The Impact of Duct Fitting Selection

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- Joined AMCA in February 2019
- Responsible for development of AMCA's education programs; staff liaison for the Education & Training Subcommittee
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Senior Project Manager, SMACNA

- Over 35 years experience in HVAC ductwork design and manufacturing
- Bachelor’s & master's degrees in mechanical engineering, and masters’ degree in business
- Member of ASHRAE and SPIDA technical committees on duct design; recently named ASHRAE Distinguished Lecturer

SMACNA

The Impact of Duct Fitting Selection

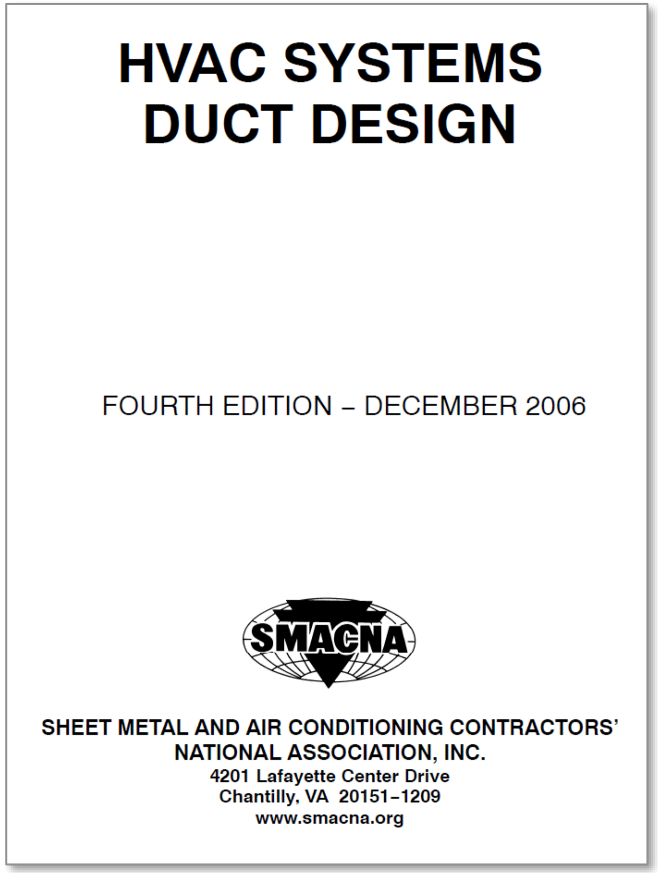
Purpose and Learning Objectives

The purpose of this presentation to help duct system designers learn how to calculate friction and dynamic losses as well as understand how the velocity and type of fitting impacts the design.

At the end of this presentation participants will be able to:

1. Explain how friction loss is calculated and how velocity affects the friction loss.
2. Explain fitting loss coefficients and how fitting losses are calculated.
3. Explain how the selection of a fitting affects the design leg of the duct system.
4. Describe how the size of ductwork or fitting selection can affect the system balance.

SMACNA Manual


HVAC SYSTEMS
DUCT DESIGN

FOURTH EDITION – DECEMBER 2006

SHEET METAL AND AIR CONDITIONING CONTRACTORS'
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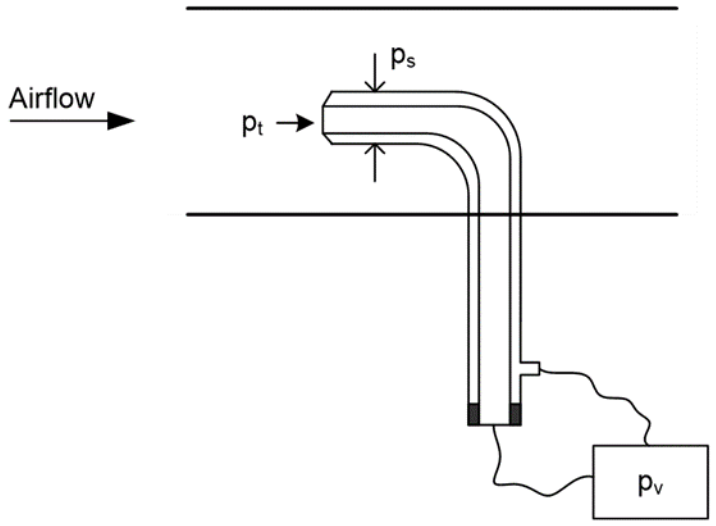
Pressure

$$p_t = p_s + p_v$$



Pitot-static tube

Pressure - Changes in Pressure

$$\Delta p_t = \Delta p_s + \Delta p_v$$

Derived from the Bernoulli Equation:

$$p_{s1} + \frac{\rho_1 V_1^2}{2g_c} + \frac{g}{g_c}\rho_1 z_1 = p_{s2} + \frac{\rho_2 V_2^2}{2g_c} + \frac{g}{g_c}\rho_2 z_2 + \Delta p_{t,1-2}$$

Pressure - Velocity Pressure (p_v)

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

Where:

p_v = velocity pressure, in. of water
V = velocity, ft/min
ρ = density, lb_m/ft^3

Pressure - Velocity Pressure (p_v)

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

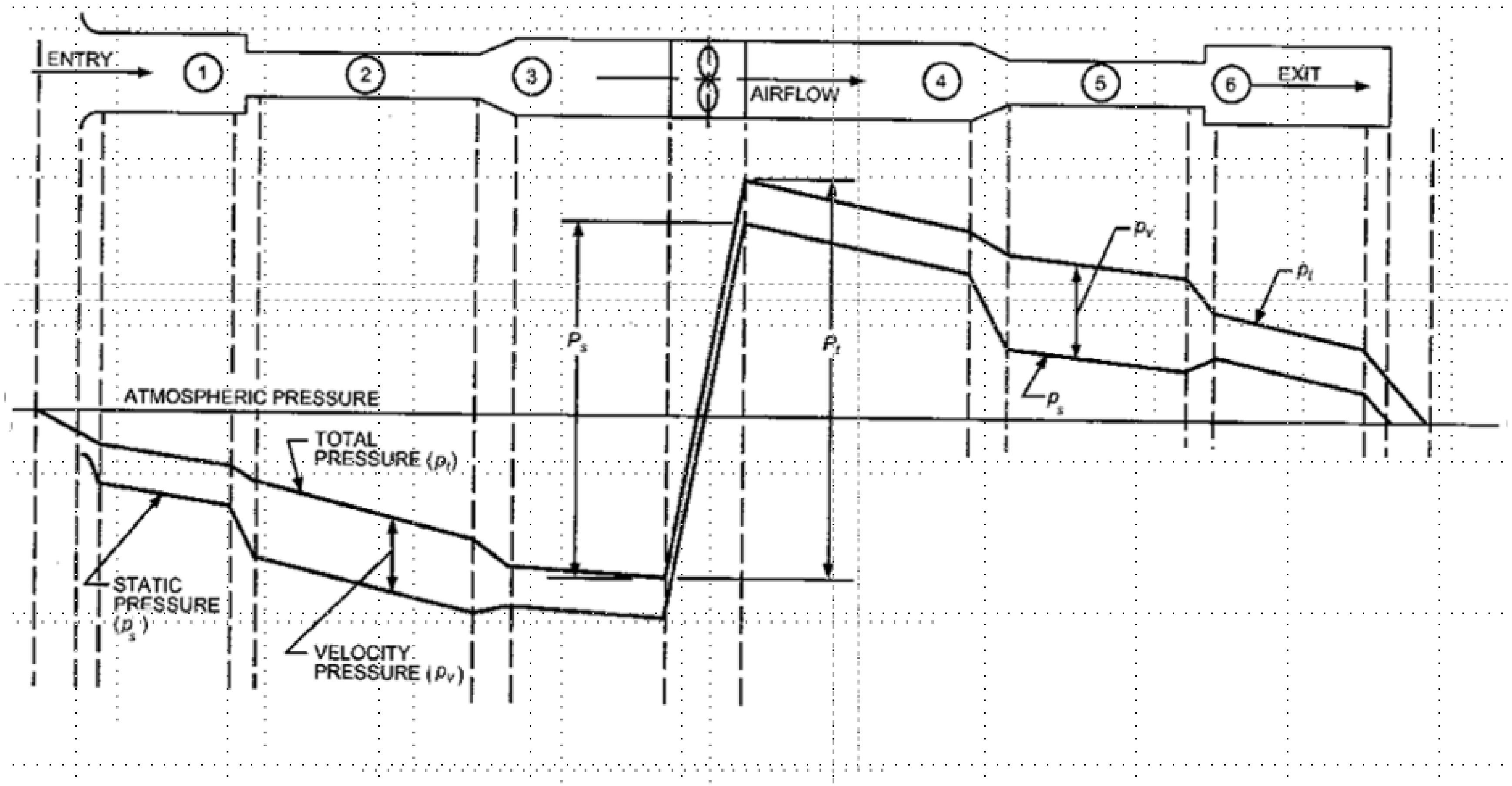
Where:

p_v = velocity pressure, in. of water
V = velocity, ft/min
ρ = density, lb_m/ft^3

$$p_v = \left(\frac{V}{4005}\right)^2$$ *for standard air ρ = 0.075* **lb_m/ft^3**

Pressure

Pressure Changes During Flow in Ducts - Graphically



Pressure Losses

- **Types**
  - Friction Losses
  - Dynamic Losses

Pressure Losses

Darcy-Weisbach Equation

$$\Delta p_t = \left(\frac{f\,L}{D_h} p_v\right) + \sum(C) * p_v$$

Where:

f = friction factor

L = Length, ft

D_h = hydraulic diameter, ft

Pressure Losses

Friction – Darcy Equation

The left-hand side of the Darcy-Weisbach Equation is the Darcy Equation:

$$\Delta p_f = \left(\frac{f\ L}{D_h} p_v\right)$$

Pressure Losses

Friction – Colebrook Equation

$$\frac{1}{\sqrt{f}} = -2\, log\left(\frac{\varepsilon}{3.7\, Dh} + \frac{2.51}{Re\sqrt{f}}\right)$$

The Colebrook equation was developed to calculate the friction factor, *f*; requires you to also know the Reynolds Number, *Re*, and the absolute roughness, ε *(ft)*, which is determined experimentally.

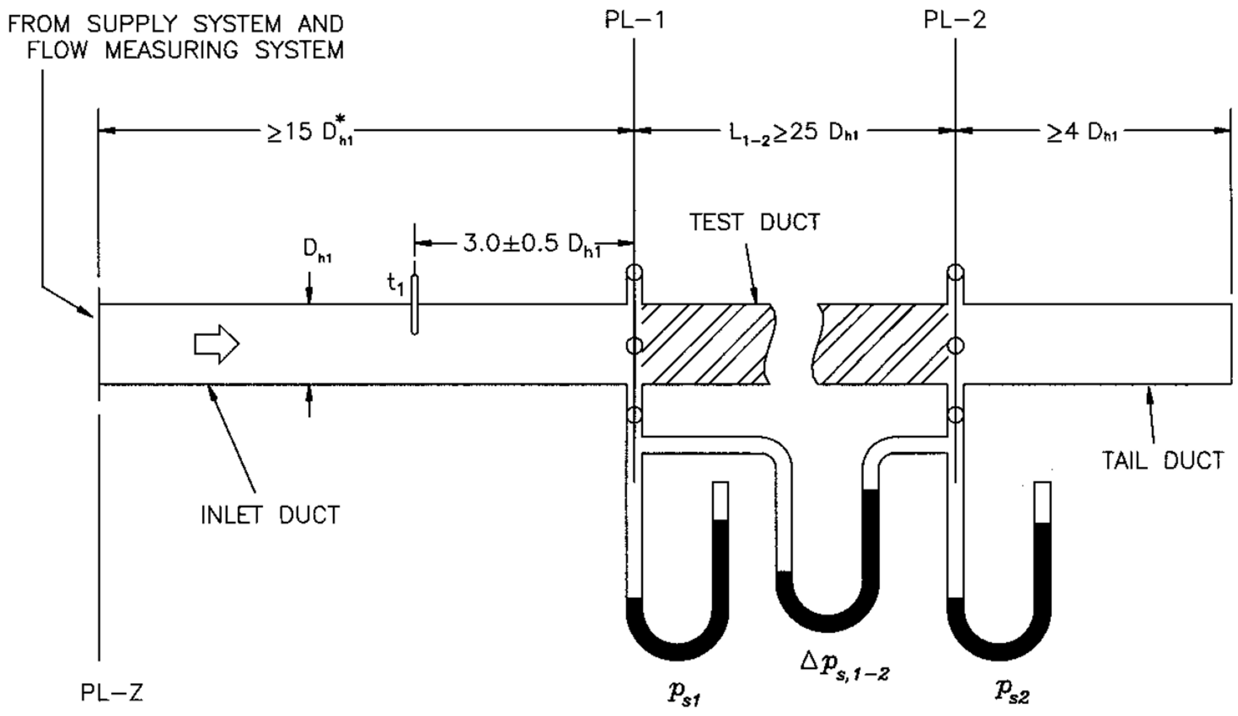
Pressure Losses - Friction

Friction Losses are a function of the length, hydraulic diameter, the roughness of the material and the velocity pressure. Higher friction losses are caused by:

- Rougher Material (including joints)
- Longer Lengths
- Larger Velocity Pressures
- Smaller Diameters

Pressure Losses

Friction – How Friction and Roughness Factors are determined



$$\Delta p_{f,\,1-2} = \frac{\Delta p_{s,\,1-2}}{L_{1-2}}\,.$$

Pressure Losses

Friction – Colebrook Equation

Duct Material	Roughness Category	Absolute Roughness ε_1	
		ft	mm
Uncoated carbon steel, clean (Moody 1944) (0.00015 ft) (0.05 mm) PVC plastic pipe (Swim 1982) (0.0003 to 0.00015 ft) (0.01 to 0.05 mm) Aluminum (Hutchinson 1953) (0.00015 to 0.0002 ft) (0.04 to 0.06 mm)	Smooth	0.0001	0.03
Galvanized steel, longitudinal seams, 4 ft (1200 mm) joints (Griggs 1987) (0.00016 to 0.00032 ft) (0.05 to 0.1 mm)	Medium Smooth	0.0003	0.09
Galvanized steel, spiral seam with 1, 2, and 3ribs, 12 ft (3600 mm) joints (Jones 1979, Griggs 1987) (0.00018 to 0.00038 ft) (0.05 to 0.12 mm)	(New Duct Friction Loss Chart)		
Hot-dipped galvanized steel, longitudinal seams, 2.5ft (760 mm) joints (Wright 1945) (0.0005 ft) (0.15 mm)	Old Average	0.0005	0.15
Fibrous glass duct, rigid Fibrous glass duct liner, air side with facing material (Swim 1978) (0.005 ft) (1.5 mm)	Medium Rough	0.003	0.9
Fibrous glass duct liner, air side spray coated (Swim 1978) (0.015 ft) (4.5 mm) Flexible duct, metallic, (0.004 to 0.007 ft (1.2 to 2.1 mm) when fully extended) Flexible duct, all types of fabric and wire (0.0035 to 0.015 ft (1.0 to 4.6 mm) when fully extended) Concrete (Moody 1944) (0.001 to 0.01 ft) (0.3 to 3.0 mm)	Rough	0.01	3.0

Table A–1 Duct Material Roughness Factors

HVAC SYSTEMS DUCT Table A-1, pg A.4.

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 (ε = 0.0003 ft) and lined duct (ε = 0.003 ft)

Pressure Losses – Friction

Comparison of Different Velocities and Materials

Solution		
L =	**100**	**ft**
Area =	**5.33**	**ft^2**
P =	**9.33**	**ft**
D_h =	**2.29**	**ft**
$\rho = 0.075\ lb_m/ft^3$		**Standard Conditions**

			Standard Galvanized ($\varepsilon = 0.0003$ ft)		Lined Duct, Corrugated Duct ($\varepsilon = 0.003$ ft)	
Velocity (fpm)	Velocity Pressure p_v (inch water)	Q = AV Flow Rate (cfm)	Friction Factor, *f*	Δp_f Friction Loss (inch water)	Friction Factor, *f*	Δp_f Friction Loss (inch water)
1000	0.06	5333	0.0163	0.04	0.0220	0.06
2000	0.25	10667	0.0148	0.16	0.0215	0.23
3000	0.56	16000	0.0142	0.35	0.0213	0.52
4000	0.99	21333	0.0139	0.60	0.0212	0.92

Pressure Losses

Dynamic

The right-hand side of the Darcy-Weisbach Equation is the Weisbach Equation

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

Pressure Losses

Dynamic - How Loss Coefficients are Determined

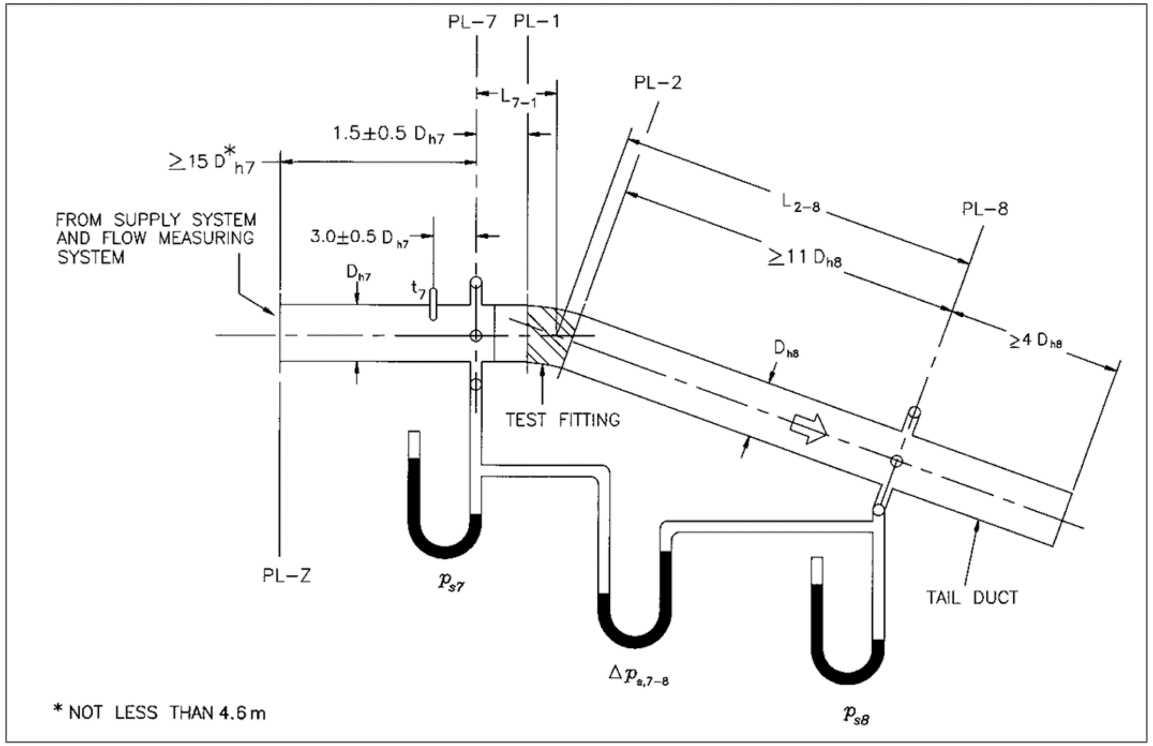
$$\Delta p_{t,fitting} = C \ * pv$$

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

Pressure Losses

Dynamic – How Loss Coefficients are Determined

$$\Delta p_{t,fitting} = C * pv \quad , \quad C = \frac{\Delta p_{t,fitting}}{p_v}$$



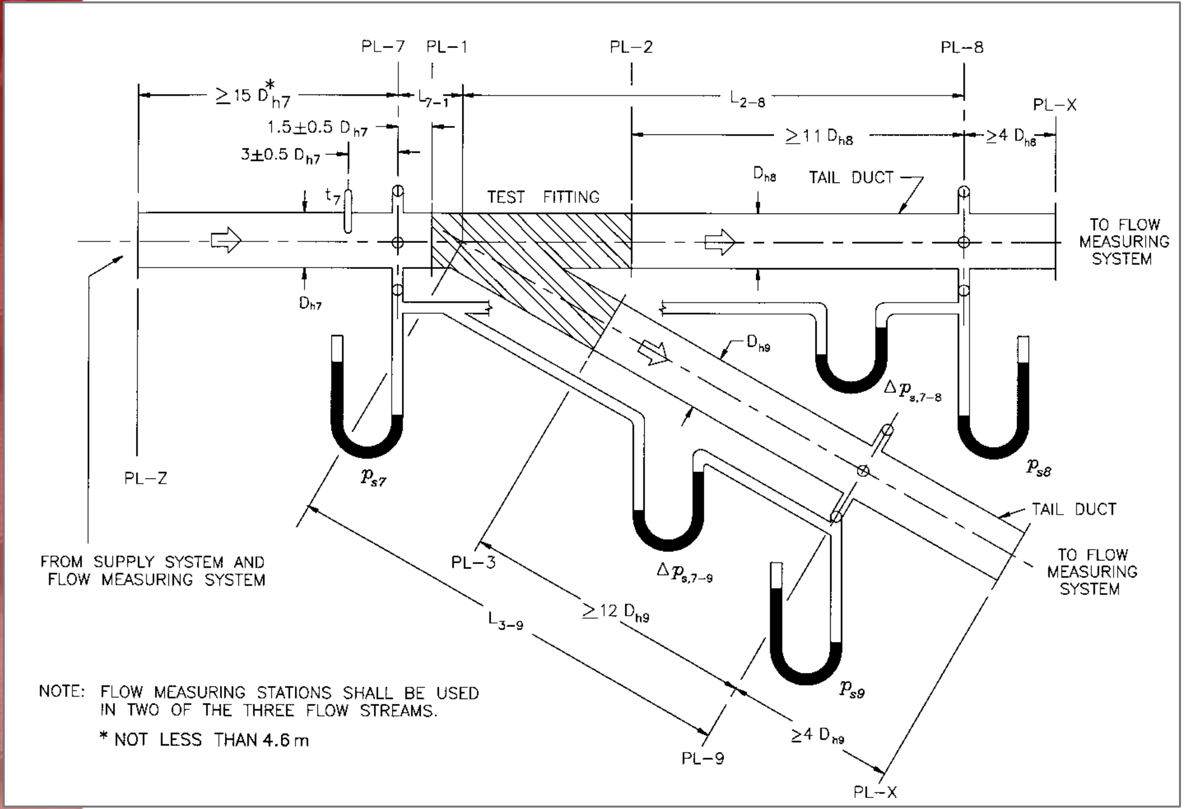
$$\Delta p_{t,1\text{-}2} = \Delta p_{s,7\text{-}8} + (p_{v7} - p_{v8}) - (L_{7\text{-}1}\Delta p_{f,7\text{-}1} + L_{2\text{-}8}\Delta p_{f,2\text{-}8})$$

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

Pressure Losses

Dynamic - How Loss Coefficients are Determined – *Diverging Fittings*

$L_{7\text{-}1}$, $L_{2\text{-}8}$ and $L_{3\text{-}9}$
are measured to the centerline of the fitting



Main: $\Delta p_{t,1\text{-}2} = \Delta p_{s,7\text{-}8} + (p_{v7} - p_{v8}) - (L_{7\text{-}1}\Delta p_{f,7\text{-}1} + L_{2\text{-}8}\Delta p_{f,2\text{-}8})$

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

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

$$C_b = \frac{\Delta p_{t,1-3}}{p_{v9}}$$

Pressure Losses

Dynamic - Loss Coefficient Tables

- Loss coefficients are often published in table form or equations. See tables A-7 to A-15 in the SMACNA 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.

Pressure Losses

Dynamic - Loss Coefficient Tables

***Example**: 10" Dia, 90° Smooth Radius Elbow, R/D = 1.5. Airflow is 1000 acfm. Elevation is 5000 ft.*

Solution:

$\mathbf{A_d} = (\pi d^2 / 4)/144 = (\pi \times 10^2/4)/144 = 0.545\ ft^2$

$V = \frac{Q}{A_d} = 1000/0.545 = 1834\ fpm$

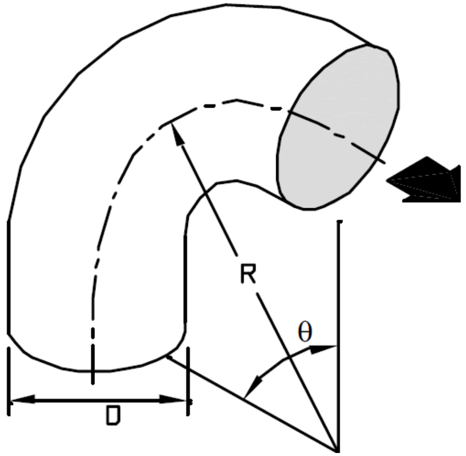
$$p_v = \left(\frac{V}{4005}\right)^2 = \left(\frac{1834}{4005}\right)^2 = 0.21 \text{ in wg.}$$

Pressure Losses

Dynamic - Loss Coefficient Tables

***Example**: 10" Dia, 90° Smooth Radius Elbow, R/D = 1.5. Airflow is 1000 acfm. Elevation is 5000 ft.*

A. ELBOW, SMOOTH RADIUS (DIE STAMPED), ROUND



Coefficients for 90° Elbows (*See* Note 1)						
R/D	0.5	0.75	1.0	1.5	2.0	2.5
C	0.71	0.33	0.22	0.15	0.13	0.12

Note 1: For angles other than 90° multiply by the following factors:											
θ	0°	20°	30°	45°	60°	75°	90°	110°	130°	150°	180°
K	0	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

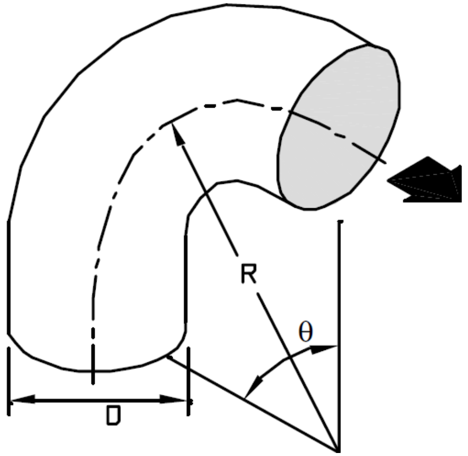
Table A-7A, page A.15

Pressure Losses

Dynamic - Loss Coefficient Tables

***Example**: 10" Dia, 90° Smooth Radius Elbow, R/D = 1.5. Airflow is 1000 acfm. Elevation is 5000 ft.*

A. ELBOW, SMOOTH RADIUS (DIE STAMPED), ROUND



Coefficients for 90° Elbows (*See* Note 1)						
R/D	0.5	0.75	1.0	1.5	2.0	2.5
C	0.71	0.33	0.22	0.15	0.13	0.12

Note 1: For angles other than 90° multiply by the following factors:											
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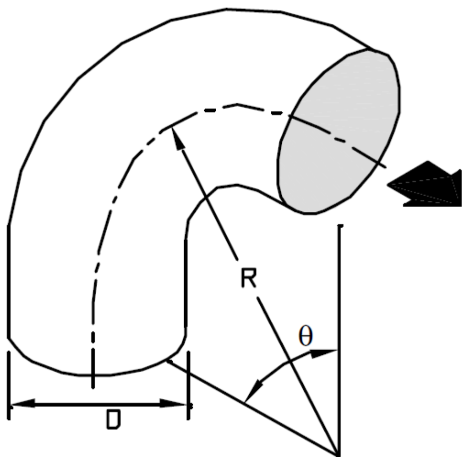
Table A-7A, page A.15

Pressure Losses

Dynamic - Loss Coefficient Tables

***Example**: 10” Dia, 90° Smooth Radius Elbow, R/D = 1.5. Airflow is 1000 acfm. Elevation is 5000 ft.*

A. ELBOW, SMOOTH RADIUS (DIE STAMPED), ROUND



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C	0.71	0.33	0.22	0.15	0.13	0.12

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θ	0°	20°	30°	45°	60°	75°	90°	110°	130°	150°	180°
K	0	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

Table A-7A, page A.15

Pressure Losses

Dynamic - Loss Coefficient Correction Factors

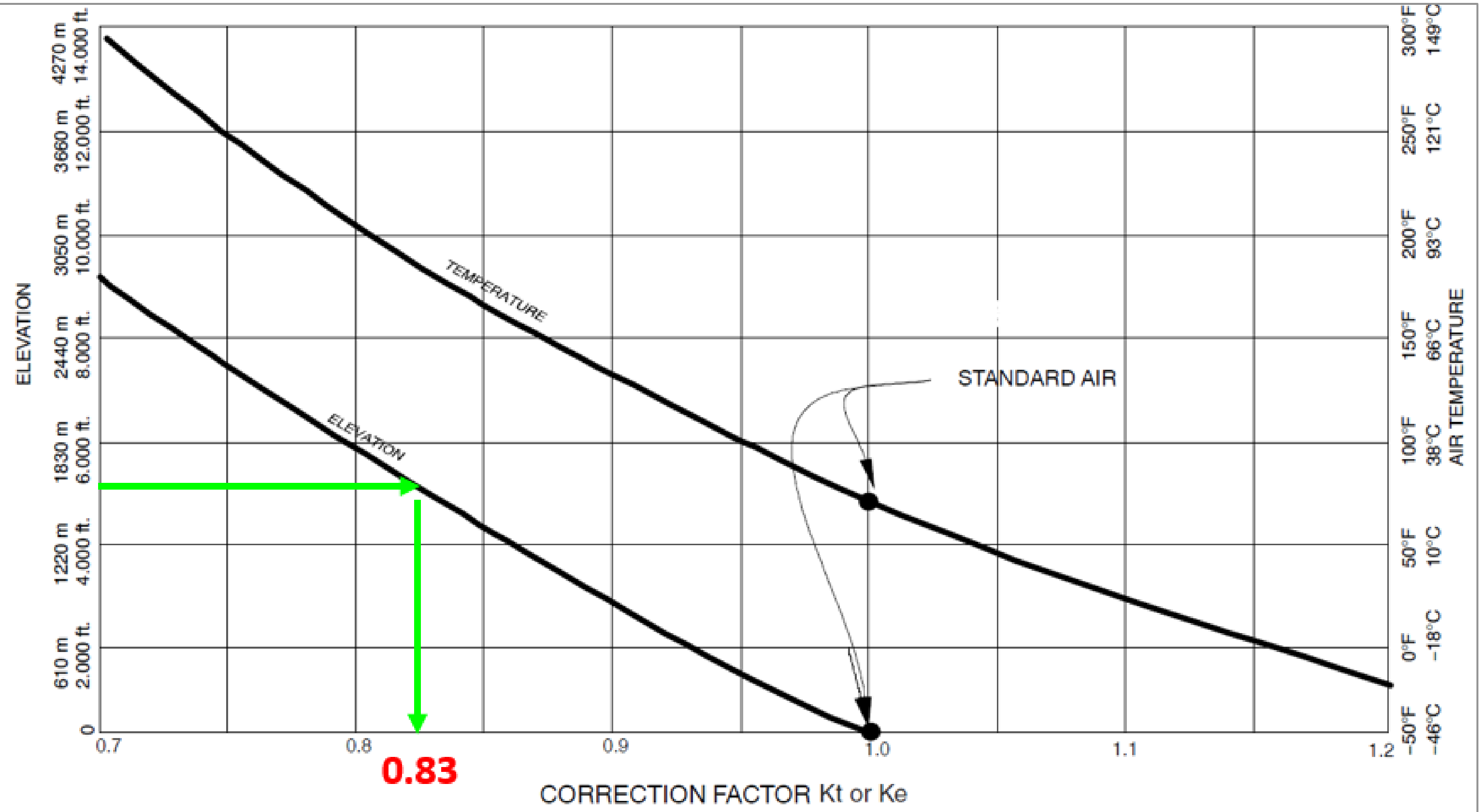


FIGURE A–4 AIR DENSITY FRICTION CHART CORRECTION FACTORS

Pressure Losses

Dynamic - Pressure Loss for the Elbow

$\Delta p_t = C \times p_v \times Ke$

$\Delta p_t = 0.15 \times 0.21 \times 0.83 = 0.03$ inch of water

Pressure Losses

Dynamic - Loss Coefficient Tables

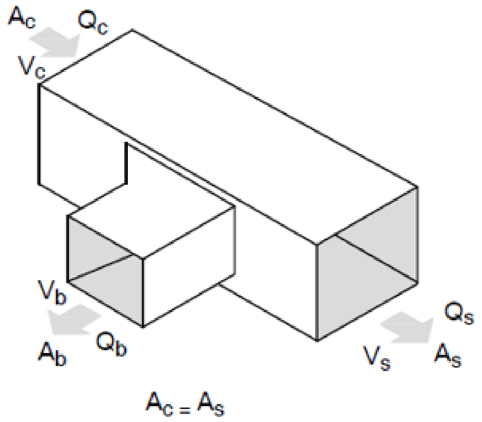
Example: *Tee, 45°, 10” x 10” Rectangular Main and 7” x 7” Rectangular Branch. Airflow is 1000 cfm in Main and 500 cfm in Branch.*

Pressure Losses

Dynamic - Loss Coefficient Tables

***Example:** Tee, 45°, 10” x 10” Rectangular Main and 7” x 7” Rectangular Branch. Airflow is 1000 cfm in Main and 500 cfm in Branch.*

N. TEE, 45° RECTANGULAR MAIN AND BRANCH



V_b/V_c	Branch, Coefficient C (*See* Note 8)								
	Q_b/Q_c								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.2	0.91								
0.4	0.81	0.79							
0.6	0.77	0.72	0.70						
0.8	0.78	0.73	0.69	0.66					
1.0	0.78	0.98	0.85	0.79	0.74				
1.2	0.90	1.11	1.16	1.23	1.03	0.86			
1.4	1.19	1.22	1.26	1.29	1.54	1.25	0.92		
1.6	1.35	1.42	1.55	1.59	1.63	1.50	1.31	1.09	
1.8	1.44	1.50	1.75	1.74	1.72	2.24	1.63	1.40	1.17

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 × V_p

Table A–11 Loss Coefficients, Diverging Junctions (Tees, Wyes) (Continued)

Pressure Losses

Dynamic - Loss Coefficient Tables

Example: *Tee, 45°, 10" x 10" Rectangular Main and 7" x 7" Rectangular Branch.* ***Airflow is 1000 cfm in Main and 500 cfm in Branch.***

Area Main, A_c = (10 x 10) /144 = 0.69 ft^2

Area Branch, A_b = (7 x 7) /144 = 0.34 ft^2

Velocity, V_c = 1000/0.69 = 1440 fpm

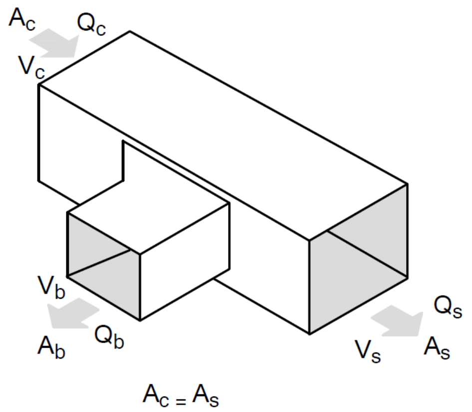
Velocity, V_b = 500/0.34 = 1469 fpm

Velocity pressure $p_{vc} = (1440/4005)^2$ = 0.13 in H_20

Velocity pressure $p_{vb} = (1469/4005)^2$ = 0.13 in H_20

Velocity Ratio, V_b / V_c = 1469/1440 = 1.02

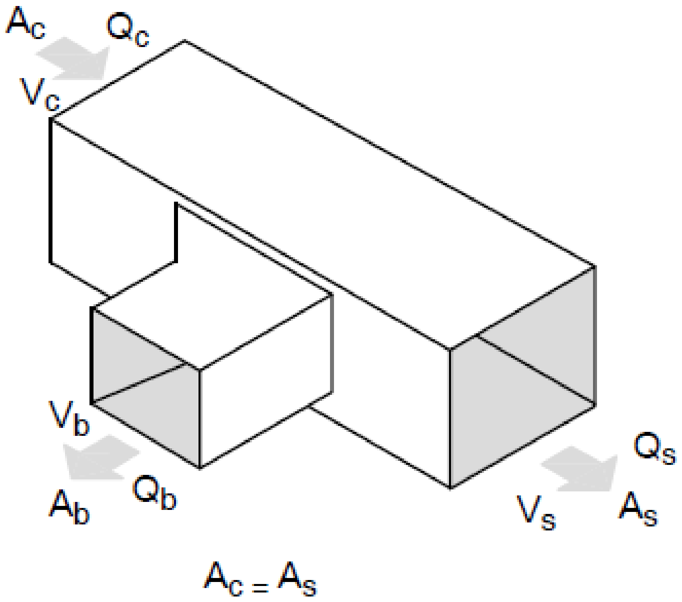
Flow Rate Ratio, Q_b / Q_c = 500/1000 = 0.50



Pressure Losses

Dynamic - Loss Coefficient Tables

N. TEE, 45° RECTANGULAR MAIN AND BRANCH



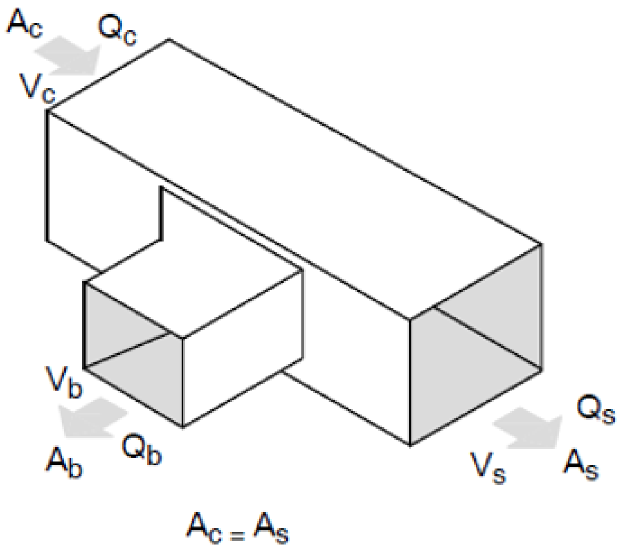
Branch, Coefficient C (*See* Note 8)									
V_b/V_c	Q_b/Q_c								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.2	0.91								
0.4	0.81	0.79							
0.6	0.77	0.72	0.70						
0.8	0.78	0.73	0.69	0.66					
1.0	0.78	0.98	0.85	0.79	0.74				
1.2	0.90	1.11	1.16	1.23	1.03	0.86			
1.4	1.19	1.22	1.26	1.29	1.54	1.25	0.92		
1.6	1.35	1.42	1.55	1.59	1.63	1.50	1.31	1.09	
1.8	1.44	1.50	1.75	1.74	1.72	2.24	1.63	1.40	1.17

Pressure Losses

Dynamic - Loss Coefficient Tables

Page A.33

N. TEE, 45° RECTANGULAR MAIN AND BRANCH



Branch, Coefficient C (*See* Note 8)									
V_b/V_c	Q_b/Q_c								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.2	0.91								
0.4	0.81	0.79							
0.6	0.77	0.72	0.70						
0.8	0.78	0.73	0.69	0.66					
1.0	0.78	0.98	0.85	0.79	0.74				
1.2	0.90	1.11	1.16	1.23	1.03	0.86			
1.4	1.19	1.22	1.26	1.29	1.54	1.25	0.92		
1.6	1.35	1.42	1.55	1.59	1.63	1.50	1.31	1.09	
1.8	1.44	1.50	1.75	1.74	1.72	2.24	1.63	1.40	1.17

Table A-11N, $C_b = 0.74$

$\Delta p_{t,c\text{-}b} = 0.74 \times 0.13 = 0.10$ inch of water

Pressure Losses – Designed Fitting Won’t Fit

How to Determine What Will Work

Consider:

- ❑ Is the Fitting in a Design Leg?
- ❑ What is the Velocity Pressure?
- ❑ What are the Options For Replacement?
- ❑ Which of the Fitting Options is Most Economical?
- ❑ Will the Fitting Change the Design Leg, i.e.:
  - Will it Cause the Fan Operating Pressure to Increase?
  - Will the Change Affect the System Balance?

Pressure Losses

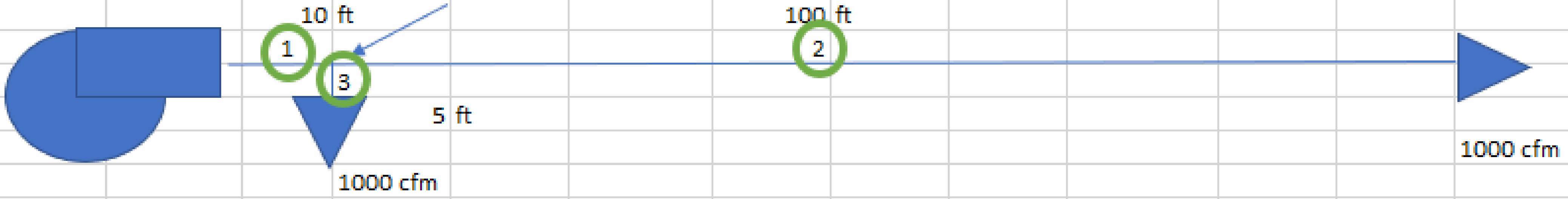
The Design Leg – Critical Path

Critical paths are the duct sections from a fan outlet to the terminal device with the highest 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.

Will a Fitting Change Affect the Design Leg or Balance of the System?

Pressure Losses – Critical Path

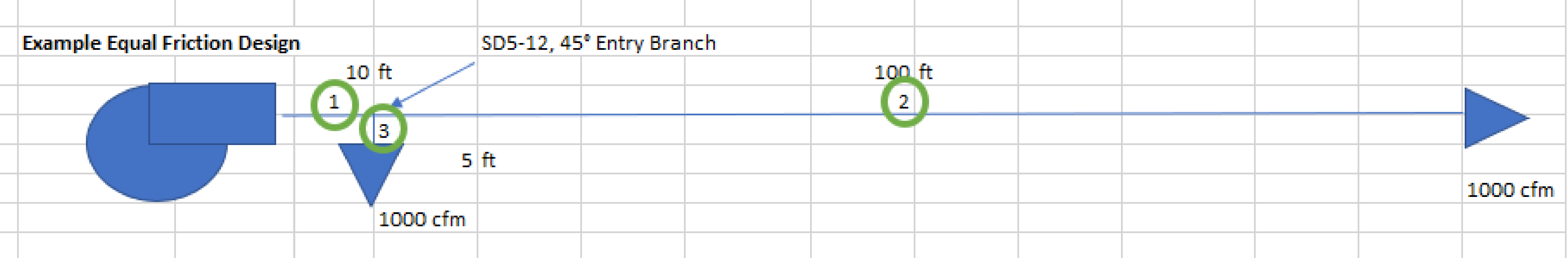
Example Equal Friction Design



For $p_f/100$ = 0.10 inch water

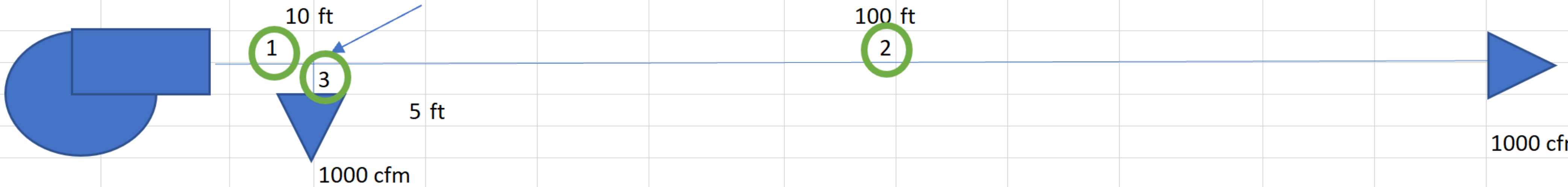
Section 1			Section 2			Section 3		
Q1 =	2000	cfm	Q2 =	1000	cfm	Q3 =	1000	cfm
D1 =	18	inch	D2 =	14	inch	D3 =	14	inch
V1 =	1132	fpm	V2 =	935	fpm	V3 =	935	fpm
p_v1 =	0.08	inch water	p_v2 =	0.05	inch water	p_v3 =	0.05	inch water
p_f 1 =	0.09	inch water /100 ft	p_f2 =	0.09	inch water /100 ft	p_f3 =	0.09	inch water /100 ft
Δp_{D1}=	0.01	inch water	p_D2 =	0.09	inch water	p_D3 =	0.00	inch water
			$\Delta p_{t1\text{-}2,fitting}$	0.01	inch water	$\Delta p_{t1\text{-}3,fitting}$	0.03	inch water
			Outlet Loss	0.05	inch water	Outlet Loss	0.05	inch water
Path 1 -2 Δp =	0.16	inch water						
Path 1 -3 Δp =	0.09	inch water	$\Delta p_{t,section\ 2}$	0.15	inch water	$\Delta pt_{,\ section\ 3}$	0.08	inch water
Total Pressure =	0.16	inch water	For Path 1 - 2					
Excess Pressure	0.07	inch water	For Path 1 - 3					

Pressure Losses – Critical Path



Path 1 -2 Δp =	0.16	inch water	
Path 1 -3 Δp =	0.09	inch water	
Total Pressure =	0.16	inch water	For Path 1 - 2
Excess Pressure	0.07	inch water	For Path 1 - 3

Pressure Losses – Critical Path

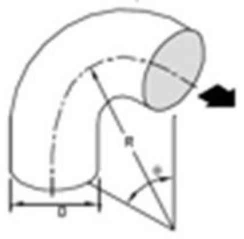
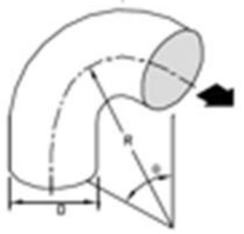
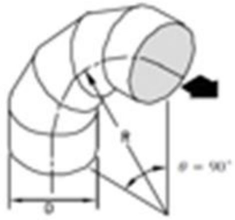
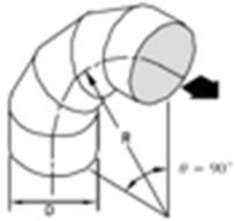
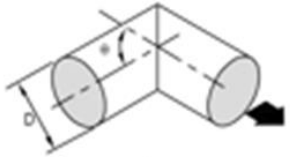


Section 3		
Q3 =	1000	cfm
D3 =	14	inch
V3 =	935	fpm
p_v3 =	0.05	inch water
p_f3 =	0.09	inch water /100 ft
p_D3 =	0.00	inch water
$\Delta p_{t1\text{-}3,fitting}$	0.09	inch water
Outlet Loss	0.05	inch water
$\Delta pt_{, section\ 3}$	0.14	inch water

Path 1 -2 Δp =	0.16	inch water	Did not Change!!
Path 1 -3 Δp =	0.15	inch water	Increased from 0.09 in wg
Total Pressure =	0.16	inch water	For Path 1 - 2
Excess Pressure	0.01	inch water	For Path 1 - 3

Pressure Losses

Fitting Efficiency

					
Smooth Radius, R/D = 1.5 (Table A-7A)	Smooth Radius, R/D = 0.5 (Table A-7A)	5 Piece, R/D = 1.5 (Table A-7B)	3 Piece, R/D = 1.5 (Table A-7B)	Mitered w Vanes (ASHRAE DFDB CD3-20)	Mitered without Vanes (Table A-7C)
C = 0.15	C = 0.71	C = 0.24	C = 0.34	C = 0.35	C = 1.2

Pressure Losses

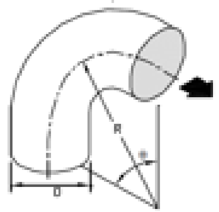
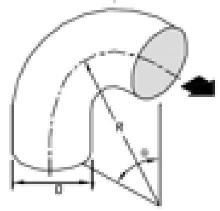
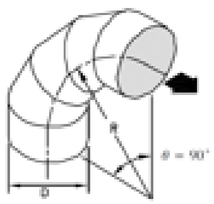
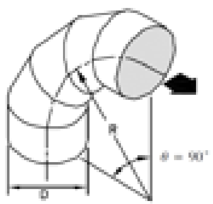
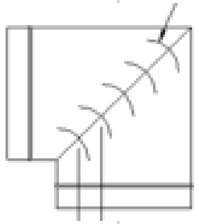
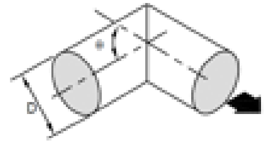
Fitting Efficiency – Round Elbows

Comparison of Round Elbow Losses — Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

D = 12 inch

Area = 0.79 ft^2

ρ = 0.075 lb_m/ft^3 Standard Conditions

														
			Smooth Radius, R/D = 1.5 (Table A-7A)		Smooth Radius, R/D = 0.5 (Table A-7A)		5 Piece, R/D = 1.5 (Table A-7B)		3 Piece, R/D = 1.5 (Table A-7B)		Mitered w Vanes (ASHRAE DFDB CD3-20)		Mitered without Vanes (Table A-7C)	
Velocity (fpm)	Velocity Pressure p_v (inch water)	Q = AV Flow Rate (cfm)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
1000	0.06	785	0.15	0.01	0.71	0.04	0.24	0.01	0.34	0.02	0.45	0.03	1.2	0.07
2000	0.25	1571	0.15	0.04	0.71	0.18	0.24	0.06	0.34	0.09	0.45	0.11	1.2	0.30
3000	0.56	2356	0.15	0.08	0.71	0.40	0.24	0.13	0.34	0.19	0.45	0.25	1.2	0.67
4000	0.99	3142	0.15	0.15	0.71	0.70	0.24	0.24	0.34	0.34	0.45	0.45	1.2	1.19
			Best				Better				Good			

Pressure Losses

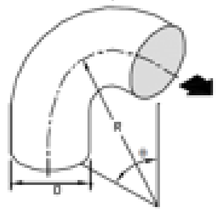
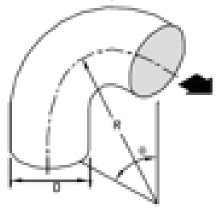
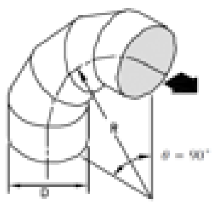
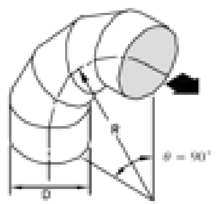
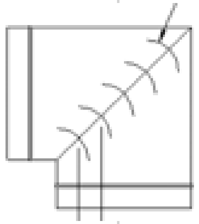
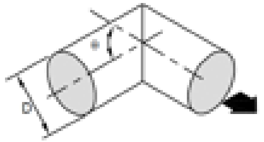
Fitting Efficiency – Round Elbows

Comparison of Round Elbow Losses Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

D = 12 inch

Area = 0.79 ft^2

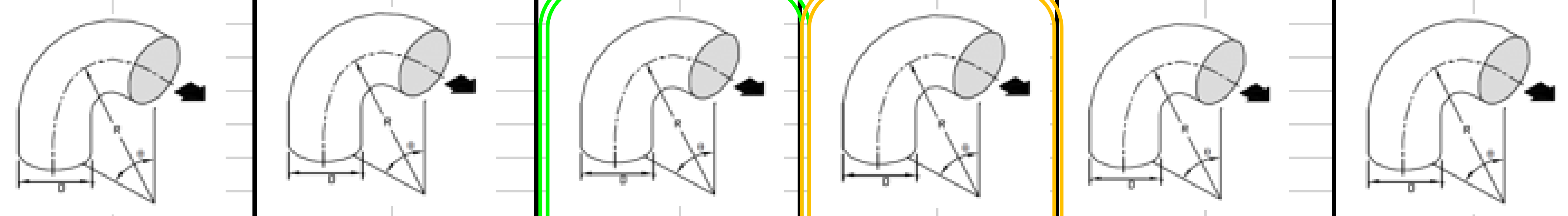
$\rho = 0.075\ lb_m/ft^3$ Standard Conditions

														
			Smooth Radius, R/D = 1.5 (Table A-7A)		Smooth Radius, R/D = 0.5 (Table A-7A)		5 Piece, R/D = 1.5 (Table A-7B)		3 Piece, R/D = 1.5 (Table A-7B)		Mitered w Vanes (ASHRAE DFDB CD3-20)		Mitered without Vanes (Table A-7C)	
Velocity (fpm)	Velocity Pressure p_v (inch water)	Q = AV Flow Rate (cfm)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
1000	0.06	785	0.15	0.01	0.71	0.04	0.24	0.01	0.34	0.02	0.45	0.03	1.2	0.07
2000	0.25	1571	0.15	0.04	0.71	0.18	0.24	0.06	0.34	0.09	0.45	0.11	1.2	0.30
3000	0.56	2356	0.15	0.08	0.71	0.40	0.24	0.13	0.34	0.19	0.45	0.25	1.2	0.67
4000	0.99	3142	0.15	0.15	0.71	0.70	0.24	0.24	0.34	0.34	0.45	0.45	1.2	1.19

Best Better Good

Pressure Losses

Fitting Efficiency – Round Elbows

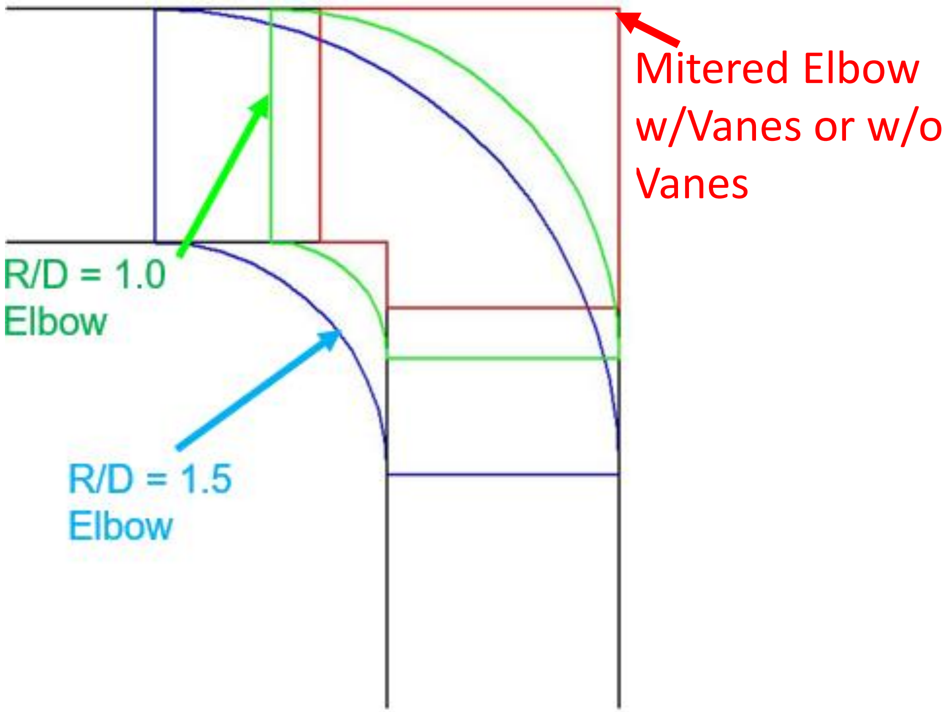


	Smooth Radius, R/D = 2.5 (Table A-7A)		Smooth Radius, R/D = 2.0 (Table A-7A)		Smooth Radius, R/D = 1.5 (Table A-7A)		Smooth Radius, R/D = 1.0 (Table A-7A)		Smooth Radius, R/D = 0.75 (Table A-7A)		Smooth Radius, R/D = 0.50 (Table A-7A)	
Velocity (fpm)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
1000	0.12	0.01	0.13	0.01	0.15	0.01	0.22	0.01	0.33	0.02	0.71	0.04
4000	0.12	0.12	0.13	0.13	0.15	0.15	0.22	0.22	0.33	0.33	0.71	0.70

Pressure Losses -Fitting Efficiency – Elbows

What if the Elbow Doesn’t Fit?

Example: *a Round Elbow with an R/D =1.5 was specified but wont fit. Will a smaller R/D fit or do I have to use a Mitered Elbow? The Velocity is 2000 fpm.*



Losses of the Four Different Elbows:

- R/D = 1.5 Elbow, Pressure Loss is 0.04 in wg
- R/D = 1.0 Elbow, Pressure Loss is 0.06 in wg
- Mitered Elbow w Vanes, Pressure Loss is 0.11 in wg
- Mitered Elbow w/o Vanes, Pressure Loss is 0.30 in wg

Questions:

- Will the R/D= 1.0 Elbow Fit?
- Will R/D=1.0 Elbow Change the Design Leg?
- Will the Mitered Elbow Change the Design Leg and Thus increase the Fan Operating Pressure?
- What is the Cost Differential?
- How will it Affect the Balancing?

Pressure Losses

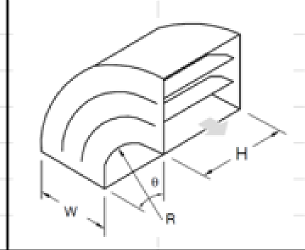
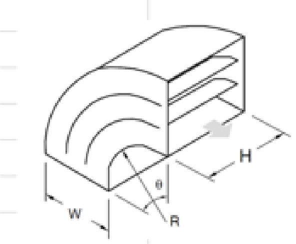
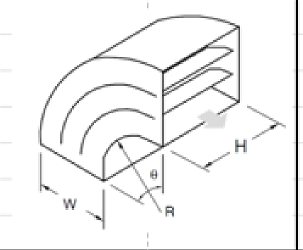
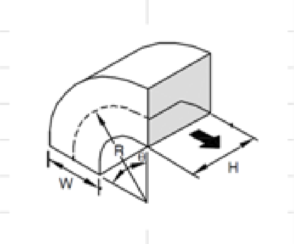
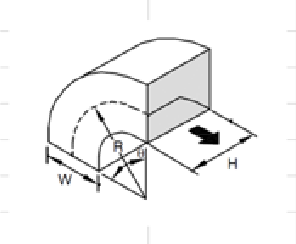
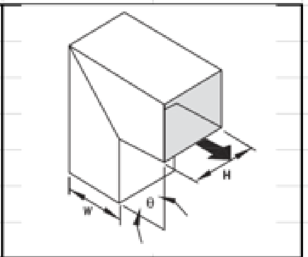
Fitting Efficiency – Rectangular Elbows

Comparison of Round Elbow Losses Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

W x H **12 x** 12 inches **H /W = 1.0**

Area = **1.00 ft^2**

ρ = 0.075 lb$_m$/ft^3 **Standard Conditions**

														
			Smooth Radius w 3 Splitter Vane R/W = 0.50 (Table A-7G)		**Smooth Radius w 2 Splitter Vanes R/W = 0.50 (Table A-7G)**		**Smooth Radius w 1 Splitter Vanes R/W = 0.50 (Table A-7G)**		**Smooth Radius without Vanes R/W = 1 (Table A-7F)**		**Smooth Radius without Vanes R/W = 1.5 (Table A-7F)**		**Mitered without Vanes (Table A-7D)**	
Velocity (fpm)	**Velocity Pressure p_v (inch water)**	**Q = AV Flow Rate (cfm)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**
1000	0.06	1000	0.01	0.00	0.02	0.00	0.05	0.00	0.21	0.01	0.17	0.01	1.2	0.07
2000	0.25	2000	0.01	0.00	0.02	0.01	0.05	0.01	0.21	0.05	0.17	0.04	1.2	0.30
3000	0.56	3000	0.01	0.01	0.02	0.01	0.05	0.03	0.21	0.12	0.17	0.10	1.2	0.67
4000	0.99	4000	0.01	0.01	0.02	0.02	0.05	0.05	0.21	0.21	0.17	0.17	1.2	1.19
			Best				Better				Good			

Pressure Losses

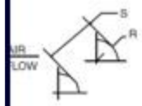
Fitting Efficiency – Rectangular Elbows

Comparison of Round Elbow Losses Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A

W x H **12 x** 12 inches **H /W = 1.0**

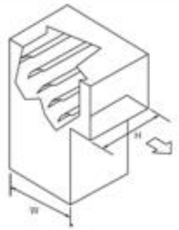
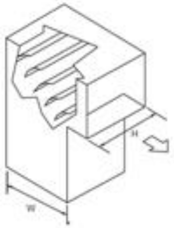
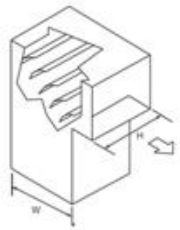
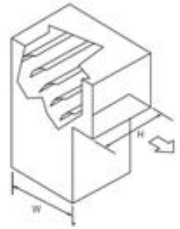
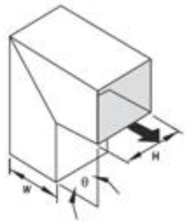
Area = **1.00 ft^2**

ρ = 0.075 lb$_m$/ft^3 **Standard Conditions**



Single Thickness

Double hickness

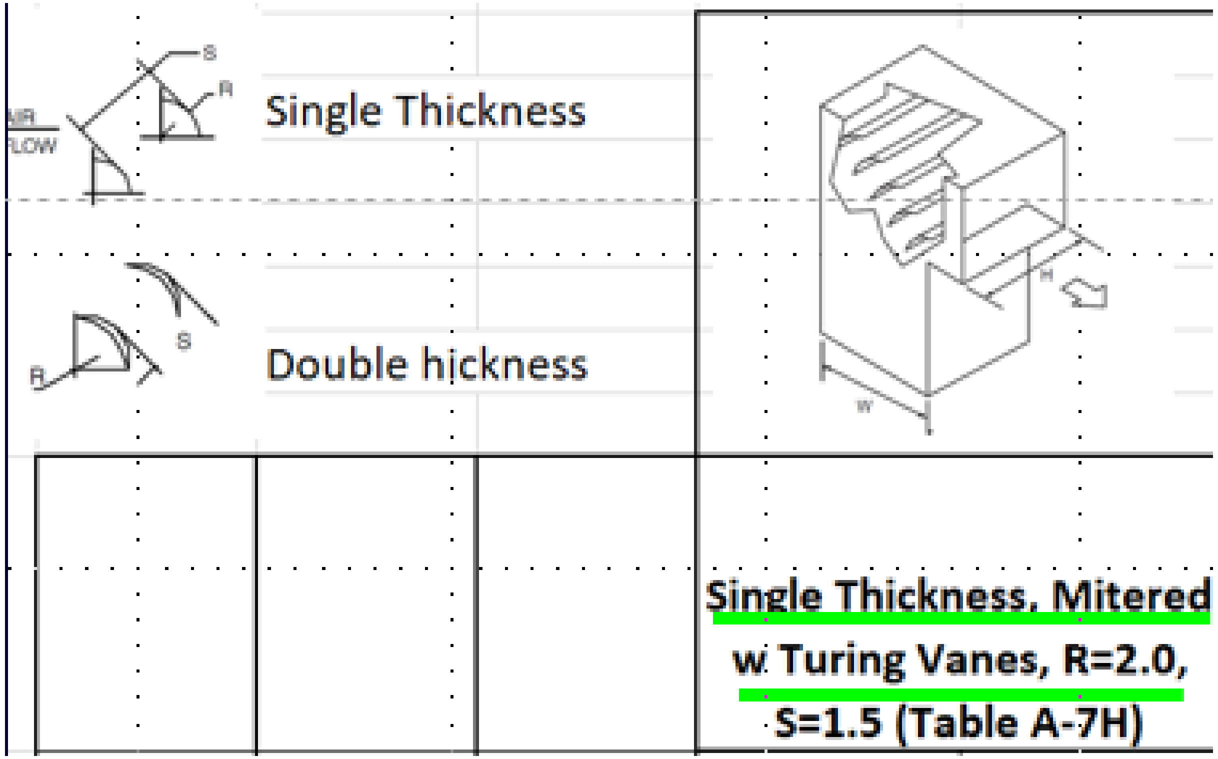







			Single Thickness, Mitered w Turing Vanes, R=2.0, S=1.5 (Table A-7H)		Single Thickness, Mitered w Turing Vanes, R=4.5, S=3.25 (Table A-7H)		Double Thickness, Mitered w Turing Vanes, R=4.5, S=3.25 (Table A-7H)		Double Thickness, Mitered w Turing Vanes, R=2.0, S=1.5 (Table A-7H)		Double Thickness, Mitered w Turing Vanes, R=2.0, S=2.25 (Table A-7H)		Mitered without Vanes (Table A-7D)	
Velocity (fpm)	Velocity Pressure p$_v$ (inch water)	Q = AV Flow Rate (cfm)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)
1000	0.06	1000	0.24	0.01	0.26	0.02	0.27	0.02	0.43	0.03	0.53	0.03	1.2	0.07
1500	0.14	1500	0.23	0.03	0.24	0.03	0.25	0.04	0.42	0.06	0.53	0.07	1.2	0.17
2000	0.25	2000	0.22	0.05	0.23	0.06	0.24	0.06	0.41	0.10	0.50	0.12	1.2	0.30
2500	0.39	2500	0.20	0.08	0.22	0.09	0.23	0.09	0.40	0.16	0.49	0.19	1.2	0.47
			Best				Better		Good					

Pressure Losses

Fitting Efficiency – Rectangular Elbows

Most Efficient Mitered Elbow



Pressure Losses

Fitting Efficiency – Rectangular Elbows

SMACNA Research Shows:

- Vanes with trailing edges have higher loss coefficients than standard construction. (section 5.16.2)
- Removing every other vane can more than double the pressure loss. (section 5.16.3)
- Turning vanes are 90°; if used in elbows of other angle the pressure loss will increase.

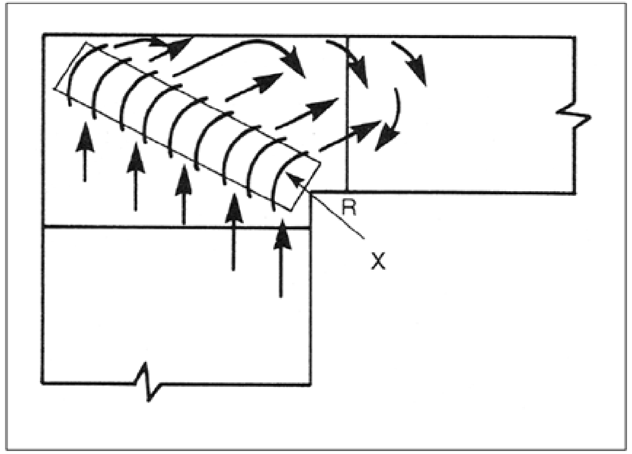
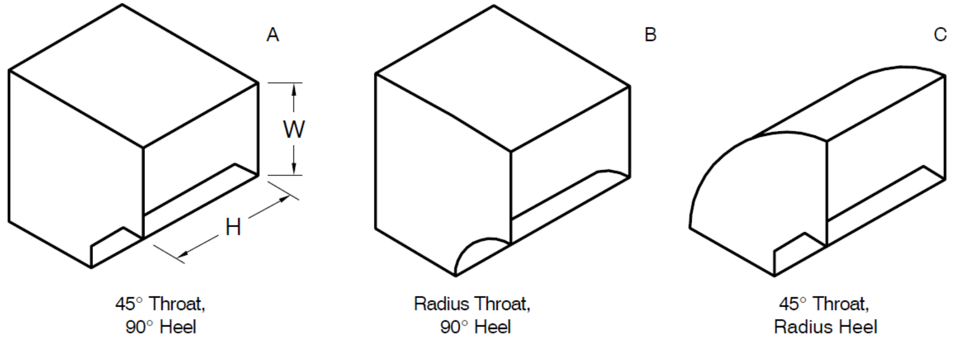


FIGURE 5-14 TURBULENCE CAUSED BY IMPROPER MOUNTING AND USE OF TURNING VANES

Pressure Losses

Fitting Efficiency – Other Rectangular Elbows

Other elbows without turning vane configurations can reduce the elbow loss coefficient, including:

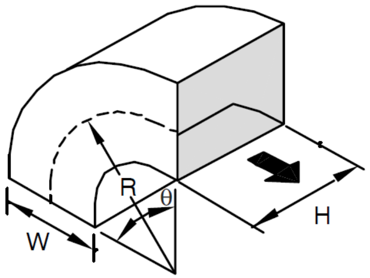


Elbow	Fitting Loss Coefficient (C)		
	H/W		
	0.36	**1.00**	**2.75**
A	0.41	0.60	0.53
B	0.36	0.58	0.45
C	0.34	0.33	0.32
*R/W = 0.75	0.55	0.44	0.39
*R/W = 1.0	0.26	0.21	0.18

*Smooth radius rectangular elbow w/o vanes, *see* Table A-7F

FIGURE 5–21 DIFFERENT CONFIGURATION ELBOW RESEARCH

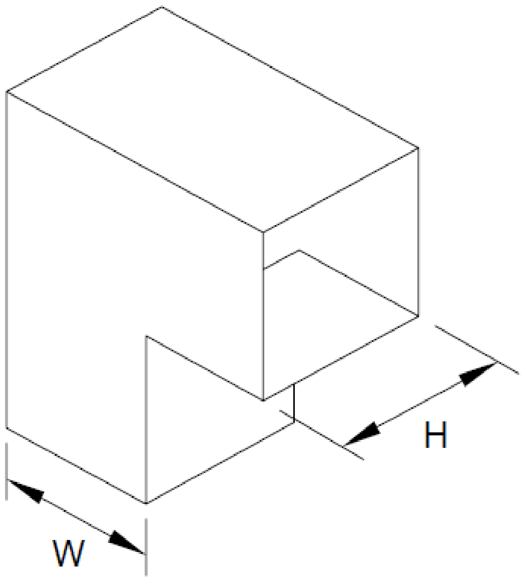
F. ELBOW, RECTANGULAR, SMOOTH RADIUS WITHOUT VANES



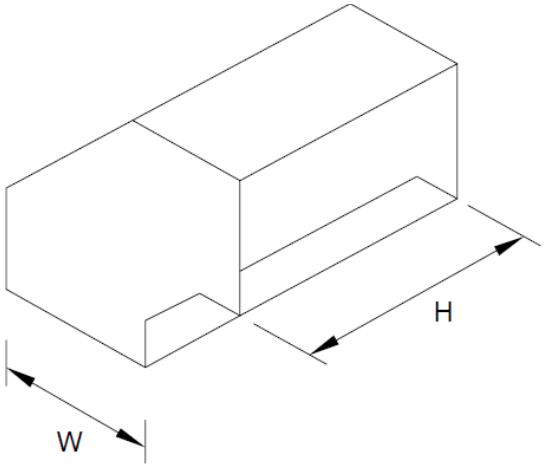
Coefficients for 90° elbows (*See N*							
Coefficient C							
R/W	H/W						
	0.25	0.5	0.75	1.0	1.5	2.0	3.0
0.5	1.5	1.4	1.3	1.2	1.1	1.0	1.0
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39
1.0	0.27	0.25	0.23	0.21	0.19	0.18	0.18
1.5	0.22	0.20	0.19	0.17	0.15	0.14	0.14
2.0	0.20	0.18	0.16	0.15	0.14	0.13	0.13

Pressure Losses

Fitting Efficiency – Other Rectangular Elbows



TYPE RE 4
SQUARE THROAT ELBOW
WITHOUT VANES
(1000 FPM (5 mps) MAXIMUM VELOCITY)

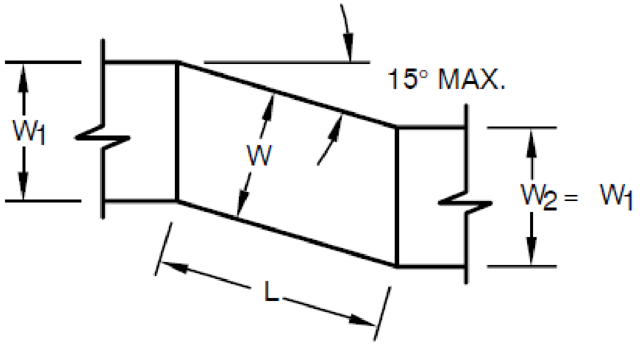


TYPE RE 7
45° THROAT
45° HEEL

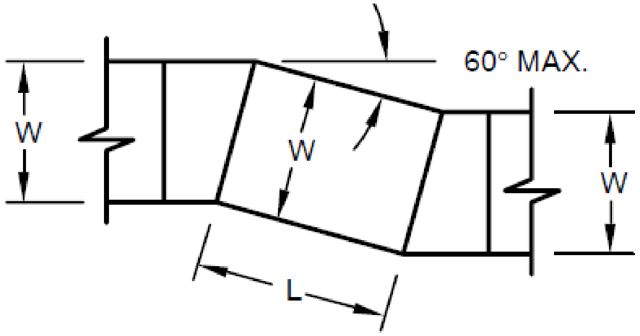
ALL 45° THROATS ARE 4" (100 MM) MINIMUM

Pressure Losses

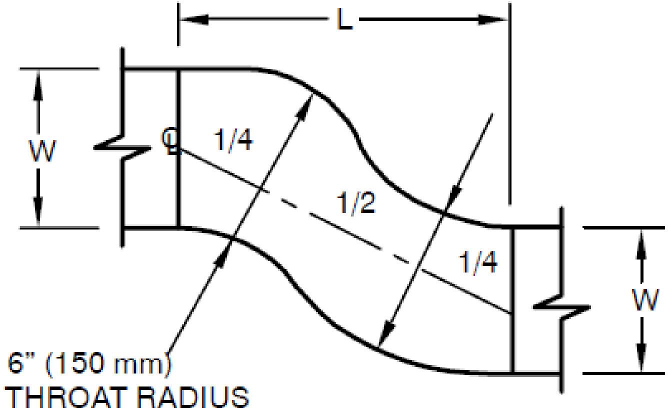
Fitting Efficiency – Offsets



OFFSET TYPE 1
(ANGLED)



OFFSET TYPE 2
(MITERED)

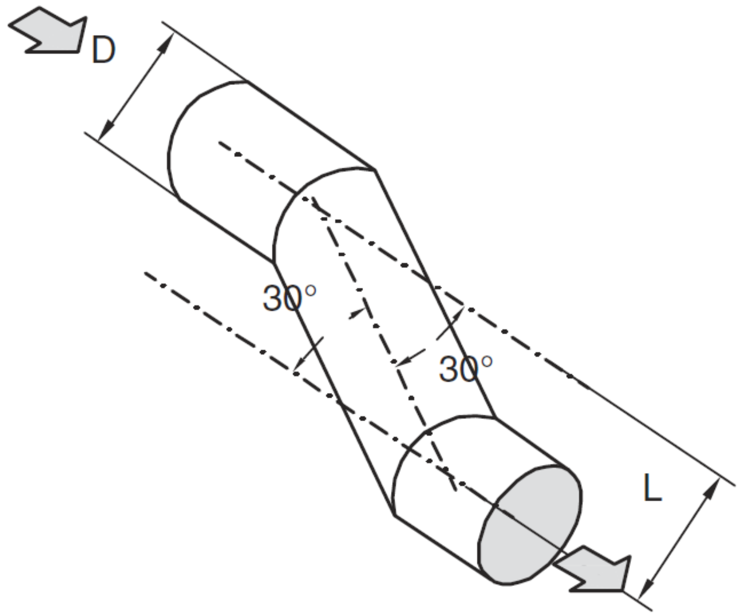


OFFSET TYPE 3
(RADIUSSED
OR OGEE)

Pressure Losses

Fitting Efficiency – Offsets

K. ELBOWS, 30°, ROUND, OFFSET

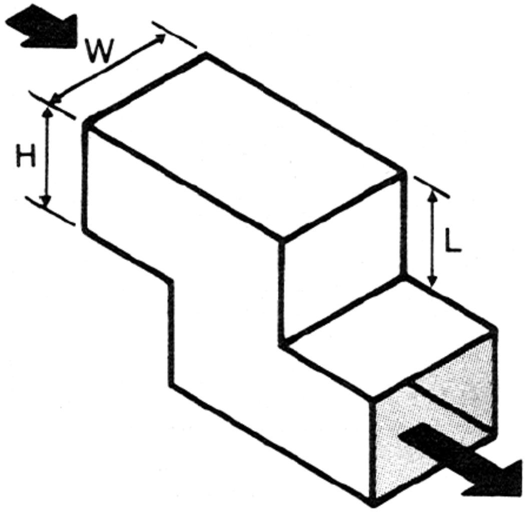


Coefficients C (*See* Note 5)							
L/D	0	0.5	1.0	1.5	2.0	2.5	3.0
C	0	0.15	0.15	0.16	0.16	0.16	0.16

Pressure Losses

Fitting Efficiency – Offsets

I. ELBOWS, 90 DEGREES, RECTANGULAR, Z-SHAPED



(NO VANES)

Coefficients for W/H = 1.0 (*See* Notes 4)										
L/H	0	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
C	0	0.62	0.90	1.6	2.6	3.6	4.0	4.2	4.2	4.2
L/H	2.4	2.8	3.2	4.0	5.0	6.0	7.0	9.0	10.0	∞
C	3.7	3.3	3.2	3.1	2.9	2.8	2.7	2.6	2.5	2.3

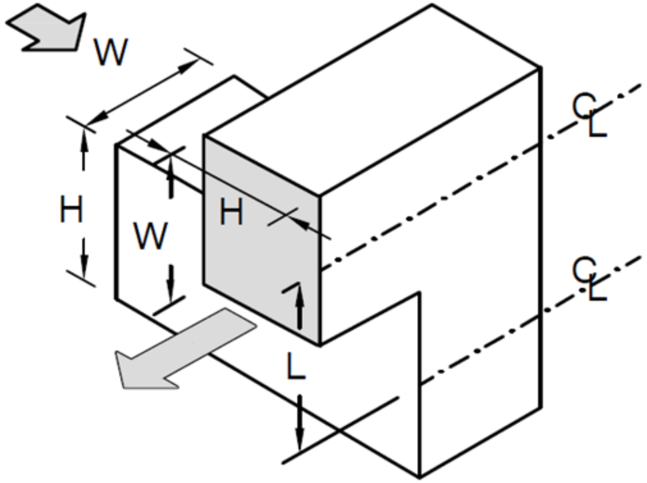
Note 4: For W/H values other than 1.0 apply the following factor:

W/H	0.25	0.50	0.75	1.0	1.5	2.0	3.0	4.0	6.0	8.0
K	1.10	1.07	1.04	1.0	0.95	0.90	0.83	0.78	0.72	0.70

Pressure Losses

Fitting Efficiency – Offsets

J. ELBOWS, 90°, RECTANGULAR IN DIFFERENT PLANES

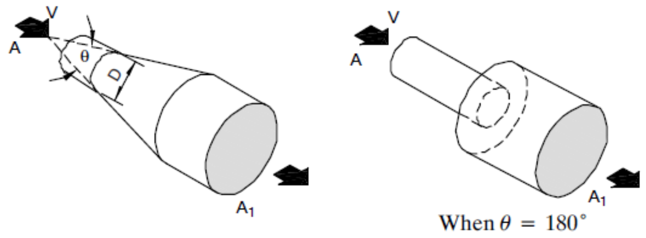


Coefficients for H/W = 1.0: (*See* Notes 4 & 5)										
L/W	0	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
C	1.2	2.4	2.9	3.3	3.4	3.4	3.4	3.3	3.2	3.1
L/W	2.4	2.8	3.2	4.0	5.0	6.0	7.0	9.0	10.0	∞
C	3.2	3.2	3.2	3.0	2.9	2.8	2.7	2.5	2.4	2.3

Pressure Losses

Fitting Efficiency – Diverging Transitions

A. TRANSITION, ROUND, CONICAL



U.S. Units: $R_e = 8.56\ DV$

Metric Units: $R_e = 66.4\ DV$

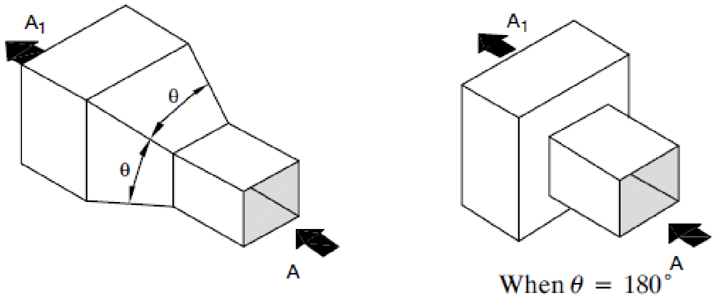
where:

D = Upstream Diameter (inches)

V = Upstream Velocity (fpm)

		Coefficient C (*See* Note 6)							
		θ							
R_e	A_1/A	16°	20°	30°	45°	60°	90°	120°	180°
0.5×10^5	2	0.14	0.19	0.32	0.33	0.33	0.32	0.31	0.30
	4	0.23	0.30	0.46	0.61	0.68	0.64	0.63	0.62
	6	0.27	0.33	0.48	0.66	0.77	0.74	0.73	0.72
	10	0.29	0.38	0.59	0.76	0.80	0.83	0.84	0.83
	≥ 16	0.31	0.38	0.60	0.84	0.88	0.88	0.88	0.88
2×10^5	2	0.07	0.12	0.23	0.28	0.27	0.27	0.27	0.26
	4	0.15	0.18	0.36	0.55	0.59	0.59	0.58	0.57
	6	0.19	0.28	0.44	0.90	0.70	0.71	0.71	0.69
	10	0.20	0.24	0.43	0.76	0.80	0.81	0.81	0.81
	≥ 16	0.21	0.28	0.52	0.76	0.87	0.87	0.87	087
$\geq 6 \times 10^5$	2	0.05	0.07	0.12	0.27	0.27	0.27	0.27	0.27
	4	0.17	0.24	0.38	0.51	0.56	0.58	0.58	0.57
	6	0.16	0.29	0.46	0.60	0.69	0.71	0.70	0.70
	10	0.21	0.33	0.52	0.60	0.76	0.83	0.84	0.83
	≥ 16	0.21	0.34	0.56	0.72	0.79	0.85	0.87	0.89

B. TRANSITION, RECTANGULAR, PYRAMIDAL



	Coefficient C (*See* Note 6)							
	θ							
A_1/A	16°	20°	30°	45°	60°	90°	120°	180°
2	0.18	0.22	0.25	0.29	0.31	0.32	0.33	0.30
4	0.36	0.43	0.50	0.56	0.61	0.63	0.63	0.63
6	0.42	0.47	0.58	0.68	0.72	0.76	0.76	0.75
≥ 10	0.42	0.49	0.59	0.70	0.80	0.87	0.85	0.86

Note 6: A = Area (Entering airstream), A_1 = Area (Leaving airstream)

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

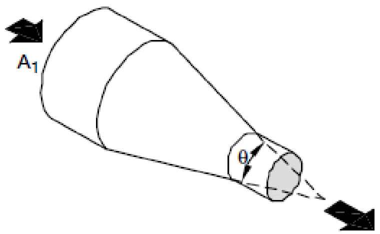
Table A-8 Loss Coefficients, Transitions (Diverging Flow)

Keep the angle and change in area low. 16° , A1/A = 2 has much lower loss coefficient than 180°, A1/A = 10

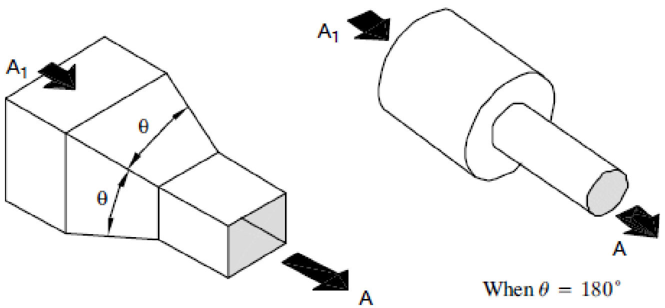
Pressure Losses

Fitting Efficiency – Converging Transitions

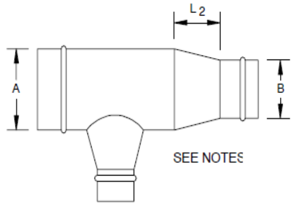
A. CONTRACTION, ROUND AND RECTANGULAR, GRADUAL TO ABRUPT



A_1/A	Coefficient C (*See* Note 3) θ: 10°	15°–40°	50°–60°	90°	120°	150°	180°
2	0.05	0.05	0.06	0.12	0.18	0.24	0.26
4	0.05	0.04	0.07	0.17	0.27	0.35	0.41
6	0.05	0.04	0.07	0.18	0.28	0.36	0.42
10	0.05	0.05	0.08	0.19	0.29	0.37	0.43



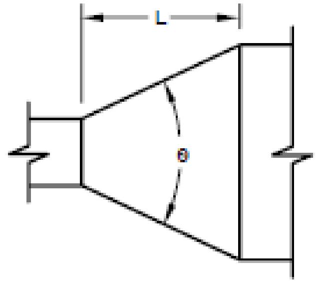
When $\theta = 180°$



CONICAL TEE AND REDUCER FITTING

ALTERNATE ARRANGEMENT

L_2 = A – B (4" (102 mm) MIN.)



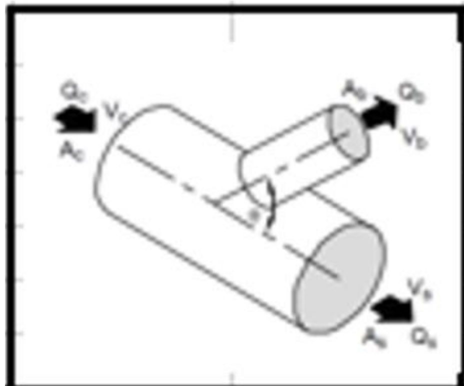
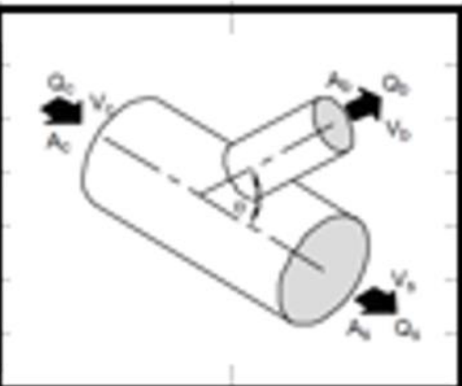
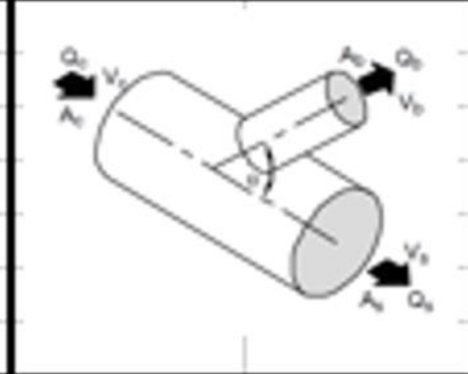
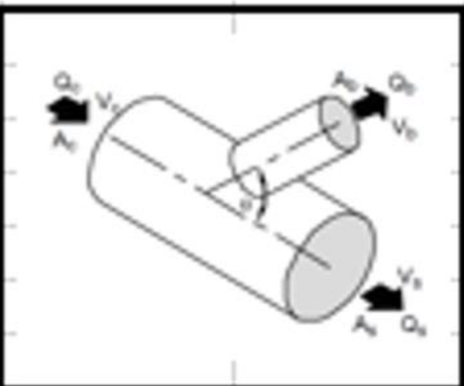
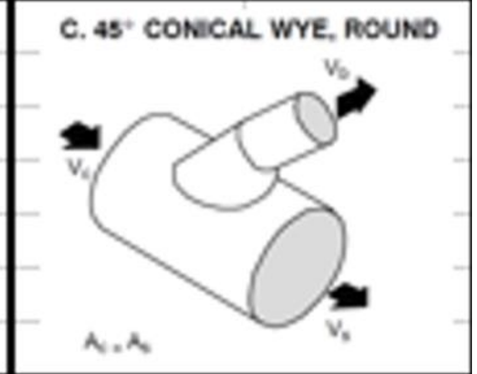
CONCENTRIC TRANSITION
θ MAX. 45° DIVERGING, 60° CONVERGING

Keep the angle and change in area low. 10° , A1/A = 2 has much lower loss coefficient than 180°, A1/A = 10

amca INTERNATIONAL

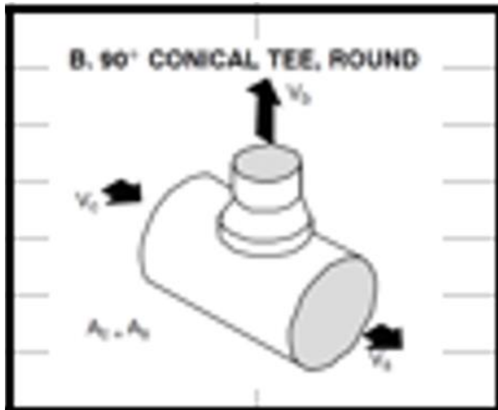
Pressure Losses

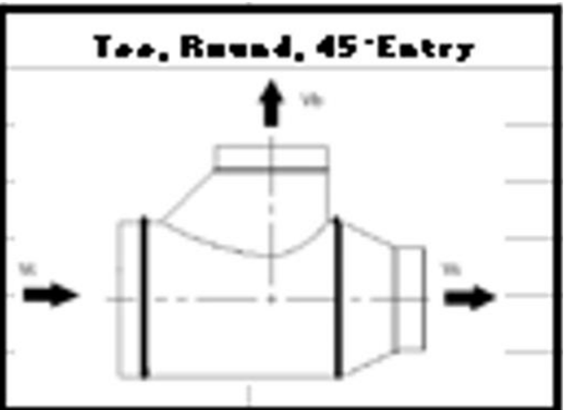
Fitting Efficiency – Diverging Flow Fittings

									
Wye , 30°		Wye , 45°		Wye , 60°		Wye , 90°		Conical Wye	
Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)	Loss Coefficient C	Δp$_t$ (inch water)
0.18	0.02	0.40	0.04	0.68	0.07	1.4	0.14	0.17	0.02

Pressure Losses

Fitting Efficiency – Diverging Flow Fittings

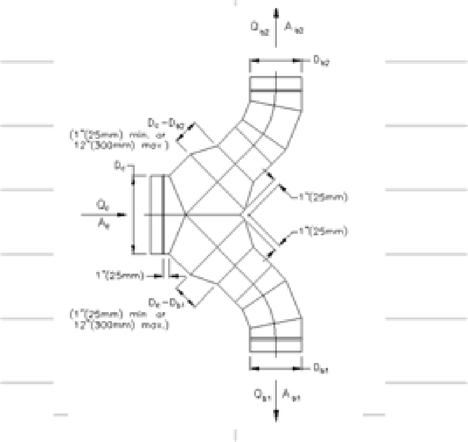
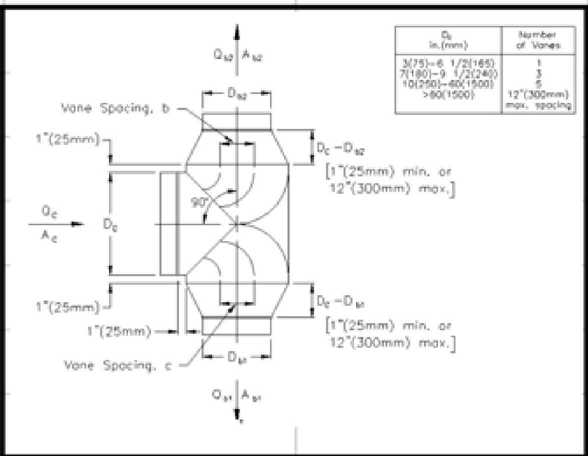
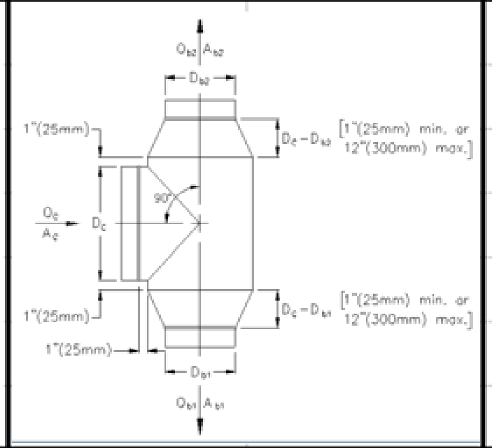
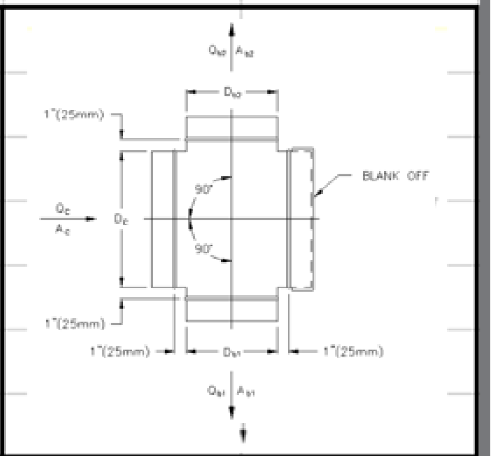




Conical Tee		45° Entry Tee	
Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
0.42	0.04	0.35	0.04

Pressure Losses

Fitting Efficiency – Diverging Flow Fittings

							
Symmetrical Wye, SD5-22		Bullhead Tee with Vanes, SD5-19		Bullhead Tee without Vanes, SD5-18		Capped Cross, SD5-20	
Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
0.16	0.02	0.42	0.04	1.02	0.10	4.38	0.44

Pressure Losses

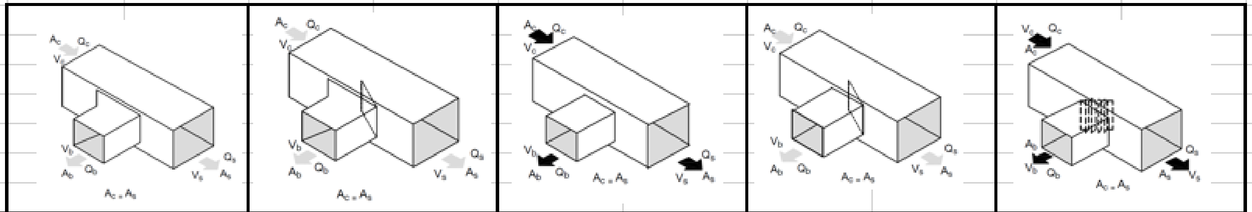
Fitting Efficiency – Diverging Flow Fittings

Comparison of Rectangular Diverging Flow Fittings								Loss Coefficients from SMACNA HVAC Systems Duct Design Appendix A					
$W_c \times H_c$	12	x	12	inch	$A_c =$	1.00	ft^2	$Q_c =$	1000	cfm	$V_c =$	1000	fpm
$W_s \times H_s$	12	x	12	inch	$A_s =$	1.00	ft^2	$Q_b =$	500	cfm	$V_s =$	500	fpm
$W_b \times H_b$	7	x	7	inch	$A_b =$	0.34	ft^2	$Q_s =$	500	cfm	$V_b =$	1469	fpm
$Q_b/Q_c =$	0.50		$V_b/V_c =$	1.47							$P_{vc} =$	0.06	inch water
											$P_{vs} =$	0.02	inch water
											$P_{vb} =$	0.13	inch water

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 × V_p

$\rho = 0.075\ lb_m/ft^3$
Standard Conditions

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



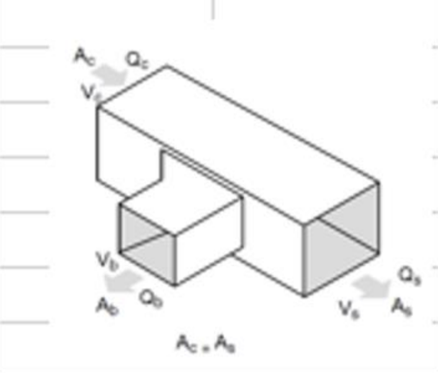
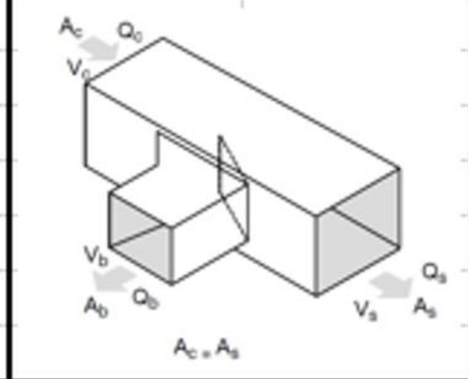
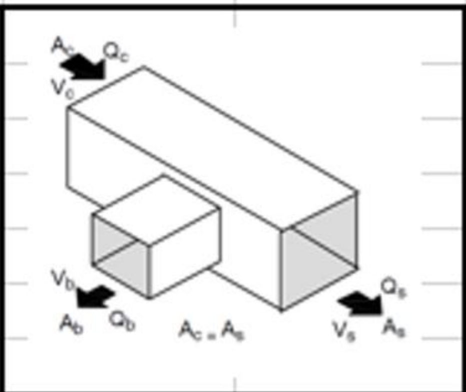
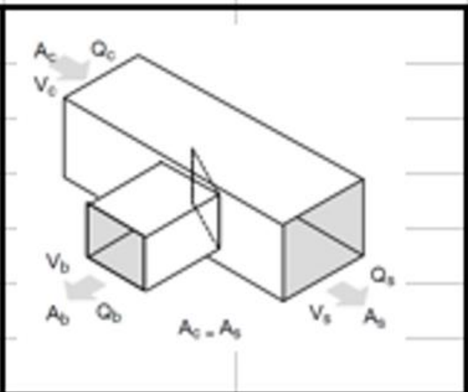
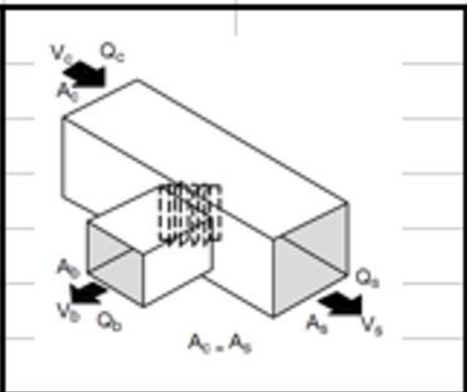
		N. Tee, 45° Main to Branch		O. Tee, 45° Main to Branch w Damper		P. Tee, 90° Main to Branch		Q. Tee, 90° Main to Branch w Damper		R. Tee, 90° Main to Branch w Extracotr	
Velocity Vu = Vc (fpm)	Velocity Pressure p_v (inch water)	Loss Coefficient C	Δp_t (inch water)		Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
1000	0.06	1.59	0.10	1.62	0.10	1.88	0.12	2.01	0.13	2.09	0.13
		Best		Better, but will increase Loss in Main		Good		Good. But will increase loss in main		Increases Loss in Main, not recommend	

5.11.4 Branch Fittings

Chapter 3 discusses the use of less expensive tap fittings for branch ducts and the elimination of "robber" dampers and extractors. A 45 degree entry tap fitting (Table A-11N), when used within the proper range of velocity and airflow volume ratios, has lower fitting loss coefficients than rectangular taps with the dampers or extractors (Tables A-11Q and R). Not only did the "bubble" videotape *Destroying Duct Design Myths* show the turbulence created by these air extractor devices in the branch ducts, but also the turbulence created in the main supply air duct.

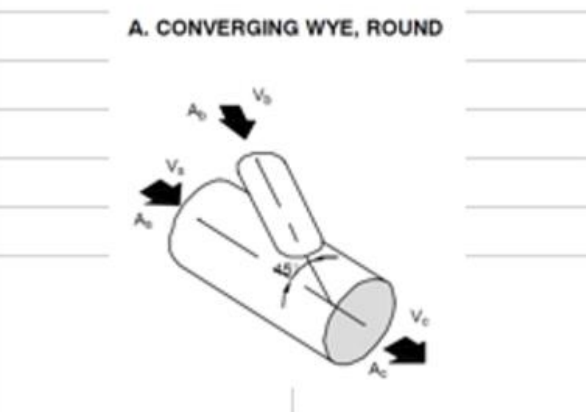
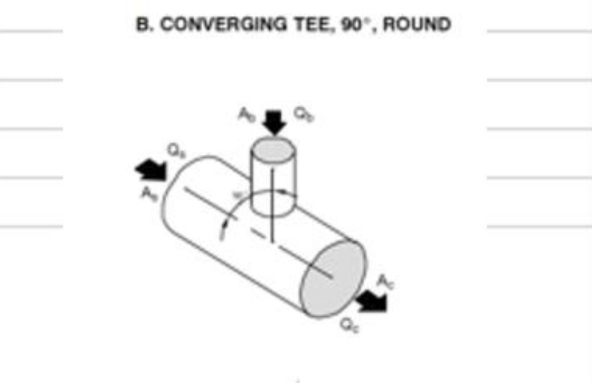
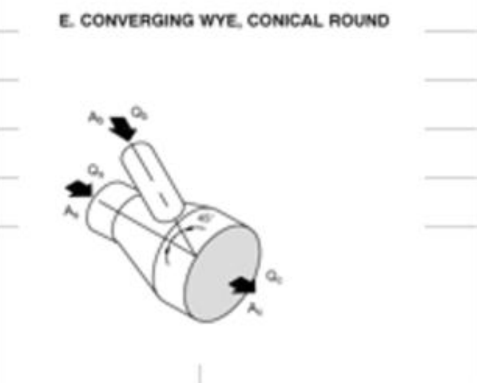
Pressure Losses

Fitting Efficiency – Diverging Flow Fittings

									
N. Tee, 45° Main to Branch		O. Tee, 45° Main to Branch w Damper		P. Tee, 90° Main to Branch		Q. Tee, 90° Main to Branch w Damper		R. Tee, 90° Main to Branch w Extracotr	
Loss Coefficient C	Δp_t (inch water)		Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
1.59	0.10	1.62	0.10	1.88	0.12	2.01	0.13	2.09	0.13

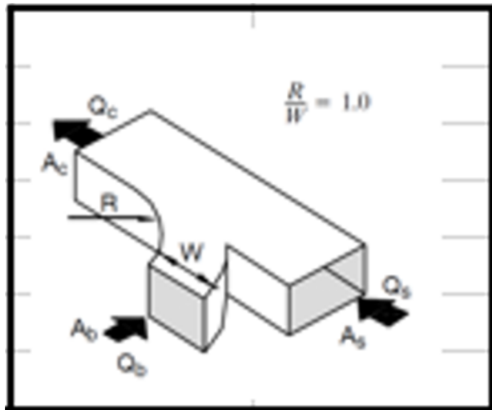
Pressure Losses

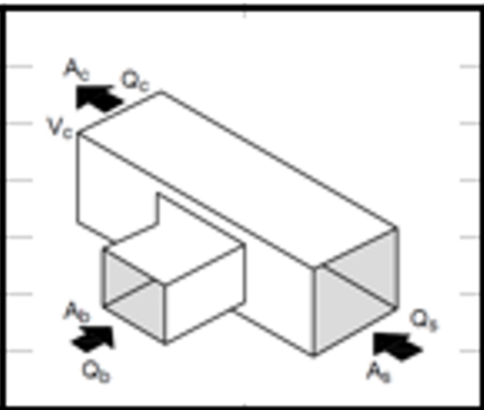
Fitting Efficiency – Converging Flow Fittings

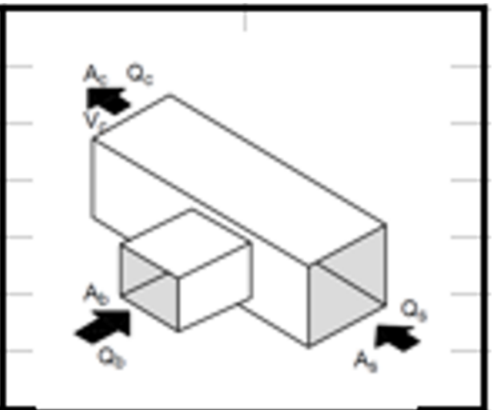
							
Wye , 30°		**Wye , 45°**		**Wye , 90°**		**Conical Wye , 45°**	
Loss Coefficient C	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**	**Loss Coefficient C**	**Δp_t (inch water)**
0.48	0.05	0.49	0.05	0.88	0.09	0.88	0.09
0.02	0.00	0.06	0.01	0.53	0.05	0.06	0.01

Pressure Losses

Fitting Efficiency – Converging Flow Fittings

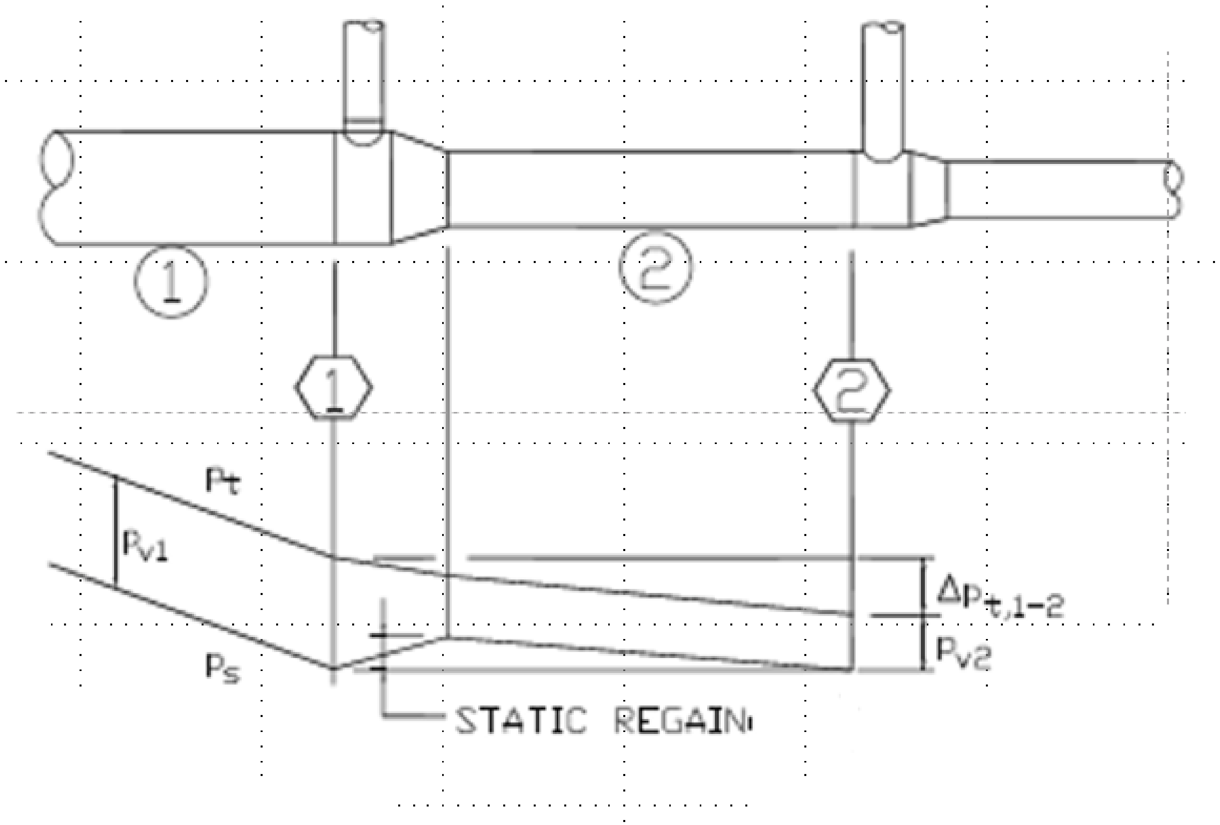






H. Converging Wye, Rectangular		F. Converging Tee, 45 ° Entry Branch to Rectanglar Main		D. Converging Tee, Rectangular Main and Branch	
Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)	Loss Coefficient C	Δp_t (inch water)
0.45	0.03	0.55	0.03	1.03	0.06
-0.08	0.00	-0.26	-0.02	0.53	0.03

Duct Design –Static Regain



$$\Delta p_{t,1\text{-}2} = \Delta p_{s,1\text{-}2} + \Delta p_{v,1\text{-}2}$$

$$\Delta p_{s,1\text{-}2} = \Delta p_{t,1\text{-}2} - \Delta p_{v,1\text{-}2}$$

$$\Delta p_{s,1\text{-}2} = 0$$

$$\Delta p_{t,1\text{-}2} = \Delta p_{v,1\text{-}2}$$

Satisfid When:

$$\Delta p_{v,1\text{-}2} - \Delta p_{t,1\text{-}2} - = 0$$

or

$$p_{v1} - p_{v2} - \Delta p_{t,1\text{-}2} - = 0$$

If you are designing using Static Regain Duct Design:

- Use Efficient Fittings in the Initial Design.
- If there is Excess Pressure in a Non-Design Leg, Consider Using a Smaller Size Duct.
- If there is still Excess Pressure Look at Substituting Less Efficient Fittings.

Resources

- **AMCA International**: www.amca.org
- **AMCA Publication:** www.amca.org/store
  - **> 200-95 (R2011):** Air Systems *(Available for purchase)*
- **SMACNA - HVAC Systems Duct Design Manual** - 2006, 4th Edition: www.smacna.org/store *(Available for purchase)*

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Attendees will receive an email at the address provided on your registration, listing the credit hours awarded and a link to a printable certificate of completion.

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- Wednesday, April 21
- 6:00-7:00pm CT
- ***RSES Journal & AMCA insite WEBINAR: Field Modifications of Fire, Smoke, and Combination Fire/Smoke Dampers***
- Presenters: James Carlin, Product Manager- Dampers, AMCA Member Company

>> For additional webinar details go to: *www.amca.org/webinar*