Duct Construction and Design

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Design Methods

- There are 3 typical methods used for designing “non-residential” duct systems
- Equal Friction
- Static Regain
- Constant Velocity (exhaust and industrial)

Equal Friction

- Designed so each path has the same resistance
- Typically based on duct sized at 0.8 in wg/100ft
- Works for supply and return
- Most versatile option
- Can be done “manually”
- Design wheel

Static Regain

- Similar to equal friction
- Recovery in static pressure ≈ total pressure loss
- Supply systems only
- Works best on "medium to high" pressure systems (upstream of VAV)
- Best done using software (iterative process)

Constant Velocity

- Design to maintain a minimum velocity
- Used for material handling/conveying
- Fitting choices extremely important
- Use wyes not tees (30° to 60°)
- Never use crosses

Fittings

- Fittings are where the majority of pressure losses occur.

- Selecting the proper fittings in the proper places can have a significant impact on energy use, and even cost.

- Critical path

Fittings

- To vane or not to vane…
- Often specifications require the use of turning vanes in all mitered elbows
- This is “ok” but on elbows at low velocity, or not on the critical path this could be wasting money without adding benefit
- Specifications should indicate the number of splitter vanes required (if required) these are not turning vanes.

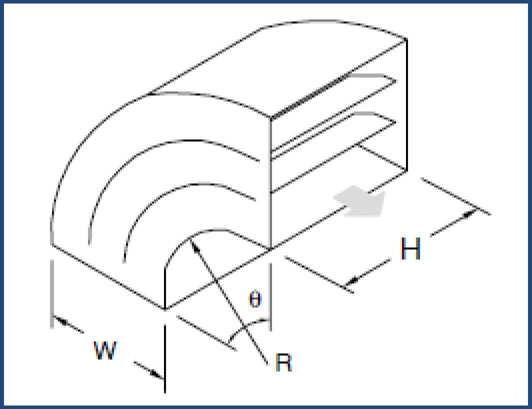
Pressure Loss

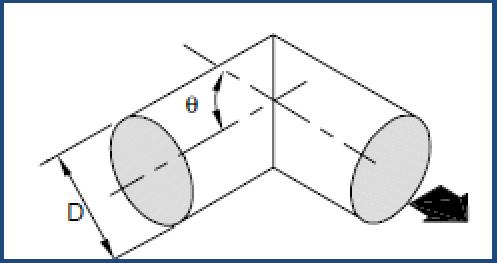
- To evaluate the pressure lost (used) as air moves through a fitting you should first determine the velocity pressure V_P

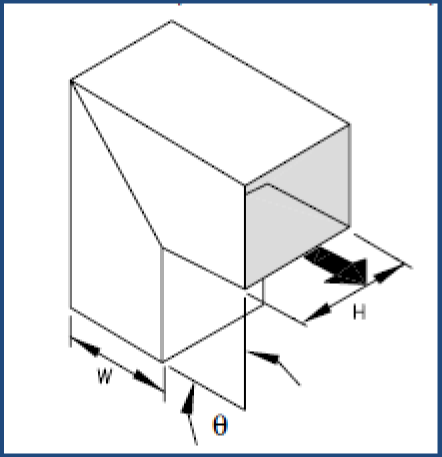
$$V_P = \left(\frac{V}{4005} \right)^2$$

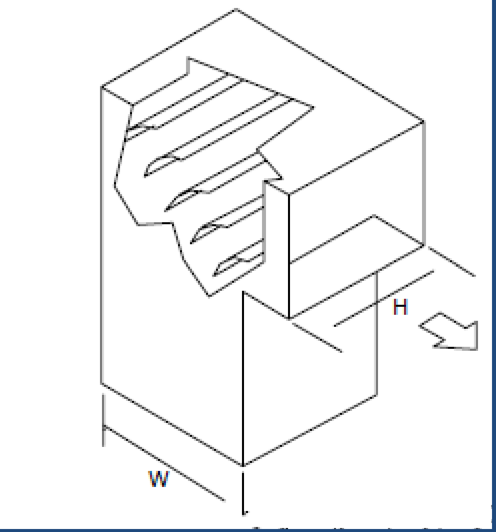
- V_P (in. w.g.) which is a square function of V
- V (fpm)

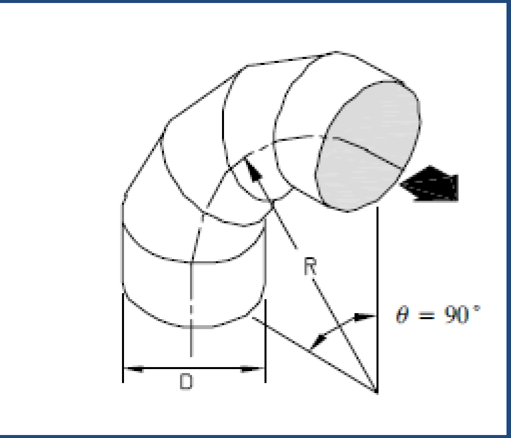
Elbow Comparison

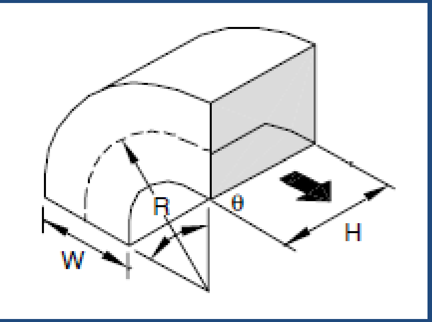












Example Scenario

- As designed the plans indicate that a 24 x 12 radiused elbow (r/w=1.5) be used. Because of field conditions that radiused elbow will not fit. The contractor is faced with finding an acceptable alternative that fits
- The designer wants to know what the impact of changing the elbow has on the system

Example Scenario

- It is fairly common for contractors to simply find an elbow that fits. Because of job schedule they are often reluctant to send an RFI about these kinds of situations.
- Many times specifications are written to force a particular type of elbow to be used.

Fitting Comparison

Velocity (fpm)		2000	4000
Elbow	C	ΔP (in. w.g.)	ΔP (in. w.g.)
radiused throat heel, r/w=1.5	0.2	0.05	0.20
square throat rad heel	1.38	0.34	1.38
mitered no vanes	1.27	0.32	1.27
mitered vanes (single @ 3.25)	0.33	0.08	0.33
radiused throat heel, r/w=1.0	0.25	0.06	0.25
mitered vanes (single @ 1.5)	0.11	0.03	0.11

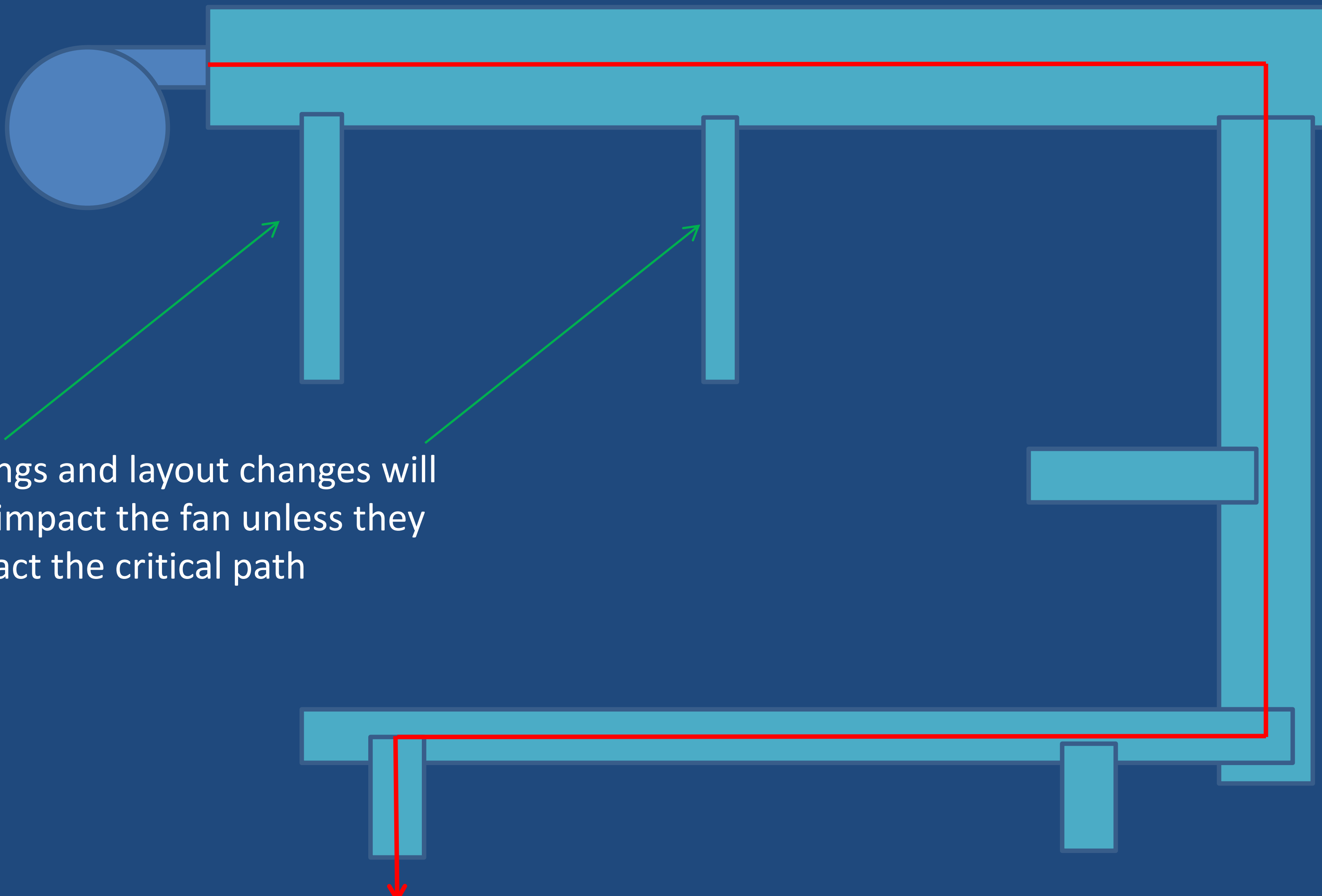
Low Velocity

Velocity (fpm)		800	1000	1200
Elbow	C	ΔP (in. w.g.)	ΔP (in. w.g.)	ΔP (in. w.g.)
radiused throat heel, r/w=1.5	0.2	0.01	0.01	0.02
square throat rad heel	1.38	0.06	0.09	0.12
mitered no vanes	1.27	0.05	0.08	0.11
mitered vanes (single @ 3.25)	0.33	0.01	0.02	0.03
radiused throat heel, r/w=1.0	0.25	0.01	0.02	0.02
mitered vanes (single @ 1.5)	0.11	0.00	0.01	0.01

Duct Design Basics

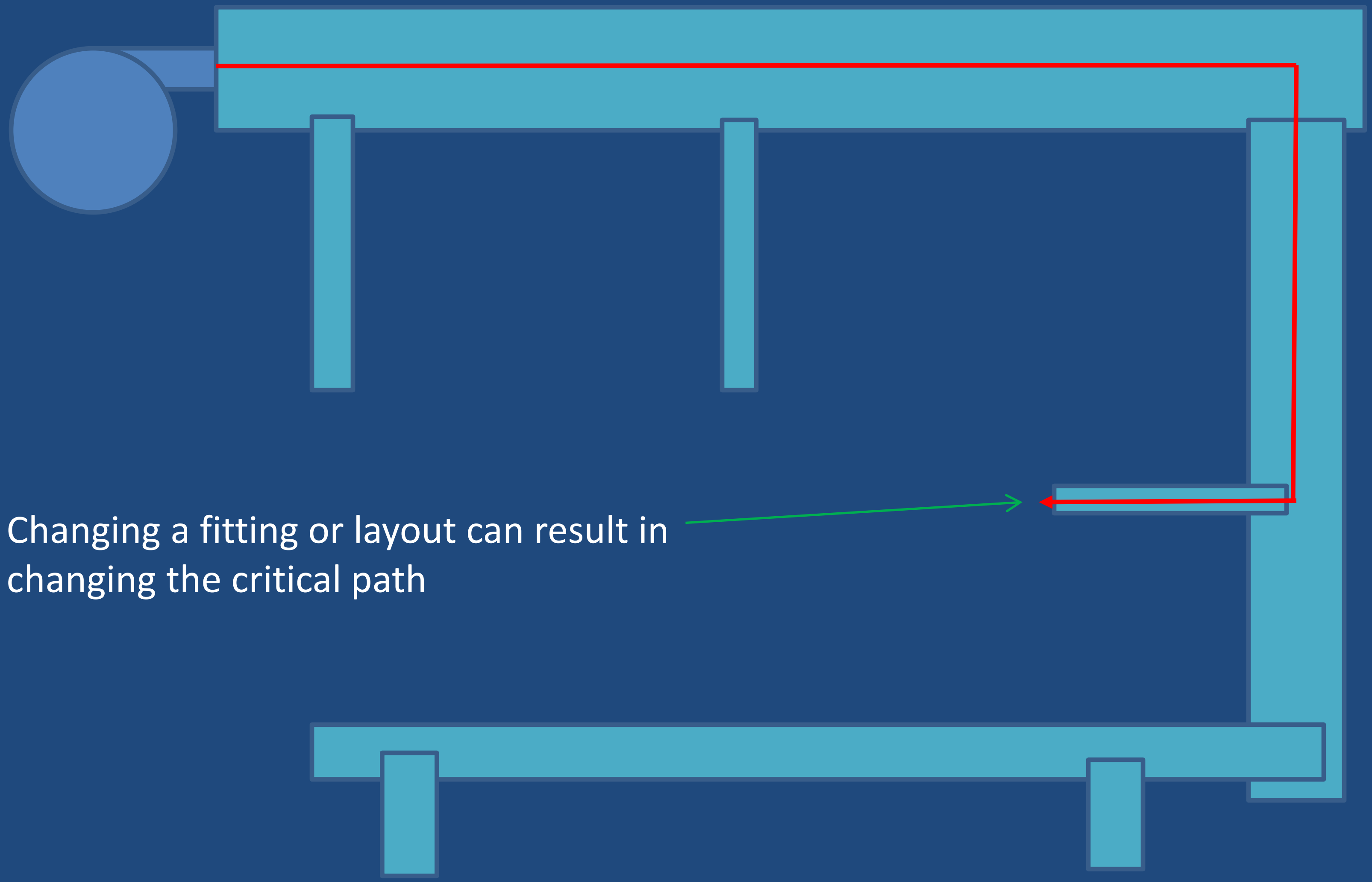
- One often misunderstood idea is the critical leg or critical path.
- All other paths are over pressurized by design
  - Unless all paths are the same (great but not likely)
- The point is that fittings used in the non critical paths will not impact the energy required for the system unless, by using the fitting, the critical path changes.

Duct Design Basics



Fittings and layout changes will not impact the fan unless they impact the critical path

Duct Design Basics



Duct

- The reality is that pressure drops are fairly insignificant in the straight sections of duct
- However there are some good guidelines to follow
- There are some misconceptions as well

Duct

- Round duct should be the basis of design
  - Systems should be designed in round and then converted where necessary
- For non-round duct keep the aspect ratio as close to 1:1 as possible
  - This impacts cost and pressure drops (energy)

Convert Duct Shapes

- There are a number of reasons that duct shape is converted
  - Coordination
  - Primary design is often based on round duct
  - Cost factors
  - Availability

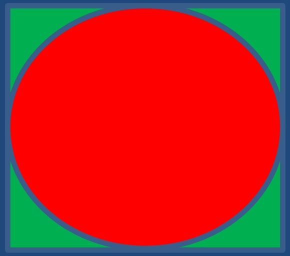
Misconceptions

- For a given “footprint” round duct has less resistance (pressure drop) than square duct.
- Is this true? Let’s do an example calculation
- 1600 CFM, compare 12 inch round to 12 x 12 rectangular

Misconceptions

- First convert the rectangular to the equivalent round (SMACNA Duct Design or ASHRAE handbook)

$$D_e = \frac{1.3(ab)^{0.625}}{(a+b)^{0.250}}$$



- 12 x 12 rectangular = 13.1 inch round
  – Please note that equivalent area is not a correct way to convert

Misconceptions

- Velocity for the round duct
  - V=Q/A = 1600/.785 (ft^3/min, ft^2) = 2037 fpm

- Velocity for square duct
  - V=Q/A = 1600/1 (ft3/min, ft2) = 1600 fpm

Misconceptions

- Pressure drop for 100 feet of 12 inch round @ 1600 CFM ~ 0.5
- Pressure drop for 100 feet of 12 x 12 inch rectangular @ 1600 CFM ~ 0.3 in. w.g.
- That's almost 40% less "friction"

Misconceptions

- What about flat oval?

$$D_e = \frac{1.55AR^{0.625}}{P^{0.250}}$$

- Oval 24 x 12 in. ~ 17.7 in. round
- Rectangular 24 x 12 in. ~ 18.3 in. round

Misconceptions

- Velocity in the Oval @ 1600 CFM
  - V=Q/A = 1600/1.79 = 896 FPM
- Velocity in Rectangular
  - V=Q/A = 1600/2 = 800 FPM
- Pressure drop for 100 feet
  - Oval ~0.066
  - Rect ~0.057
  - 14% less “friction”-but actually insignificant

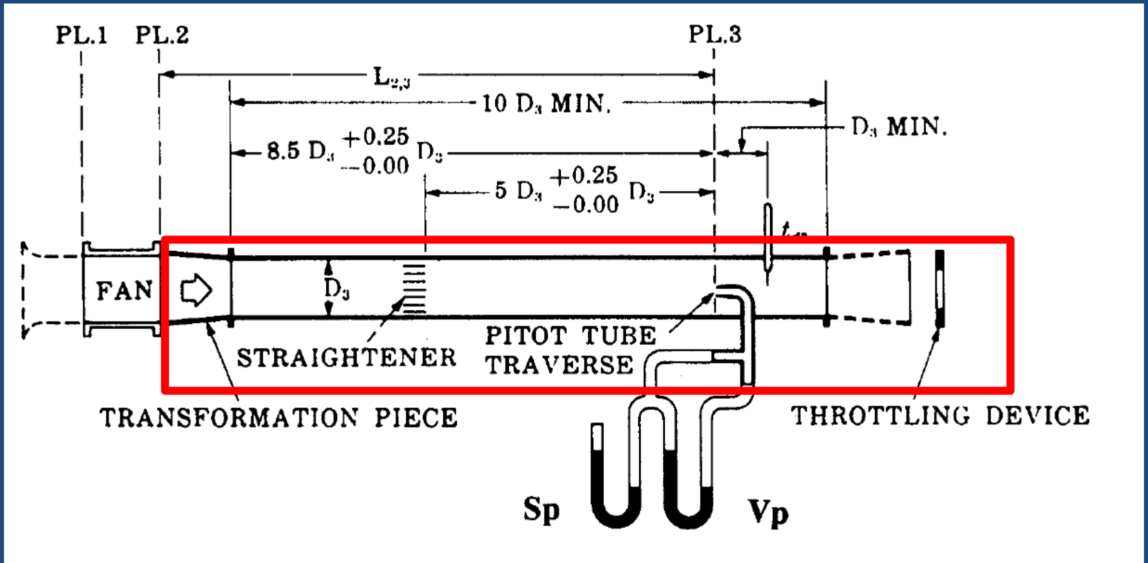
System Effect

- Field measurements of fan performance often indicate lower values than manufacture's ratings.
  - Are the manufacturer’s lying? No.

- Three main causes to lower field values
  - Improper outlet conditions
  - Non-uniform inlet flow
  - Swirl at the fan inlet

System Effect

- Outlet Conditions
- Fans for ducted systems, tested to AMCA 210 or ASHRAE 51, have "outlet duct" in place
- For 100% recovery use 100% effective length



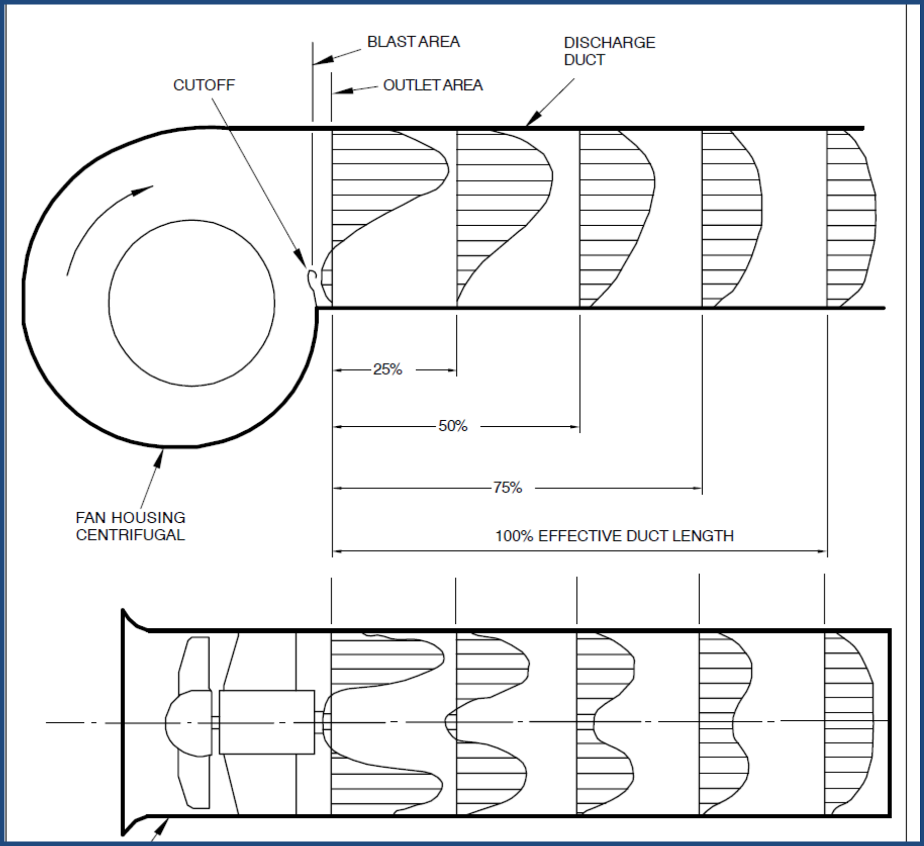
System Effect

- Effective Length
- Depends on velocity
- If V<=2500 fpm

$$L_e = \frac{\sqrt{A_o}}{4.3}$$

- If V>2500 fpm

$$L_e = \frac{V_o\sqrt{A_o}}{10{,}600}$$



System Effect

- Using 60 x 30 inch duct
  - @ 30,000 CFM
    - V=2400 fpm
    - Le = 10 ft.
  - @ 50,000 CFM
    - V=4000 fpm
    - Le = 16 ft.
- Using 60 x 50 inch duct
  - @30,000 CFM
    - V=1440 fpm
    - Le=12.7 ft.
  - @ 50,000 CFM
    - V=2400 fpm
    - Le= 13 ft.

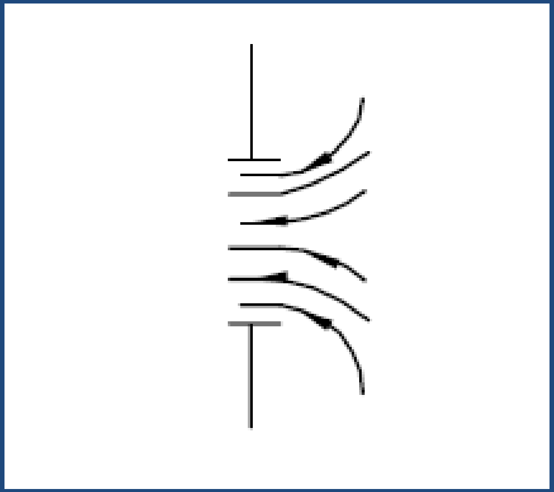
System Effect

- Non-uniform inlet flow
  - Major impact on fan performance
  - Creates a “new” fan curve

- Use inlet duct 3 to 8 diameters
  - Depends on velocity but losses without any inlet duct can add 3.5 inches of pressure loss

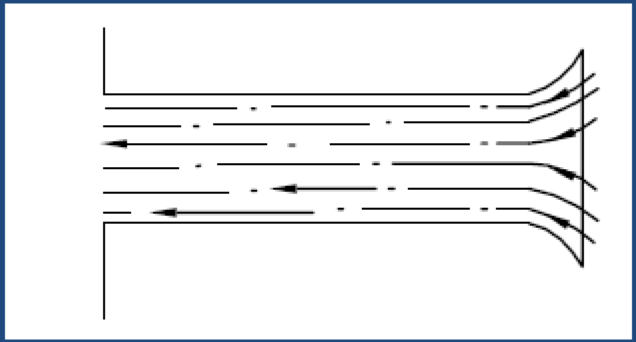
System Effect

- Inlet conditions
  - Abrupt inlets actually reduce the effective inlet area because of vena contracta effect

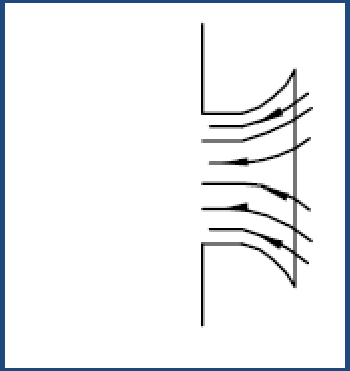


System Effect

- If duct isn't used try using a bellmouth or other smooth inlet

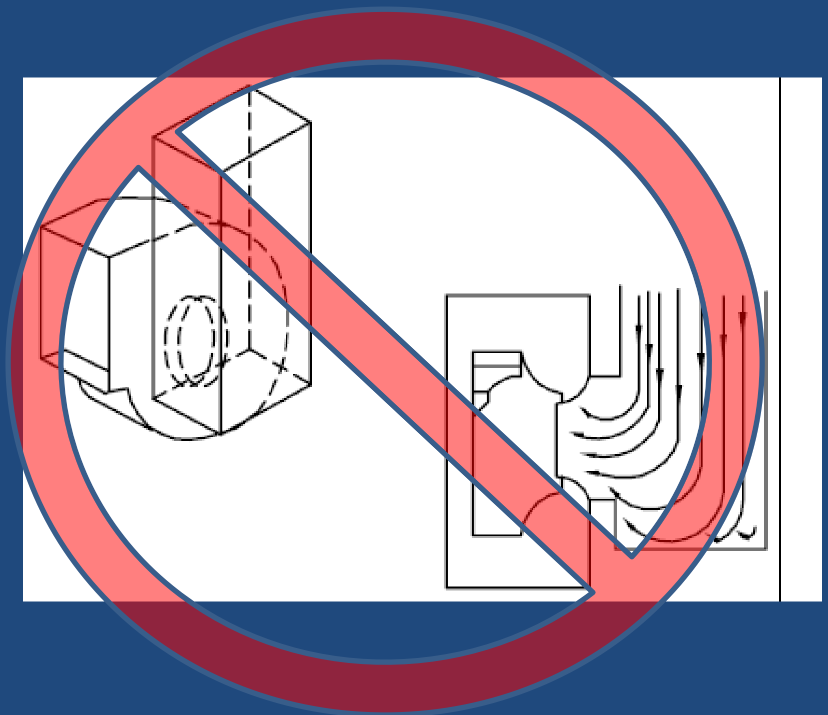


Ideal uses a smooth inlet with straight section of duct

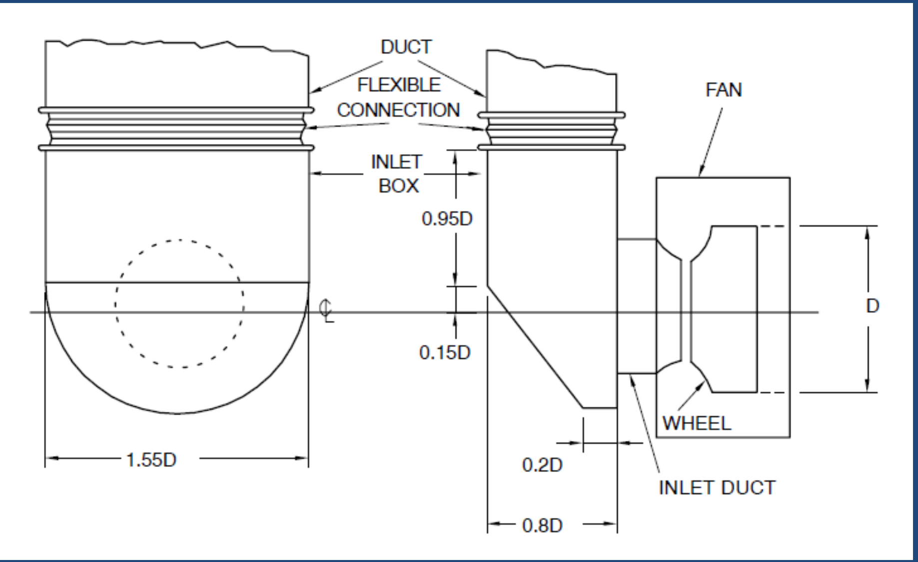


A good option at least provides a smooth transition into the fan

System Effect



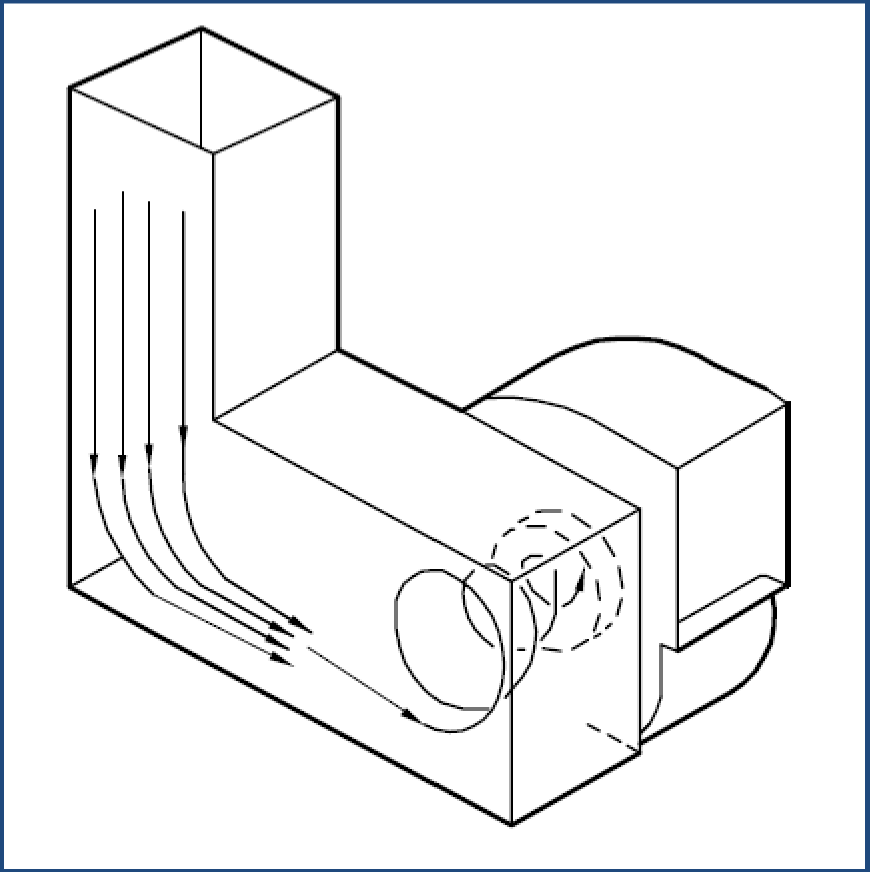
- Inlet boxes are not ideal but will reduce system effect



- Avoid

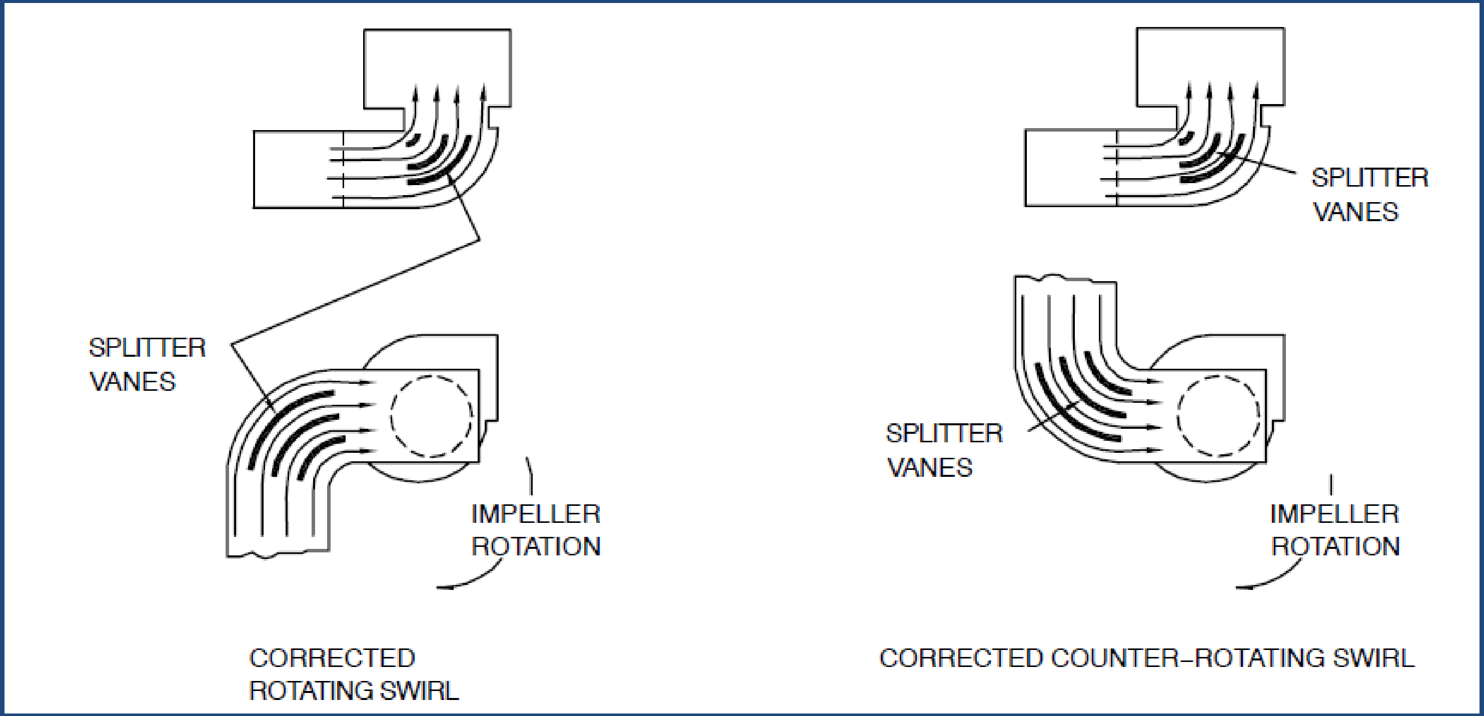
System Effect

- Swirl
  - In the direction of the impeller reduces the pressure/volume curve
  - Opposite the direction of the impeller actually increases the pressure/volume curve slightly but greatly increases the power consumed



System Effect

- To address swirl you can increase the inlet duct length, or use vanes to correct the spin



System Effect

- The best way to eliminate or reduce system effect is to provide space. The better the inlet and outlet conditions the better the fan will perform.
- Even providing duct lengths of 25% of the ideal length can result in 80% gains, 50% lengths show up to 90% gains
- Leave room for expansion, as equipment becomes more efficient it typically increases in size

System Effect

- Adequate space not provided
- Less than ideal inlet and outlet conditions
- Detailed discussion on System effect can be found in Chapter 6 of SMACNA's Duct Design Guide

Insulation

- Most codes require some of the ductwork to be insulated.
- Insulation reduces the effects of heat gain/loss as the duct moves conditioned air.
- Internal liners can provide thermal resistance
  - Be careful about through metal
- Consult the manufacturer’s data for performance, make sure to use installed values

Insulation

- 75’ of 24” round duct @ 6,500 CFM
  - V = 2070 fpm
  - Desired outlet temp 120°F
  - Air temp where duct run is located 65°
  - The temp required at the start of the duct 123°F
  - The heat loss is 26,000 Btu/hour
    - 7,643 watts (76 - 100 watt light bulbs)

Insulation

- 75’ of 24” round duct @ 6,500 CFM with R6 (2 inches of insulation)
  - – V = 2070 fpm
  - – Desired outlet temp 120°F
  - – Air temp where duct run is located 65°
  - – The temp required at the start of the duct 121°F
  - – The heat loss is 5,800 Btu/hour
    - 1,700 watts (17 - 100 watt light bulbs)
    - 78% reduction in heat loss

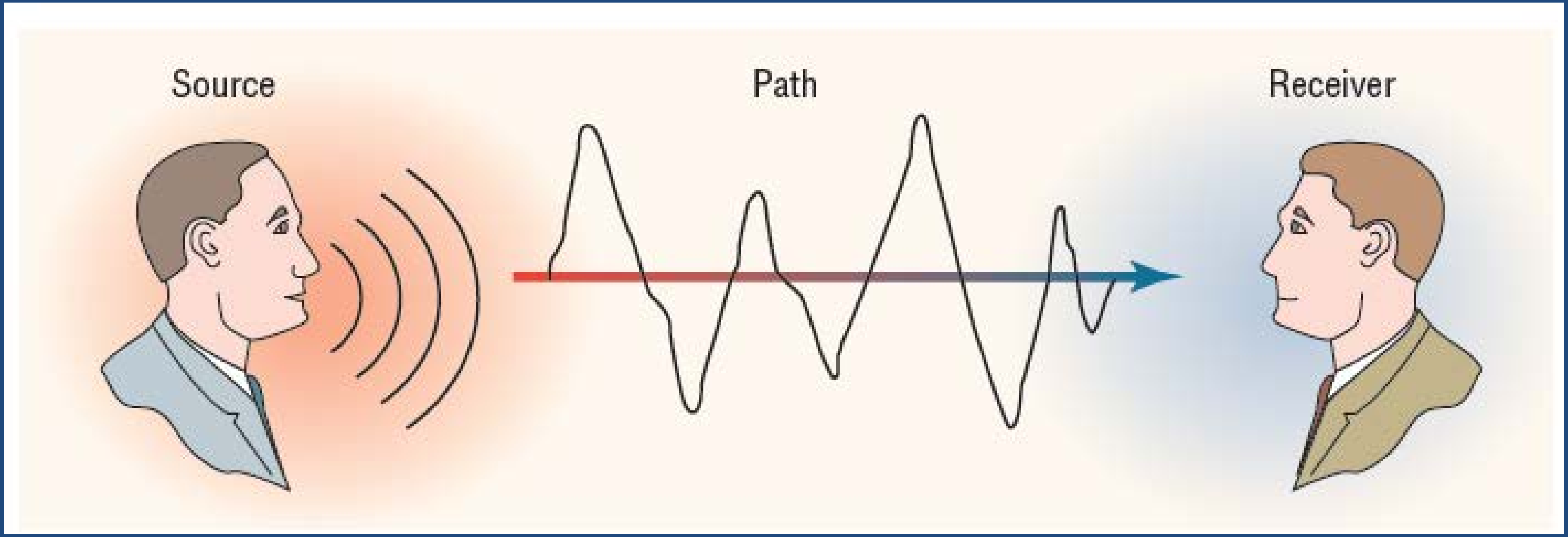
Insulation

- Remember to account for the weight of insulation when specifying duct construction
  - 1 in. w.g. = 5.2 lbs./ft^2
- Duct liner provides thermal benefit, main purpose is sound attenuation
  - Be careful of through metal (condensation)

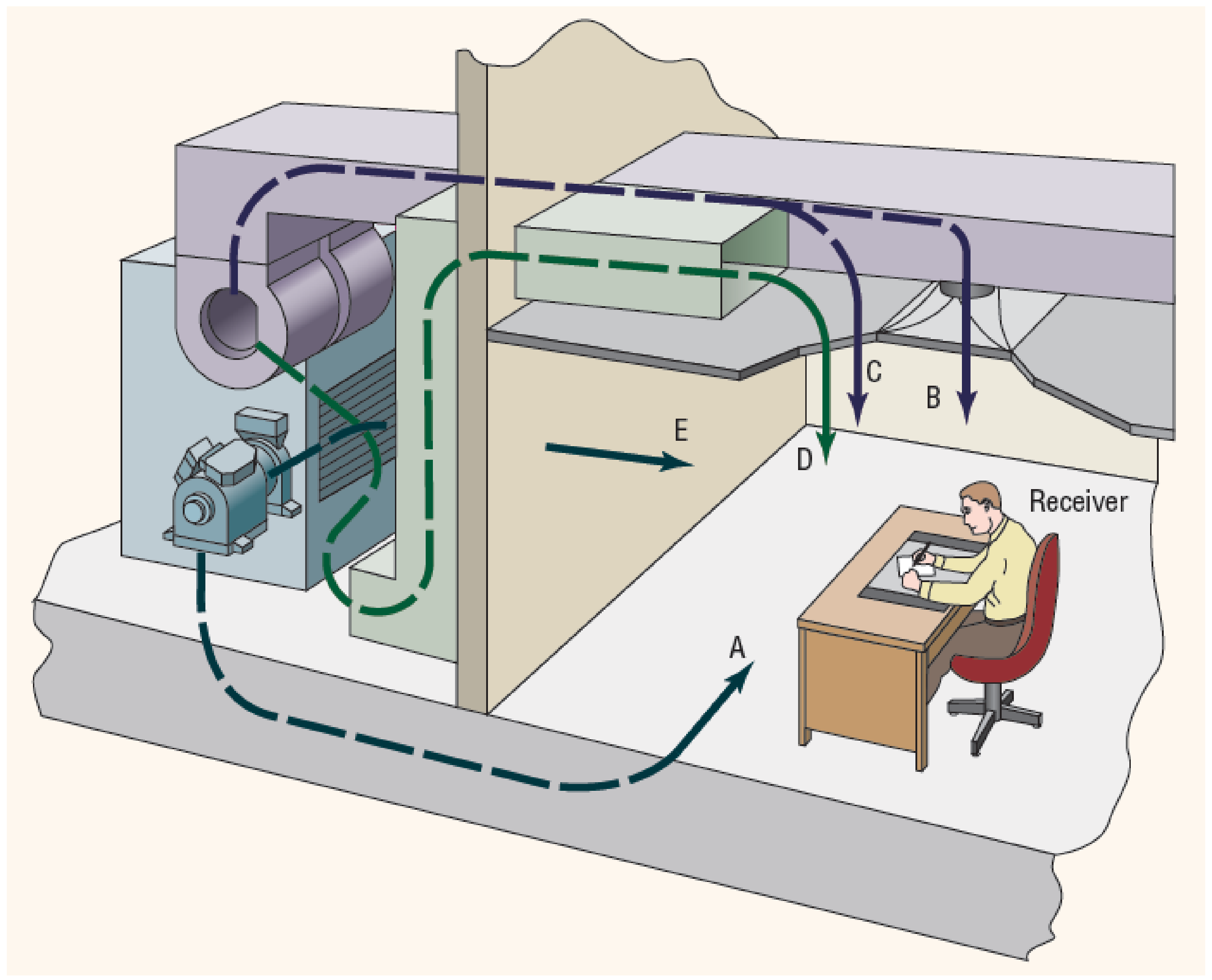
Acoustics

- If it is good for airflow it is usually good for acoustics.
- Three components:
  - Source
  - Path
  - Receiver

Acoustics



Acoustics



Acoustics

- Easy Math

Difference	Add to higher level
0 to 1 dB	3 dB
2 to 4 dB	2 dB
5 to 9 dB	1 dB
10-plus dB	0 dB

Acoustics

- Weighting
  - Human ear is less sensitive to low and high frequencies
  - More sensitive to mid-frequencies

Acoustics

- A-Weighting
  - Usually used for outdoor sound calculations
- NC
  - Sound is fitted to a curve
  - Based on 8 frequencies
  - Does not evaluate the overall shape of the curve
  - Most used method
  - NC-35
  - 63 Hz – 8K Hz

Acoustics

- ROOM CRITERIA Mark II (RC)
  - Evaluates the shape
  - Currently ASHRAE'S preferred method
  - Addresses lower frequencies
  - R – rumble
  - H – hiss
  - N – neutral
  - Data not always available for products

Acoustics

- Start with quiet equipment
- Locate air-handling equipment in less sensitive areas
- Allow for proper fan outlet conditions
  - Rectangular length 1.5 x largest dimension
  - Round length 1.5 x diameter
  - “system effect”

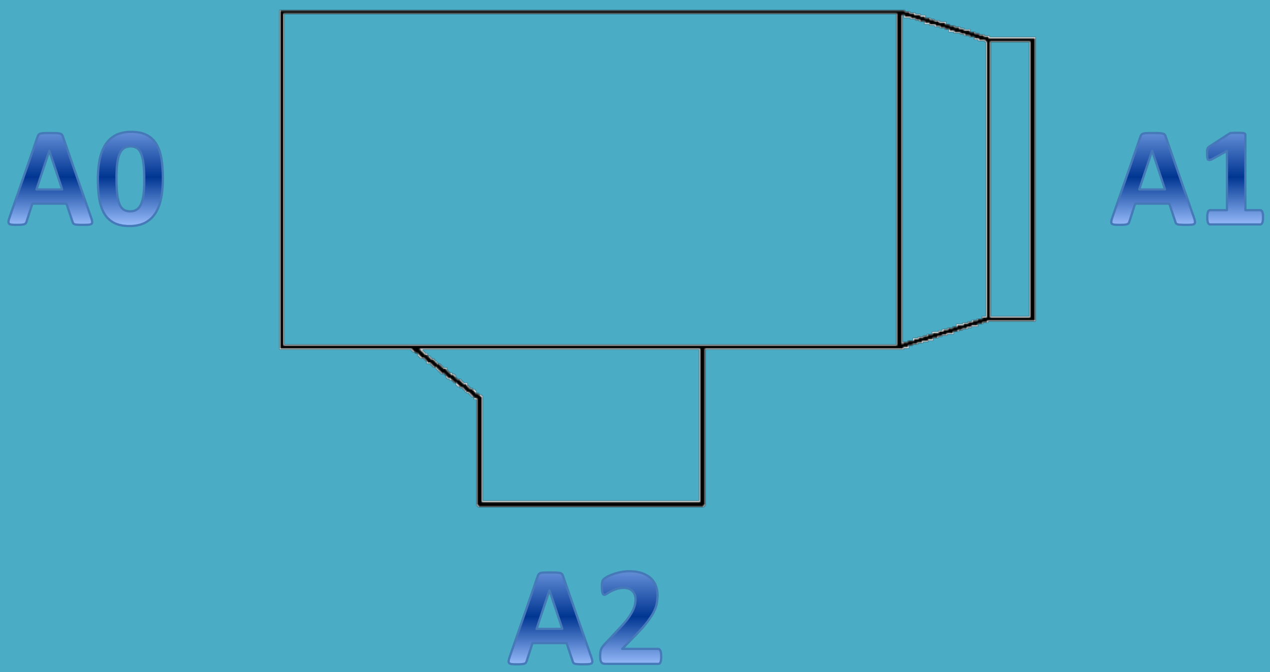
Acoustics

- Use radiused elbows where possible
- Larger ductwork reduces velocity and reduces generated noise
- Avoid abrupt changes in layout
- Place dampers away from outlets
- Flexible connections to equipment

Acoustics

- Power splits
  - Ratio of areas
    - $L1 = 10 \times \log (A1 \div (A1 + A2))$
    - $L2 = 10 \times \log (A2 \div (A1 + A2))$
  - Units dB
  - Applies across all frequencies
  - Straight subtraction

Power Split



Acoustics

- Low Frequency Noise
  - Breakout – Break in
  - Rectangular
    - Where breakout noise is beneficial
    - Do not use where break in noise is a concern
  - Round
    - Does not allow as much breakout
    - Does not allow as much break in
  - Thicker liner attenuates lower frequencies
  - More mass better at attenuating lower frequencies

Acoustics

- Medium-High frequency
  - Easier to attenuate than low
  - Lined or double walled duct
  - Lengthen runs if necessary
  - Silencers

Acoustics

- Silencers
  - Can be very effective at attenuating sound
    - Insertion loss
  - Pressure drops
  - Generated noise
  - Elbow
  - Locate in the wall or as close as possible
  - Do not locate right off of a fan

Acoustics

- Reactive silencers
  - Low to no pressure drops
- Dissipative
  - No fill use baffles and “chambers”

Air Tightness/Leakage

- Duct Leakage
- Accessory Leakage
- Equipment Leakage

Air Tightness/Leakage

- Duct Leakage – As the term should imply is the leakage of air from the “duct”
- Accessory Leakage – Leakage of air from accessories (dampers, access doors)
- Equipment Leakage – Leakage of air from equipment (AHU, VAV)
- System Leakage is the combination of the above

Air Tightness/Leakage

- Cost for air leaks - It is difficult to put an exact cost on leakage because it depends on energy costs, where the leak occurs, environmental conditions, even altitude. It is safe to say that leakage does not provide a benefit and should be reduced as appropriate for the application

Air Tightness/Leakage

- Avoid arbitrary % to design as pass fail for duct tests. It is perfectly acceptable to design with a % of leakage, but this should be converted to a leakage class for duct field tests.
- Using a leakage class provides a way to determine pass/fail for portions of duct and at different pressures

Air Tightness/Leakage

- If you end up with leakage classes below 3 you are not asking for “good duct” you are asking for high performance duct which will likely have a cost impact.
- Contractors not aware of this requirement are likely to have difficulty passing a leakage test with these lower leakage rates
- Make sure to provide allowance for accessories if they are included in the test

Misconceptions

- Leakage tests provide the actual leakage rate under operating conditions
  - Not true, traditional tests would typically provide rates that are higher than actual leakage under operating conditions because the leakage is measured at a higher pressure than operating pressure.

Misconceptions

- Values for "low leakage" dampers should provide better performance for leakage tests
  - This depends on what kind of leakage is being referenced
  - Most damper leakage rates refer to the leakage across the blade(s) when the damper is closed
  - These values do not represent "sleeve" leakage which is the leakage of air from inside the system to outside the system

Recommendations

- Require that all duct be sealed to Seal Class A
- Be careful not to create a pass/fail so low that meeting it would require voiding listings or warranties – leakage class is best for duct
- Test some portion of the duct
  - 10 – 20 - 100
- Focus on critical areas
- Test early in the process

Summary

- Provide proper inlet and outlet conditions for the fan – Space in the mechanical room
- Use a duct layout that is efficient (direct) with as few fittings as possible
- Fitting choices are important in the critical path. Other paths are “not so critical”
- Specify seal class “A” for ducts and fittings
- Insulate

Tools

- SMACNA apps
  - http://www.smacna.org/technical/index.cfm?fuseaction=apps
  - Leakage
  - Duct construction
- Fitting Losses
  - SMACNA Duct Design Manual
  - ASHRAE ~$160
  - App Store ($9.99)

THANK YOU

Questions?