Fans, Ducts and Air Handling Systems: Design, Performance and Commissioning Issues

Ducts

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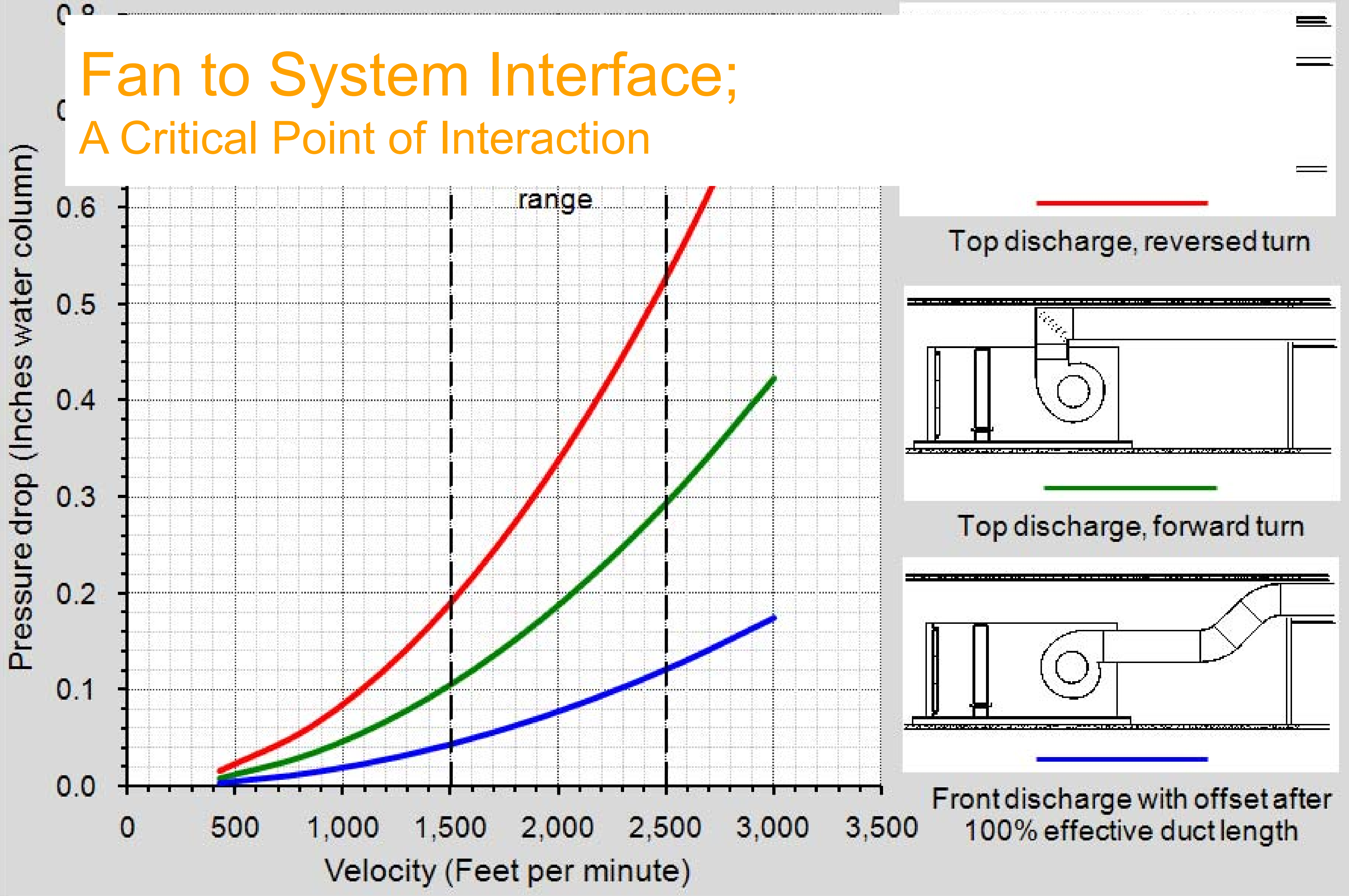
November 7, 2017

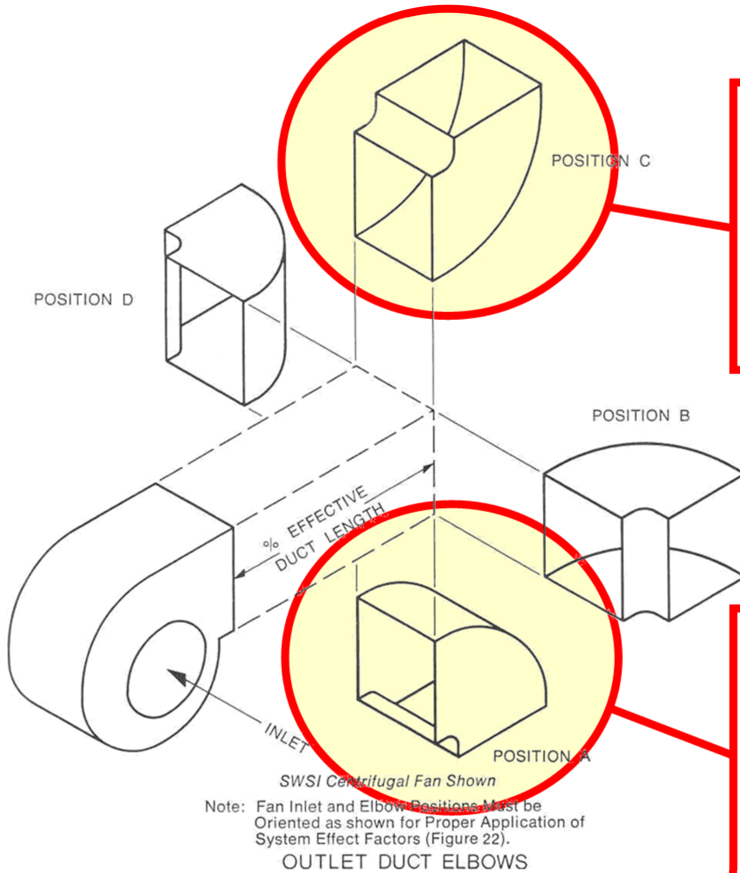
Fan to System Interface;

A Critical Point of Interaction



System Effect Varies with Configuration

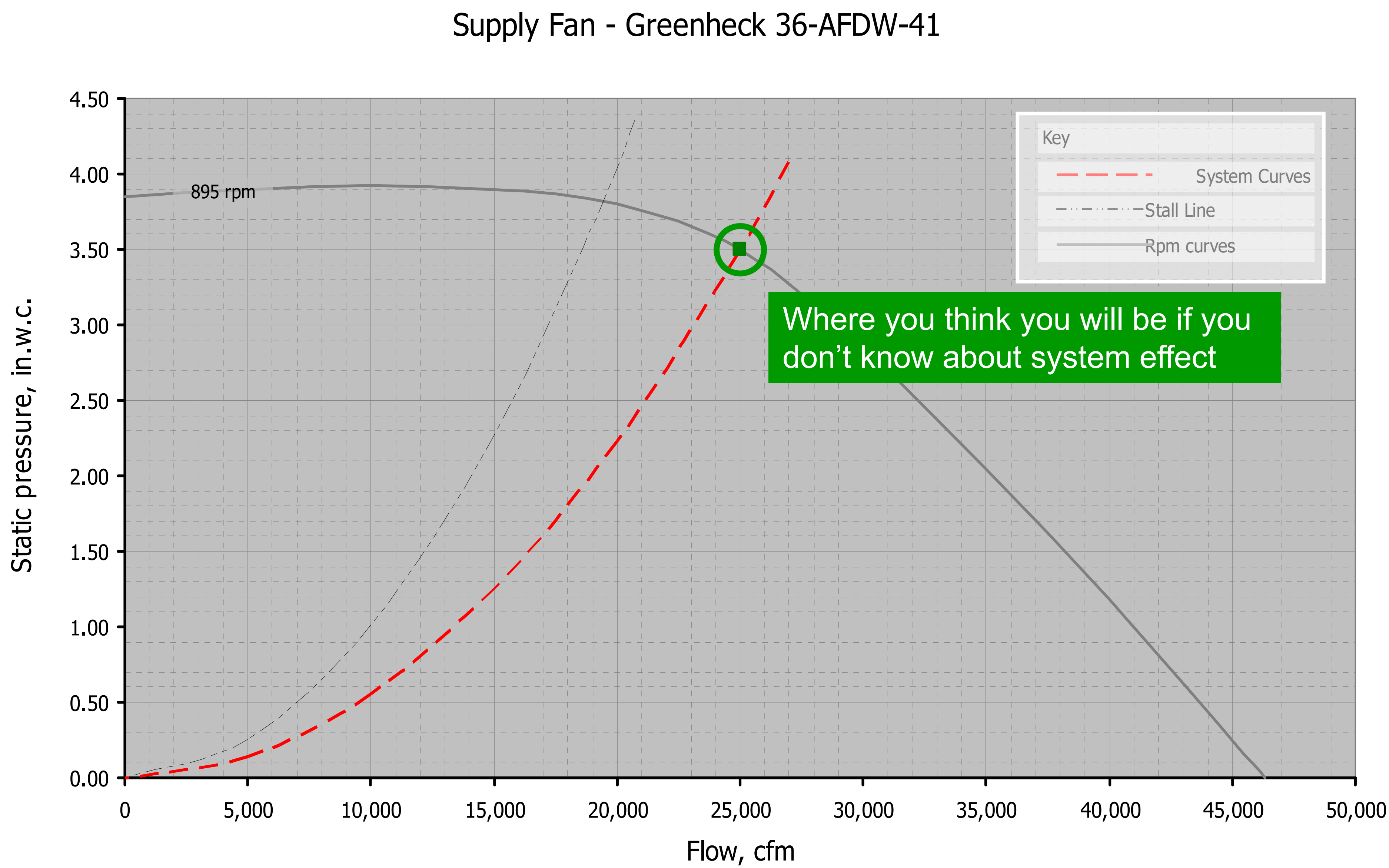
Fitting placement and/or lack of a discharge duct has the same effect as adding static pressure

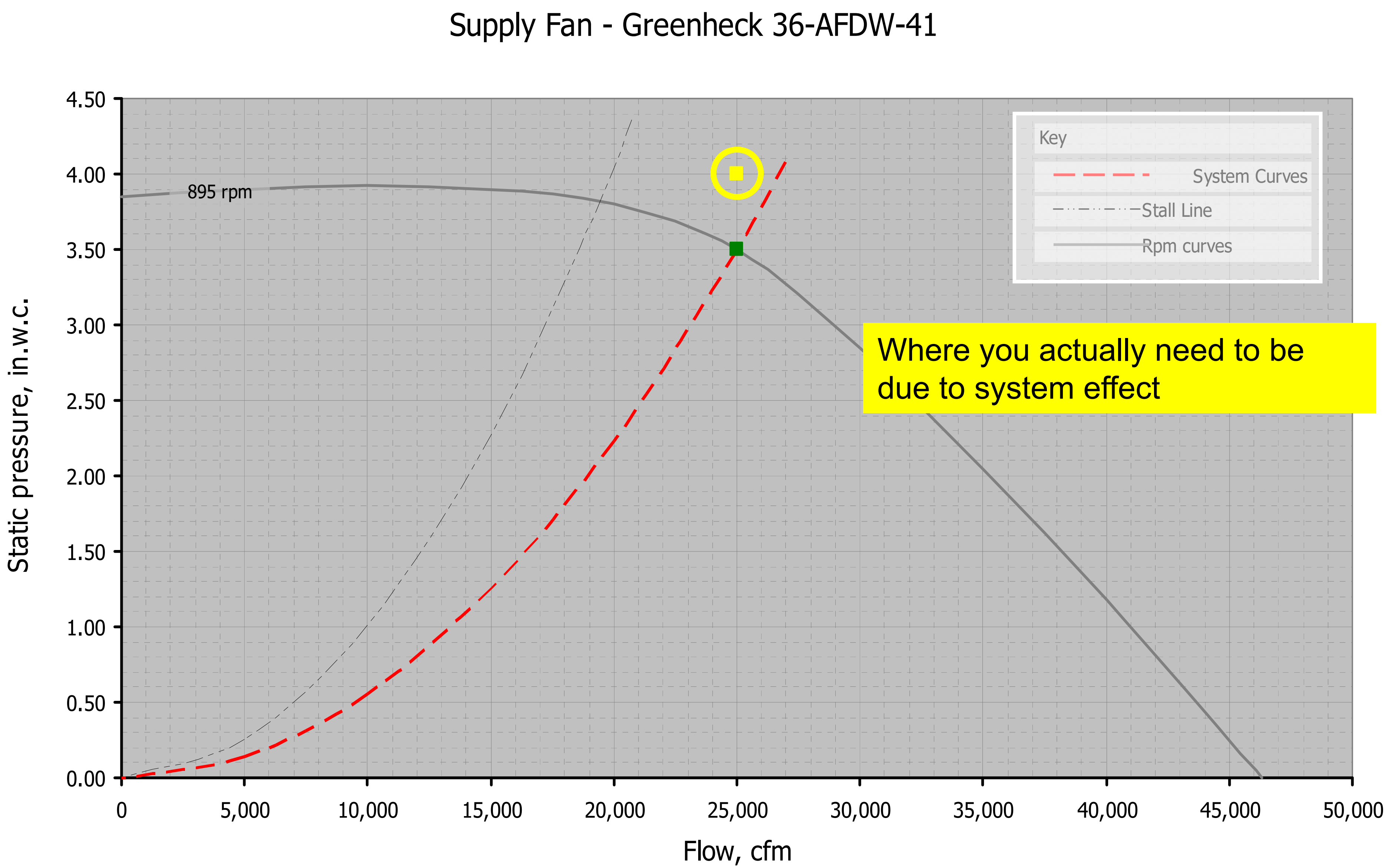


- .55 in.w.c. at 0% effective duct length
- .18 in.w.c. at 50% effective duct length

System effect assessed at 2,500 fpm and an outlet area to blast area ratio of 70%

- .20 in.w.c. at 0% effective duct length
- .05 in.w.c. at 50% effective duct length


Supply Fan - Greenheck 36-AFDW-41
Static pressure, in.w.c.
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
Flow, cfm
895 rpm
Key
System Curves
Stall Line
Rpm curves
Where you think you will be if you don't know about system effect


Supply Fan - Greenheck 36-AFDW-41
Static pressure, in.w.c.
4.50
4.00
3.50
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1.50
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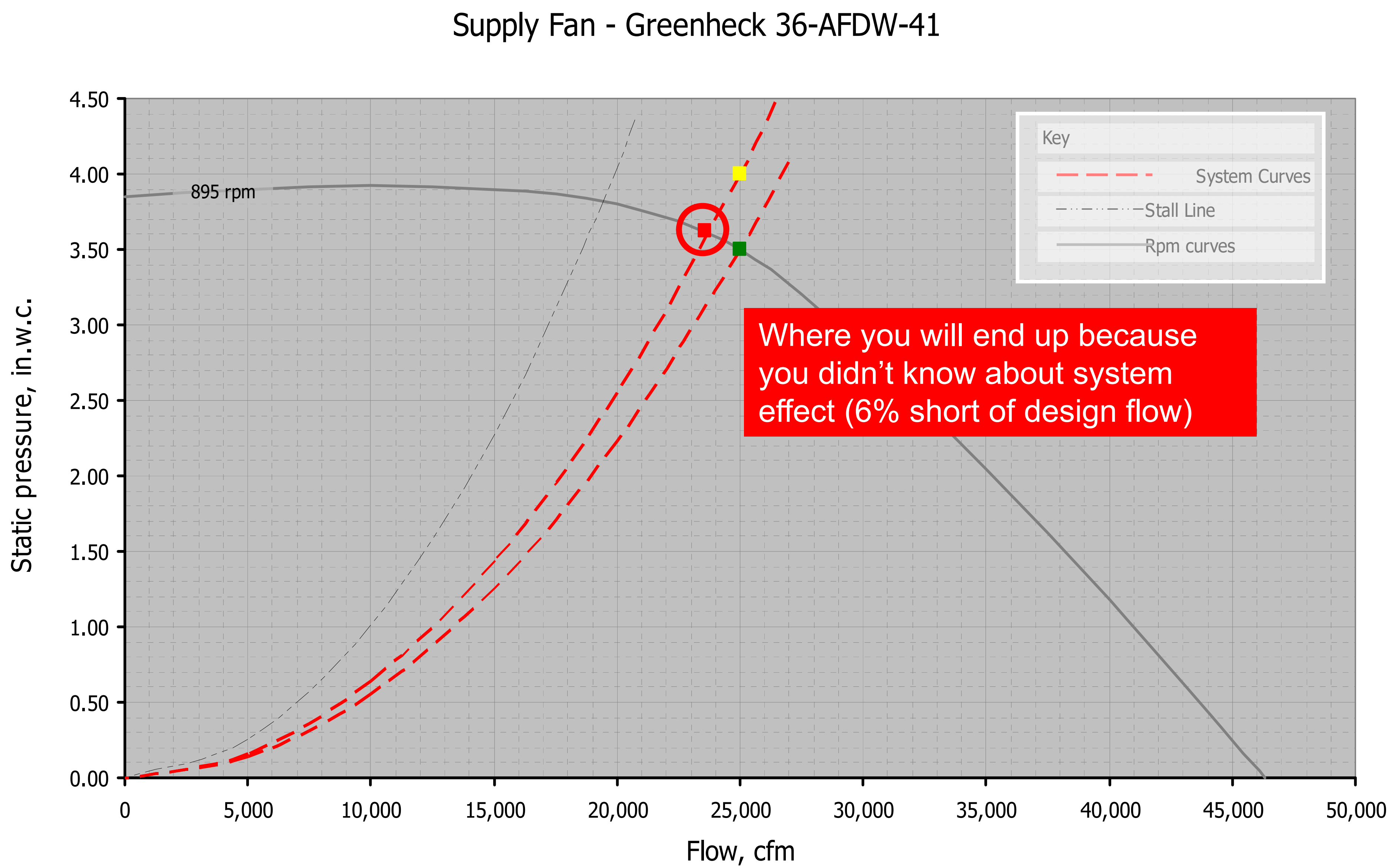
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
Flow, cfm
895 rpm
Key
System Curves
Stall Line
Rpm curves
Where you actually need to be due to system effect



Supply Fan - Greenheck 36-AFDW-41
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Static pressure, in.w.c.
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
Flow, cfm
895 rpm
Key
System Curves
Stall Line
Rpm curves
Where you will end up because you didn't know about system effect (6% short of design flow)

Fan Energy is Directly Related to Flow and Fan Static Pressure

Flow rate – 25,000 cfm

Unnecessary static pressure burden – 0.50 in.w.c.

Fan static efficiency – 72%

Brake horsepower used - 2.8 bhp

Motors Come in Standard Incremental Sizes

Fan brake horsepower requirement is typically less than the incremental motor horsepower supplied

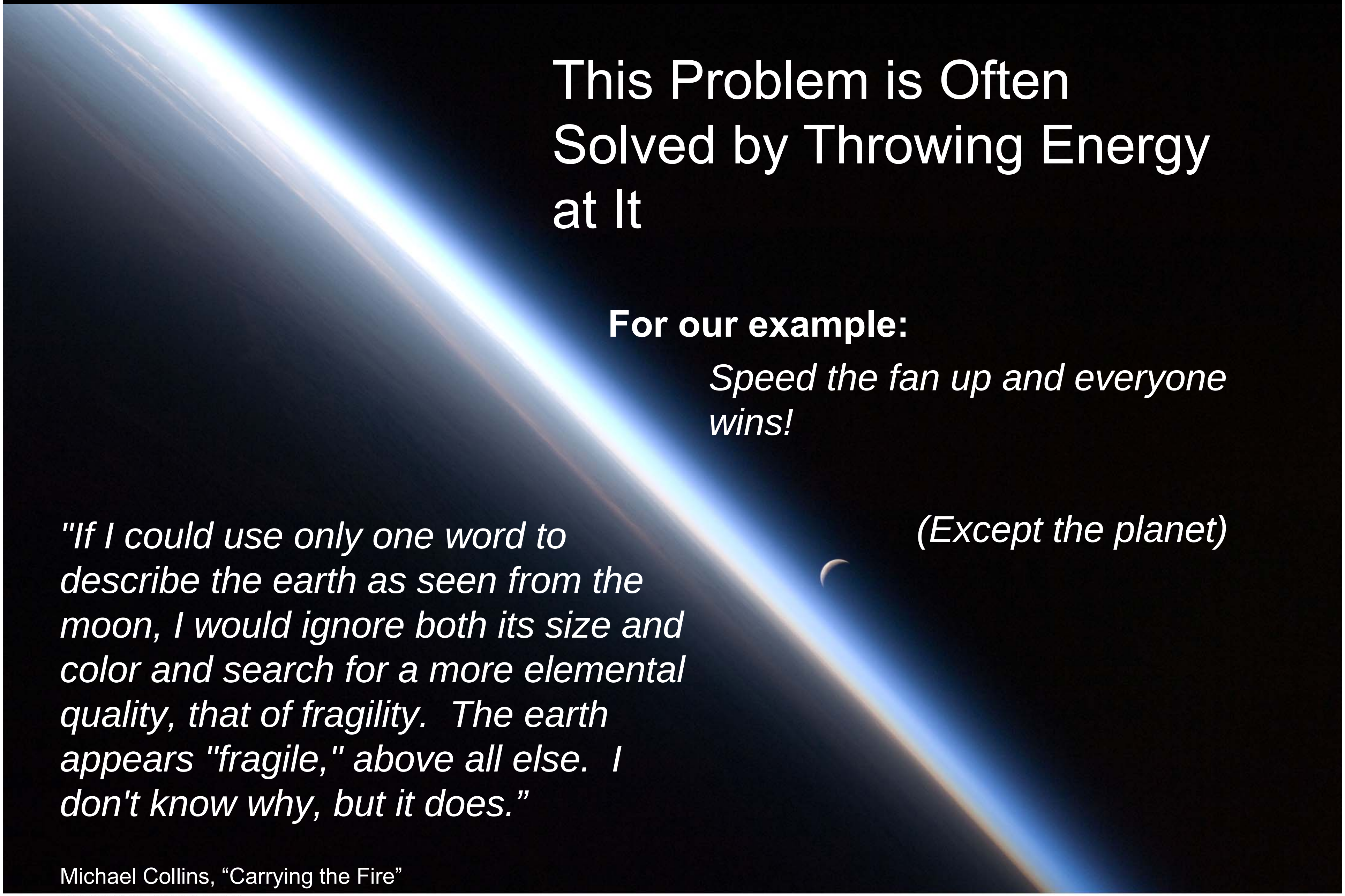
Motor service factor provides some margin for error

- For our example:
  - Brake horsepower at design is approximately 18 bhp
  - Brake horsepower required if system effect is accommodated is approximately 21 bhp
  - Horsepower available from a 20 hp motor with a service factor of 1.15 is 23 hp

This Problem is Often Solved by Throwing Energy at It

For our example:

Speed the fan up and everyone wins!



This Problem is Often Solved by Throwing Energy at It

For our example:

Speed the fan up and everyone wins!

(Except the planet)

"If I could use only one word to describe the earth as seen from the moon, I would ignore both its size and color and search for a more elemental quality, that of fragility. The earth appears "fragile," above all else. I don't know why, but it does."

Michael Collins, "Carrying the Fire"

ISS024E013421

Image Courtesy NASA ISS Image Archives

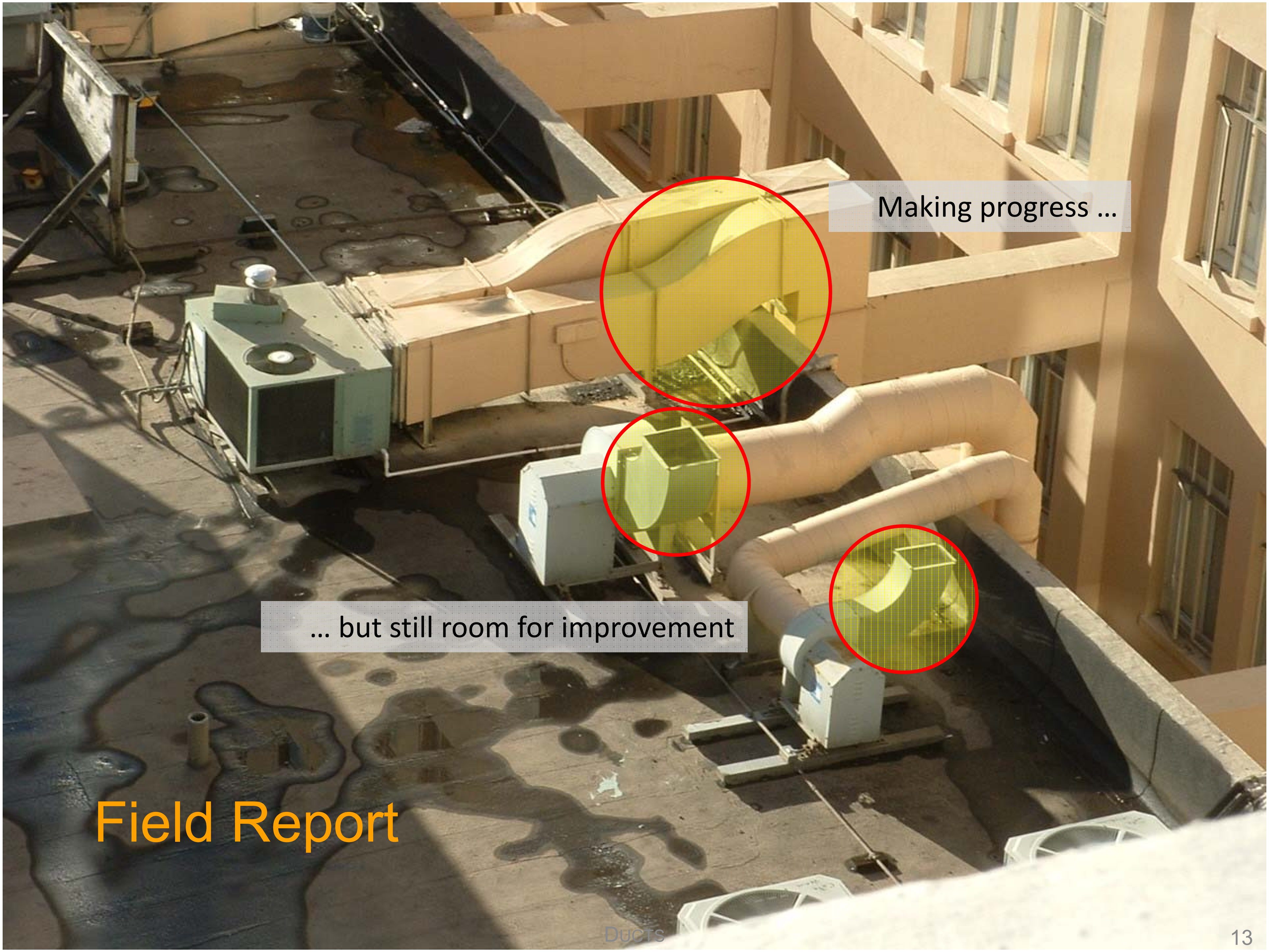
This Problem is Often Solved by Throwing Energy at It

We don't inherit the world
from our ancestors;
We borrow it from our children
Unknown

Remember …

Simply using "Best Practices" could save significant fan energy

"Best Practices" are things we already know how to do


Making progress …
… but still room for improvement
Field Report

Effective Duct Length

For velocities of 2,500 fpm or less:

$$L_{Effective100\%} = 2.5 \times D_E$$

Where:

$L_{Effective100\%}$ = 100% effective duct length as defined by AMCA in consistent units

D_E = Equivalent duct diameter in consistent units.

Note that the ASHRAE definition of an equivalent duct diameter for a round duct uses a different formula from the AMCA definition. The results are very similar however.

For velocities over 2,500 fpm:

$$L_{Effective100\%} = 2.5 \times D_E + \left(D_E \times \left(\frac{V - 2{,}500}{1{,}000} \right) \right)$$

Where:

V = Duct velocity in feet per minute

AMCA 210 requires that the outlet duct has an area no greater than 105% and no less than 95% of the fan outlet area. It also specifies that the slope of a transition element on the discharge be no greater than 15° for converging elements and no greater than 7° for diverging elements.

Rectangular Duct Equivalent Diameter

ASHRAE Basis

$$D_e = \frac{1.3 \times (a \times b)^{.625}}{(a+b)^{.25}}$$

Where:

D_e = The equivalent circular duct diameter in consistent units

a = The dimension of one side of the rectangular duct in consistent units

b = The dimension of the other side of the rectangular duct in consistent units

Source = ASHRAE Handbook of Fundamentals based on work by Huebscher (1948), who developed the relationship. ASHRAE uses it to determine size equivalency based on equal flow, resistance, and length for the table in the Handbook of Fundamentals.

Rectangular Duct Equivalent Diameter
AMCA Basis

$$D_e = \left(\frac{4 \times a \times b}{\pi} \right)^{0.5}$$

Where:

D_e = The equivalent circular duct diameter in consistent units
a = The dimension of one side of the rectangular duct in consistent units
b = The dimension of the other side of the rectangular duct in consistent units
Source = AMCA 201-01, referencing AMCA 99-0066

Flat Oval Duct Equivalent Diameter

ASHRAE Basis

$$D_e = \frac{1.55 \times A_{FlatOval}^{.625}}{P_{FlatOval}^{.25}}$$

Where:

D_e = The equivalent circular duct diameter in consistent units

$A_{FlatOval}$ = The cross sectional area of the flat oval duct in consistent units (see below)

$P_{FlatOval}$ = The perimeter of the flat oval duct in consistent units

$$A_{FlatOval} = \left(\frac{\pi a^2}{4}\right) + \left(a \times \left(A - a\right)\right)$$

Where:

A = The major axis of the flat oval duct (the wide dimension) in consistent units

a = The minor axis of the flat oval duct (the narrow dimension) in consistent units

$$P_{FlatOval} = \left(\pi \times a\right) + \left(2 \times \left(A - a\right)\right)$$

Source = ASHRAE Handbook of Fundamentals based on work by Heyt and Diaz (1975) who developed the relationship. ASHRAE uses it to determine size equivalency based on equal flow, resistance, and length for the table in the Handbook of Fundamentals.

Hydraulic Diameter

$$D_h = 4 \times \left(\frac{A}{P}\right)$$

Where:

D_h = The hydraulic diameter of the duct or pipe in consistent units

A = The duct or pipe area in consistent units

P = The perimeter of the duct or pipe cross-section in consistent units

Source = ASHRAE Handbook of Fundamentals Chapter 21

Darcy Equation for Friction Loss in Duct

$$\Delta p_{Friction} = \left(\frac{12 \times f \times L}{D_h}\right) \times \rho \times \left(\frac{V}{1{,}097}\right)^2$$

Where:

$\Delta p_{Friction}$ = Friction loss for a given length of duct in inches of water column
f = Dimensionless friction factor from the Colebrook equation or a Moody Diagram
L = Duct length in feet
D_h = Hydraulic diameter in inches
ρ = Density in pounds per cubic foot
V = Velocity in feet per minute

Reynolds Number

If you look up the friction factor in a Moody Chart, you will need to know Reynolds number and relative roughness.

$$Re = \left(\frac{D_h \times V}{720 \times \upsilon} \right)$$

Where:

Re = Reynolds number (dimensionless)
D_h = Hydraulic diameter in inches
V = Velocity in feet per minute
υ = kinematic viscosity in feet squared per second

For air between 40 and 100°F, this equation can be simplified to:

$$Re = 8.50 \times D_h \times V$$

Source - ASHRAE Handbook of Fundamentals Chapter 21

Relative Roughness

Relative roughness is determined from absolute roughness and hydraulic diameter as follows:

$$\text{Relative Roughness} = \frac{\varepsilon}{D_h}$$

Where

ε = Absolute roughness factor in feet (determined by experiement)

Absolute roughness is determined via experiment.

If you use the Colebrook equation, you have to itterate to a solution based on Reynolds number, absolute roughness, and hydraulic diameter.

Nikuardse's Experiment

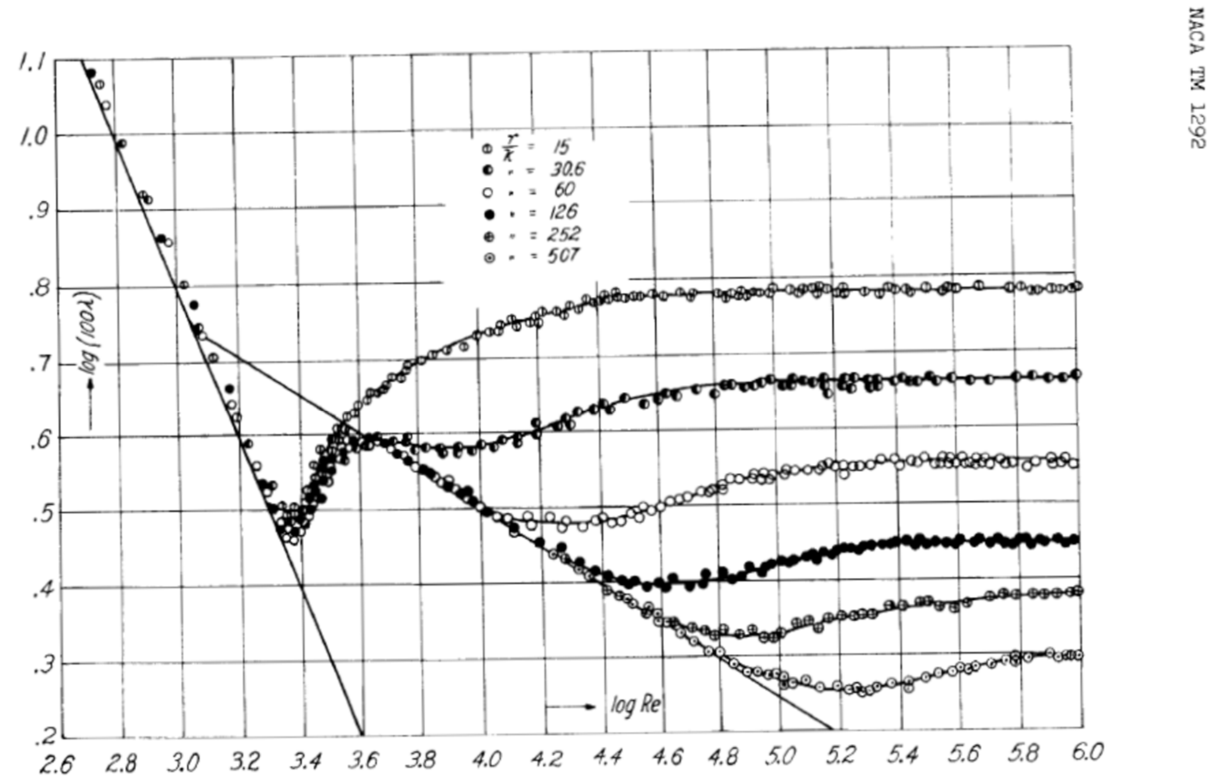
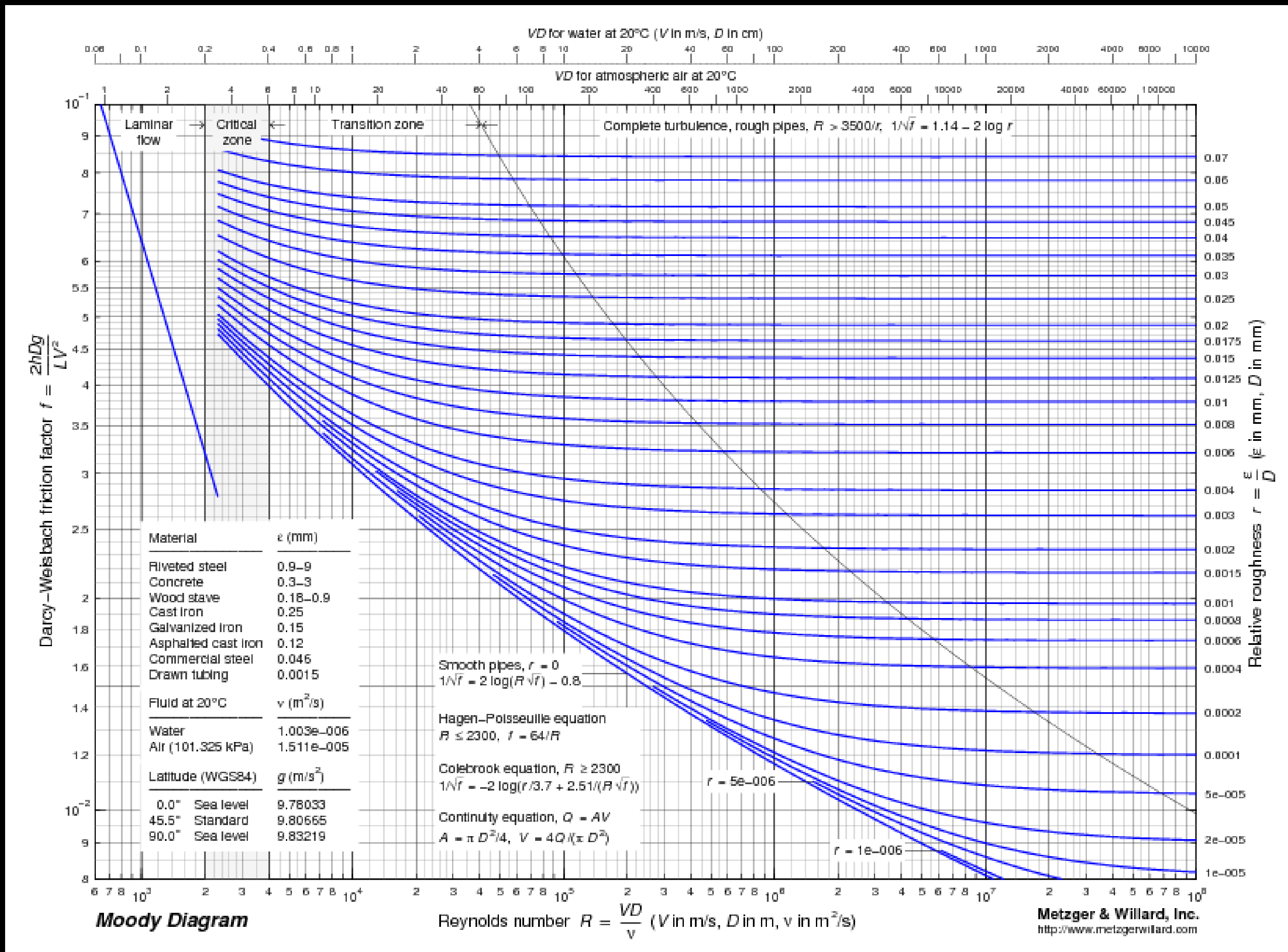


Figure 9.- Relation between log(100 λ) and log Re.

Moody Diagram



Duct Friction Chart

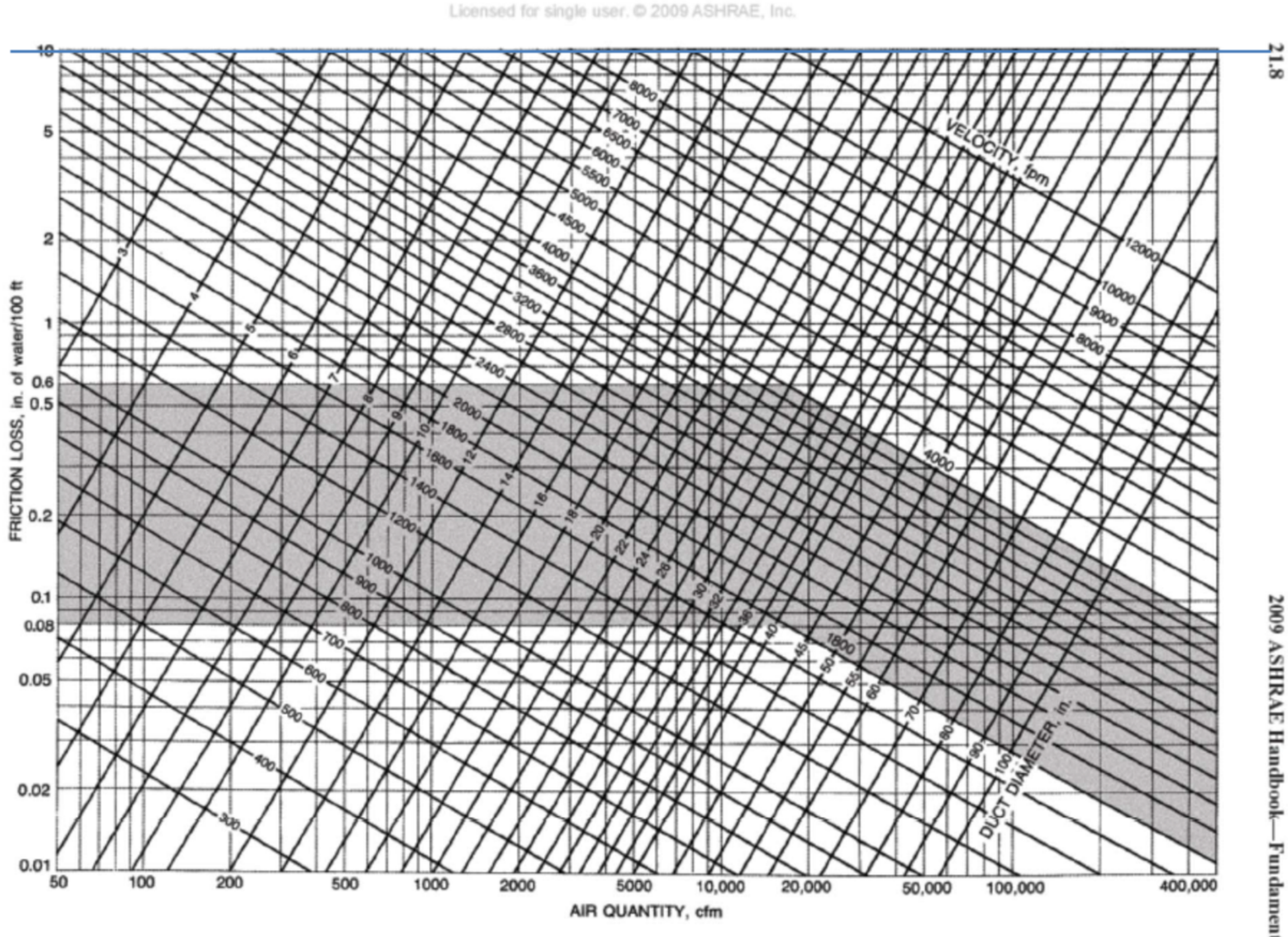
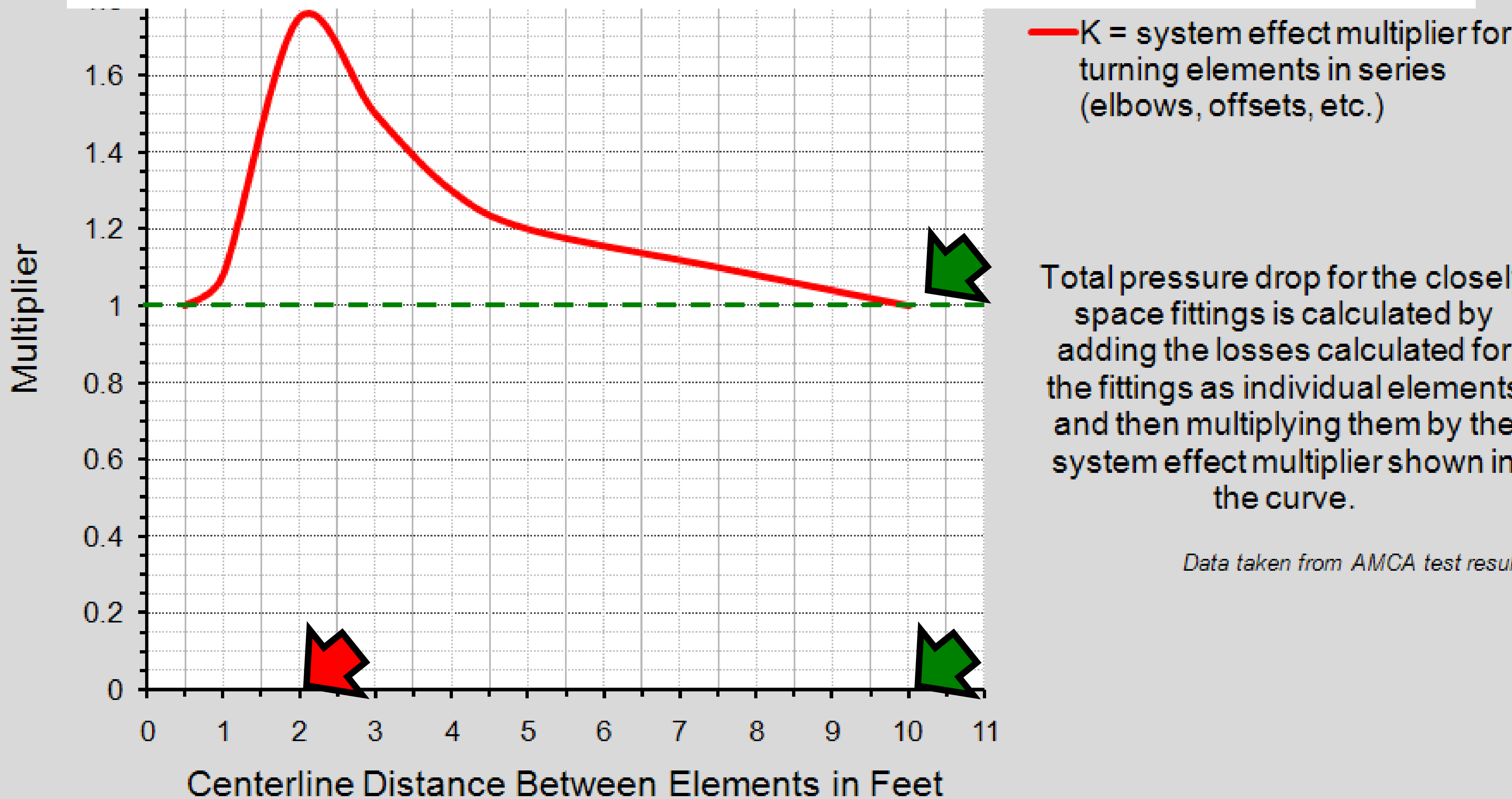


Fig. 9 Friction Chart for Round Duct ($\rho = 0.075\ lb_m/ft^3$ and $\varepsilon = 0.0003$ ft)

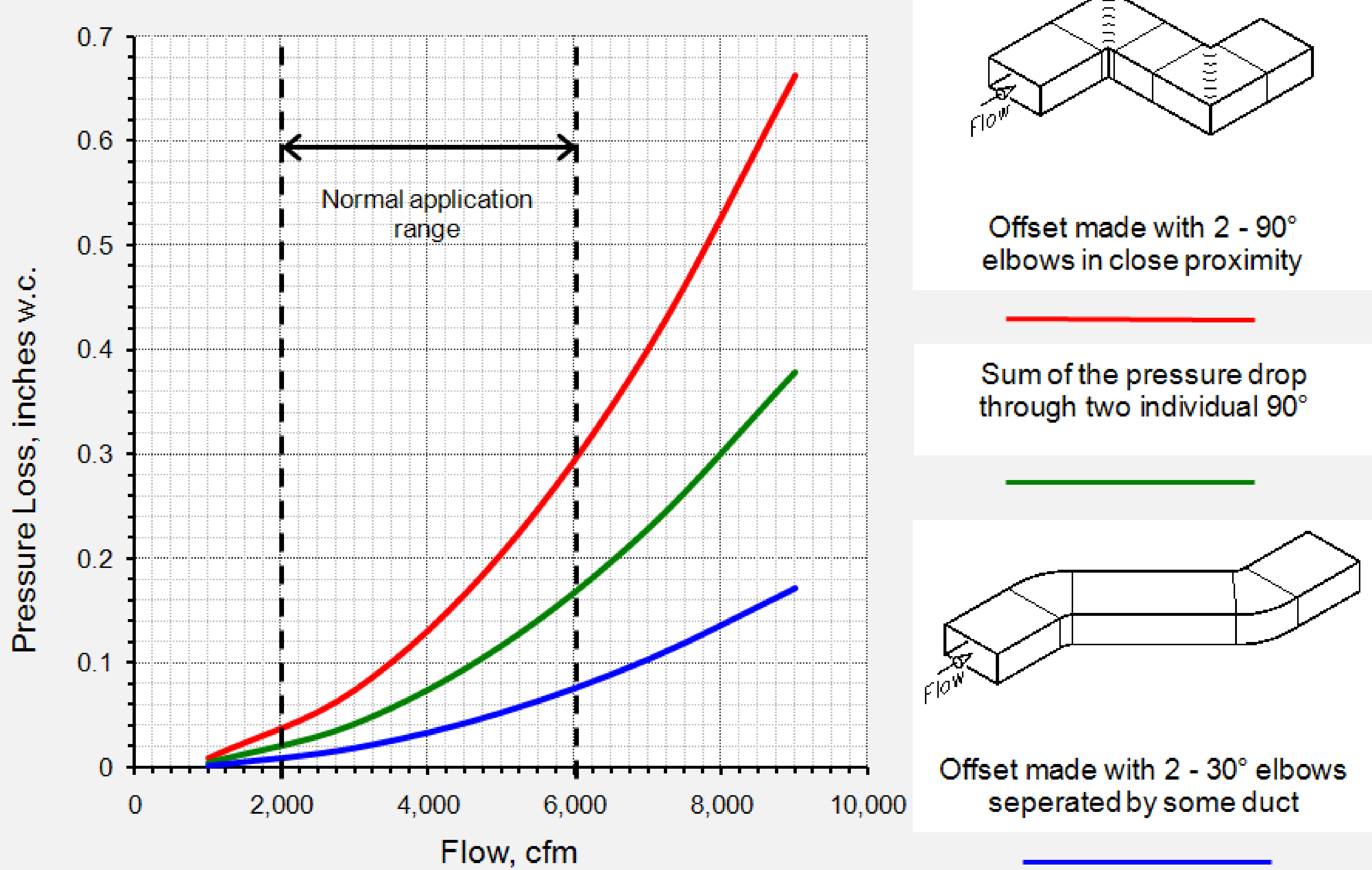
System Effect and Duct Fittings
(Fittings Interact!)



Total pressure drop for the closely space fittings is calculated by adding the losses calculated for the fittings as individual elements and then multiplying them by the system effect multiplier shown in the curve.

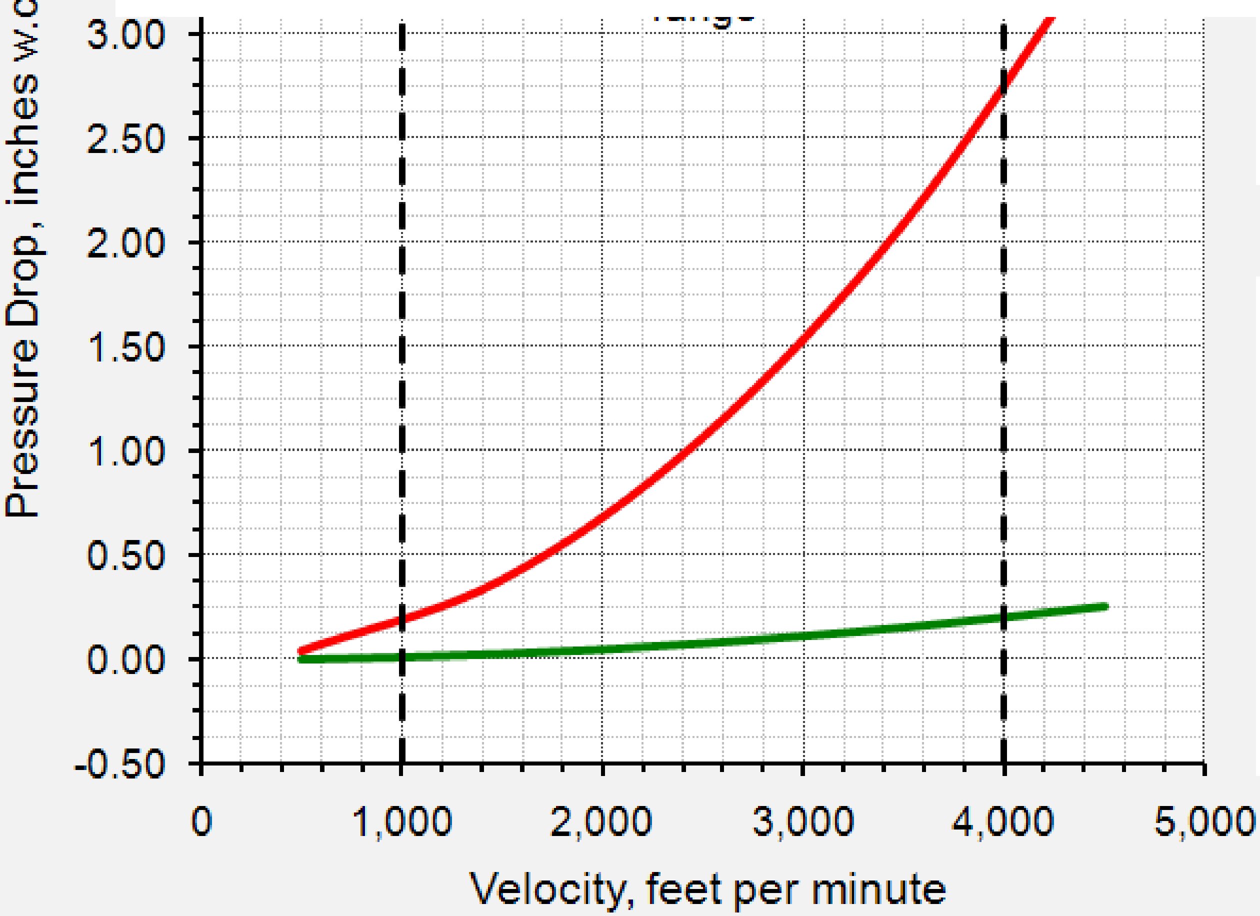
Data taken from AMCA test results

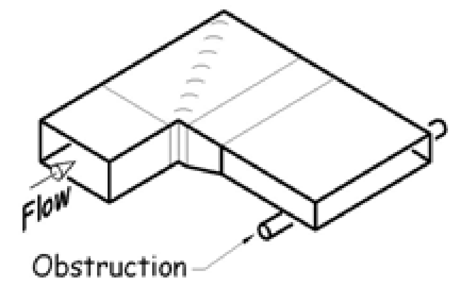
Duct Offset Options

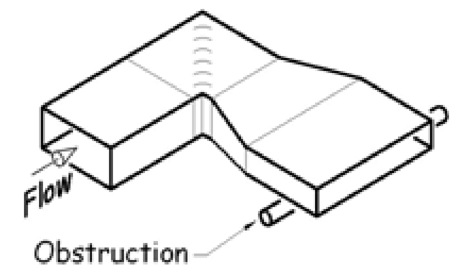


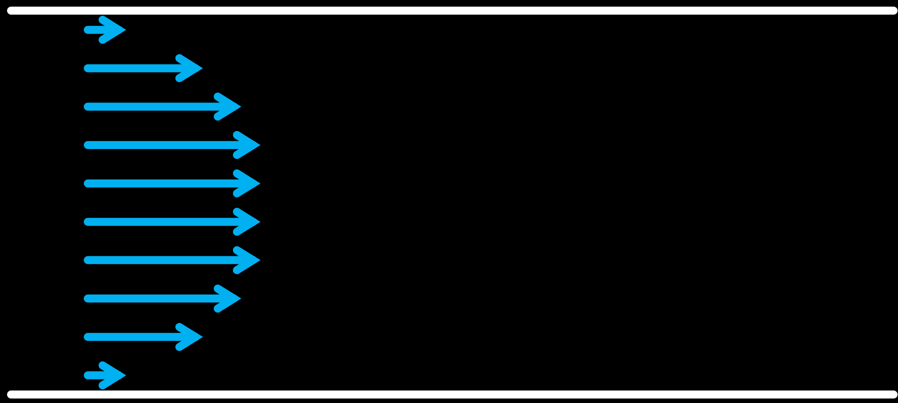
Expanding Elbow vs. Non-expanding Elbow

Subtle Geometry Difference = Big Pressure Drop Difference

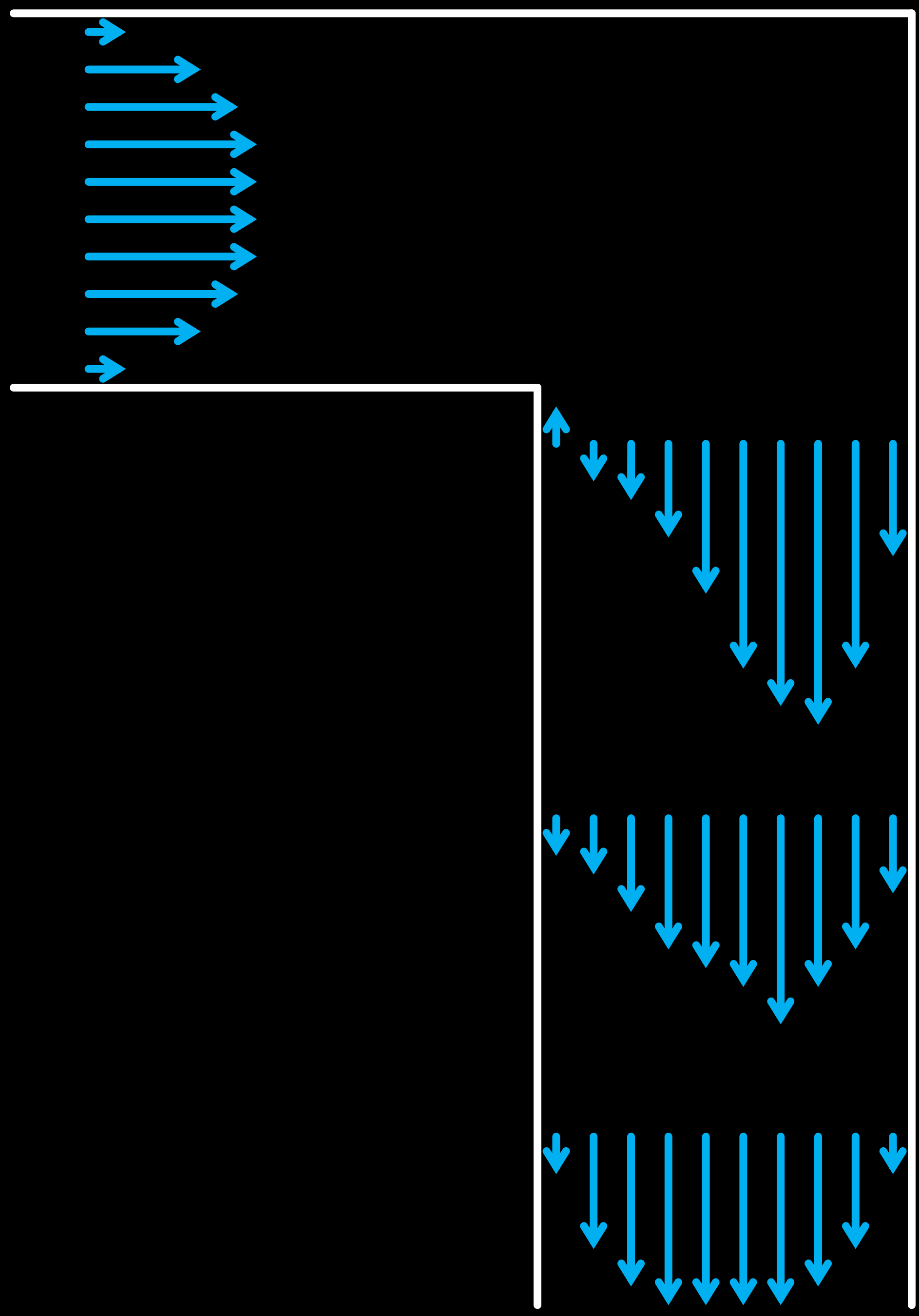








Loss coefficients rely on a uniform velocity profile for accurate measurements



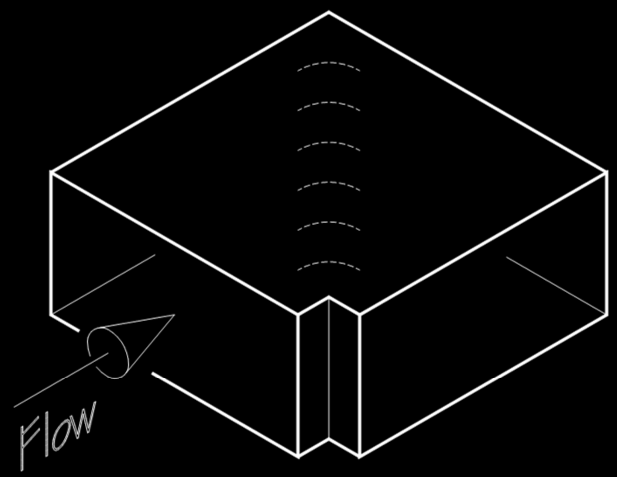
Turns and other obstructions distort the flow profile

Interactions between the air and the duct wall will eventually restore the uniform flow profile

Generally takes 5-10 equivalent duct diameters of distance

Typical Terminal Unit Inlet Duct

Using Loss Coefficients



$$\Delta p_{fitting} = C_o \, p_{velocity}$$

Where :

$\Delta p_{fitting}$ = Fitting pressure loss

C_o = Local loss coefficient from ASHRAE tables or equivalent

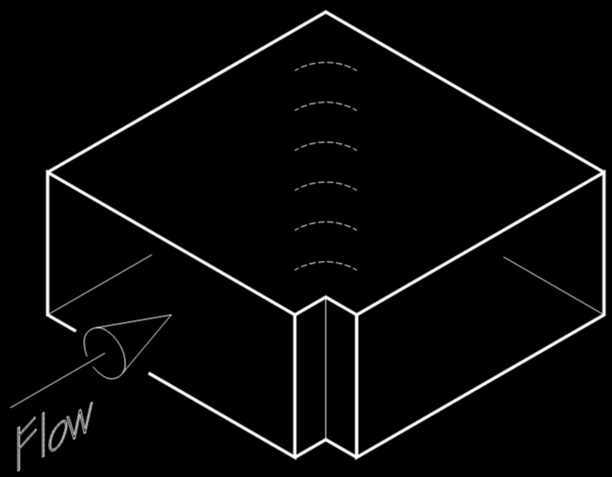
$p_{velocity}$ = Velocity pressure

Velocity Pressure is *VERY* significant

$$V = 4{,}005\sqrt{p_{velocity}}$$

Therefore :

$$p_{velocity} = \left(\frac{V}{4{,}005}\right)^2$$



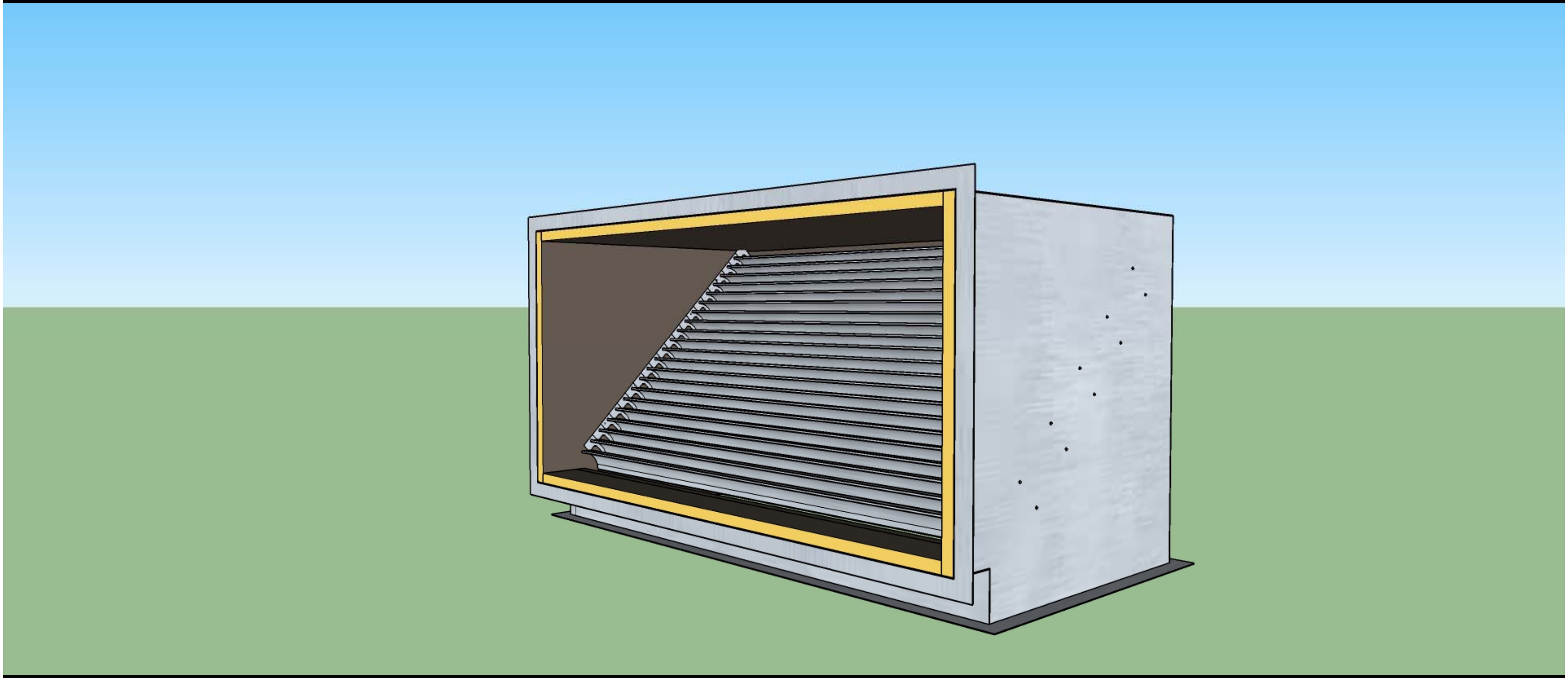
Where :

$p_{velocity}$ = Velocity pressure in inches water column

V = Velocity in feet per minute

4,005 = A units conversion constant

A Closer Look at a Mitered Elbow



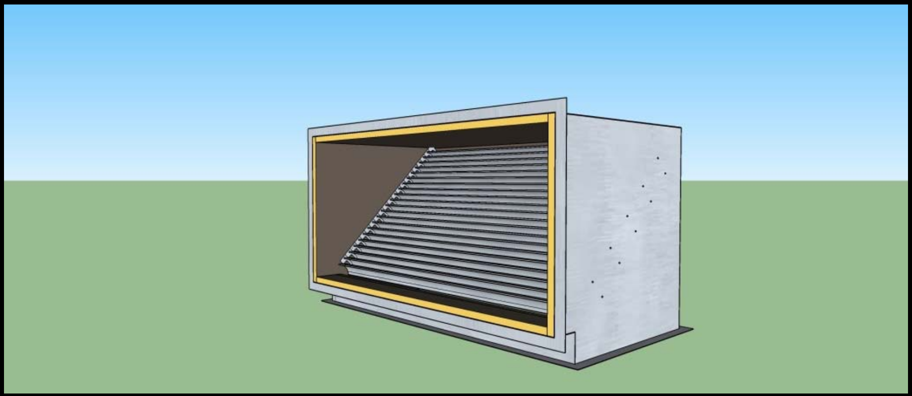
An Exercise

Velocity Pressure Calculation

$$p_{velocity} = \left(\frac{V}{4{,}005}\right)^2$$

$$p_{velocity} = \left(\frac{1{,}500}{4{,}005}\right)^2$$

$$p_{velocity} = 0.14 \text{ inches w.c.}$$



What is the loss for the fitting?

An Exercise

Velocity Pressure Calculation

$$p_{velocity} = \left(\frac{V}{4,005}\right)^2$$

$$p_{velocity} = \left(\frac{1,500}{4,005}\right)^2$$

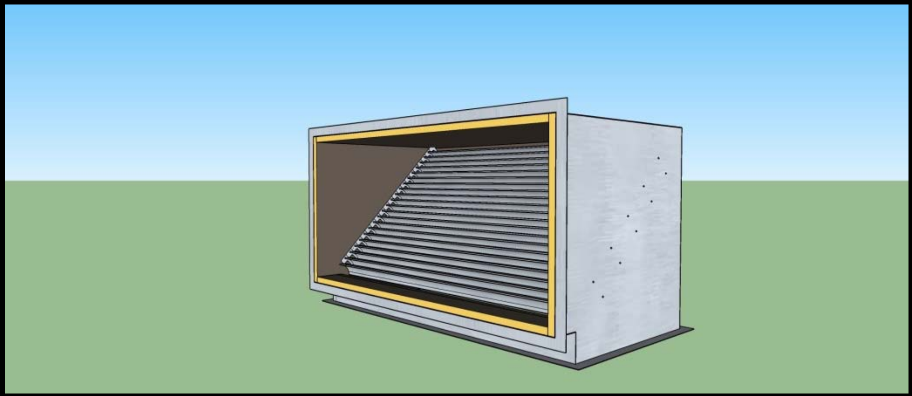
$$p_{velocity} = 0.14 \text{ inches w.c.}$$

Fitting Loss Calculation

$$\Delta p_{fitting} = C_o \times p_{velocity}$$

$$\Delta p_{fitting} = 0.41 \times 0.14$$

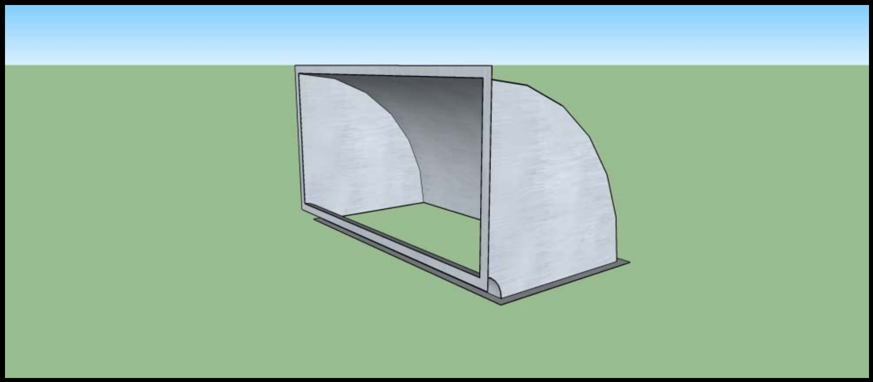
$$\Delta p_{fitting} = 0.06 \text{ inches w.c.}$$



What is the loss for the fitting?

Different Geometry = Different Loss

Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case

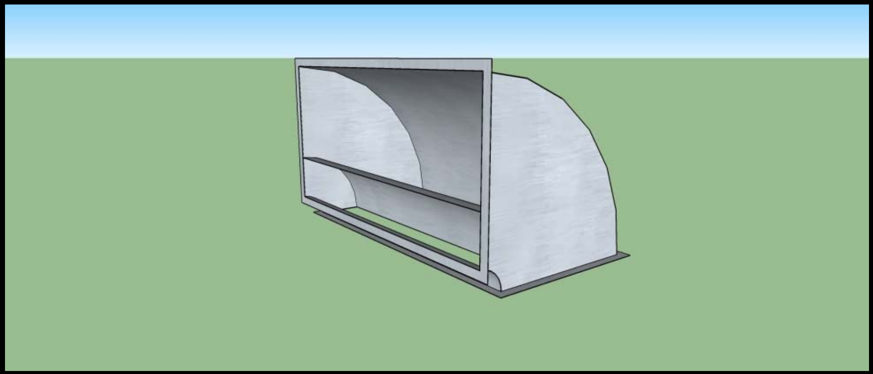


Base Case

- Square duct
- Low velocity
- 12” centerline radius
- No vanes

Different Geometry = Different Loss

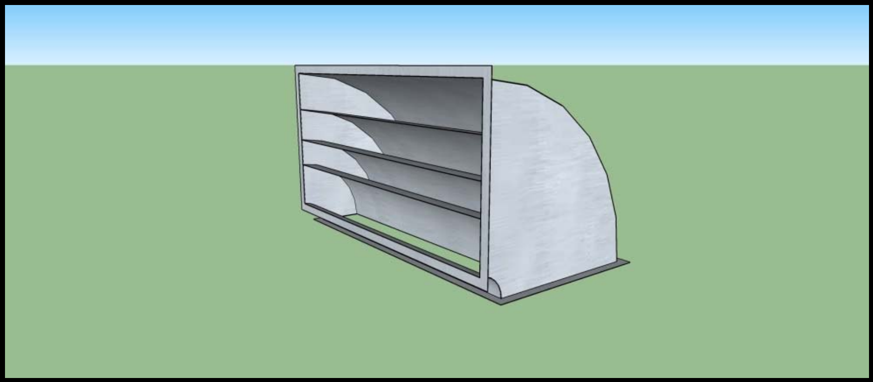
Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case
12	12	12	1	1,500	1,500	0.14	0.05	0.01	33%



Base Case with One Vane

Different Geometry = Different Loss

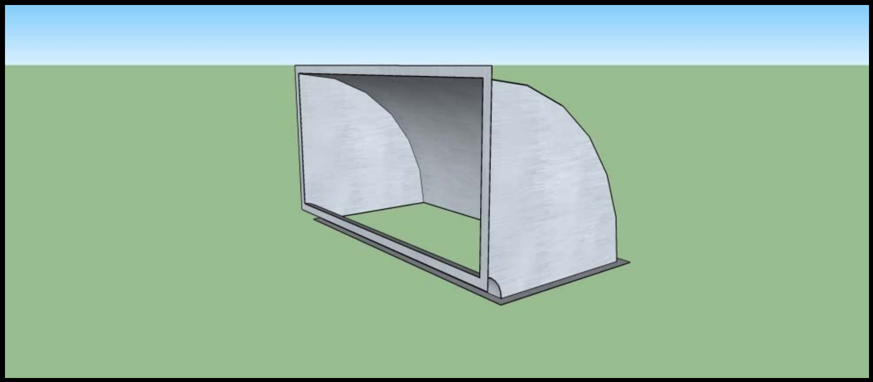
Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case
12	12	12	1	1,500	1,500	0.14	0.05	0.01	33%
12	12	12	3	1,500	1,500	0.14	0.01	No measurable loss	



Base Case with Three Vanes

Different Geometry = Different Loss

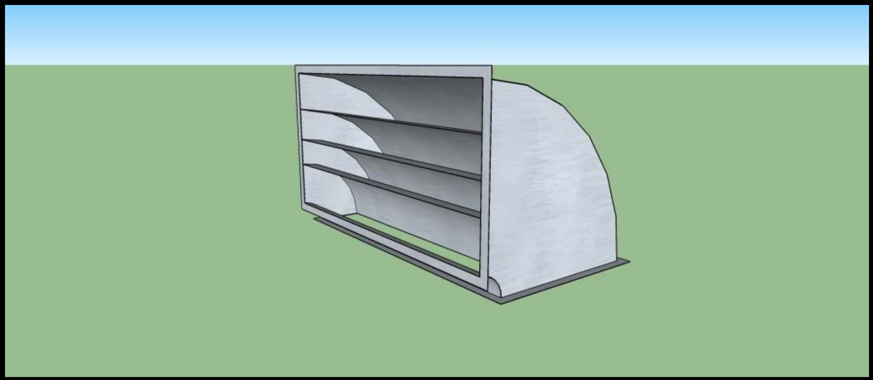
Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case
12	12	12	1	1,500	1,500	0.14	0.05	0.01	33%
12	12	12	3	1,500	1,500	0.14	0.01	No measurable loss	
12	12	12	0	3,000	3,000	0.56	0.21	0.12	400%



Base Case with Twice as Much Air Flow (Twice the Velocity)

Different Geometry = Different Loss

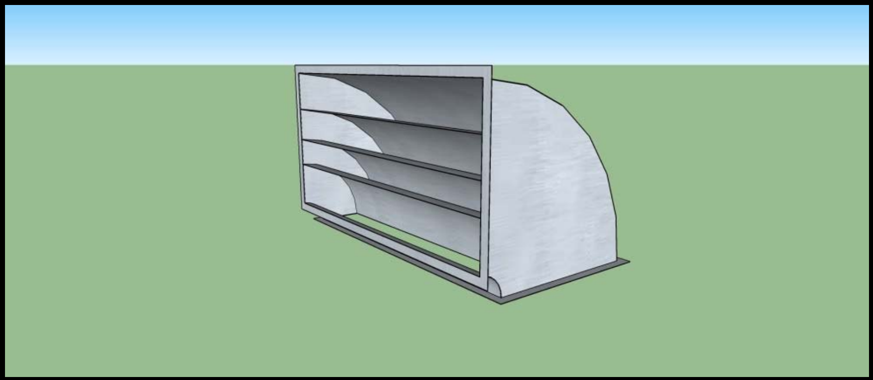
Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case
12	12	12	1	1,500	1,500	0.14	0.05	0.01	33%
12	12	12	3	1,500	1,500	0.14	0.01	No measurable loss	
12	12	12	0	3,000	3,000	0.56	0.21	0.12	400%
12	12	12	3	3,000	3,000	0.56	0.01	0.01	33%



Base Case with Three Vanes and Twice as Much Air Flow (Twice the Velocity)

Different Geometry = Different Loss

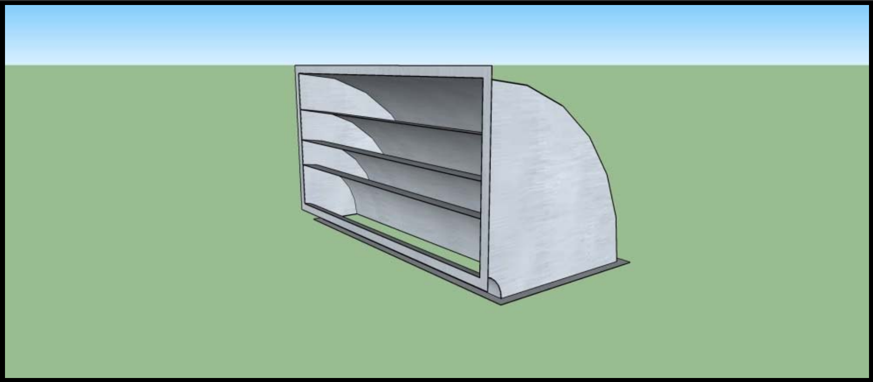
Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case
12	12	12	1	1,500	1,500	0.14	0.05	0.01	33%
12	12	12	3	1,500	1,500	0.14	0.01	No measurable loss	
12	12	12	0	3,000	3,000	0.56	0.21	0.12	400%
12	12	12	3	3,000	3,000	0.56	0.01	0.01	33%
12	12	8	3	3,000	3,000	0.56	0.04	0.02	67%



Base Case with Three Vanes and a Smaller Centerline Radius and Twice as Much Air Flow (Twice the Velocity)

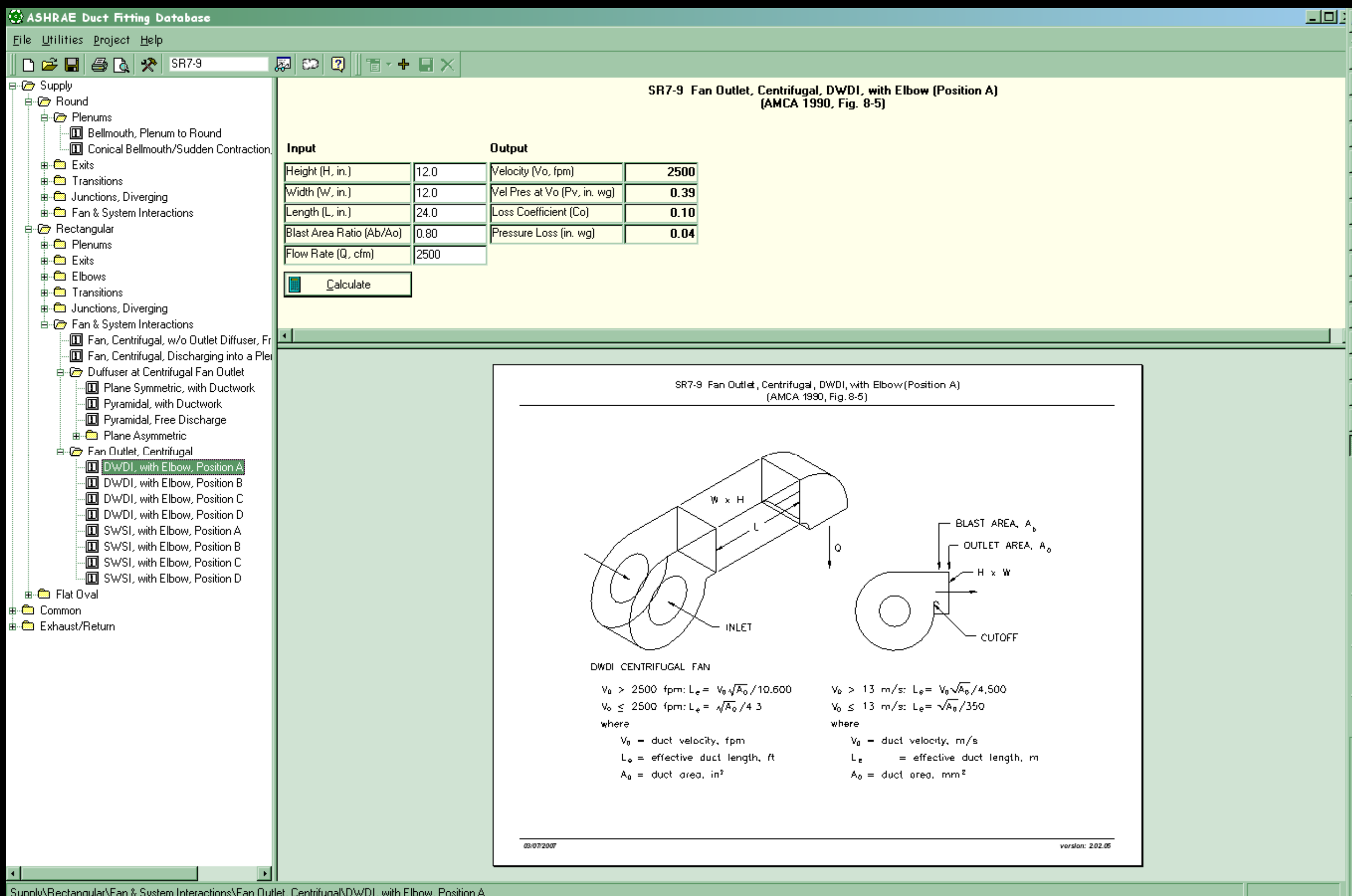
Different Geometry = Different Loss

Losses Through A Radius 90 Degree Elbow with Different Flows, Numbers of Vanes, Turning Radiuses, and Aspect Ratios									
Height (inches)	Width (inches)	Centerline Radius (inches)	Number of Vanes	Flow (cfm)	Velocity (fpm)	Velocity Pressure (inches w.c.)	Loss Coefficient	Loss	
								inches w.c.	% of base case
12	12	12	0	1,500	1,500	0.14	0.21	0.03	Base Case
12	12	12	1	1,500	1,500	0.14	0.05	0.01	33%
12	12	12	3	1,500	1,500	0.14	0.01	No measurable loss	
12	12	12	0	3,000	3,000	0.56	0.21	0.12	400%
12	12	12	3	3,000	3,000	0.56	0.01	0.01	33%
12	12	8	3	3,000	3,000	0.56	0.04	0.02	67%
21	7	12	3	3,000	2,939	0.54	0.09	0.05	167%



Base Case with Three Vanes, and a High Aspect Ratio (Thin and Wide) and Twice as Much Air Flow (Twice the Velocity)

A Tool that Makes the Analysis Easy



A Recent Field Example

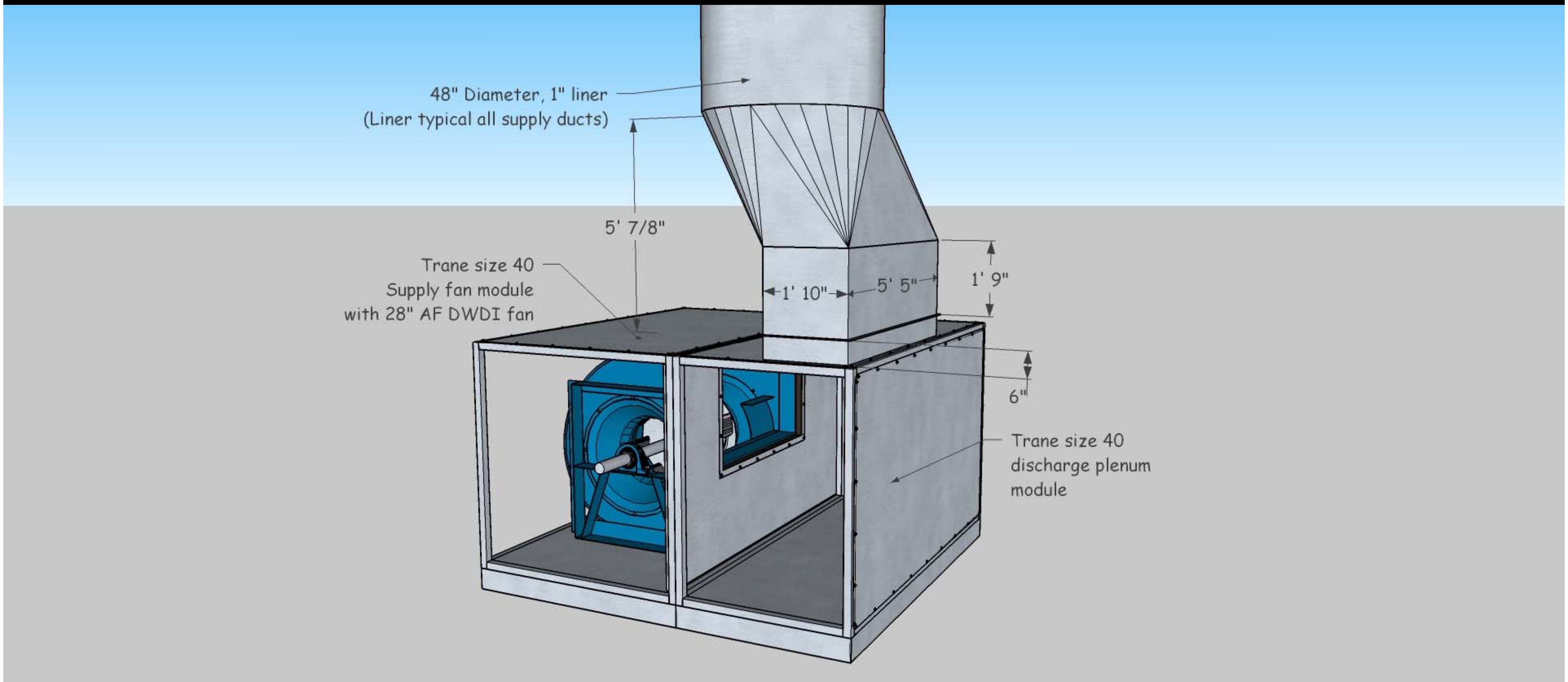

Shortridge Instruments, Inc.
In: -2.652
•AIR FLOW • VELOCITY • PRESSURE • TEMPERATURE•
AIRDATA™ MULTIMETER ADM-870
MADE IN USA
ELECTRONIC MICROMANOMETER


AHU-1


PEC
Shortridge Instruments, Inc.
In: -2.430
•AIR FLOW • VELOCITY • PRESSURE • TEMPERATURE•
AIRDATA™ MULTIMETER ADM-870
ELECTRONIC MICROMANOMETER

Assessing the Operating Point

Flow based on coil pressure drop - AHU2 Retested		
Entering coil pressure at the time of my test -	0.8429	in.w.c.
Leaving coil pressure at the time of my test -	0.7294	in.w.c.
Coil pressure drop -	0.1135	in.w.c.
Rated coil pressure drop at design flow -	0.384	in.w.c.
Coil rated flow -	20,000	cfm
Estimated flow rate based on coil pressure drop and the square law -	10,871	cfm


48" Diameter, 1" liner
(Liner typical all supply ducts)
5' 7/8"
Trane size 40
Supply fan module
with 28" AF DWDI fan
1' 10"
5' 5"
1' 9"
6"
Trane size 40
discharge plenum
module

Interesting Relationships

Looking at Different Options for Moving 10,000 cfm at a Nominal .2 in.w.c./100 ft., 2 inch Pressure Class Duct

Duct Size - inches			Aspect Ratio	Cross Sectonal Area - sq.ft.	Perimeter - ft.	Ratio of Cross Sectional Area to Perimeter	Gauge	Pounds of Sheetmetal per lineal foot of duct	Velocity - fpm
Height	Width	Diameter							
N/A	N/A	29.0	N/A	4.59	7.59	0.60	24	9.10	2,180
26.5	26.5	N/A	1.0	4.88	8.83	0.55	26	8.00	2,051
18.0	41.0	N/A	2.3	5.13	9.83	0.52	24	11.37	1,951
14.0	56.0	N/A	4.0	5.44	11.67	0.47	24	13.49	1,837
12.0	70.0	N/A	5.8	5.83	13.67	0.43	24	15.80	1,714

Round duct weight information based on spiral construction.

Interesting Relationships

Looking at Different Options for Moving 10,000 cfm at a Nominal .2 in.w.c./100 ft.,
2 [illegible]

Higher velocities for ducts with less sheet metal implies higher operating cost all things being equal and more susceptibility problems due to poor fitting design

Duct Size - inches			Aspect Ratio	Cross Sectional Area - sq.ft.	Perimeter - ft	Ratio of Cross Sectional Area to Perimeter	Gauge	Pounds of Sheetmetal per lineal foot of duct	Velocity - fpm
Height	Width	Diameter							
N/A	N/A	29.0	N/A	4.59	7.59	0.60	24	9.10	2,180
26.5	26.5	N/A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.00	2,051
18.0	41.0	N/A	[illegible]	[illegible]	[illegible]	[illegible]	24	11.37	1,951
14.0	56.0	N/A	[illegible]	[illegible]	[illegible]	[illegible]	24	[illegible]	1,837
12.0	70.0	N/A	[illegible]	5.8	5.83	13.67	0.43	24	15.80	1,714

Round duct weight information based on spiral construction

Less sheet metal for a round or low aspect ratio duct implies a more sustainable solution (fewer resources used) assuming building height is not affected

Interesting Relationships

Velocities and Velocity Pressures in Small vs. Large Ducts at Equal Friction Rates

Duct Size - inches			Aspect Ratio	Cross Sectonal Area - sq.ft.	Perimeter - ft.	Ratio of Cross Sectional Area to Perimeter	CFM Capcity at a Friction Rate of .15 in.w.c. per 100 ft.	Velocity - fpm	Velocity Pressure - in.w.c.
Height	Width	Diameter							
N/A	N/A	6.0	N/A	0.20	1.57	0.13	130	662	0.03
N/A	N/A	48.0	N/A	12.57	12.57	1.00	32,000	2,546	0.40
6.0	12.0	N/A	2.0	0.50	3.00	0.17	420	840	0.04
24.0	48.0	N/A	2.0	8.00	12.00	0.67	16,500	2,063	0.27

Interesting Relationships

Velocities and Velocity Pressures in Small vs. Large Ducts at Equal Friction Rates

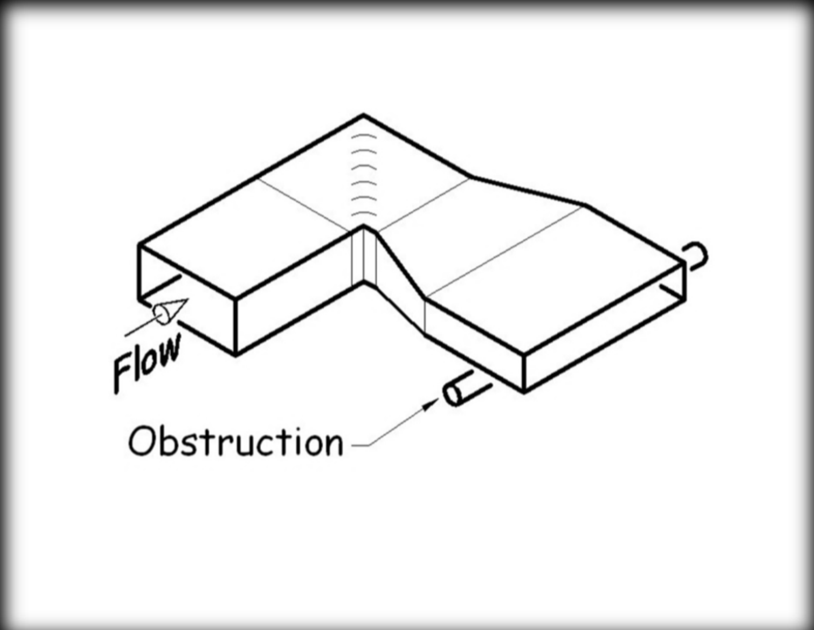
Duct Size - inches			Aspect Ratio	Cross Sectonal Area - sq.ft.	Perimeter - ft.	Ratio of Cross Sectional Area to Perimeter	CFM Capcity at a Friction Rate of .15 in.w.c. per 100 ft.	Velocity - fpm	Velocity Pressure - in.w.c.
Height	Width	Diameter							
N/A	N/A	6.0	N/A	0.20	1.57	0.13	130	662	0.03
N/A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00	32,000	2,546	0.40
6.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.67	[illegible]	[illegible]	[illegible]

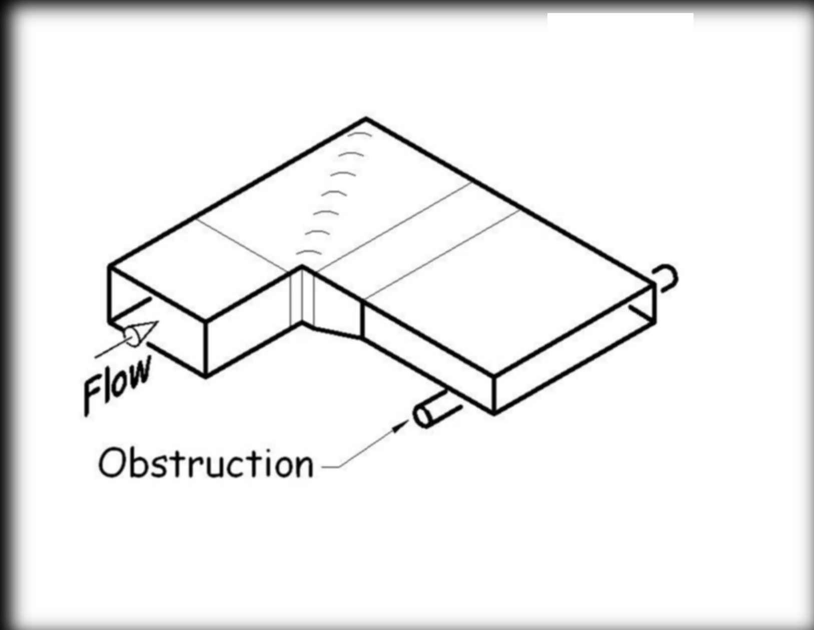
Small ducts don't handle much air relative to large ducts at the same friction rate because a relatively small volume of air is contained by a relatively large sheet metal perimeter.

Thus, small duct velocities and velocity pressures are low relative to large ducts and poor fittings are not as much of an issue.

I Specify Construction to SMACNA Standards so I'll Get Low Loss Fittings

Maybe … **… or Maybe Not**





SMACNA is a design and construction standard, not an efficiency standard

For Any Given SMACNA Duct or Fitting:

There are multiple combinations of metal thickness (gauge) and reinforcement

3 in. w.c. Positive or Negative Duct Construction (SMACNA HVAC Duct Construction Standards Metal and Flexible, 3rd Edition)

Duct Dimension - in	No	Reinforcement Spacing Options - feet							
					5	4	3	2.5	2
11-					B-26	B-26	B-26	B-26	B-26
13-					C-24	C-26	C-26	B-26	B-26
15-					C-26	C-26	C-26	C-26	
17-18	20		D-24	D-24	C-24	C-26	C-26	C-26	C-26
19-20	18		D-22	D-22	D-24	D-24	C-26	C-26	C-26
21-22	18		E-22	E-22	D-24	D-24	D-26	C-26	C-26
23-24	18		E-20	E-22	E-24	E-24	D-26	D-26	C-26
25-26	18		F-20	E-22	E-24	E-24	D-26	D-26	C-26
27-28	18		F-20	F-20	F-22	E-24	E-26	D-26	D-26
29-30	18		G-20	F-20	F-22	E-24	E-26	E-26	D-26
31-36	16	H-18G	H-18G	H-18G	G-20	F-22	F-24	E-26	E-26
37-42			I-16G	H-18G	H-20G	G-22	F-24	F-24	E-26
43-48			J-16H	I-18G	I-18G	H-20	G-22	G-24	F-24
49-54				J-16H	I-18G	I-18G	H-22G	G-24	G-24
55-60				J-16H	I-18G	I-18G	H-20G	H-22G	G-24
61-72					J-16I	J-18H	I-20G	I-22G	I-24G
73-84		Not Designed			L-16I	K-16H	J-18H	I-20H	I-22G
85-96						L-16I	K-18I	J-18I	I-20H
97-108							L-16I	L-18I	K-18I
109-120							L-16I	L-18I	K-18I

Note 1 The number in the table cell is the minimum gauge.

Note 2 The letter in the box to the left of the gage is the minimum reinforcement grade for joints and intermediate stiffeners occurring at a maximum spacing interval in the column heading.

Note 3 A letter to the right of the gage gives a tie-rodded reinforcement alternative.

Note 4 A "t" compels the use of tie rods for the reinforcement listing.

Note 5 Beading and cross bracing may also be required

Internal Reinforcement

External Reinforcement and a Flow Division Fitting

Inside the Fitting

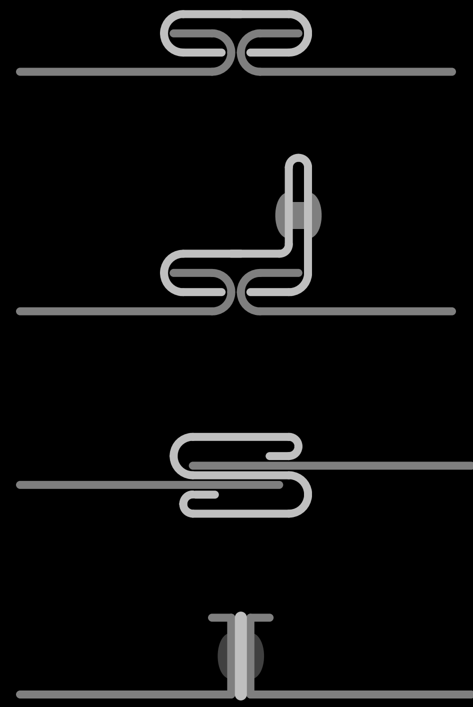
Spiral Duct and a “Boot” Type Duct Tap

Inside Spiral Duct

For Any Given SMACNA Duct or Fitting:

There are multiple combinations of metal thickness (gauge) and reinforcement

There are multiple joint and seam specifications



Drive slip

Standing drive slip

Hemmed S slip

Flange with gasket; bolted or riveted

SMACNA shows about 27 transverse joint options and about 7 longitudinal joint options

For Any Given SMACNA Duct or Fitting:

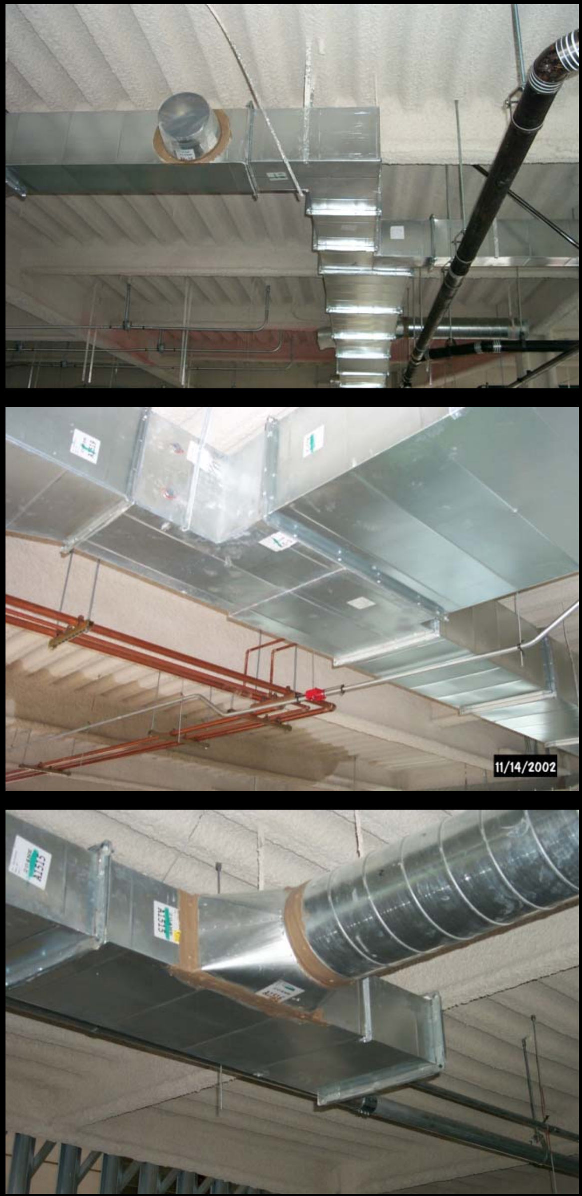
There are multiple combinations of metal thickness (gauge) and reinforcement

There are multiple joint and seam specifications

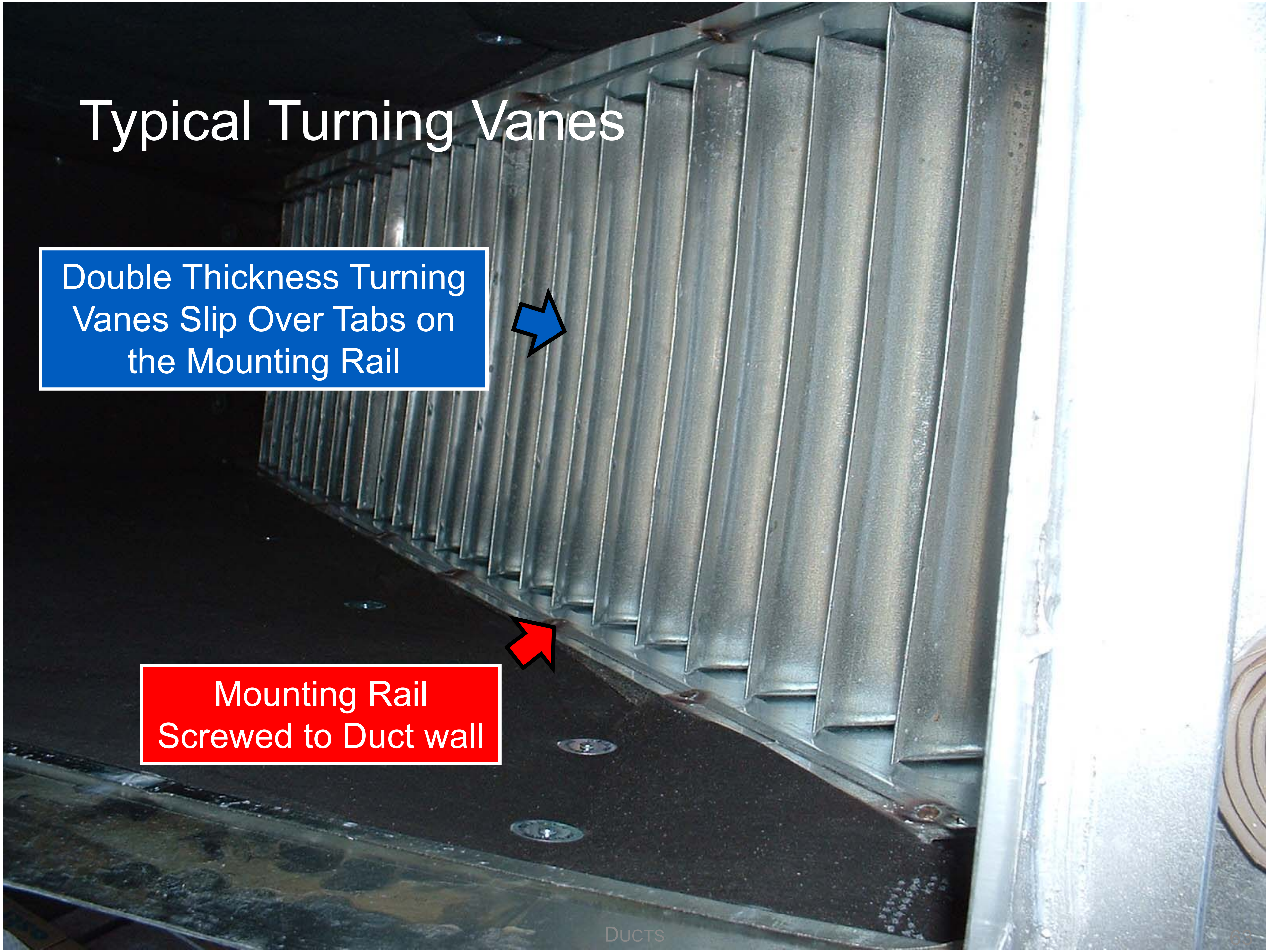
There are multiple geometries; SMACNA details:

- 15 different elbow designs
- 21 different branch connections
- 9 different ways to offset around an obstruction

ASHRAE documents 11 different turning vane designs



Three different ways to split of flow; three different pressure drops; three different costs to fabricate


Typical Turning Vanes
Double Thickness Turning Vanes Slip Over Tabs on the Mounting Rail
Mounting Rail Screwed to Duct wall

Leakage;
Another SMACNA Standard

Multiple leakage classes in terms of cfm per hundred square feet of duct area for a given test pressure

General procedure:

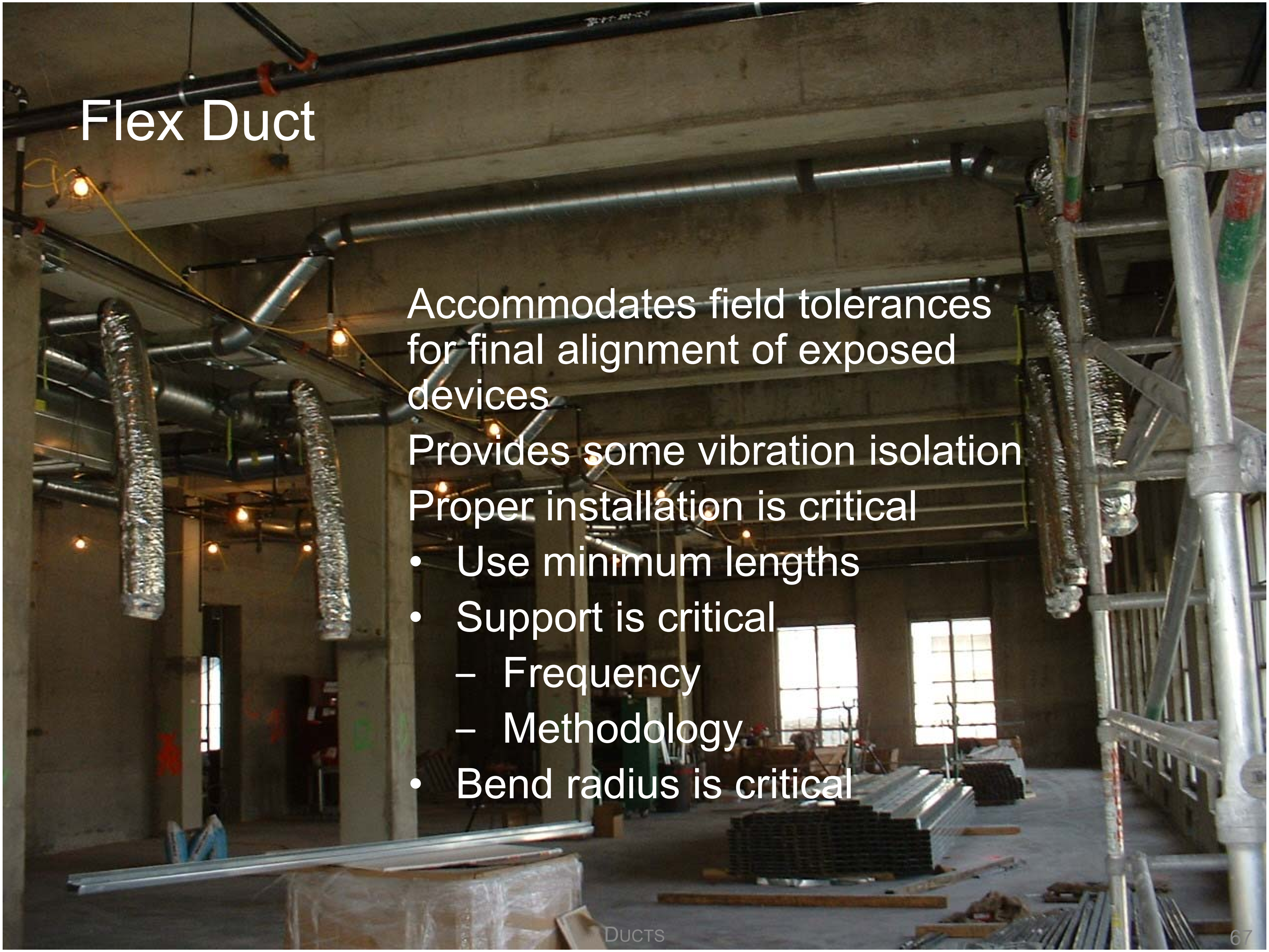
- Calculate anticipated leakage
- Select test section based on test machine capacity
- Temporarily seal open ends of duct
- Gradually pressurize duct
- Read leakage from flow meter


206NW
A1311
Duct Sealant


A8-28

Duct Sealant as a Clue to a Different Problem

Flex Duct



Accommodates field tolerances for final alignment of exposed devices

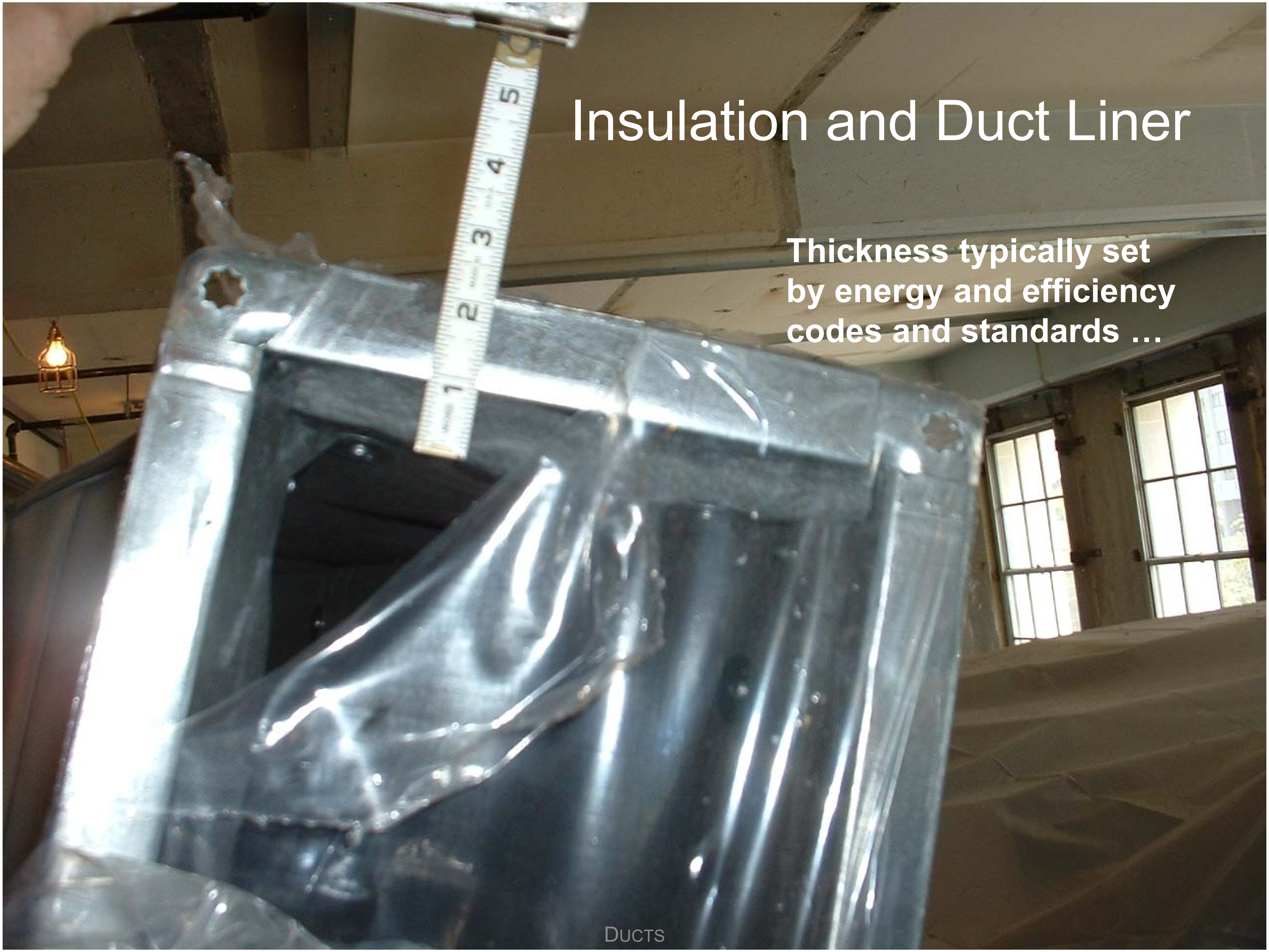
Provides some vibration isolation

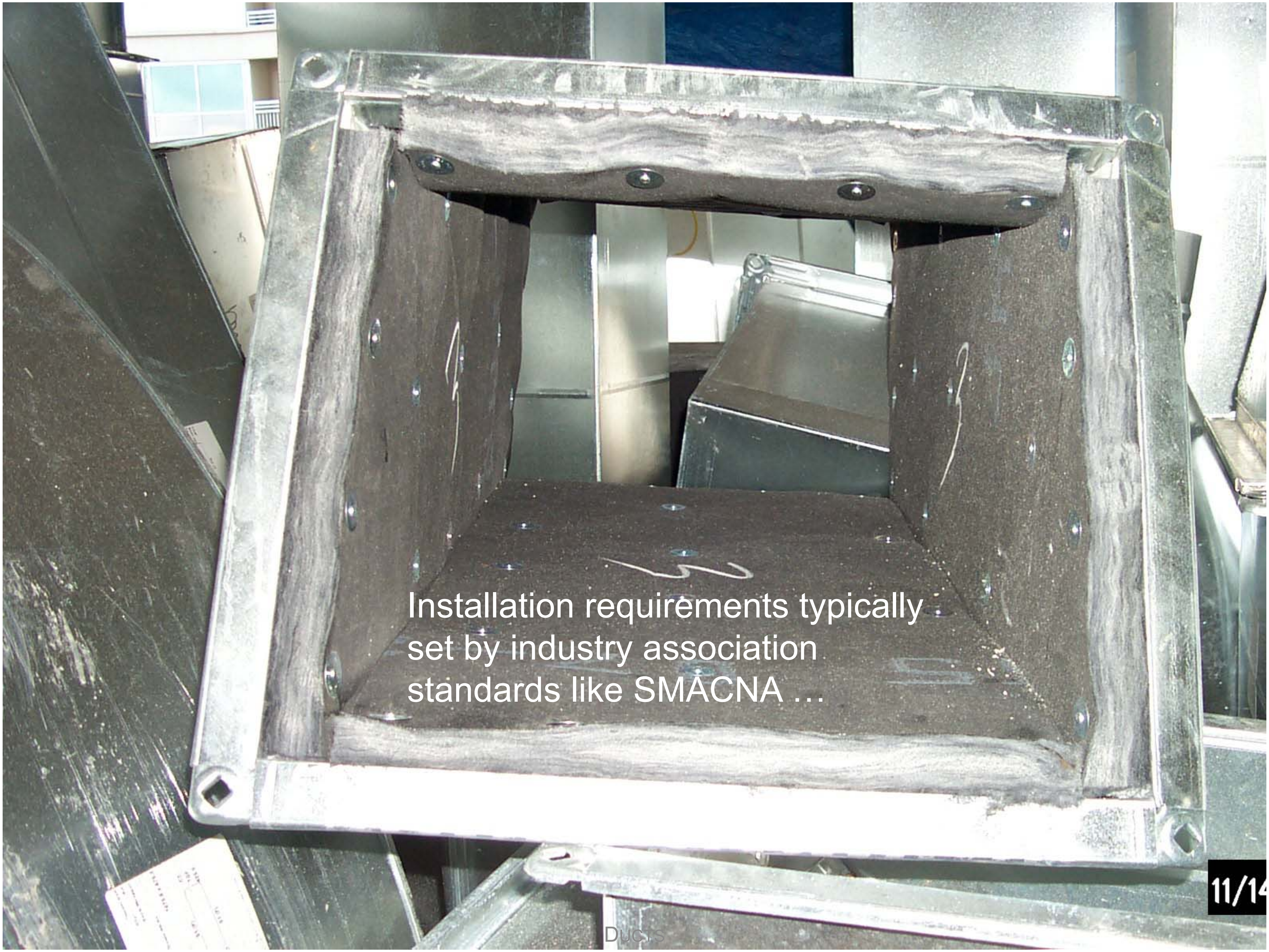
Proper installation is critical

- Use minimum lengths
- Support is critical
  - Frequency
  - Methodology
- Bend radius is critical

Insulation and Duct Liner

Thickness typically set by energy and efficiency codes and standards …




Installation requirements typically set by industry association standards like SMACNA …


Protection during construction
usually covered by LEED® or other
project contractual requirements
DUCTS


Protection during construction
usually covered by LEED® or other
project contractual requirements … or not
DUCTS

Flex Duct Resources

JPLFlex website (www.jplflex.com)

- Installation guide lines
- Friction loss calculator

Predicting the Performance of Flexible Duct Systems

- William Allen
- December 2010 Heating, Piping and Air Conditioning Magazine, page 28
- www.HPAC.com

Fans, Ductwork, & Air Handling Components:

Design, Performance, & Commissioning Issues

Supplement - Loss Coefficient Exercise

Instructor:

David Sellers

Senior Engineer

Facility Dynamics Engineering

November 10, 2015

Loss Coefficient Exercise

Given

The ASHRAE loss coefficient table that follows

A 12” x 12” duct dimension

A 12” centerline radius

A flow rate of 1,500 cfm

Determine

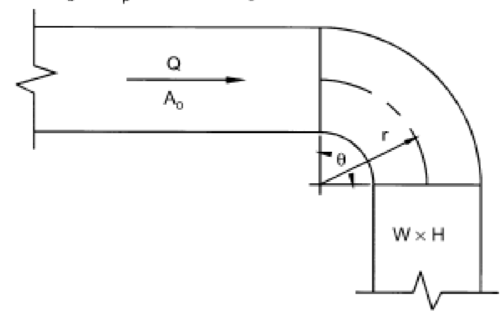
- The loss through an elbow with no vanes
- The loss through the elbow with 1 vane
- The loss through the elbow with no vanes if the flow rate is 3,000 cfm

CR3-1 Elbow, Smooth Radius, Without Vanes

	C_p Values										
	H/W										
r/W	**0.25**	**0.50**	**0.75**	**1.00**	**1.50**	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**	**8.00**
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15

	Angle Factor *K*										
θ	**0**	**20**	**30**	**45**	**60**	**75**	**90**	**110**	**130**	**150**	**180**
K	0.00	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

$C_o = KC_p$ where K = angle factor



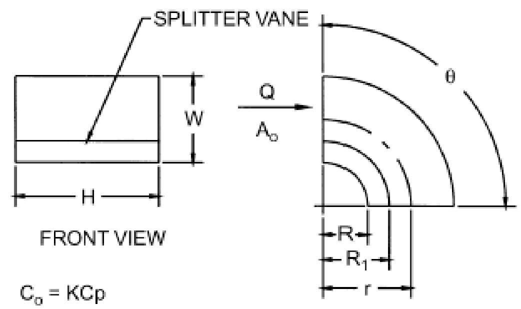
CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	**0.25**	**0.50**	**1.00**	**1.50**	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**	**7.00**	**8.00**
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

	Angle Factor *K*				
θ	**0**	**30**	**45**	**60**	**90**
K	0.00	0.45	0.60	0.78	1.00

	Curve Ratio CR									
r/W	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
CR	0.218	0.302	0.361	0.408	0.447	0.480	0.509	0.535	0.557	0.577

	Throat Radius/Width Ratio (*R/W*)									
r/W	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**1.00**
R/W	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50



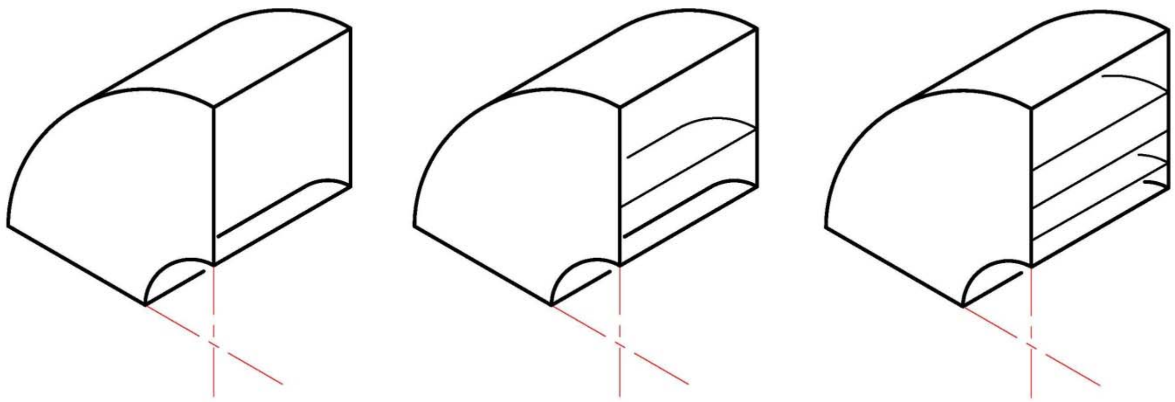
$C_o = KCp$
$R_1 = R/CR$
where
R = throat radius
R_1 = splitter vane radius
CR = curve ratio
K = angle factor

Calculating Velocity Pressure

$$V = 4{,}005\sqrt{p_{velocity}}$$

Therefore:

$$p_{velocity} = \left(\frac{V}{4{,}005}\right)^2$$



Where:

$p_{velocity}$ = Velocity pressure in inches water column

V = Velocity in feet per minute

4,005 = A units conversion constant

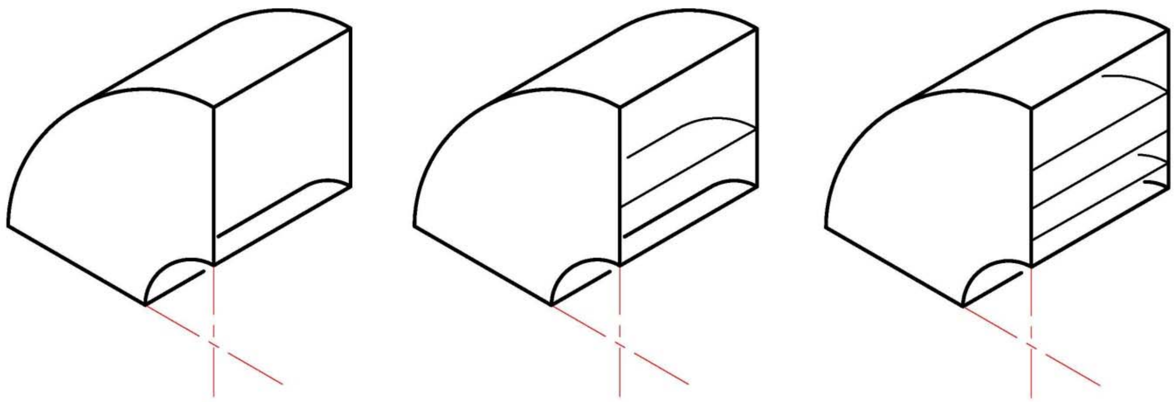
Calculating Velocity Pressure

$$V = 4{,}005\sqrt{p_{velocity}}$$

Therefore :

$$p_{velocity} = \left(\frac{1{,}500}{4{,}005}\right)^2$$

$$p_{velocity} = 0.14 \text{ in.w.c.}$$



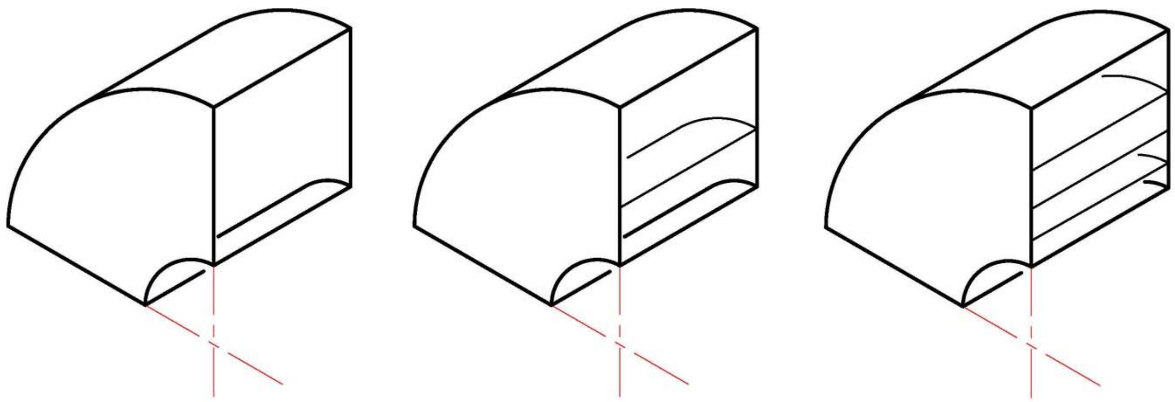
Calculating Velocity Pressure

$$V = 4{,}005\sqrt{p_{velocity}}$$

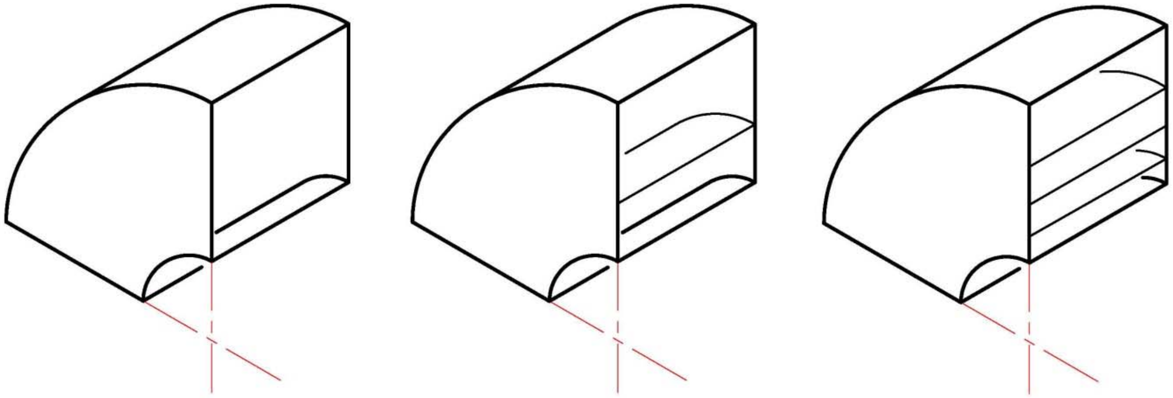
Therefore :

$$p_{velocity} = \left(\frac{3{,}000}{4{,}005}\right)^2$$

$$p_{velocity} = 0.56 \text{ in.w.c.}$$



Selecting and Applying the Loss Coefficient



$$\Delta p_{fitting} = C_o \, p_{velocity}$$

Where :

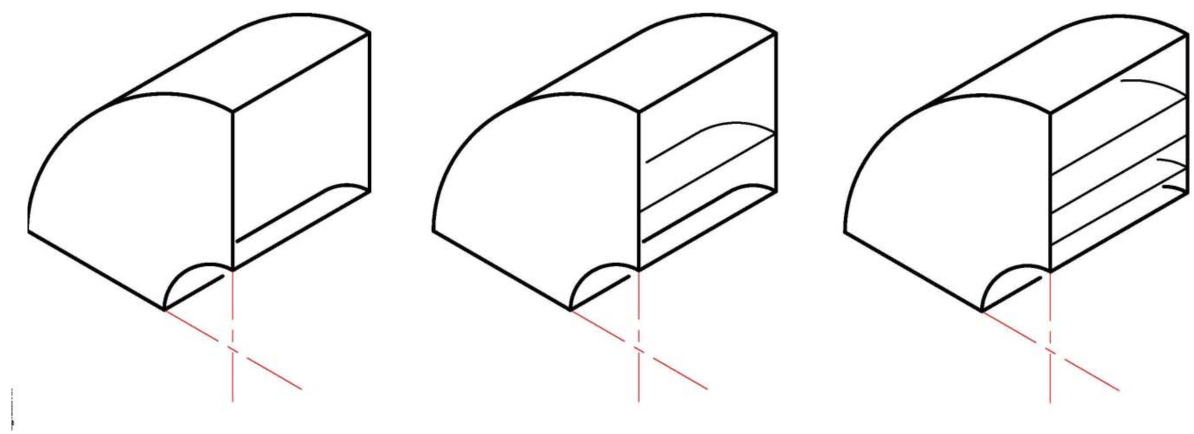
$\Delta p_{fitting}$ = Fitting pressure loss

C_o = Local loss coefficient from ASHRAE tables or equivalent

$p_{velocity}$ = Velocity pressure

Selecting and Applying the Loss Coefficient

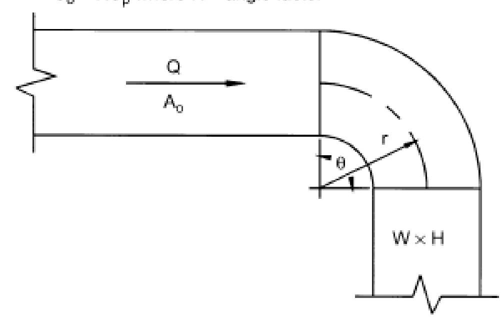
$$\Delta p_{fitting} = C_o \, p_{velocity}$$



CR3-1 Elbow, Smooth Radius, Without Vanes

						C_p Values					
						H/W					
r/W	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	8.00
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15
						Angle Factor *K*					
θ	0	20	30	45	60	75	90	110	130	150	180
K	0.00	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

$C_o = KC_p$ where K = angle factor

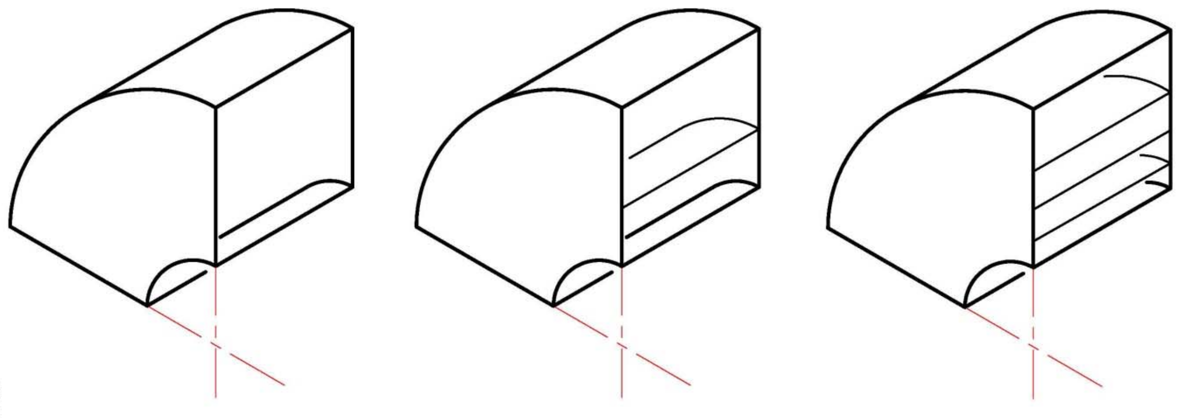


Selecting and Applying the Loss Coefficient

$$\Delta p_{fitting} = C_o\, p_{velocity}$$

$$\Delta p_{fitting} = .21 \times .14$$

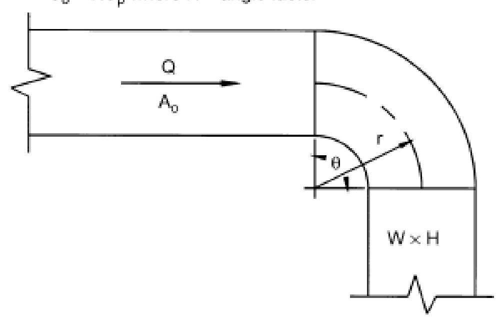
$$\Delta p_{fitting} = .03\ \text{in.w.c.}$$



CR3-1 Elbow, Smooth Radius, Without Vanes

					C_p Values						
					H/W						
r/W	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	8.00
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15
					Angle Factor *K*						
θ	0	20	30	45	60	75	90	110	130	150	180
K	0.00	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

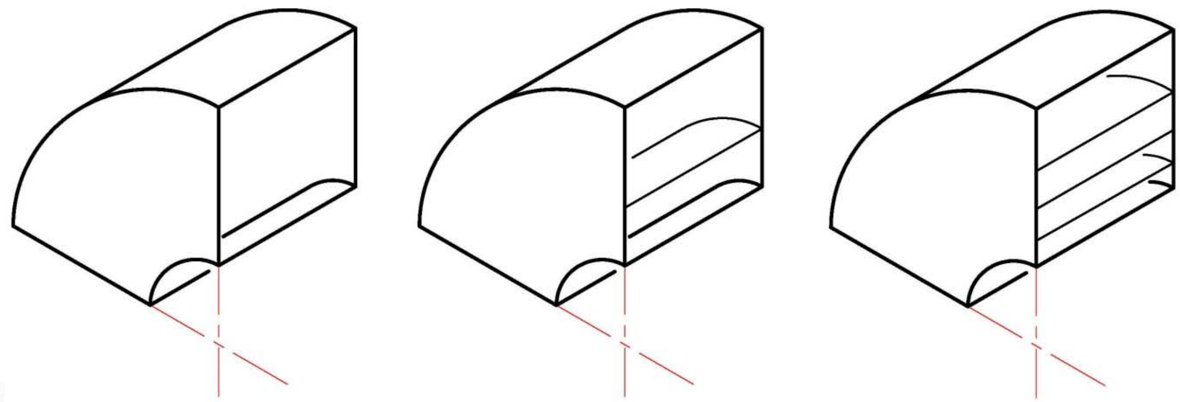
$C_o = KC_p$ where K = angle factor



Selecting and Applying the Loss Coefficient

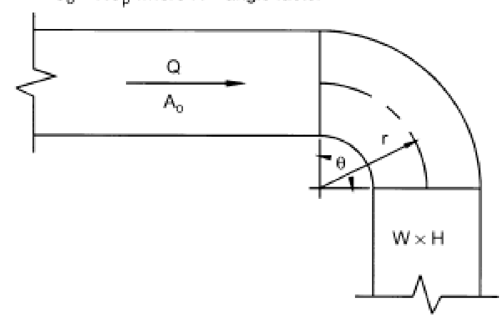
$$\Delta p_{fitting} = C_o \, p_{velocity}$$

$$\Delta p_{fitting} = .21 \times .56$$



CR3-1 Elbow, Smooth Radius, Without Vanes

	C_p Values										
	H/W										
r/W	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	8.00
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15
	Angle Factor K										
θ	0	20	30	45	60	75	90	110	130	150	180
K	0.00	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

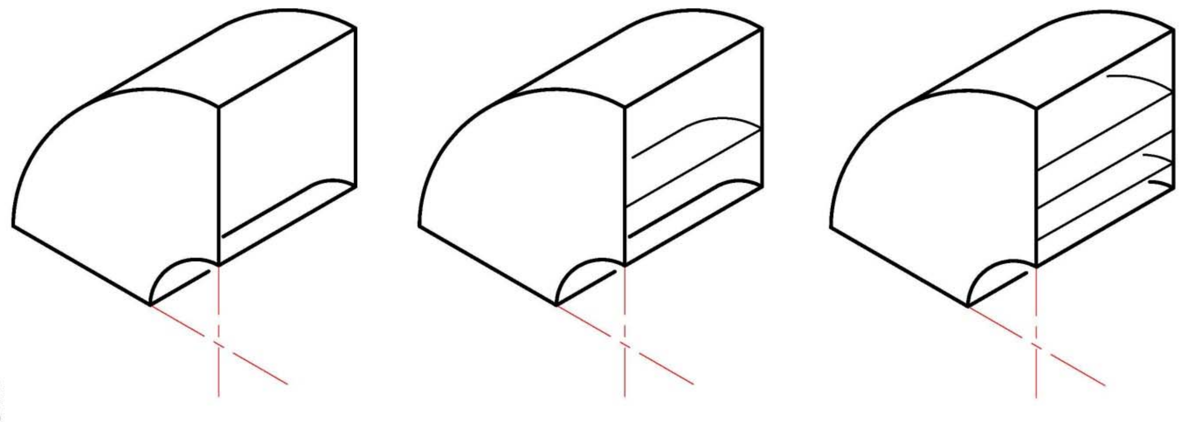


Selecting and Applying the Loss Coefficient

$$\Delta p_{fitting} = C_o \, p_{velocity}$$

$$\Delta p_{fitting} = .21 \times .56$$

$$\Delta p_{fitting} = .12 \text{ in.w.c.}$$



CR3-1 Elbow, Smooth Radius, Without Vanes

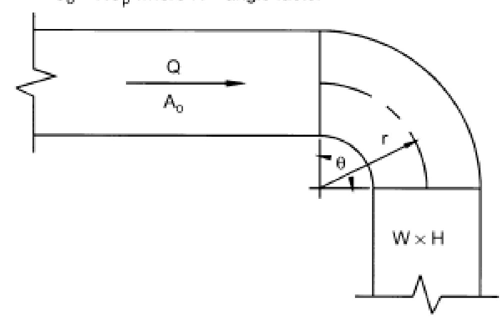
C_p Values

r/W	H/W 0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	8.00
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15

Angle Factor K

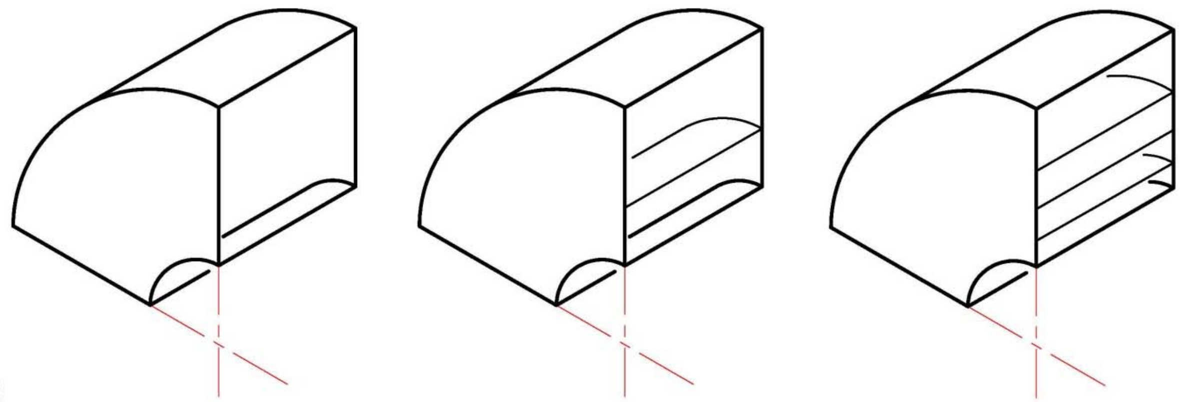
θ	0	20	30	45	60	75	90	110	130	150	180
K	0.00	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

$C_o = KC_p$ where K = angle factor



Selecting and Applying the Loss Coefficient

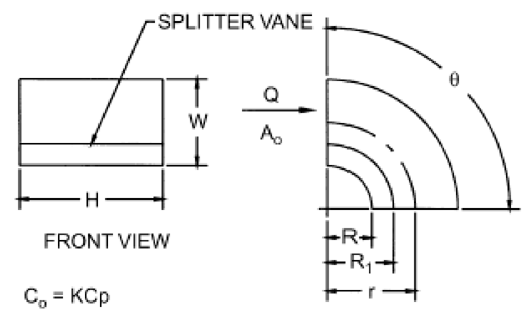
$$\Delta p_{fitting} = C_o \, p_{velocity}$$



CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor K					
θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00



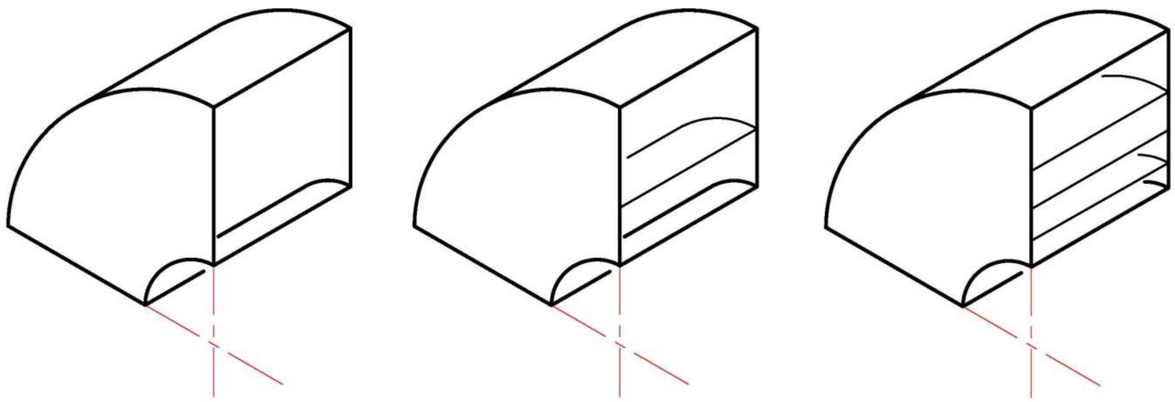
C_o = KCp
R_1 = R/CR
where
R = throat radius
R_1 = splitter vane radius
CR = curve ratio
K = angle factor

Selecting and Applying the Loss Coefficient

$$\Delta p_{fitting} = C_o \, p_{velocity}$$

$$\Delta p_{fitting} = .05 \times .14$$

$$\Delta p_{fitting} = .01 \text{ in.w.c.}$$

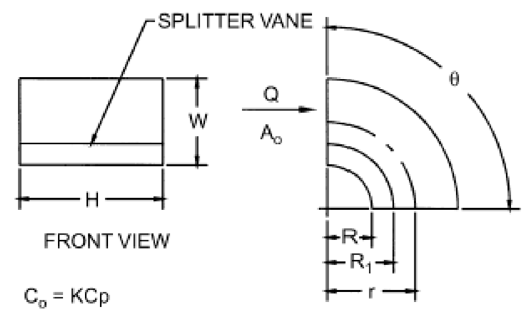


CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor *K*

θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00



$C_o = KC_p$

$R_1 = R/CR$

where

R = throat radius

R_1 = splitter vane radius

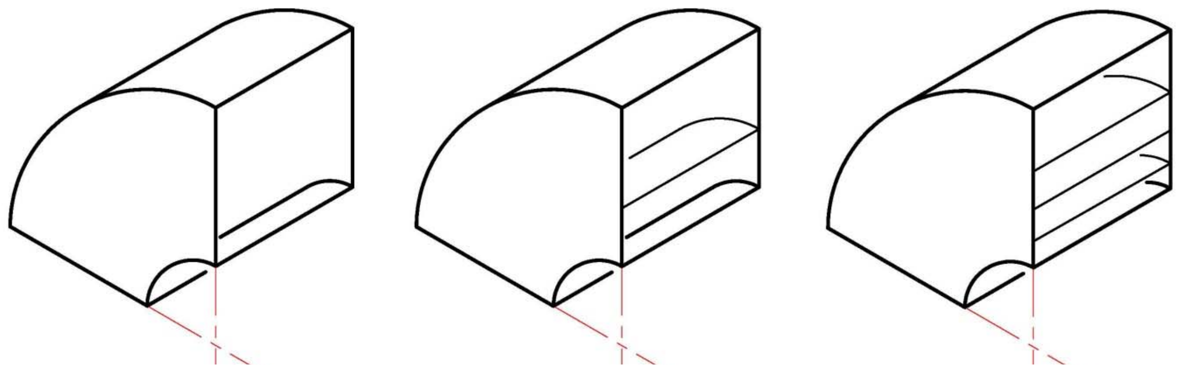
CR = curve ratio

K = angle factor

Selecting and Applying the Loss Coefficient

$$\Delta p_{fitting} = C_o \, p_{velocity}$$

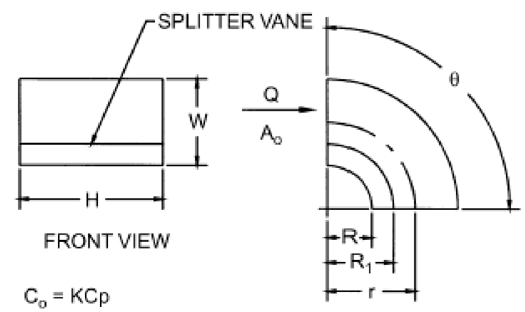
$$\Delta p_{fitting} = .05 \times .56$$



CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor *K*					
θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00



$C_o = KC_p$

$R_1 = R/CR$

where

R = throat radius

R_1 = splitter vane radius

CR = curve ratio

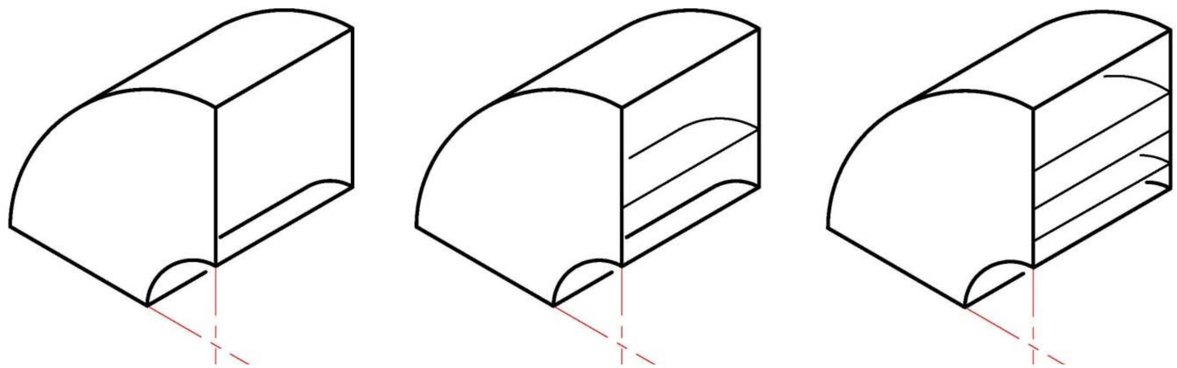
K = angle factor

Selecting and Applying the Loss Coefficient

$$\Delta p_{fitting} = C_o\, p_{velocity}$$

$$\Delta p_{fitting} = .05 \times .56$$

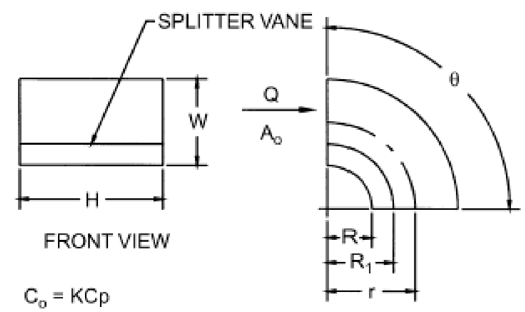
$$\Delta p_{fitting} = .03 \text{ in.w.c.}$$



CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor *K*					
θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00

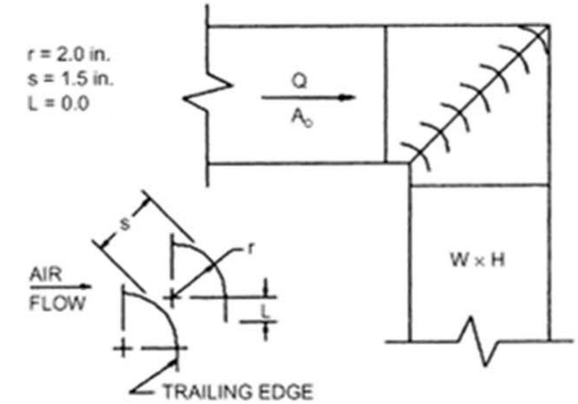


C_o = KCp
R_1 = R/CR
where
R = throat radius
R_1 = splitter vane radius
CR = curve ratio
K = angle factor

A Contrast

CR3-9 Elbow, Mitered, 90 Degree, Single-Thickness Vanes (Design 1)

$C_o = 0.11$



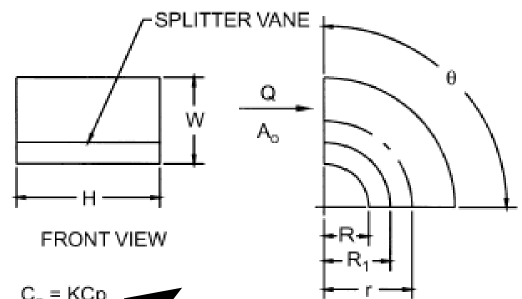
CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor K					
θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00

Curve Ratio CR										
r/W	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
CR	0.218	0.302	0.361	0.408	0.447	0.480	0.509	0.535	0.557	0.577

Throat Radius/Width Ratio (R/W)										
r/W	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
R/W	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50



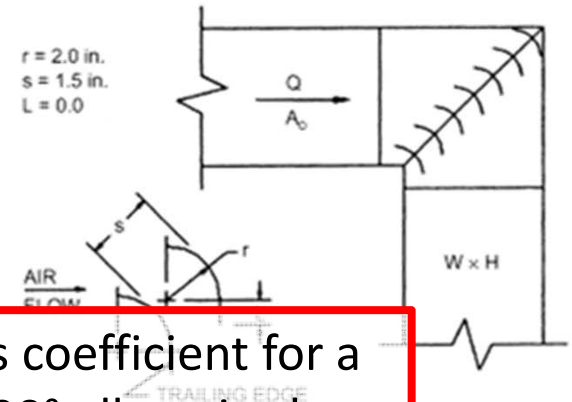
$C_o = KC_p$
$R_1 = R/CR$
where
R = throat radius
R_1 = splitter vane radius
CR = curve ratio
K = angle factor

Cp = Co for a 90° elbow

A Contrast

CR3-9 Elbow, Mitered, 90 Degree, Single-Thickness Vanes (Design 1)

$C_o = 0.11$



The loss coefficient for a mitered 90° elbow is about twice that of a radiused 90° elbow with one vane

CR3-3 Elbow, Smooth Radius, One Splitter Vane

C_p Values

r/W	H/W 0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor *K*

θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00

Curve Ratio CR

r/W	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
CR	0.218	0.302	0.361	0.408	0.447	0.480	0.509	0.535	0.557	0.577

Throat Radius/Width Ratio (R/W)

r/W	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
R/W	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50

$C_o = KC_p$

R/CR

where

R = throat radius

R_1 = splitter vane radius

CR = curve ratio

K = angle factor