Better Plants
U.S. DEPARTMENT OF ENERGY

# Industrial Fan Systems
## Virtual INPLT Training & Assessment

Session 5

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# Fan Virtual INPLT Facilitator

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# Acknowledgments


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- US Department of Energy , Advanced Manufacturing Office
- Oak Ridge National Laboratory
- United Nations Industrial Development Organization
- Air Movement and Control Association, AMCA International
- Many industrial clients – both in the US and internationally




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# Agenda – Session 5

- Welcome and Introductions
- Safety and Housekeeping
- Agenda for Fan System Virtual INPLT (8 weeks)
- Today's Content:

**Industrial Fan Systems Fundamentals**

  - Pressure considerations in fan systems
  - Sizing ducts and system pressure losses

**MEASUR Tool**

  - Demonstration

- Kahoot Quiz Game
- Q&A

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# Safety and Housekeeping

- Safety Moment
  - Ensure that ducts carrying dust have adequate velocity to entrain the material and that ducts do not have stagnant branches
  - Accidents can be life-threatening
- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and a the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

# Fan system Virtual INPLT Agenda

- **Week 1 – Industrial Fan Systems Fundamentals and Introduction to MEASUR**
- **Week 2 – Fan and system curves, Fan types**
- **Week 3 – Fan affinity laws, Fan system controls**
- **Week 4 – Creating a fan performance measurement plan & selecting measurement planes**
- **Week 5 – Pressure considerations, Sizing ducts and estimating losses, Optimization techniques**
- **Week 6 – Psychrometrics and air density for fan systems, System effect in fan systems**
- **Week 7 – Fan system optimization strategies, Fan system evaluation with MEASUR**
- **Week 8 – Industrial Fan System VINPLT Wrap-up Presentations**

# Session 5 Learning Objectives

**Class participants will:**

1. Discuss fan system pressure considerations;
2. Examine the definition of fan static pressure;
3. Analyze losses due to duct design
4. Calculate losses due to duct design
5. Discuss duct design parameters
6. Analyze air velocity requirements for pneumatic conveyance
7. Analyze and calculate friction losses

# Pressure considerations in fan systems

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# Fan System Pressure Considerations

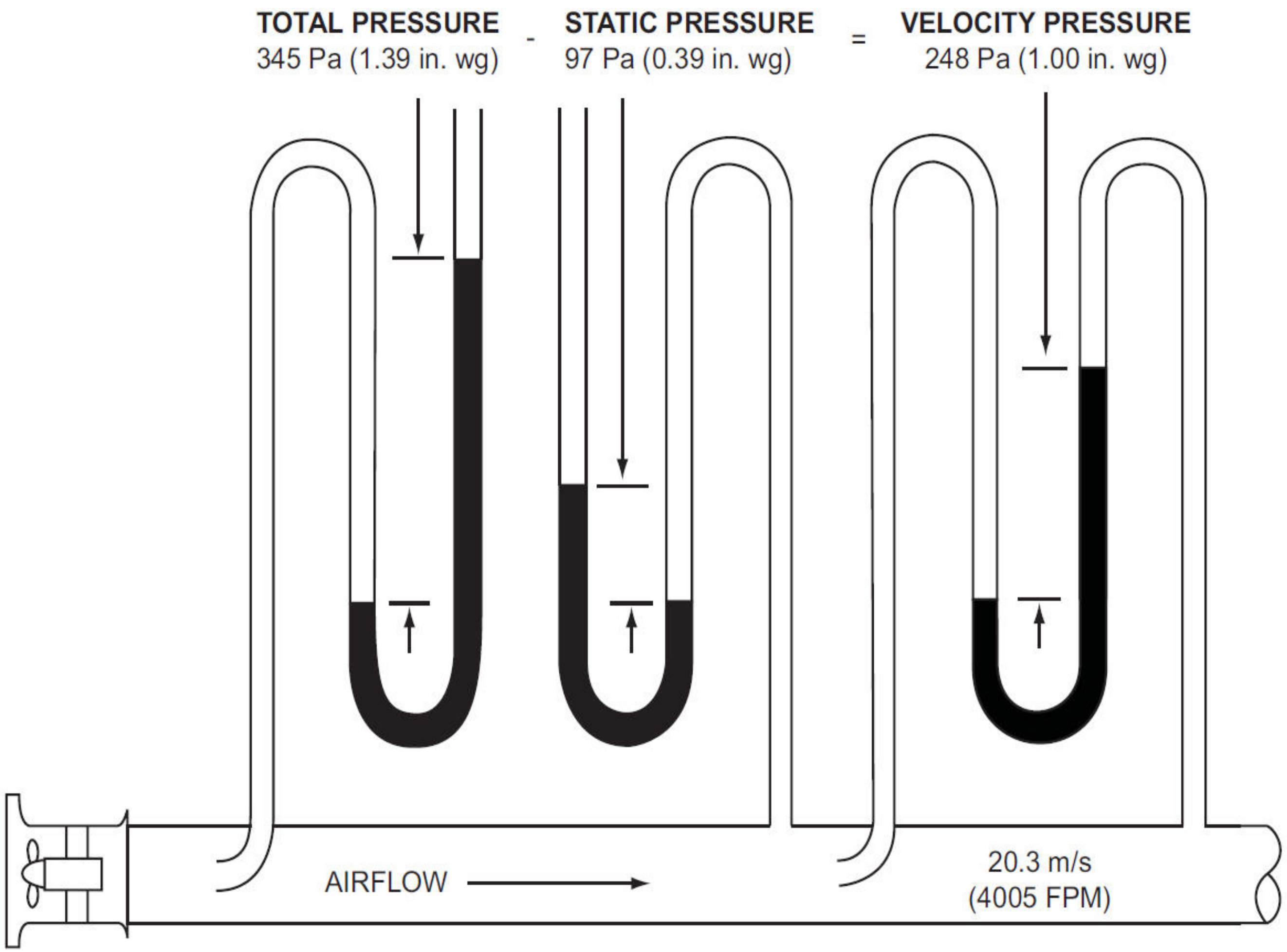
Bernoulli's equation determines the relationship between the static pressure ($P_s$), velocity pressure ($P_v$) and total pressure ($P_t$).

$$P_t = P_s + P_v$$

The fan static pressure is defined in AMCA measurement protocols as the outlet static pressure minus the inlet static pressure minus the inlet velocity pressure:

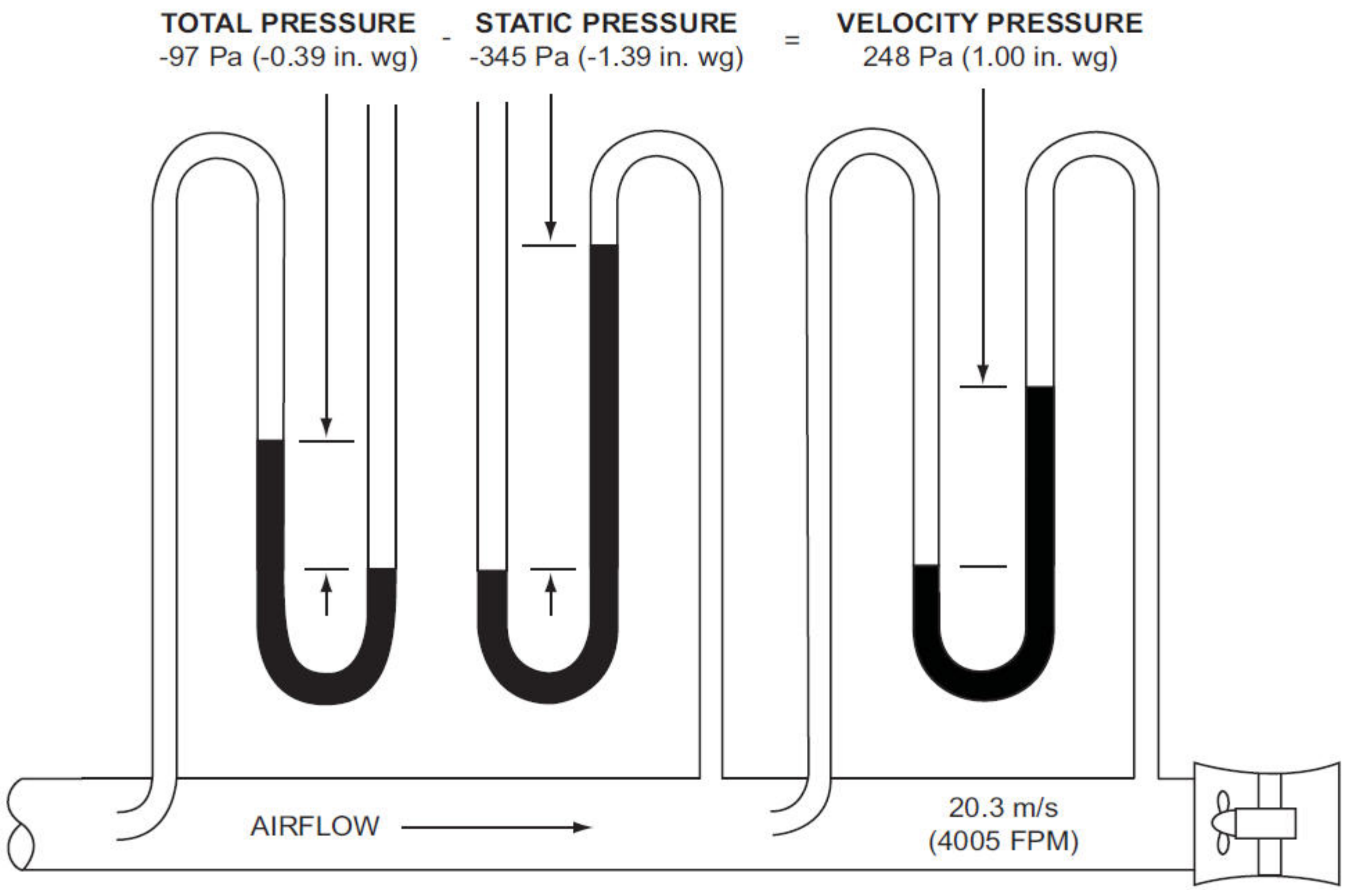
$$P_s = P_{s2} - P_{s1} - P_{v1}$$

# System Pressure Illustration- Positive Pressure




345= 97 + 248

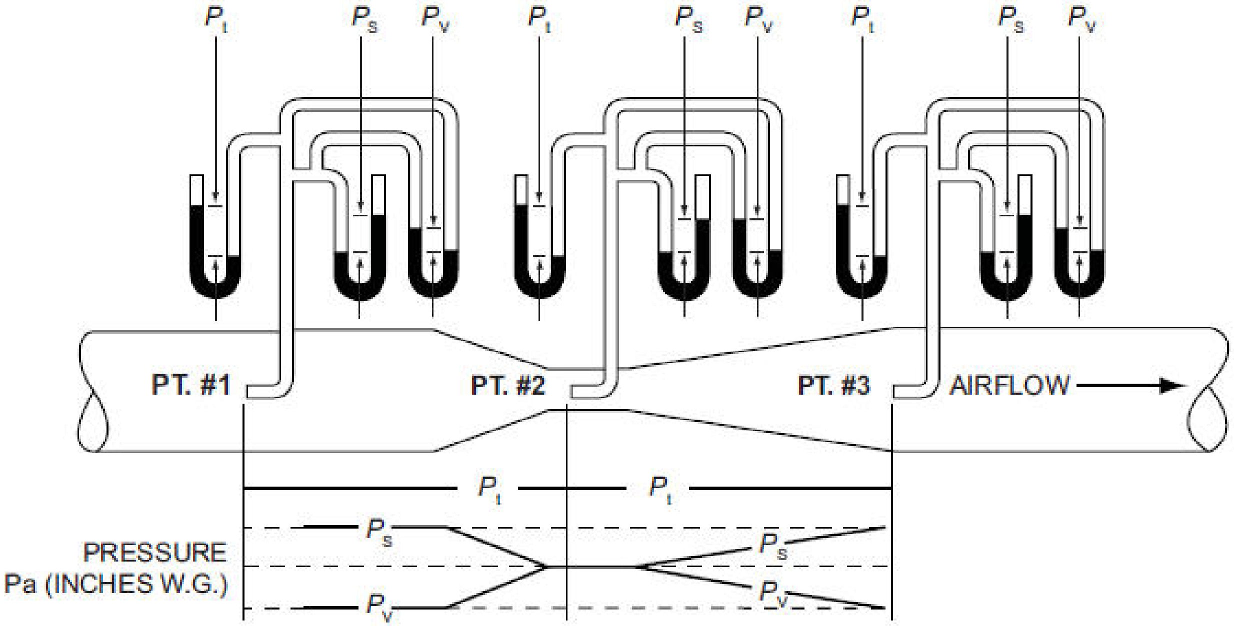
# System Pressure Illustration- Negative Pressure



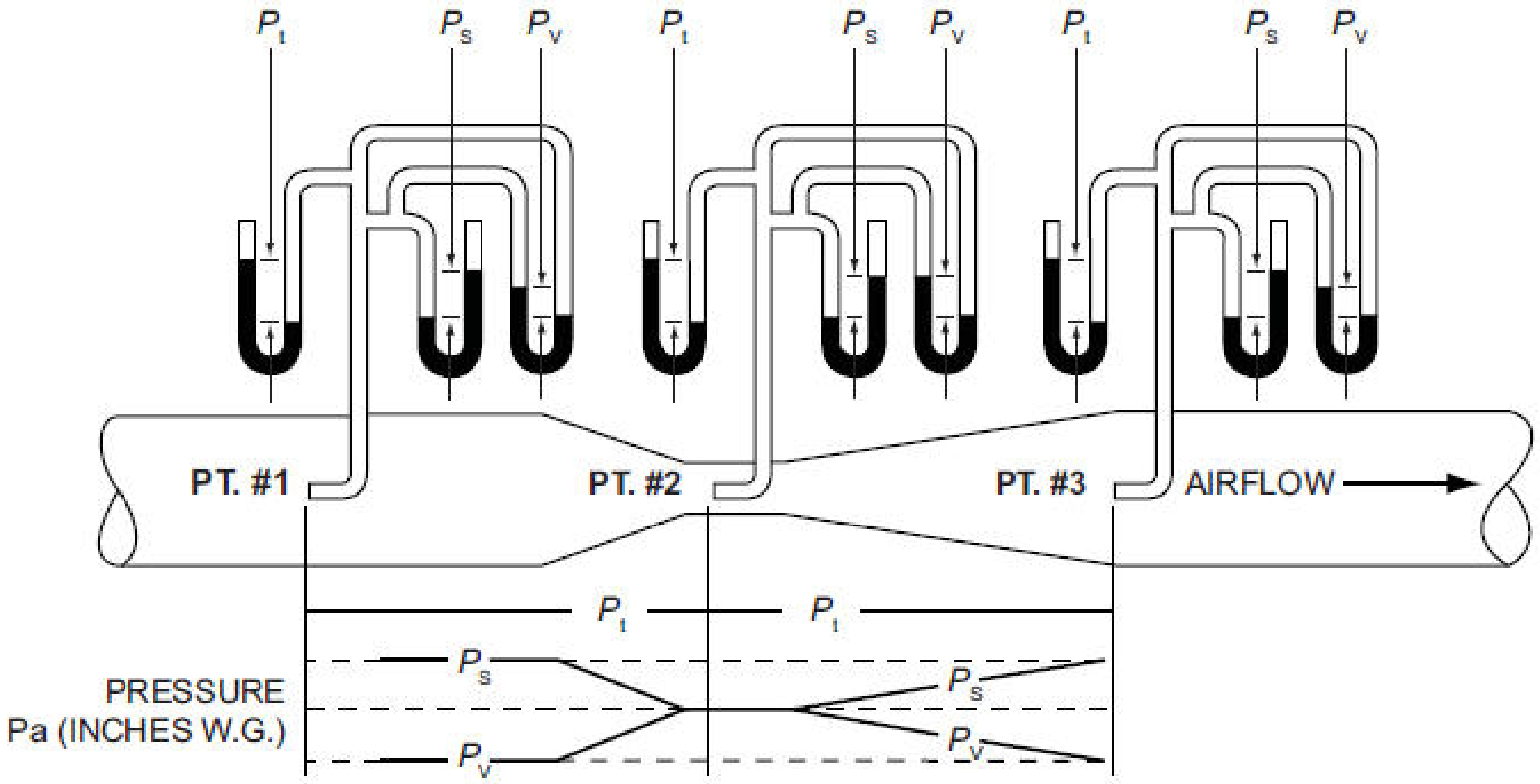

-97= -345 + 248

# Venturi Flow Meter Pressure Relationships

- Because the meter has very low losses, the total pressure at points 1, 2, and 3 are equal
- As the flow accelerates in the throat of the meter, the velocity pressure goes up, and the static pressure goes down
- Since the density, cross section and static pressure at inlet and throat are known, the flow can be calculated

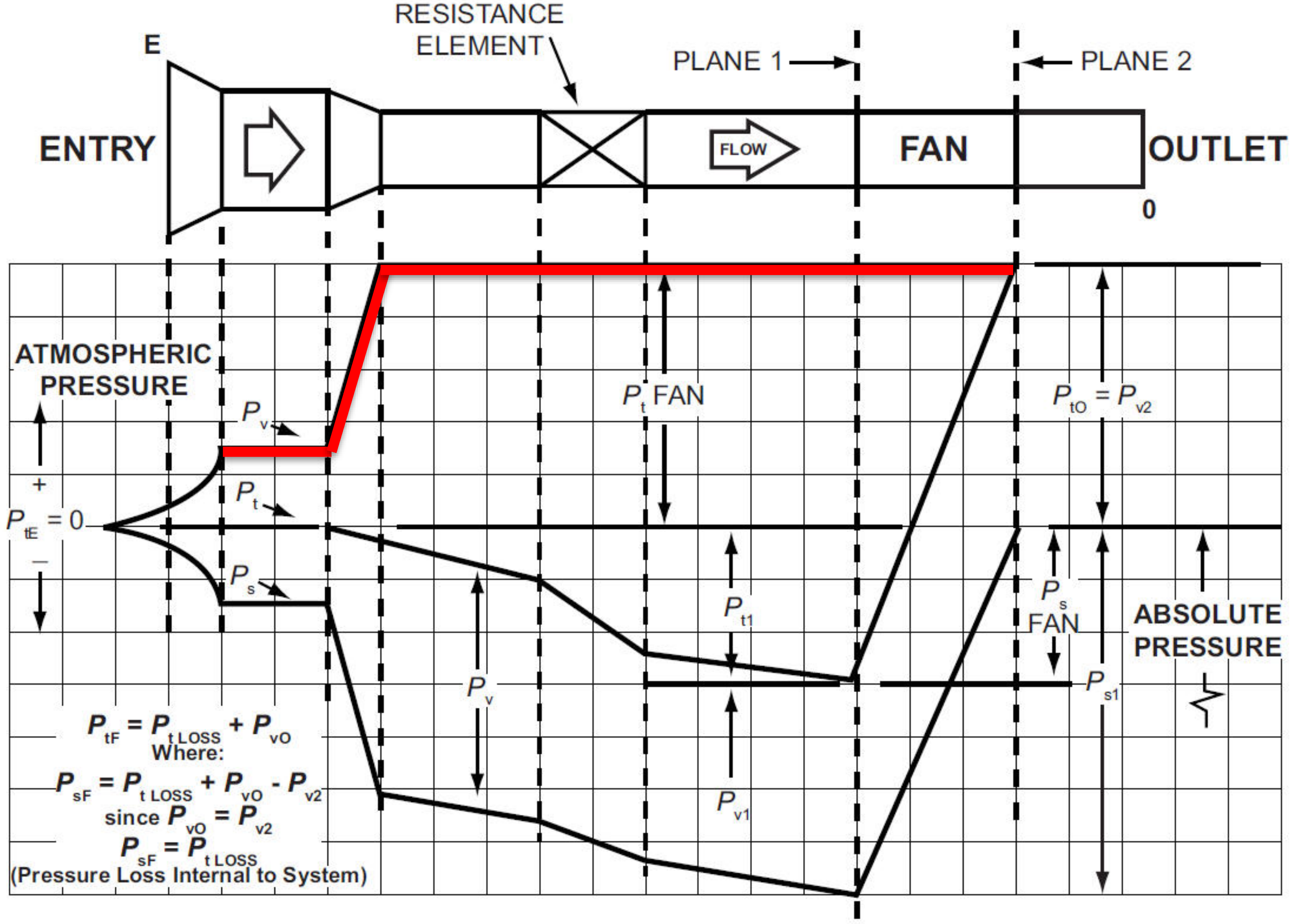


# Venturi Flow Meter Pressure Relationships



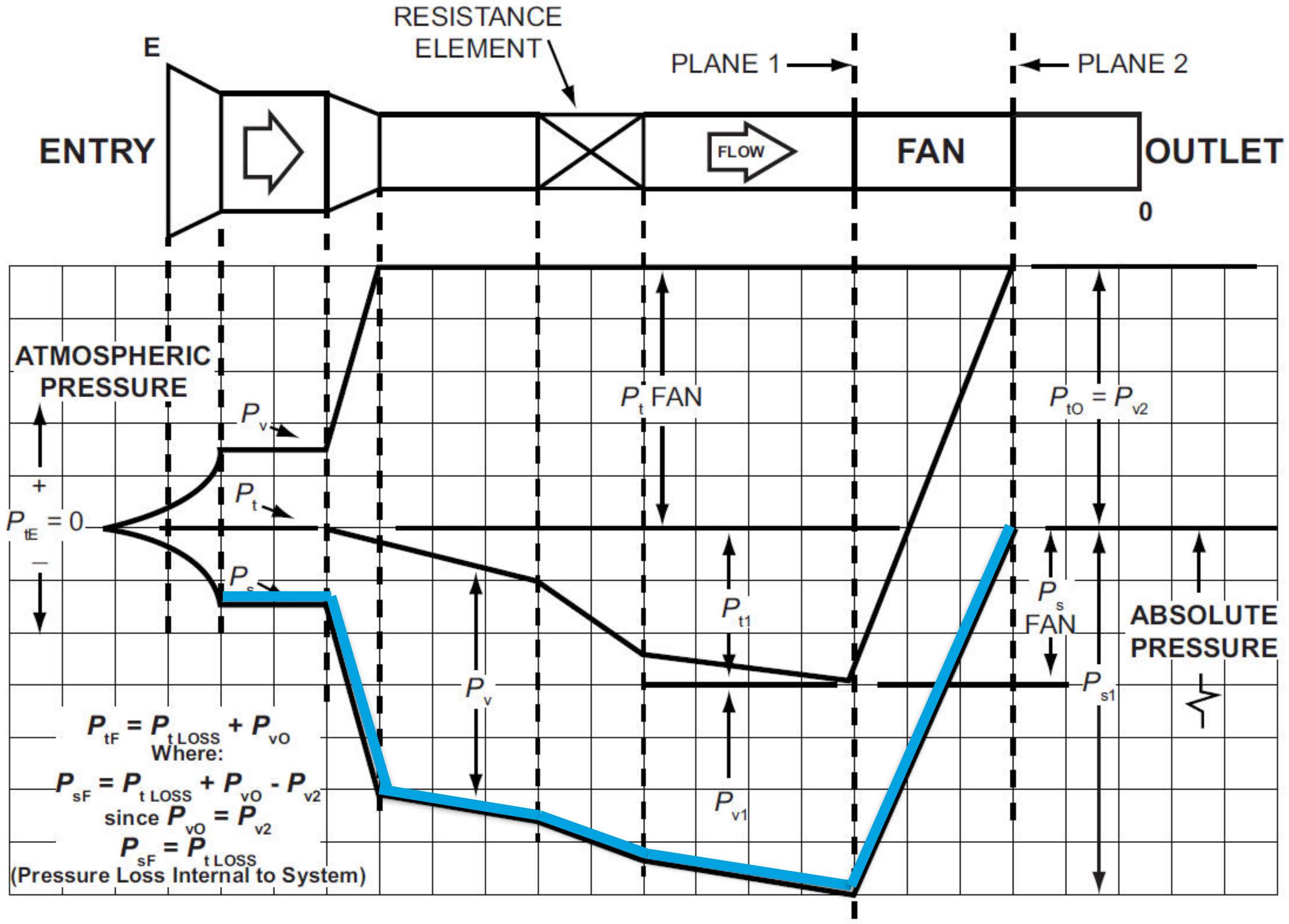
# System Pressure Variations-
# Resistance on the Inlet Side of Fan

- Typical for an ID fan (Induced Draft)
- Velocity Pressure
  - Starts out at 0 at system inlet then goes positive as air accelerates into the intake
  - Goes further positive as velocity increases with duct size reduction
  - Stays level when duct size stays constant



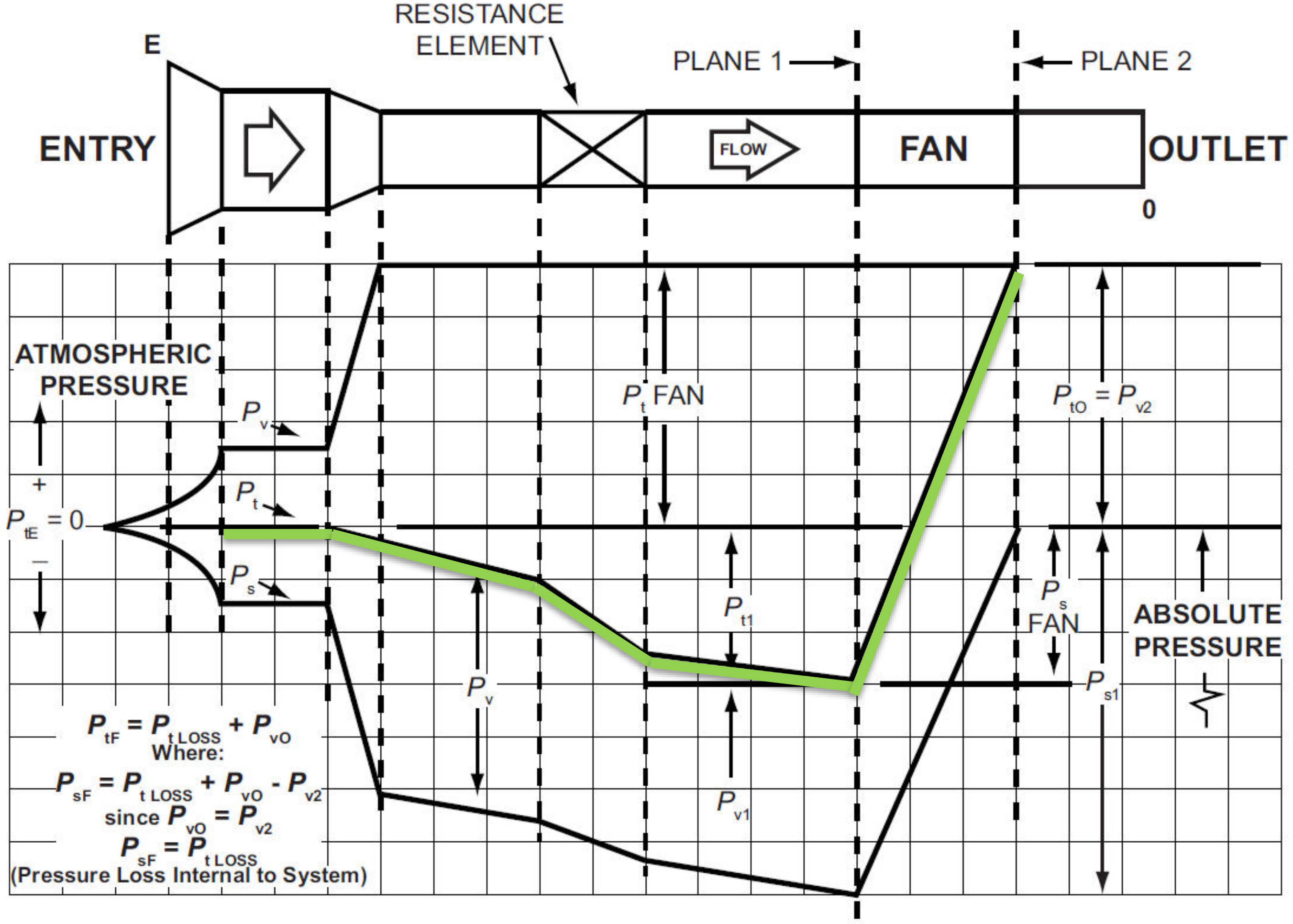
# System Pressure Variations- Resistance on the Inlet Side of Fan

- Typical for an ID fan (Induced Draft)
- Static pressure
  - Starts out at 0 at system inlet then goes negative to offset velocity pressure
  - Goes further negative as velocity and velocity pressure increases with duct size reduction
  - Continues into deeper negative value until fan inlet, then goes back to zero at fan outlet



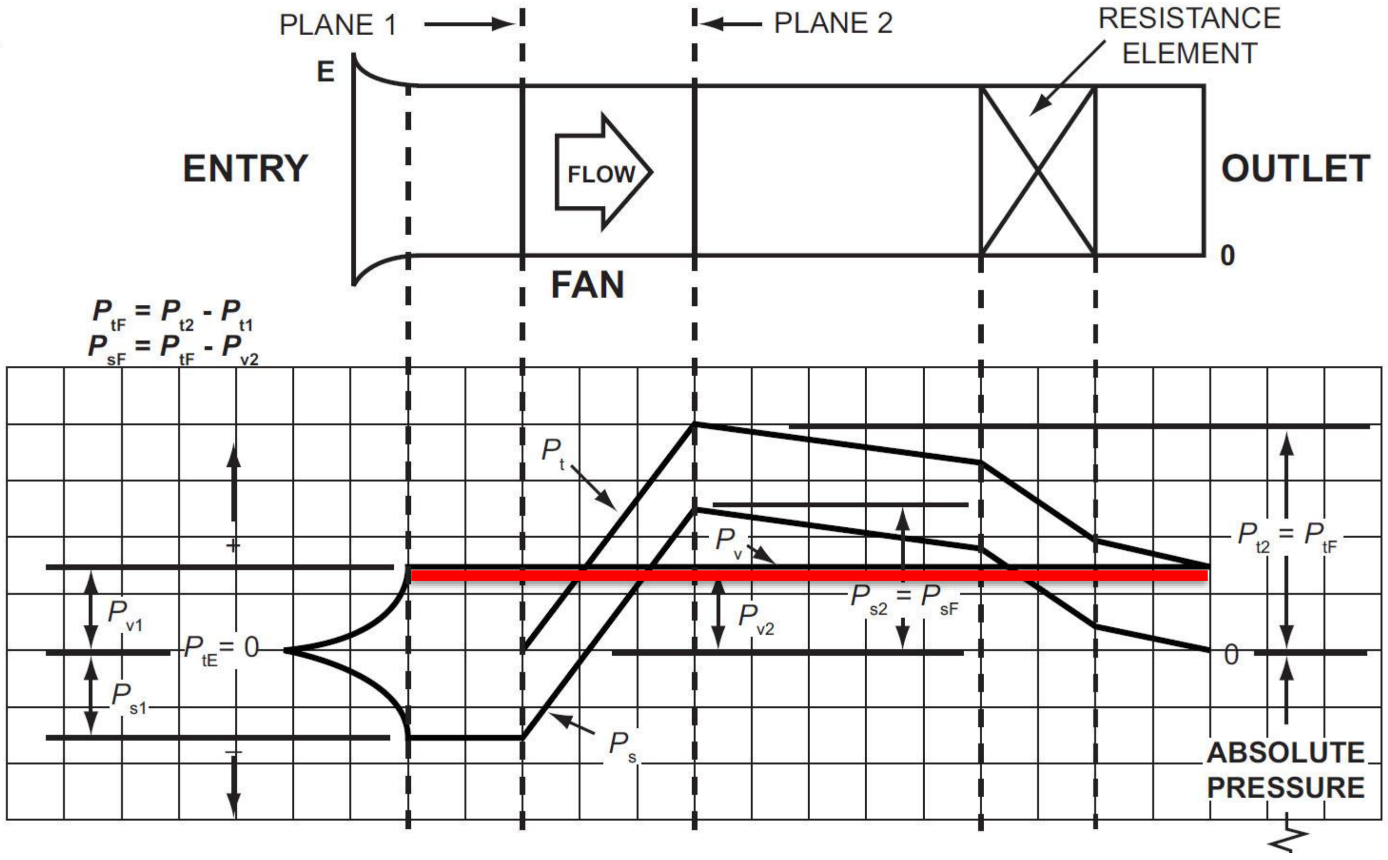
# System Pressure Variations-
# Resistance on the Inlet Side of Fan

- Typical for an ID fan (Induced Draft)
- Total pressure
  - Starts out at 0 at system inlet
  - Goes down gradually as friction losses accumulate
  - Steeper decline through resistance element
  - Rises sharply through the fan



# System Pressure Variations- Resistance on Outlet Side of Fan

- Typical for an FD fan (forced draft)
- Velocity pressure:
  - Starts at 0, then goes negative to offset the velocity pressure as air is draw into the inlet bell
  - Rises through the fan
  - Falls as air travels through ductwork
  - Returns to zero as air is discharged



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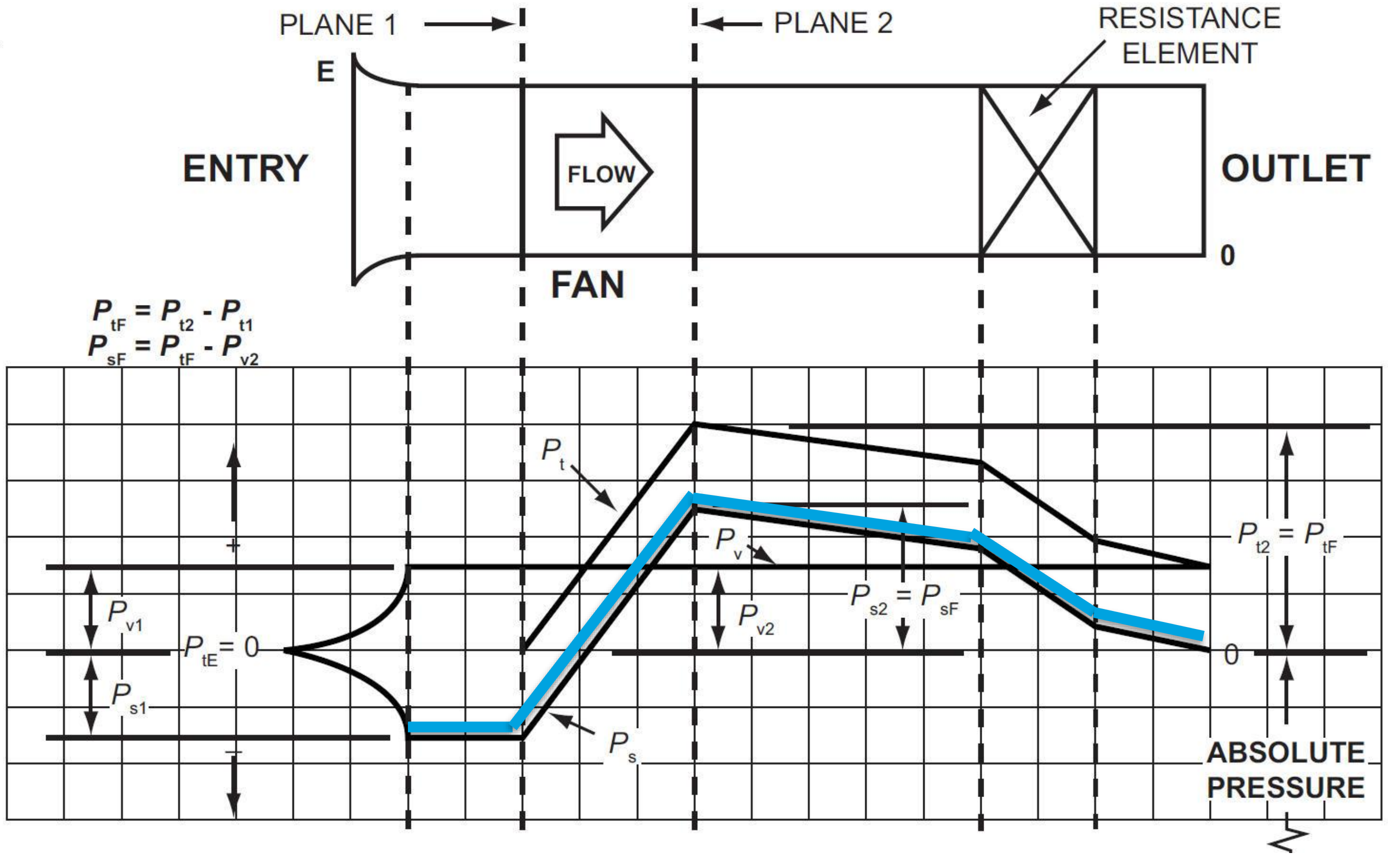
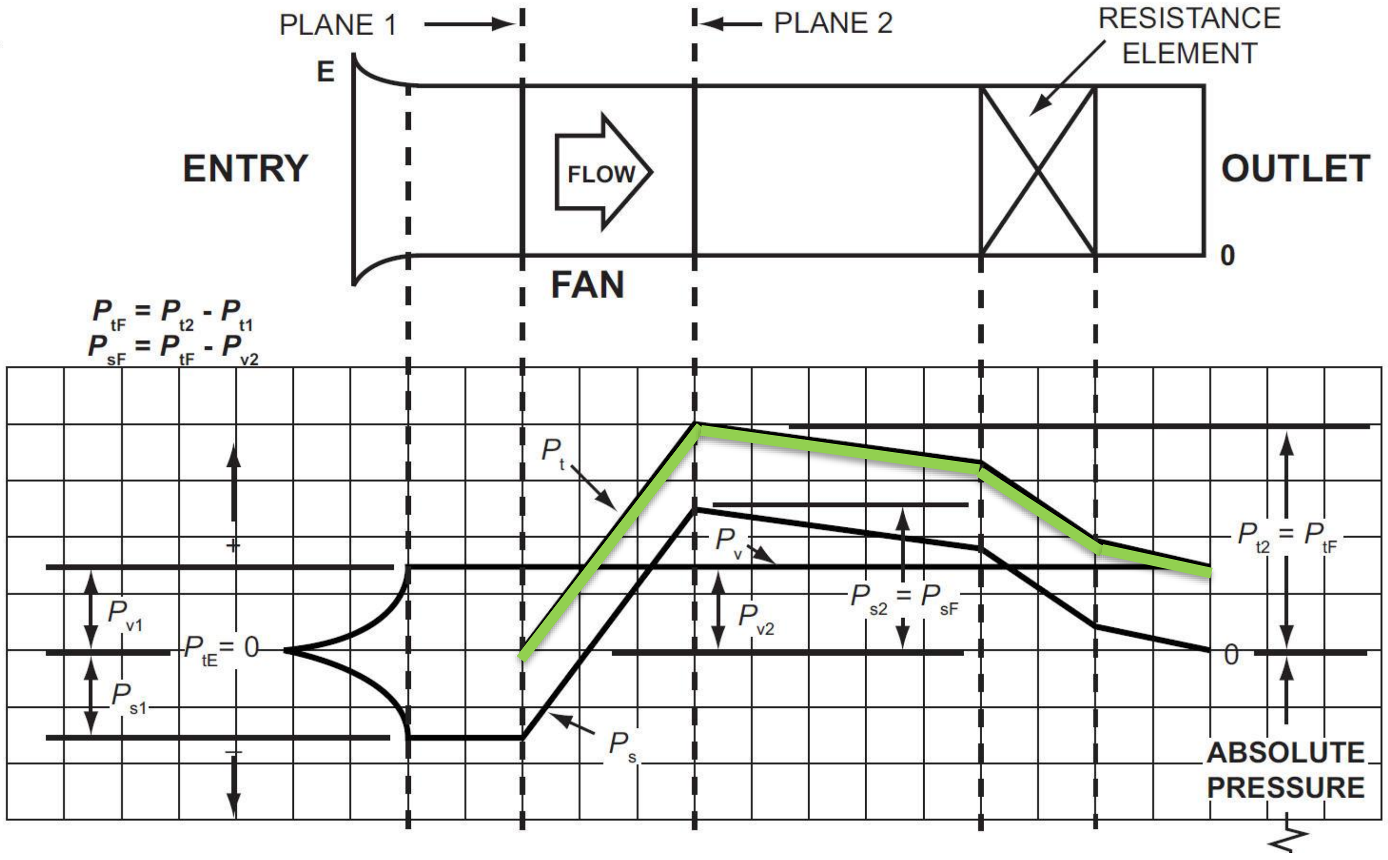


# System Pressure Variations- Resistance on Outlet Side of Fan

- Typical for an FD fan (forced draft)
- Total pressure:
  - Starts at 0
  - Rises through the fan
  - Falls as air travels through ductwork due to friction loss
  - At the discharge, the total pressure equals the velocity pressure because the static pressure is zero



# Sizing ducts and system pressure losses

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# Designing Ducting Systems

- Construction:
  - Steel
  - Sheet metal
  - Insulation
- Size:
  - Volume of air
  - Minimum velocity required

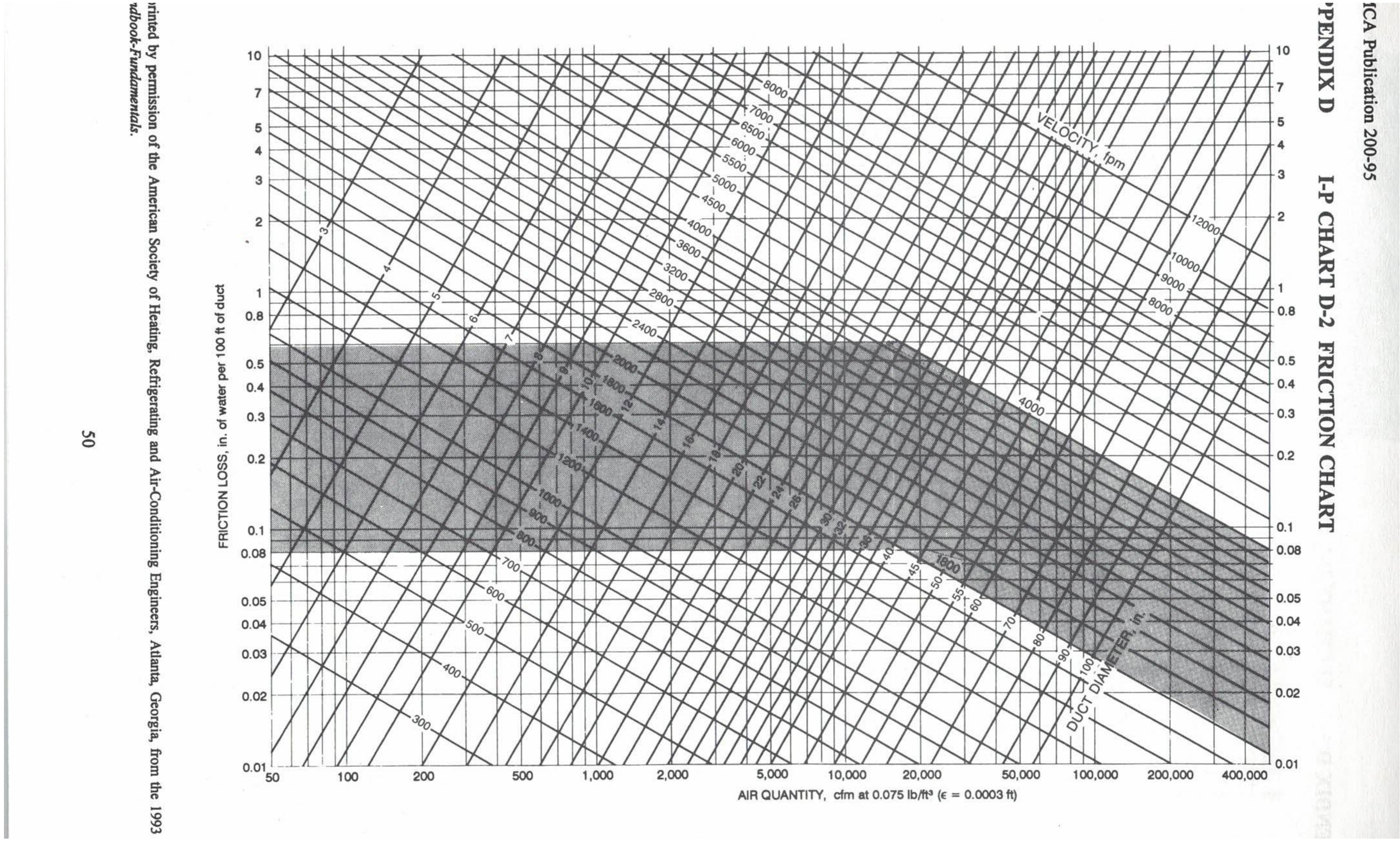
# Commonly Accepted Air Velocities for Conveying Various Materials

| Material | Velocity m/s | Velocity fpm |
|---|---|---|
| paper trim | 25 | 4900 |
| rags | 22.5 | 4400 |
| rubber pieces | 22.5 | 4400 |
| salt | 27.5 | 5400 |
| sand | 35 | 6900 |
| dry sawdust | 15 | 3000 |
| wood shavings | 17.5 | 3400 |
| wheat | 29 | 5700 |
| wool | 25 | 4900 |
| dry vegetable pulp | 22.5 | 4400 |

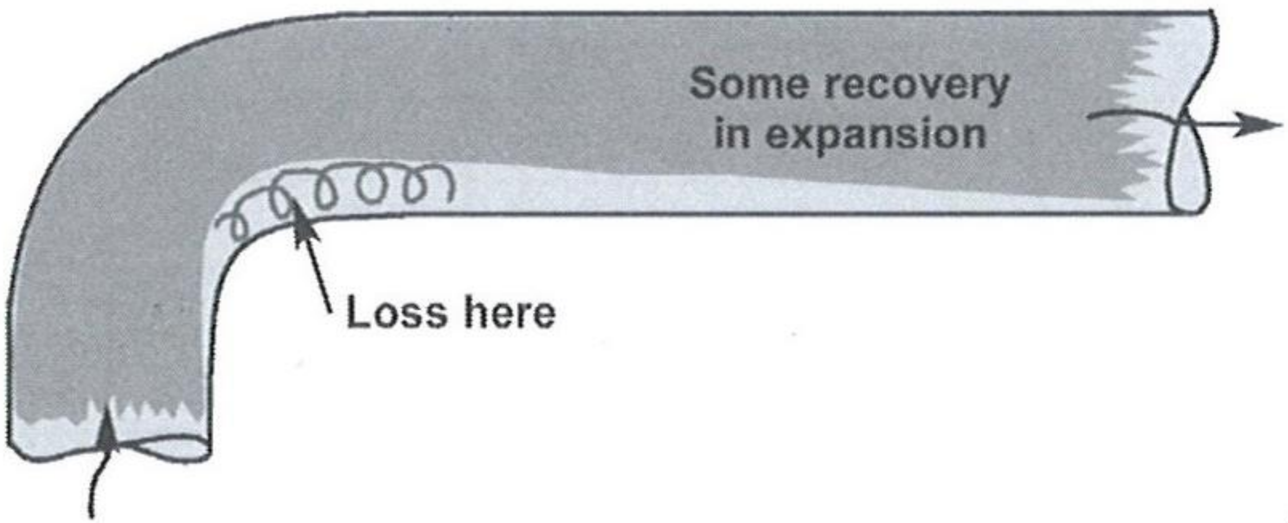
# Commonly Accepted Air Velocities for Conveying Various Materials (cont.)

| Material | Velocity m/s | Velocity fpm |
|---|---|---|
| castor beans | 25 | 4900 |
| cement | 35 | 6900 |
| powdered coal | 20 | 3900 |
| ground cork | 15 | 3000 |
| corn | 28 | 5500 |
| cotton | 22.5 | 4400 |
| Iron oxide | 32.5 | 6400 |
| pulverized limestone | 25 | 4900 |
| oats | 22.5 | 4400 |

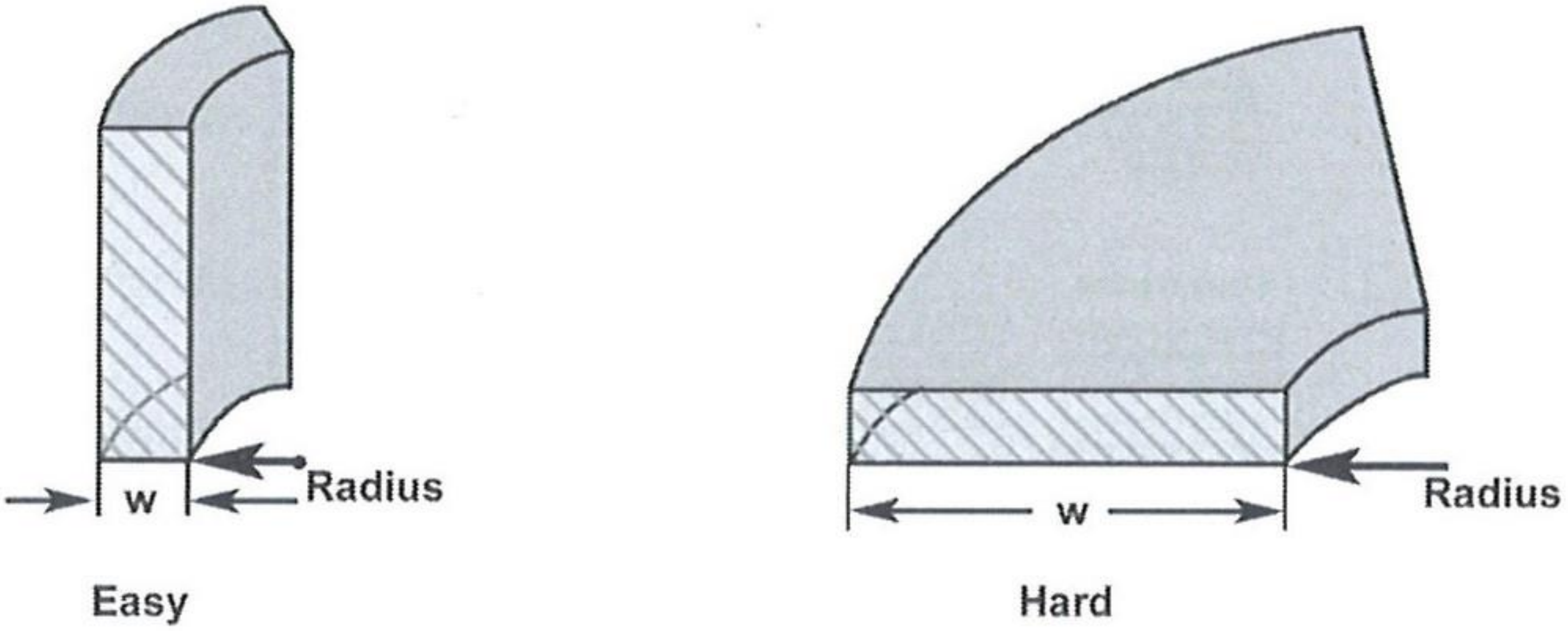
# Friction Chart for Round Duct



# Recovery in Duct After a Bend

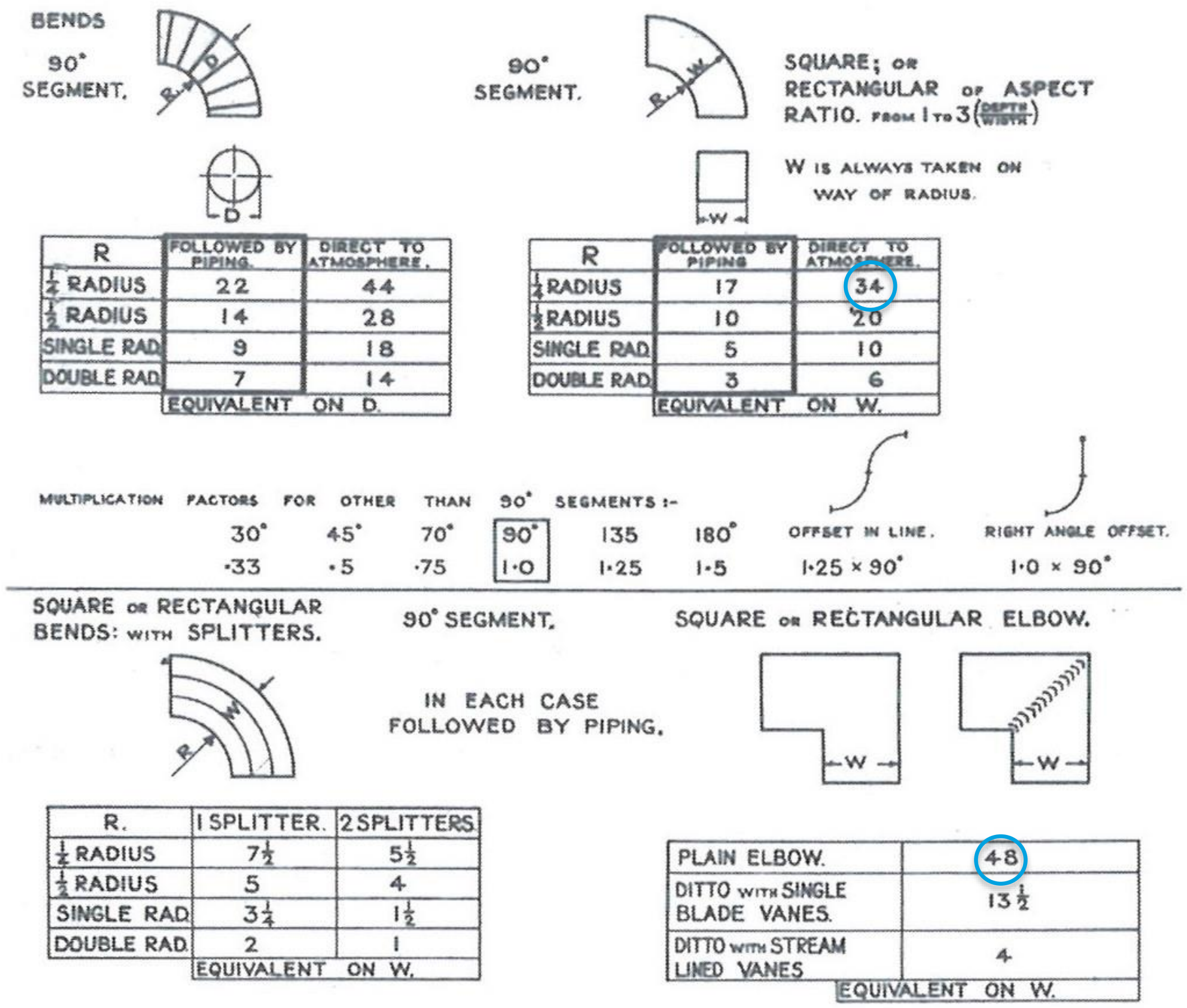


# Easy and Hard Bends



# Duct Resistance Equivalent Lengths for Bends

- Although the method is dated, and not recommended for current use, the huge variation in losses for different fittings is dramatically illustrated




| R | FOLLOWED BY PIPING. | DIRECT TO ATMOSPHERE. |
|---|---|---|
| 1/4 RADIUS | 22 | 44 |
| 1/2 RADIUS | 14 | 28 |
| SINGLE RAD | 9 | 18 |
| DOUBLE RAD | 7 | 14 |
| | EQUIVALENT ON D. | |

| R | FOLLOWED BY PIPING | DIRECT TO ATMOSPHERE. |
|---|---|---|
| 1/4 RADIUS | 17 | 34 |
| 1/2 RADIUS | 10 | 20 |
| SINGLE RAD | 5 | 10 |
| DOUBLE RAD | 3 | 6 |
| | EQUIVALENT ON W. | |

MULTIPLICATION FACTORS FOR OTHER THAN 90° SEGMENTS :-

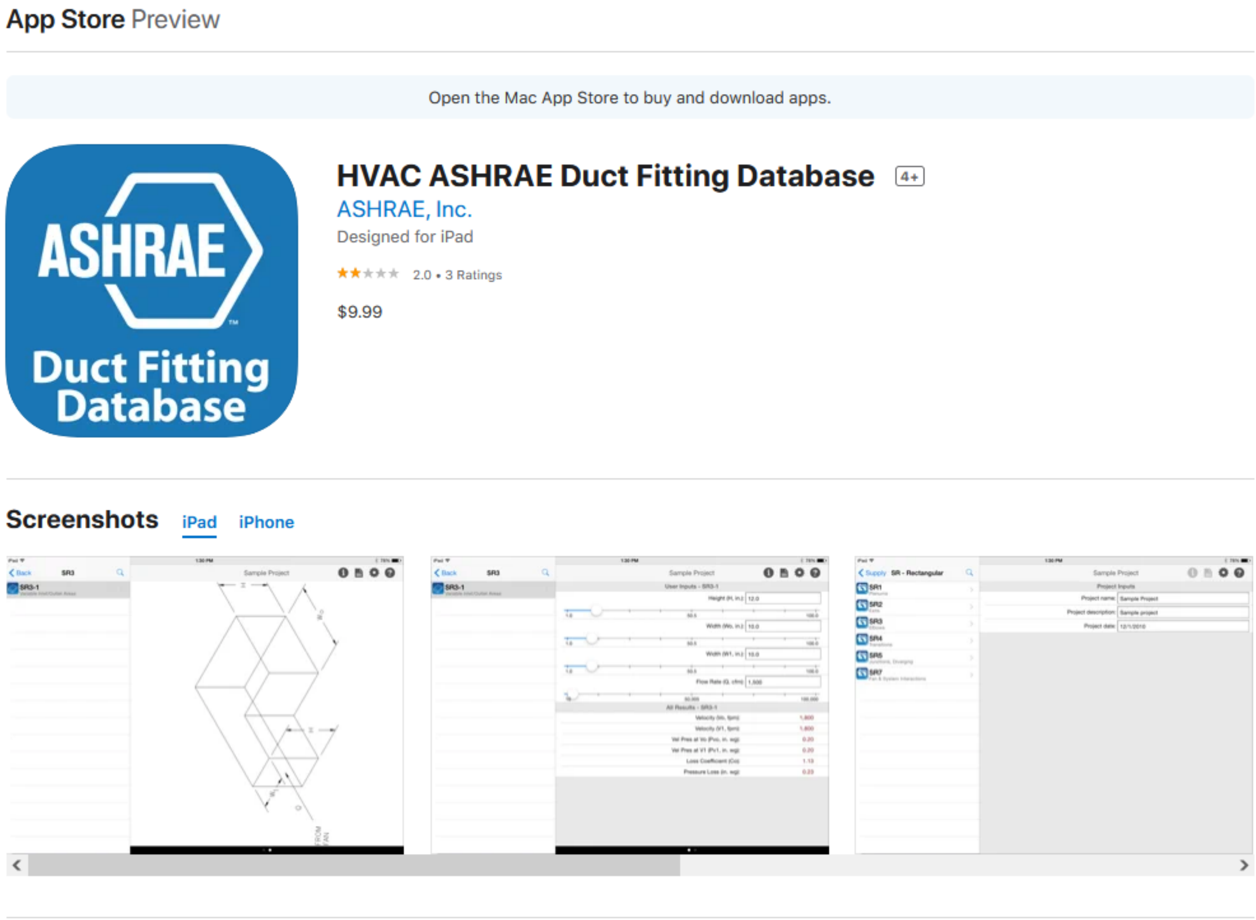
| 30° | 45° | 70° | 90° | 135 | 180° | OFFSET IN LINE. | RIGHT ANGLE OFFSET. |
|---|---|---|---|---|---|---|---|
| ·33 | ·5 | ·75 | 1·0 | 1·25 | 1·5 | 1·25 × 90° | 1·0 × 90° |

| R. | 1 SPLITTER. | 2 SPLITTERS. |
|---|---|---|
| 1/4 RADIUS | 7½ | 5½ |
| 1/2 RADIUS | 5 | 4 |
| SINGLE RAD | 3¼ | 1½ |
| DOUBLE RAD | 2 | 1 |
| | EQUIVALENT ON W. | |

| | |
|---|---|
| PLAIN ELBOW. | 48 |
| DITTO WITH SINGLE BLADE VANES. | 13½ |
| DITTO WITH STREAM LINED VANES | 4 |
| | EQUIVALENT ON W. |

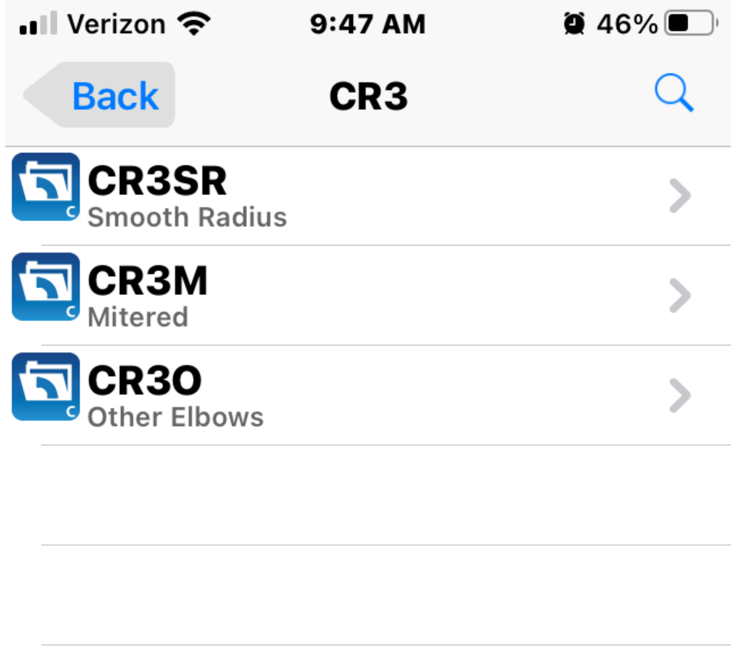
# ASHRAE Duct fitting database ap

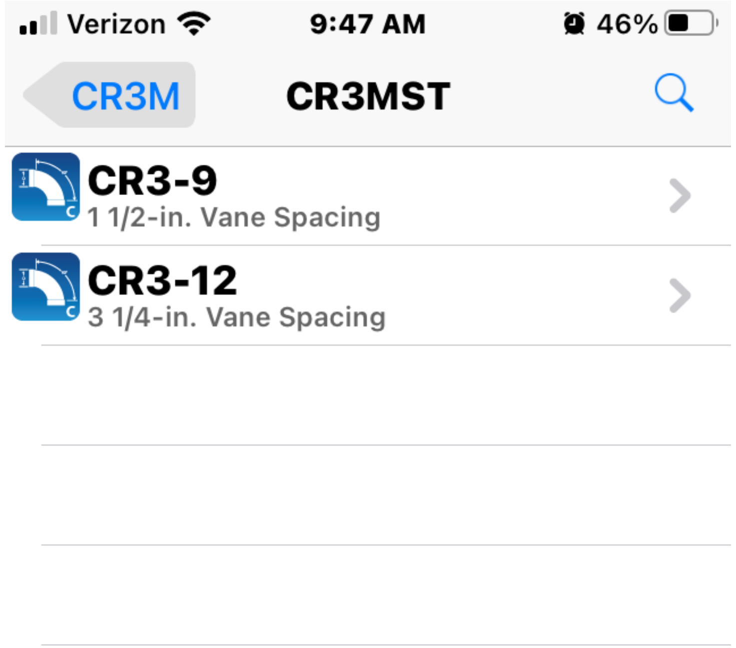
- $9.99 Ap Works on Iphone, Ipad
- Separate version for computer $147

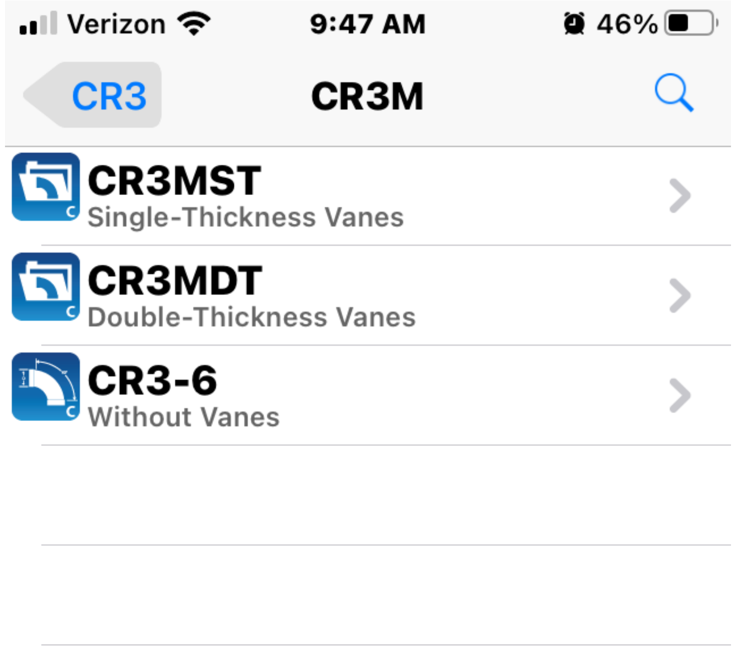


# ASHRAE Duct fitting database ap

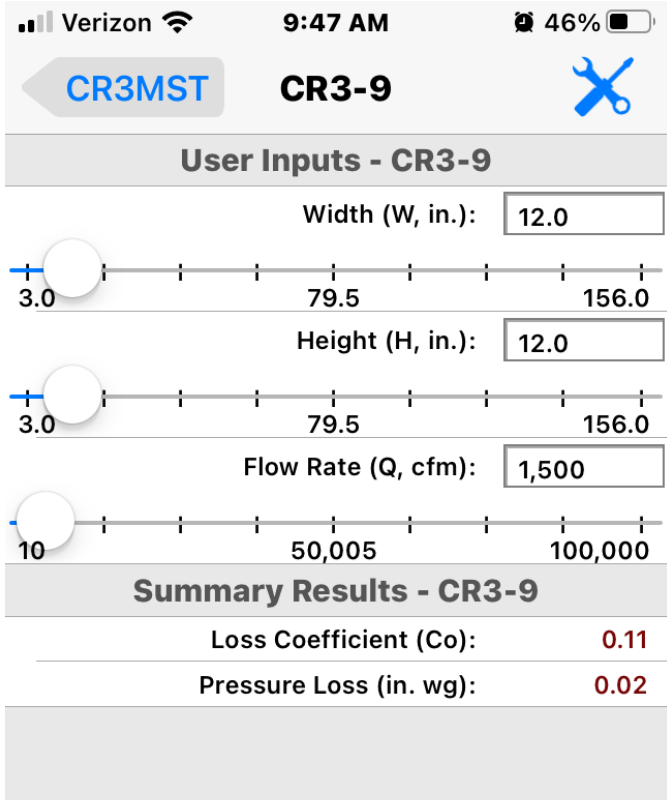
- Navigate through the choices to match the fitting type



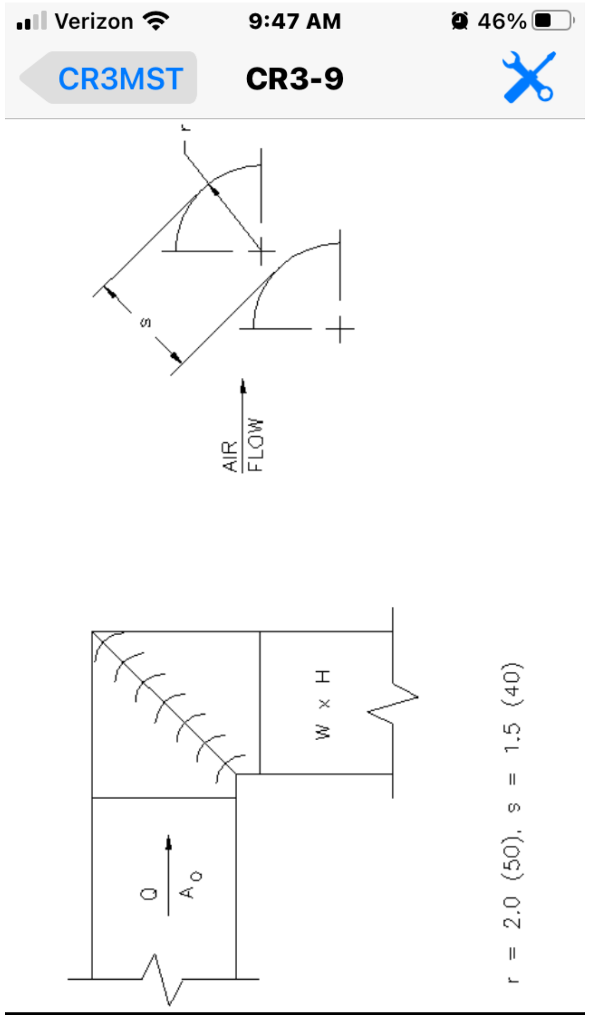



# ASHRAE duct fitting database ap

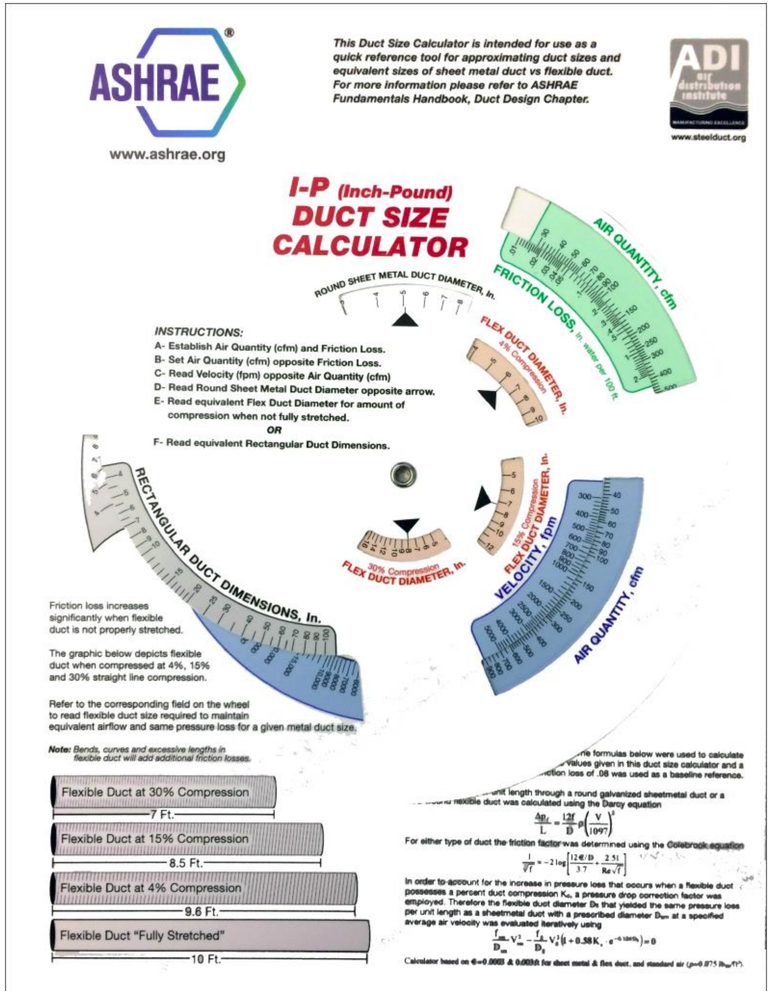






# Duct calculator wheel - ASHRAE and others

- Handheld cardboard calculator wheels are old standby for sizing ducts and calculating friction in straight sections of ductwork.
- Available from ASHRAE and some vendors of HVAC equipment



# Practice Sizing Ducts and Fans

Instructions:

Let's say we need a duct 400 feet in length to carry 20,000 cfm of air that is loaded with sawdust. The baghouse loss is 3 inches w.g.

- What size duct is needed? Q = V.A
- What would be the pressure loss across the duct?
- Estimate the fan power required for this application

# Practice Sizing Ducts and Fans

Let's say we need a duct 400 feet in length to carry 20,000 cfm of air that is loaded with sawdust. The baghouse loss is 3 inches w.g.

1. What size duct is needed? $Q = V \times A$

a. First, we look in the table to determine the minimum velocity:

3000 fpm

b. Next determine cross section: $A = Q/V$

$20{,}000/3000 = 6.67\ ft^2$

c. Determine duct diameter $A = Pi \times D^2/4$or $D = Sqrt(A / Pi)$

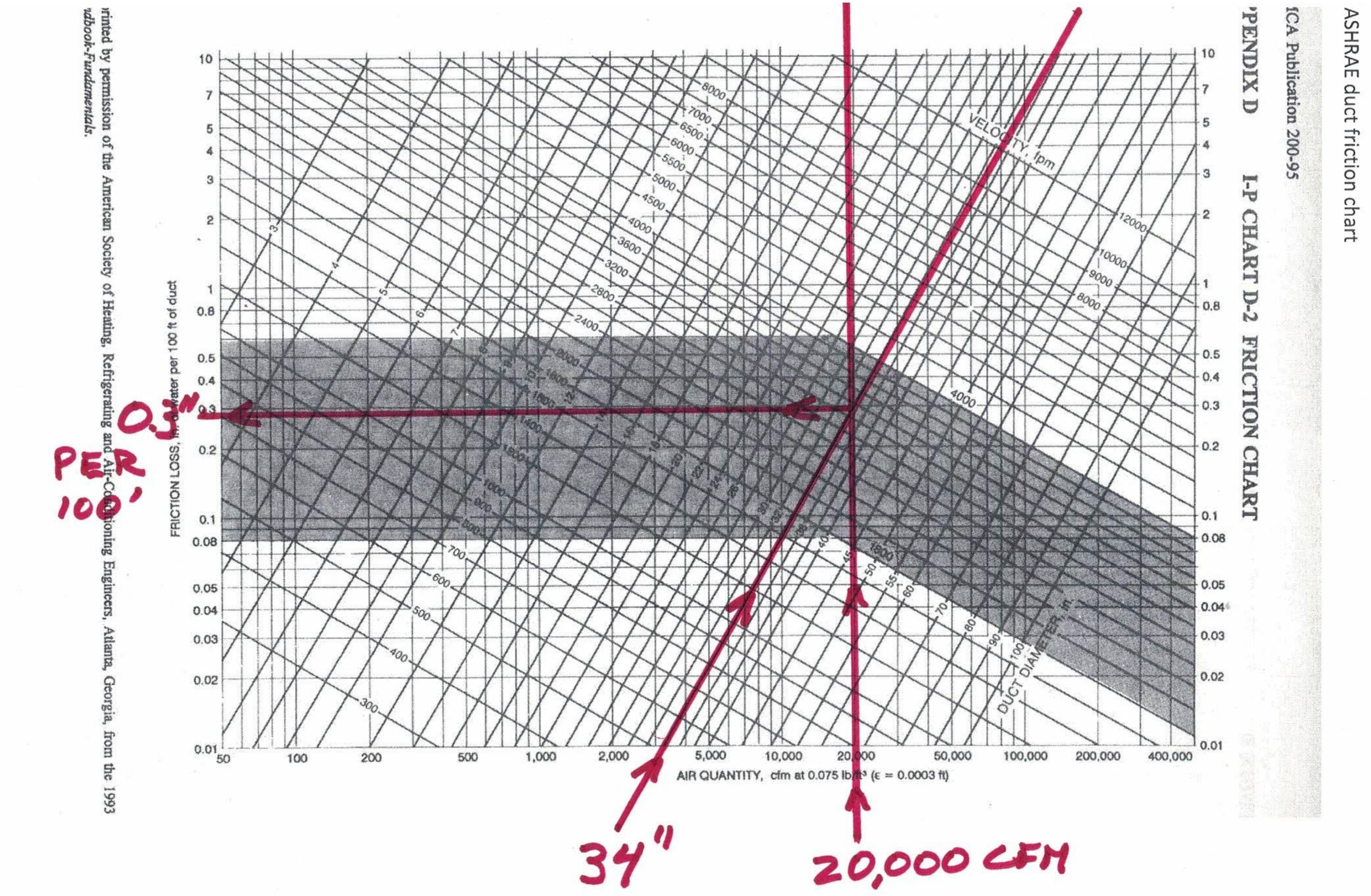
$D = 2 \times sqrt(6.67/3.1415)$ or 2.9 ft or 34.8 inches

# Practice Sizing Ducts and Fans

Let's say we need a duct 400 feet in length to carry 20,000 cfm of air that is loaded with sawdust. The baghouse loss is 3 inches w.g.

2. What would be the pressure loss across the duct?

# Using pressure loss chart



# Practice Sizing Ducts and Fans

Let's say we need a duct 400 feet in length to carry 20,000 cfm of air that is loaded with sawdust:

2. What would be the pressure loss across the duct?

a. Looking in the chart, we see that the pressure loss in a 34 inch duct with 20,000 cfm is 0.3 inches per 100 ft.

b. Since the duct is 400 feet long the overall loss is

4 x 0.3 = 1.2 in. w.g.

# Practice Sizing Ducts and Fans

Let's say we need a duct 400 feet in length to carry 20,000 cfm of air that is loaded with sawdust. The baghouse loss is 3 inches w.g.

3. Estimate the fan power required for this application

a. Total loss is 1.2 inches w.g. + 3 Inches w.g. or 4.2 inches total

b. Using fan power law, assuming our fan can be 75% efficient

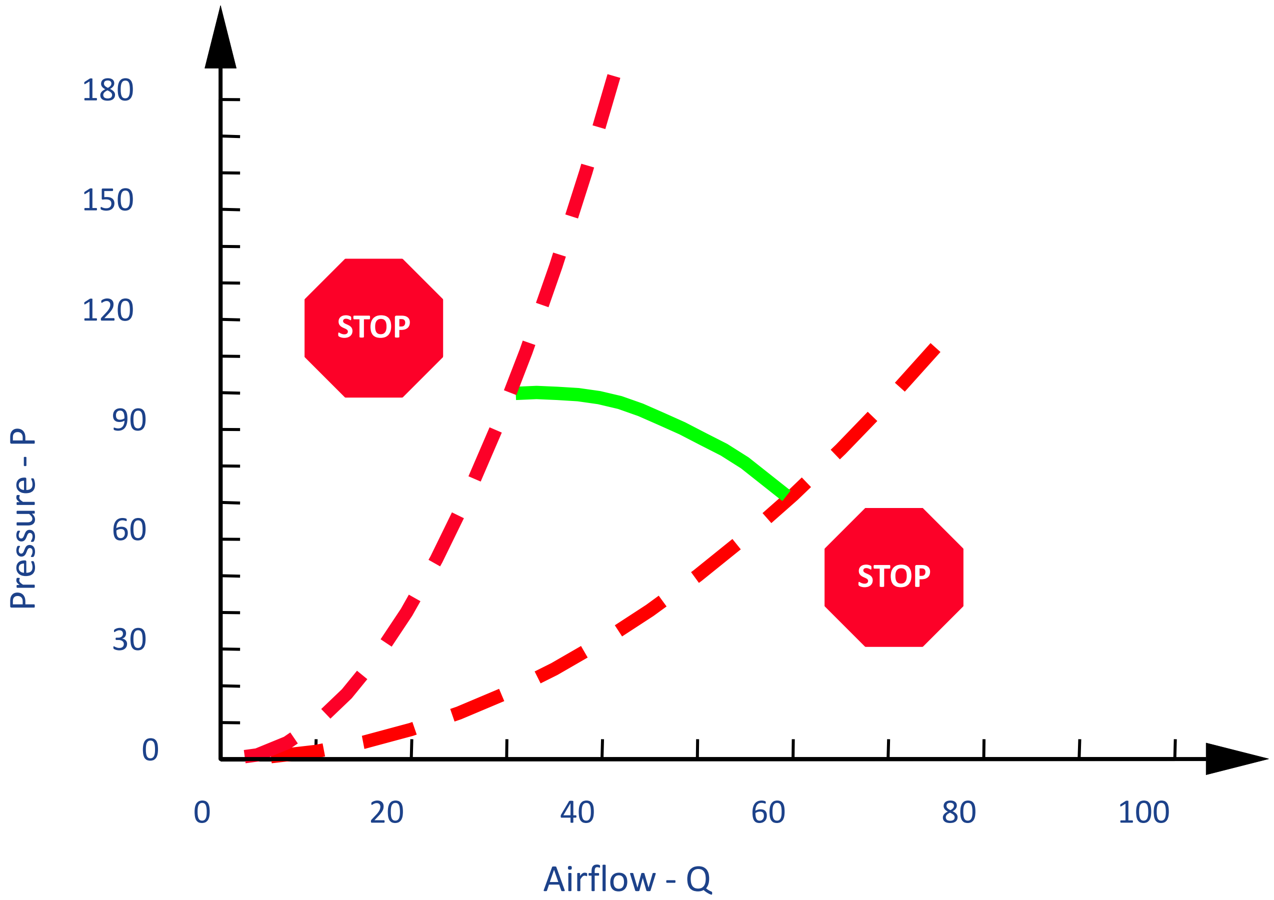
$$20{,}000 \times 4.2 \times 1.0 / (6354 \times 0.75) = 17.6 \text{ hp}$$

# Fan System Optimization Techniques

Considerations for a well-designed fan system:

1. Establish the process needs by quantifying them.
2. Select a fan that is well-matched for the task:
   - Style of fan
   - Size of the fan
   - Issues with the load
   - Special requirements

# Recommended Selection Range as Seen on the Fan Curve



# Considerations for a Well-Designed Fan System (cont.)

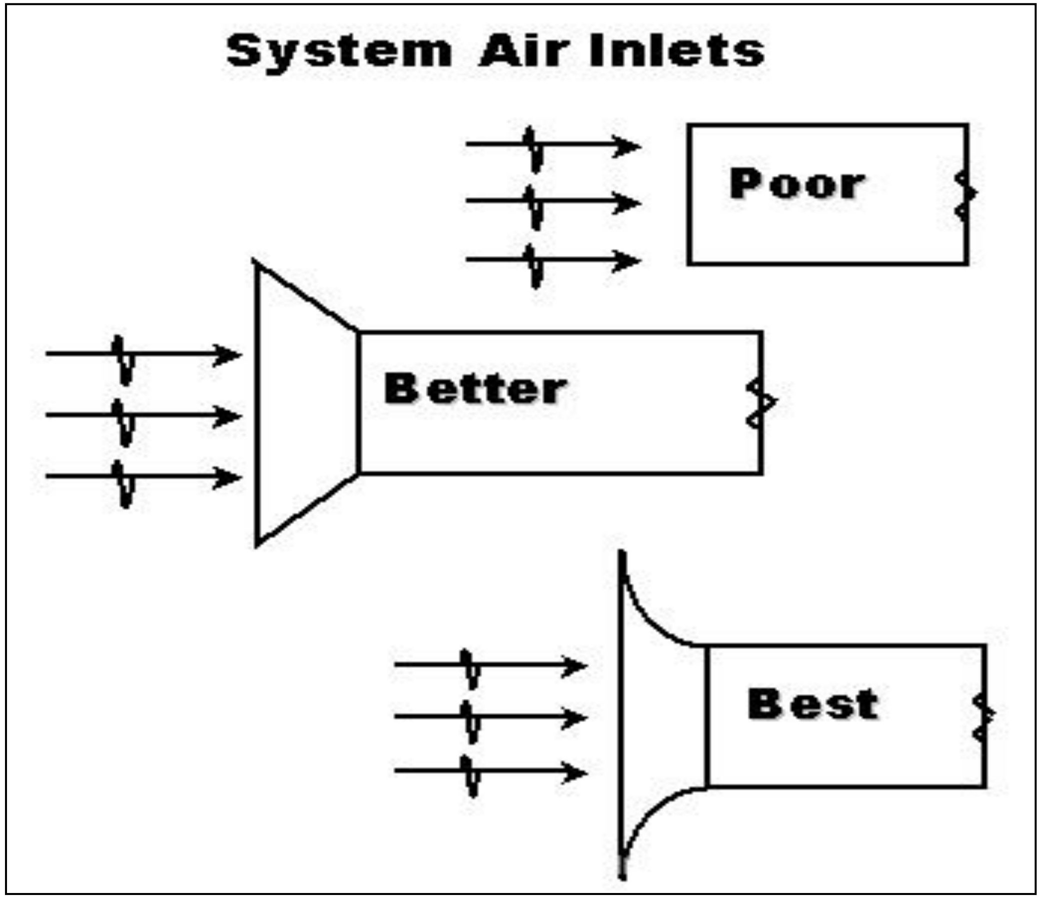
3. Eliminate unnecessary frictional losses.
4. Put the fan on the “cold” or “cooler” side of a heat exchanger, if possible.

# Considerations for a Well-Designed Fan System (cont.)

5. To achieve a smooth flow:

   - Use smooth, gradual transitions
   - Design fan inlet and outlet to optimize flow
   - Avoid adjacent elbows, if possible, or an elbow close to another component
   - Incorporate a straight length of ductwork upstream of components that may be adversely affected by uneven flow

# Various Inlet Configurations



# Fan optimization techniques overview

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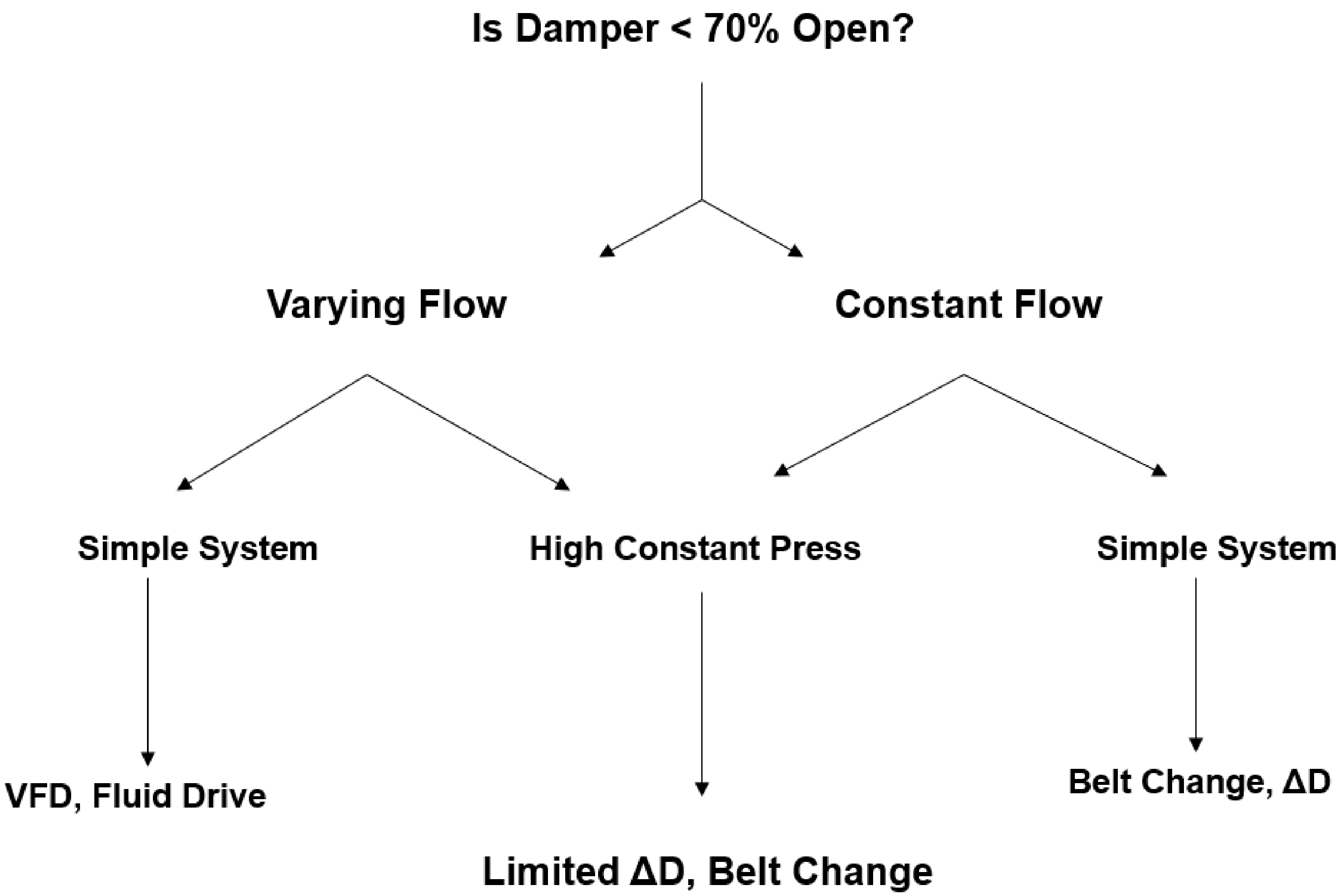
# Optimization Method Flow Chart



# Fan system optimization techniques overview

1. Reduce system pressure losses
2. Reduce system flow rate
3. Replace impeller
4. Replace fan
5. New belt drive ratio
6. Convert to belt drive
7. New variable inlet vane (VIV)
8. New VFD
9. Fluid Coupling (old technology)

# Optimization Techniques for Existing Systems

1. Replace Impeller

    + Better performance

- May not be available

$$ marginally higher cost of custom design

Best suited for 200 kW+ and where new impeller design would be more efficient

# Optimization Techniques for Existing Systems (cont.)

2. Replace Fan
   + Can be sized
- $$ New base
- $$ Modification
- $$ Ductwork may require modification
- Downtime

Best suited for fans smaller than 150 kW and for aging or deteriorating fans.

# Optimization Techniques for Existing Systems (cont.)

3. New Belt Drive Ratio
   + Inexpensive
   + Reversible
   + Ratio can be changed
- Preparation required
- Performance tests needed

Best suited when there is an existing belt drive, the load is fixed and the fan is oversized with a damper used as a control mechanism

# Optimization Techniques for Existing Systems (cont.)

4. Convert to Belt Drive
   + Fan speed can be changed
   + Less expensive than a VFD

- Fan bearings may not withstand the lateral force or belt thrust
- A new base may be required for the motor or fan
- Will require additional maintenance

# Optimization Techniques for Existing Systems (cont.)

4. Convert to Belt Drive

Best suited:

- when the current fan is oversized and has a direct drive motor operating at 190 kW or less.
- if a VFD is too expensive or otherwise unsuitable for the system

# Optimization Techniques for Existing Systems (cont.)

5. Variable Frequency Drive (VFD)

- + Fan output can be exactly matched to process needs
- + No changes needed
- + Very cost effective
- + Can easily replace throttle control
- + Can be used to over speed the fan motor

# Optimization Techniques for Existing Systems (cont.)

5. Variable Frequency Drive (VFD)

- Costly for large motors over 300 kW
- Efficiency falls at lower speeds
- Can cause problems with electrical systems
- Additional space is needed in the electrical room
- Air conditioning is needed

# Optimization Techniques for Existing Systems (cont.)

5. Variable Frequency Drive (VFD)

- Very sensitive to electrical power quality
- Purchase requires time and expertise
- The VFD vendor needs to know:
  - starting torque of the fan,
  - age and condition of the fan motor, and
  - distance between the fan and electrical room

# Optimization Techniques for Existing Systems (cont.)

5. Variable Frequency Drive (VFD)

Best suited for fan motors at 300 kW or smaller, with a system that needs variable flow

There will be no benefit to using a VFD with a system already at full capacity, under a steady load, or when there are only minor flow variations

# Optimization Techniques for Existing Systems (cont.)

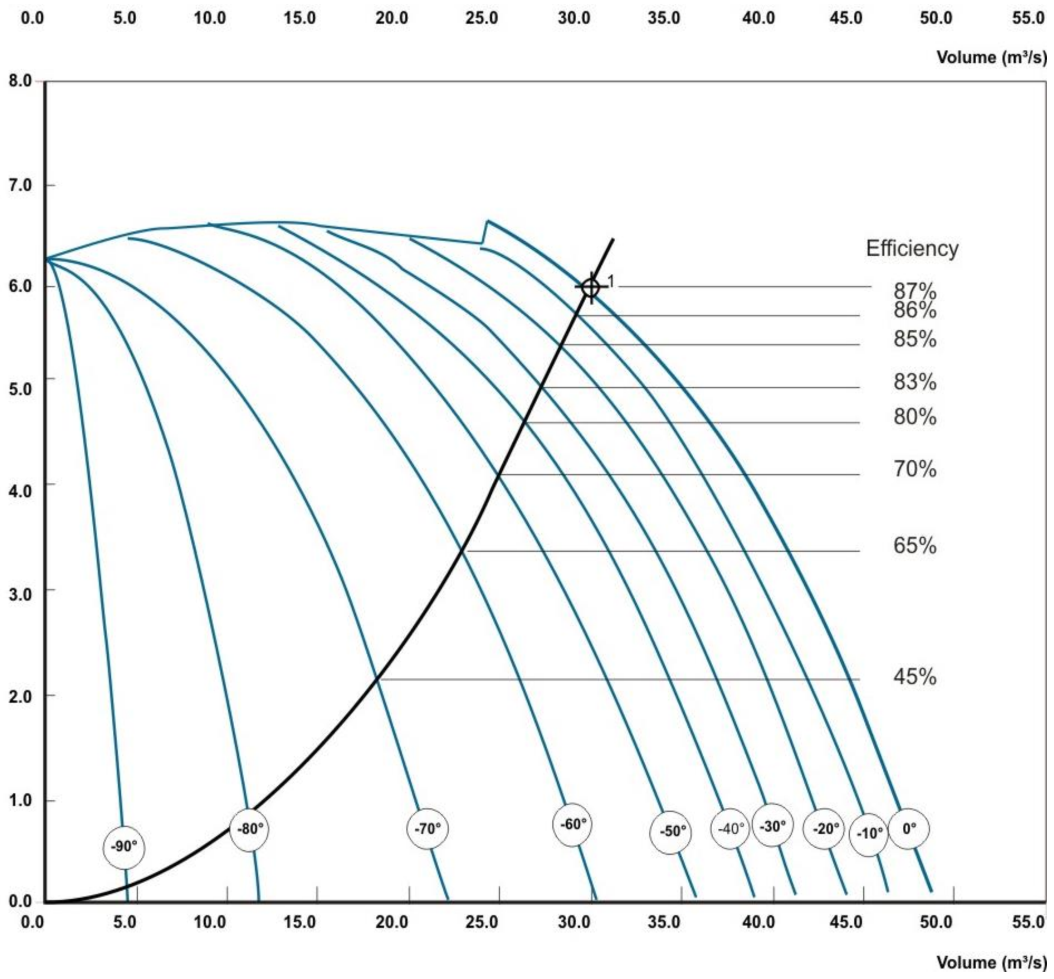
6. Fluid Couplings

+ formerly used for larger fan motors greater than 500 kW where a belt drive could not be used

- $$ Can be expensive and inefficient

Best suited to vary the speed on larger motors

# Clinker Cooler Fan Curve



# Key Points / Action Items

1. *"follow" a particle of air through the duct system and examine the trade off between static pressure and velocity pressure.*

2. *Remember that as the velocity goes up due to a duct constriction, the velocity pressure goes up also, so there is a corresponding decrease in the static pressure*

3. *When materials are conveyed through the fan system, ensure that velocities are high enough to keep particles entrained, but not excessive to incur additional losses*

4. *Use easy bends and gradual transitions in ductwork*

5. *Use ASHRAE duct fitting ap to estimate duct losses*

# Homework #5

- Collect system pressure data for the top 1 or 2 likely optimization candidate projects you've been scoping.
- Use MEASUR to conduct preliminary analysis of top 2 or 3 candidates and submit the .json files for review

**Thank You all for attending today's webinar.**

**See you all on next Thursday –**

**If you have specific questions, please stay online and we will try and answer them.**

**Alternately, you can email questions to me at ron@productiveenergy.com**

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