | 0.27 |</p>
<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>CD11-1</th>
<th>7400</th>
<th>24</th>
<th>2355</th>
<th>11</th>
<th>0.15</th>
<th>0.28</th>
<th>0.15</th>
<th>0.04</th>
<th>(0.57-0.28)-0.06</th>
</tr>
</thead>
<tbody>
<tr>
<td>11b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.08</td>
</tr>
</tbody>
</table>
## Duct Design Fundamentals

**DUCT DESIGN BY THE STATIC REGAIN METHOD**

<table>
<thead>
<tr>
<th>Duct</th>
<th>Duct Type</th>
<th>Dc</th>
<th>Ds</th>
<th>Db</th>
<th>Area</th>
<th>Static Regain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tee, 45° Entry, Main:</td>
<td>SD5-12</td>
<td>25</td>
<td>22</td>
<td>22</td>
<td>7400</td>
<td>0.14</td>
</tr>
<tr>
<td>Dc=25, Ds=22, Db=22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duct</th>
<th>Duct Type</th>
<th>Dc</th>
<th>Ds</th>
<th>Db</th>
<th>Area</th>
<th>Static Regain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tee, 45° Entry, Main:</td>
<td>SD5-12</td>
<td>25</td>
<td>21</td>
<td>21</td>
<td>7400</td>
<td>0.14</td>
</tr>
<tr>
<td>Dc=25, Ds=21, Db=21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.48</td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.11</td>
</tr>
</tbody>
</table>
DUCT DESIGN BY THE Static Regain METHOD, Section 15
<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>CD11-1</th>
<th>3400</th>
<th>22</th>
<th>1288</th>
<th>23</th>
<th>0.02</th>
<th>0.08</th>
<th>0.27</th>
<th>0.02</th>
<th>(0.40 - 0.08) - 0.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>15a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wye, 45° , Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=22, Db=22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>CD11-1</th>
<th>3400</th>
<th>21</th>
<th>1414</th>
<th>23</th>
<th>0.02</th>
<th>0.10</th>
<th>0.24</th>
<th>0.02</th>
<th>(0.40 - 0.10) - 0.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>15b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wye, 45° , Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=21, Db=21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>CD11-1</th>
<th>3400</th>
<th>20</th>
<th>1558</th>
<th>23</th>
<th>0.03</th>
<th>0.12</th>
<th>0.19</th>
<th>0.02</th>
<th>(0.40 - 0.12) - 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>15c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wye, 45° , Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=20, Db=20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duct</td>
<td>CD11-1</td>
<td>3400</td>
<td>19</td>
<td>1727</td>
<td>23</td>
<td>0.17</td>
<td>0.15</td>
<td>0.17</td>
<td>0.03</td>
<td>(0.40 - 0.15) - 0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>------</td>
<td>----</td>
<td>------</td>
<td>----</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>----------------------</td>
<td>------</td>
</tr>
<tr>
<td>Wye, 45° , Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=19, Db=19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Duct</td>
<td>CD11-1</td>
<td>3400</td>
<td>18</td>
<td>1924</td>
<td>23</td>
<td>0.16</td>
<td>0.19</td>
<td>0.16</td>
<td>0.03</td>
<td>(0.40-0.19)-0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>------</td>
<td>----</td>
<td>------</td>
<td>----</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>---------------------</td>
<td>------</td>
</tr>
<tr>
<td>Wye, 45° , Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=18, Db=18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.08</td>
</tr>
<tr>
<td>Duct</td>
<td>CD11-1</td>
<td>3400</td>
<td>17</td>
<td>2157</td>
<td>23</td>
<td>0.14</td>
<td>0.24</td>
<td>0.14</td>
<td>0.03</td>
<td>(0.40-0.24)-0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>------</td>
<td>----</td>
<td>------</td>
<td>----</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>---------------------</td>
<td>------</td>
</tr>
<tr>
<td>Wye, 45° y, Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=17, Db=17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.10</td>
</tr>
</tbody>
</table>
# Duct Design Fundamentals

**DUCT DESIGN BY THE STATIC REGAIN METHOD**

<table>
<thead>
<tr>
<th>11</th>
<th>Duct</th>
<th>CD11-1</th>
<th>3400</th>
<th>16</th>
<th>2435</th>
<th>23</th>
<th>0.09</th>
</tr>
</thead>
<tbody>
<tr>
<td>15g</td>
<td>Wye, 45° y, Main:</td>
<td>SD5-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dc=22, Ds=16, Db=16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Section Total</td>
<td>0.30</td>
<td>0.14</td>
<td>0.04</td>
<td></td>
<td>(0.40-0.30)-0.13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>0.13</th>
<th>-0.03</th>
</tr>
</thead>
</table>
### Duct Design Fundamentals

**DUCT DESIGN BY THE STATIC REGAIN METHOD**

<table>
<thead>
<tr>
<th>Section</th>
<th>Duct</th>
<th>CD/SD</th>
<th>Area</th>
<th>Static Regain</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Duct</td>
<td>CD11-1</td>
<td>3400</td>
<td>1.17</td>
<td>15°</td>
</tr>
<tr>
<td>Wye, 45°, Main:</td>
<td>SD5-1</td>
<td>18</td>
<td>1924</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=18, Db=18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.19</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03</td>
<td>(0.40 - 0.19) - 0.08</td>
</tr>
<tr>
<td>11 15°</td>
<td>Duct</td>
<td>CD11-1</td>
<td>3400</td>
<td>1.17</td>
<td>15°</td>
</tr>
<tr>
<td>Wye, 45°, Main:</td>
<td>SD5-1</td>
<td>18</td>
<td>1924</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=18, Db=18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.19</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03</td>
<td>(0.40 - 0.19) - 0.08</td>
</tr>
<tr>
<td>11 15°</td>
<td>Duct</td>
<td>CD11-1</td>
<td>3400</td>
<td>1.17</td>
<td>15°</td>
</tr>
<tr>
<td>Wye, 45°, Main:</td>
<td>SD5-1</td>
<td>18</td>
<td>2157</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Dc=22, Ds=17, Db=17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section Total</td>
<td></td>
<td></td>
<td></td>
<td>0.24</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03</td>
<td>(0.40 - 0.24) - 0.10</td>
</tr>
</tbody>
</table>
## Duct Design Fundamentals

### DUCT DESIGN BY THE STATIC REGAIN METHOD

#### Summary of Example

<table>
<thead>
<tr>
<th>Section</th>
<th>P₁ (in wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.37</td>
</tr>
<tr>
<td>4 &amp; 5</td>
<td>0.61</td>
</tr>
<tr>
<td>6</td>
<td>0.04</td>
</tr>
<tr>
<td>7</td>
<td>0.53</td>
</tr>
<tr>
<td>8</td>
<td>0.03</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>0.48</td>
</tr>
<tr>
<td>11</td>
<td>0.10</td>
</tr>
<tr>
<td>12</td>
<td>0.26</td>
</tr>
<tr>
<td>13 &amp; 14</td>
<td>0.54</td>
</tr>
<tr>
<td>15</td>
<td>0.10</td>
</tr>
<tr>
<td>16</td>
<td>0.11</td>
</tr>
<tr>
<td>17 &amp; 18</td>
<td>0.56</td>
</tr>
<tr>
<td>19</td>
<td>0.15</td>
</tr>
<tr>
<td>20</td>
<td>0.49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path A/B:</th>
<th>Path C:</th>
<th>Path D/E:</th>
<th>Path F/G:</th>
<th>Path H/I:</th>
<th>Path J:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>TP, in wg</td>
<td>Section</td>
<td>TP, in wg</td>
<td>Section</td>
<td>TP, in wg</td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
<td>1</td>
<td>0.0</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.19</td>
<td>2</td>
<td>0.19</td>
<td>2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.37</td>
<td>3</td>
<td>0.37</td>
<td>3</td>
<td>0.37</td>
</tr>
<tr>
<td>4/5</td>
<td>0.61</td>
<td>6</td>
<td>0.04</td>
<td>6</td>
<td>0.04</td>
</tr>
<tr>
<td>Total</td>
<td>1.16</td>
<td>7</td>
<td>0.53</td>
<td>8</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>1.12</td>
<td>9/10</td>
<td>0.48</td>
<td>Total</td>
<td>1.08</td>
</tr>
<tr>
<td>Total</td>
<td>1.09</td>
<td>Total</td>
<td>1.06</td>
<td>Total</td>
<td>1.04</td>
</tr>
</tbody>
</table>

#### Diagram
# Duct Design Fundamentals

**DUCT DESIGN BY THE STATIC REGAIN METHOD**

**UN-BALANCE**

<table>
<thead>
<tr>
<th>Path</th>
<th>TP (in. wg)</th>
<th>Excess Pressure (in. wg)</th>
<th>% Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B (4/5)</td>
<td>1.16</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>C (7)</td>
<td>1.12</td>
<td>0.04</td>
<td>4</td>
</tr>
<tr>
<td>D/E (9/10)</td>
<td>1.09</td>
<td>0.07</td>
<td>6</td>
</tr>
<tr>
<td>F/G (13/14)</td>
<td>1.08</td>
<td>0.08</td>
<td>7</td>
</tr>
<tr>
<td>H/I (17/18)</td>
<td>1.06</td>
<td>0.11</td>
<td>9</td>
</tr>
<tr>
<td>J (20)</td>
<td>1.04</td>
<td>0.13</td>
<td>11</td>
</tr>
</tbody>
</table>
## Duct Design Fundamentals

**Duct Design by the Static Regain Method**

Comparison with Equal Friction

<table>
<thead>
<tr>
<th>Path</th>
<th>Static Regain</th>
<th>Equal Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TP (in. wg)</td>
<td>Excess Pressure (in. wg)</td>
</tr>
<tr>
<td>A/B (4/5)</td>
<td>1.16</td>
<td>0.00</td>
</tr>
<tr>
<td>C (7)</td>
<td>1.12</td>
<td>0.04</td>
</tr>
<tr>
<td>D/E (9/10)</td>
<td>1.09</td>
<td>0.07</td>
</tr>
<tr>
<td>F/G (13/14)</td>
<td>1.08</td>
<td>0.08</td>
</tr>
<tr>
<td>H/I (17/18)</td>
<td>1.06</td>
<td>0.11</td>
</tr>
<tr>
<td>J (20)</td>
<td>1.04</td>
<td>0.13</td>
</tr>
</tbody>
</table>
## Duct Design Fundamentals

### DUCT DESIGN BY THE STATIC REGAIN METHOD

Comparison with Equal Friction

<table>
<thead>
<tr>
<th>Section</th>
<th>Static Regain Design</th>
<th>Equal Friction Design</th>
<th>Larger</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pt (in wg)</td>
<td>Size (inch)</td>
<td>Pt (in wg)</td>
<td>Size (inch)</td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
<td>20 x 27 to 25 Transition</td>
<td>0.00</td>
<td>20 x 27 to 25 Transition</td>
</tr>
<tr>
<td>2</td>
<td>0.19</td>
<td>25</td>
<td>0.19</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>0.37</td>
<td>20</td>
<td>0.42</td>
<td>17</td>
</tr>
<tr>
<td>4 &amp; 5</td>
<td>0.61</td>
<td>10</td>
<td>0.67</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>0.04</td>
<td>16</td>
<td>0.09</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>0.53</td>
<td>9</td>
<td>0.57</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>0.03</td>
<td>14</td>
<td>0.08</td>
<td>11</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>0.48</td>
<td>8</td>
<td>0.52</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>0.10</td>
<td>22</td>
<td>0.12</td>
<td>21</td>
</tr>
<tr>
<td>12</td>
<td>0.26</td>
<td>21</td>
<td>0.33</td>
<td>17</td>
</tr>
<tr>
<td>13 &amp; 14</td>
<td>0.54</td>
<td>14</td>
<td>0.61</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>0.10</td>
<td>17</td>
<td>0.13</td>
<td>16</td>
</tr>
<tr>
<td>16</td>
<td>0.11</td>
<td>17</td>
<td>0.15</td>
<td>15</td>
</tr>
<tr>
<td>17 &amp; 18</td>
<td>0.56</td>
<td>12</td>
<td>0.61</td>
<td>12</td>
</tr>
<tr>
<td>19</td>
<td>0.15</td>
<td>9</td>
<td>0.25</td>
<td>8</td>
</tr>
<tr>
<td>20</td>
<td>0.49</td>
<td>8</td>
<td>0.46</td>
<td>8</td>
</tr>
</tbody>
</table>
Step 10__ Analyze the design to improve balancing and reduce material cost.

Step 11__ Select fan according to proper guidelines – See Section 4.8, page 4.6 of the SMACNA HVAC System Duct Design Manual and AMCA Manuals

Step 12__ Analyze the design to make sure it meets the acoustical requirements. See Chapter 10 Designing For Sound and Vibration of the SMACNA HVAC System Duct Design Manual or the SMACNA Sound and Vibration Manual, First Edition – December 2004

Step 13__ Select materials that minimize cost and meet the SMACNA Duct Construction Standards Metal and Flexible, Third Edition – 2005

Step 14__ Analyze the life-cycle cost of the design

Step 15__ Commission the design to make sure it meets the OPR. Reference the SMACNA HVAC Commissioning Manual, Second Edition - 2013
Duct Design Fundamentals
Acoustics
Figure 10-4 Frequency Ranges of the Most Likely Sources of Acoustical Complaints
**Duct Design Fundamentals**

**Acoustical Analysis Overview**

**Figure 10-5** Frequency at which different types of mechanical equipment generally control sound spectra.

- Diffusers
- Reciprocating & Centrifugal Chillers
- VAV Units
- Fans & Pumps
- Fan Instability, Air Turbulence Rumble, & Structure Borne Vibration
- Throb
- Rumble
- Roar
- Whistle
- Hiss

Octave Band Center Frequency - Hz

8  16  31.5  63  125  250  500  1K  2K  4K  8K
### Sound Source
- Circulating fans, grilles, registers, diffusers, unitary equipment in room
- Induction coil and fan-powered variable air-volume mixing units
- Unitary equipment located outside of room served, remotely located air-handling equipment, such as, fans, blowers, dampers, duct fittings and air washers
- Compressors, pumps, and other reciprocating and rotating equipment (excluding air-handling equipment)
- Cooling towers; air-cooled condensers
- Exhaust fans; window air conditioners
- Sound transmission between rooms

### Transmission Paths
1. Direct sound radiated from sound source to ear
   - Reflected sound from floors, walls, and ceilings
2. Air- and structure-borne sound radiated from casings and through walls of ducts and plenums is transmitted through walls and ceiling into room
3. Airborne sound radiated through supply and return air ducts to diffusers in room and then to listener by Path 1
4. Noise is transmitted through equipment room walls and floors to adjacent rooms
5. Building structure transmits vibration to adjacent walls and ceilings, from which it radiates as sound into a room by Path 1
6. Vibration transmission along pipes and duct walls
7. Noise radiated to outside enters room windows
8. Inside noise follows Path 1
9. Noise transmitted to an air diffuser in a room into duct and out through an air diffuser in another
10. Sound transmission through, over, and around

### Recommended Noise Reduction Methods
- Direct sound can be controlled only by selecting quiet
- Reflected sound is controlled by adding sound absorption to the room and to equipment location.
- Design duct and fittings for low turbulence; locate high velocity ducts in non-critical areas; isolate ducts and sound plenums from structure with neoprene or spring hangers.
- Select fans for minimum sound power; use ducts lined with sound-absorbing material; use duct silencers or sound plenums in supply and return air ducts.
- Locate equipment rooms away from critical areas; use masonry blocks or concrete for equipment room walls and floor.
- Mount all machines on properly designed vibration isolators; masonry blocks or concrete for equipment room walls and floor.
- Isolate pipe and ducts from structure with neoprene or spring hangers; install flexible connectors between pipes, ducts, and vibrating machines.
- Locate equipment away from critical areas; use barriers and covers to interrupt noise paths; select quiet equipment.
- Select quiet equipment.
- Design and install duct attenuation to match transmission loss of wall between rooms.
- Extend partition to ceiling slab and tightly seal all around; seal all pipe, conduit, duct, and other partition penetrations.

**Table 10-1 Sound Sources, Transmission Paths, and Recommended Noise Reduction Methods**
Duct Design Fundamentals

Acoustical Analysis Overview

Page 10.9

Figure 10-6 Dissipative Passive Duct Silencers

(a) Rectangular Dissipative Duct Silencer
(b) Circular Dissipative Duct Silencer
(c) Rectangular Dissipative Elbow Duct Silencer
FIGURE 10–9 BREAKOUT AND BREAK-IN OF SOUND IN DUCTS

(a) Duct Sound Breakout

(b) Duct Sound Breakin
Duct Design Fundamentals

Step 13: Select materials that minimize cost and meet the SMACNA Duct Construction Standards Metal and Flexible, Third Edition – 2005

Step 14: Analyze the life-cycle cost of the design

Step 15: Commission the design to make sure it meets the OPR. Reference the SMACNA HVAC Commissioning Manual, Second Edition - 2013
Duct Design Fundamentals
Commissioning

HVAC SYSTEMS COMMISSIONING MANUAL

SECOND EDITION 2013

SHEET METAL AND AIR CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC.
4201 Lafayette Center Drive
Chantilly, VA 20151-1219
www.smacna.org
Duct Design Fundamentals
Commissioning

- Commissioning may be defined as: “the process of advancing systems from a state of static physical completion to a state of full, demonstrated, and documented working order, according to the owner’s project requirements and the design requirements.

- The owner’s operating staff are instructed in correct systems operation and maintenance.

- The full commissioning process should be planned and documented. Planning should begin as early as possible to ensure the owner’s project requirements are understood and suitable quality assurance strategies are utilized.

- The quality assurance process should be documented to provide an auditable record of the process.
Examples of Equipment Included:

• Hot water and steam boilers; with atmospheric or power burners; gas, oil, or combination gas/oil fired.
• Chillers; with reciprocating, scroll, screw, or centrifugal compressors; air-or water-cooled; with or without condensers; and including heat recovery models.
• Cooling towers, closed-circuit heat rejectors, and both air cooled and evaporative condensers.
• Hot water, chilled water, and condensing water pumps associated with the preceding.
• Constant volume, single zone air systems (including all components such as fans, coils, furnaces, condensing units, dampers, and controls, as applicable).
• Condensing boilers.
• Primary and secondary piping systems.
• Variable flow piping or pumping systems.
• Variable Air Volume (VAV) Systems (including various components such as terminal units and Variable Frequency Drives)
Duct Design Fundamentals

Commissioning

Pre-Design Phase
- Develop owner's goals
- Develop basis of design

Occupancy Phase
- Monitor system performance
- Provide lessons learned to all stakeholders to take to the next project
- Operations and Maintenance

Design Phase
- Review drawings for functionality, energy efficiency, operability
- Include construction-phase commissioning requirements in the contract documents

Acceptance Phase
- Verify functional performance
- Conduct owner training

Construction Phase
- Confirm proper installation
- Verify accessibility for maintenance
Chapter 6. Level 1, Basic Commissioning, The commissioning agent’s first task is to pull together:

- The Owner’s Project Requirements
- Statement of design intent
- Schedule information
- List of equipment and systems needing to be commissioned,
- List of sub trades, suppliers, and other contractors (most commonly the electrical contractor) who will be involved in the commissioning process, and
- All submittal data and controls sequence descriptions needed to prepare commissioning checklists.
Chapter 6 Level 1, Basic Commissioning - Also includes

6.1 OVERVIEW ................................................................. 6.1
6.2 PREPARATIONS .............................................................. 6.1
6.3 COMMISSIONING PLAN .................................................. 6.2
6.4 PRESTART CHECKS ....................................................... 6.2
6.5 FUNCTIONAL PERFORMANCE TESTS ................................ 6.3
6.6 OPERATIONS INSTRUCTION AND DEMONSTRATION ........ 6.3
6.7 SUMMARY ................................................................... 6.4

All the checks and tests are carried out to suit the schedule requirements of the project.