



Fan and System Curves with Fan Energy Index (FEI), Part 2 of 2

Ron Wroblewski, PE, president, Productive Energy Solutions, and William (Bill) Howarth, president, Ventilation & Fan Consulting Service International LLC

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Today's Presenters

William Howarth

- AMCA Consultant; President- Ventilation & Fan Consulting Service International
- Independent Consultant since 2017
- 30-yrs Fan Engineering & Sales at Illinois Blower and Hartzell Fan
- Instructor at North Carolina Industrial Ventilation Conference
- Member US delegation for ISO Technical Committee 117 Fans
- ASHRAE Member

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Today's Presenters

Ronald Wroblewski, PE



Industrial Fan Systems Optimization, Consulting, and Training since 1998

- Developed online FEI training for AMCA
- Lead Trainer US DOE Industrial Fan Systems Optimization since 2004
- Lead Trainer UNIDO Industrial Fan Systems Optimization since 2008
- 39 years experience designing, troubleshooting, and optimizing fan systems
- Assessed fans at hundreds of industrial and commercial facilities
- Identified fan efficiency projects savings of over \$11 Million/yr.

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Pressures in a Ventilation and Fan System

Purpose and Learning Objectives

At the end of this course, you will be able to:

- List two safety hazards of fans.
- Explain fan's role in an air system.
- Identify pressure types in an air system.
- Identify sources of pressure losses in a system.
- Calculate airflow velocities.
- Calculate velocity pressures.

Fan Safety

- Fans contain moving parts and can be dangerous.
 - Install guards.
 - Know the “Hidden Dangers”
 - Suction and Pressure
 - Windmilling
 - Temperature
 - Noise and Environment
 - Stroboscopic Effect
 - Special Purpose Fans and Systems
 - Have a “lock out” procedure.
- AMCA Publication 410-96, "Recommended Safety Practices For Users and Installers of Industrial and Commercial Fans" is an excellent resource.



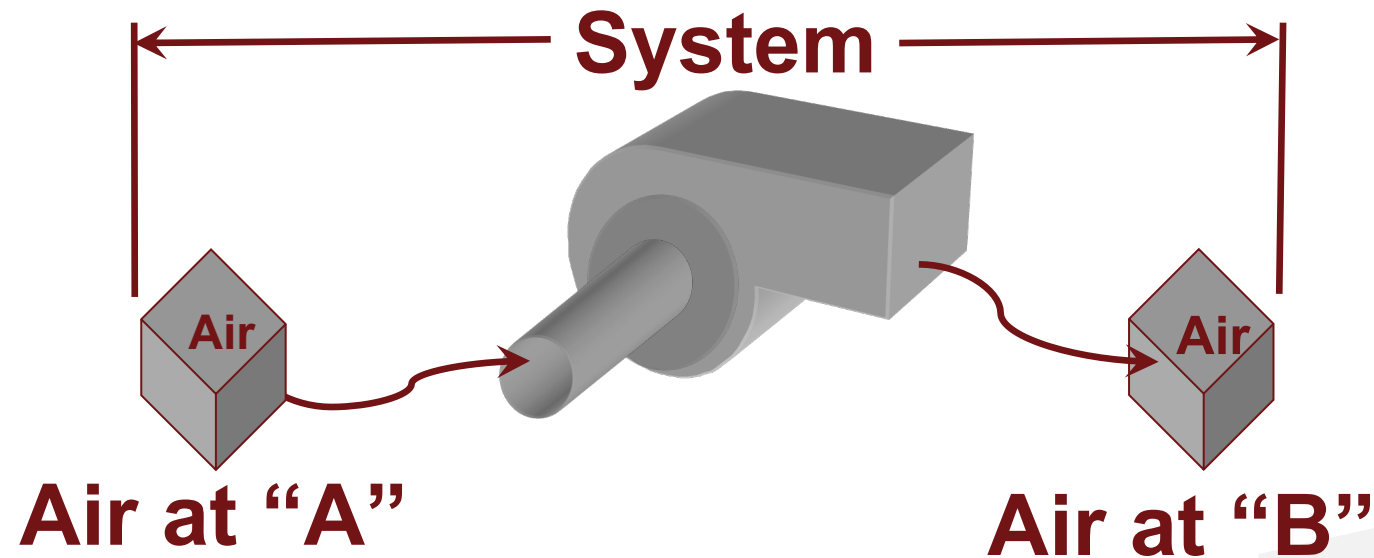
Question: What moves Air?

- Differential pressure moves air.



Fan's Role in Air System

- The purpose of a fan is to supply an air system with energy (**in the form of a pressure differential**) necessary to maintain airflow through the resistance of the system.

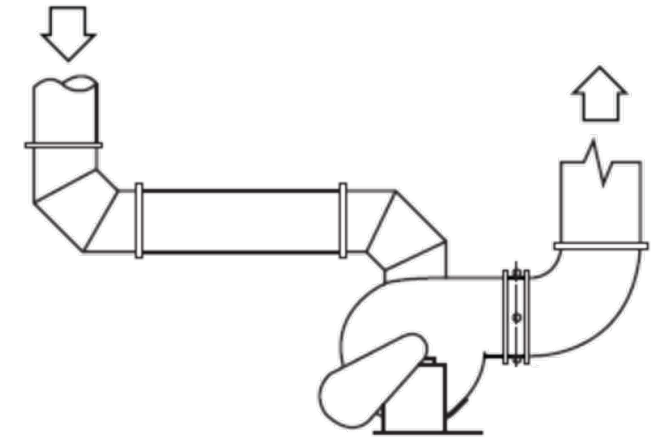


Different Fan Systems

- HVAC - heating, ventilating and air conditioning
 - Indoor environmental air comfort
- General Ventilation
 - High Flow Low Pressure Systems
 - Dilution Air Systems
- LEV System (Local Exhaust Ventilation)
 - Combination of hoods, ducts, cleaning devices, fan, and stack to control contaminant or exposure.
- Replacement Air System
 - Every CFM exhausted will be replaced.
- Process system
 - Dryer, Oven System, Boiler, Cooling System

Pressures in a System

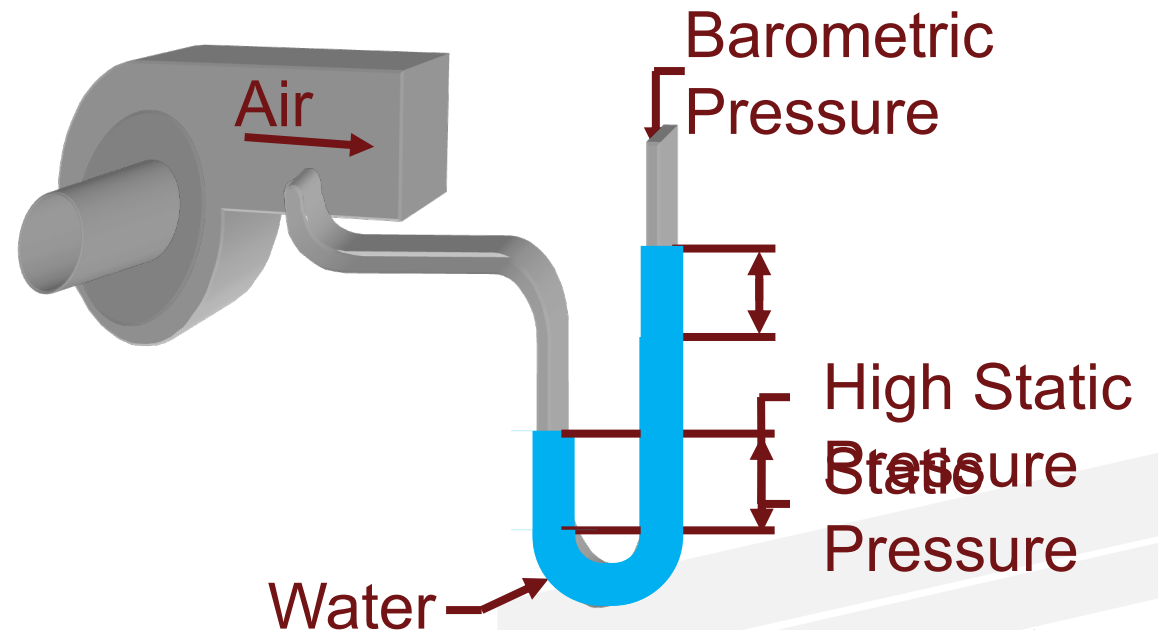
- Static Pressure, P_s (SP)
 - The portion of air pressure that exists by virtue of the state of the air.
 - measured perpendicular to flow
 - Static Pressure may be positive or negative
- Total Pressure, P_t (TP)
 - The air pressure state and motion of the air.
 - Algebraic sum of P_s and $P_v \rightarrow P_t = P_v + P_s$
 - measured parallel to flow
 - If air is at rest the total pressure will equal the static pressure
- Velocity Pressure, P_v (VP)
 - “Dynamic pressure” resulting from the motion of the air
- The pressures are changing throughout the system.



$$P_t = P_s + P_v$$

Static Pressure, P_s

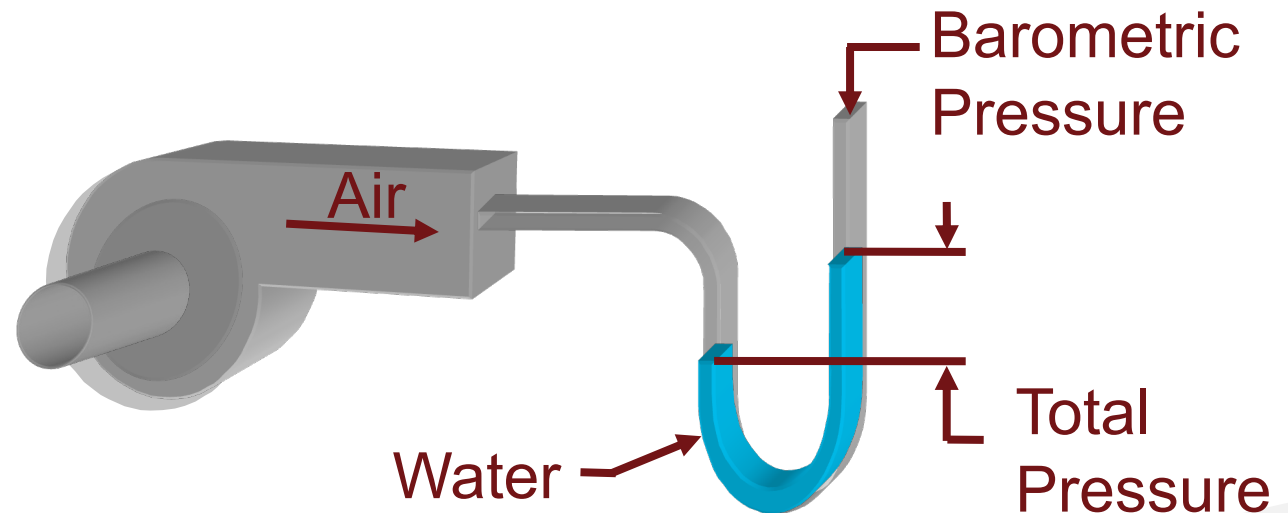
- “Potential pressure” in all directions
- Measured perpendicular to direction of flow
- Overcomes resistance in flow due to:
 - Dynamic losses:
 - Hood and duct entries
 - Fittings (e.g., dampers, elbows, etc.)
 - Air cleaners
 - Duct friction



Total Pressure P_t

- Measured parallel and in the direction of flow
- Sum of static pressure P_s and velocity pressure P_v

$$P_t = P_s + P_v$$



Velocity Pressure, P_v

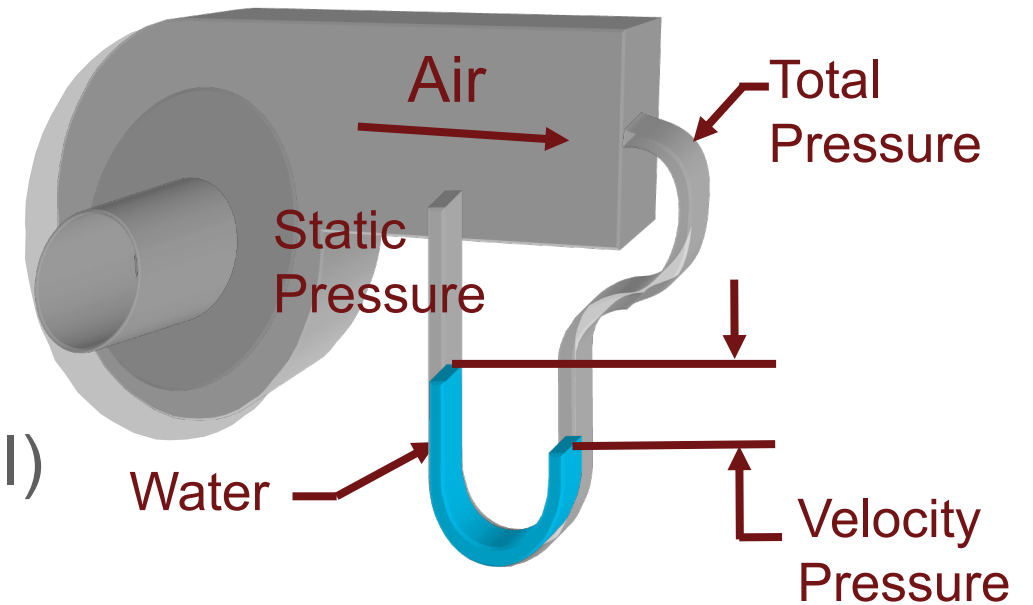
- Measured indirectly (the difference between P_t and P_s) in existing system
- “Dynamic pressure”
- $P_v = (V / 1097)^2 \cdot \rho$ (I-P)
- $P_v = 0.5 V^2 \cdot \rho$ (S-I)
- Where:

P_v = velocity pressure, inch wg (Pa S-I)

V = velocity, fpm (m/s S-I)

ρ = density, lbm/ft³ (kg/m³ S-I)

1097 = I-P Units Constant



Flow Rate (Q) Equation

Calculate velocity of the air (in duct).

Q=Flow (volume/time)

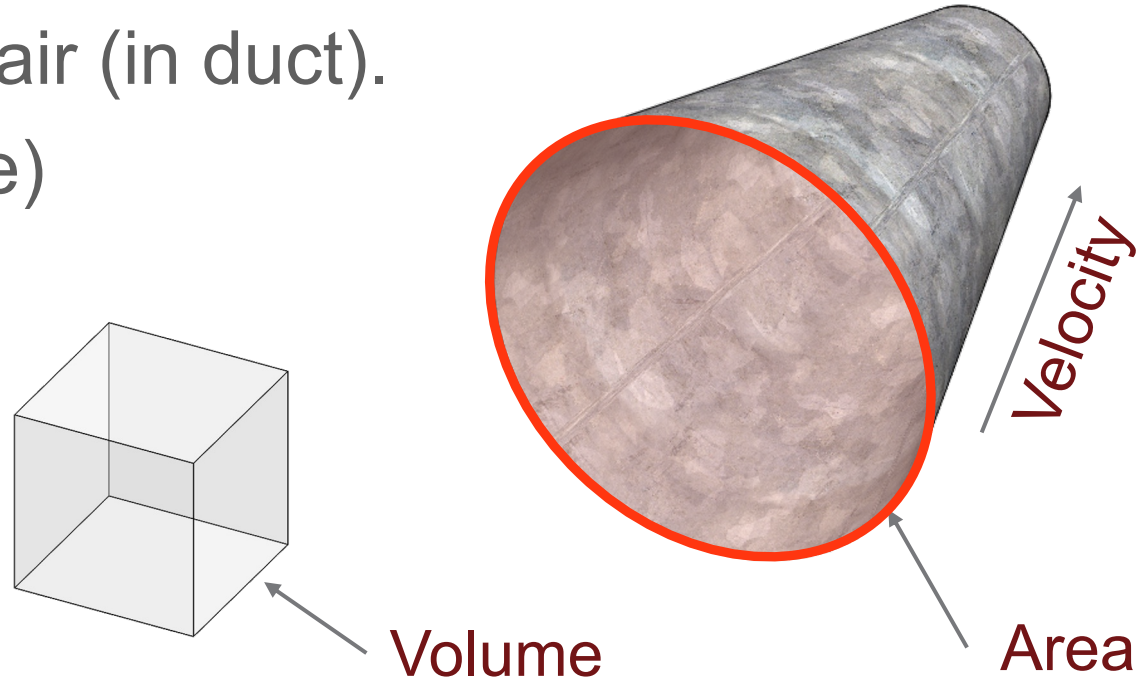
- ft^3/m (I-P)
- m^3/s (S-I)

V=Velocity

- ft/m (I-P)
- m/s (S-I)

A=Area

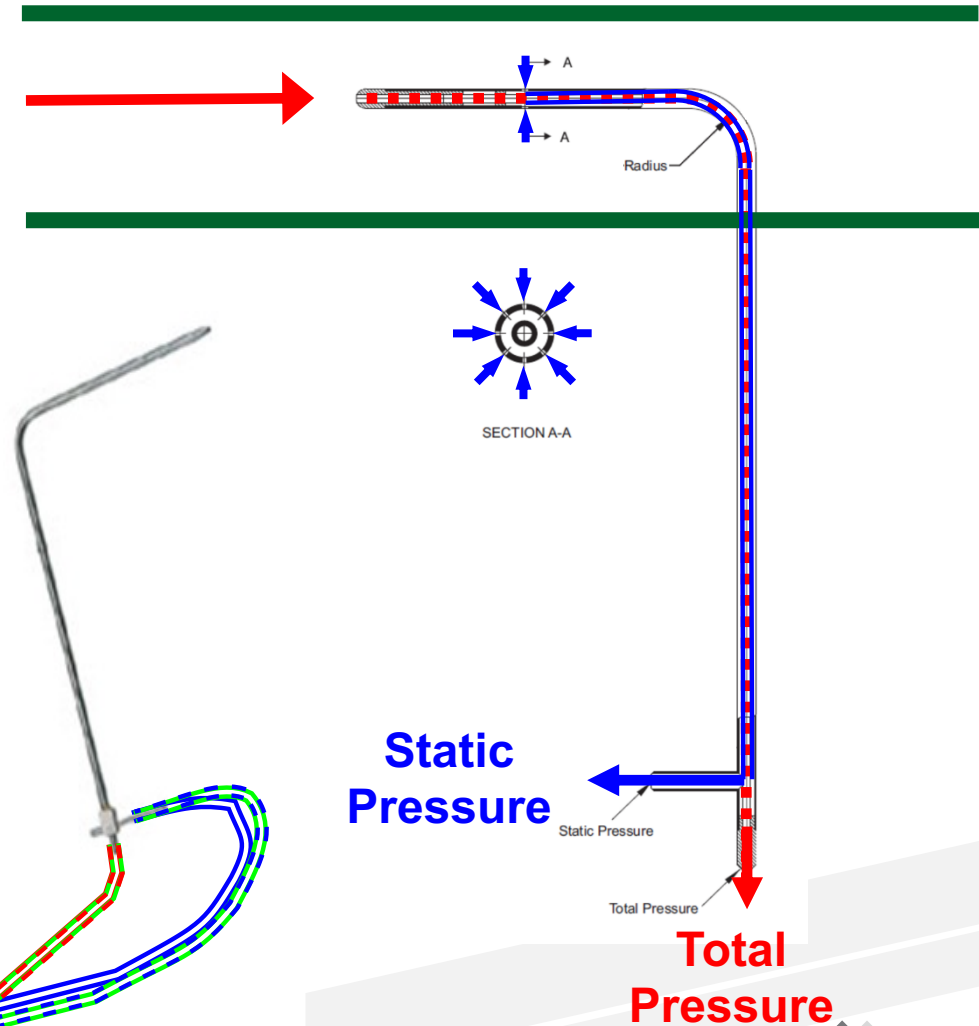
- ft^2 (I-P)
- m^2 (S-I)



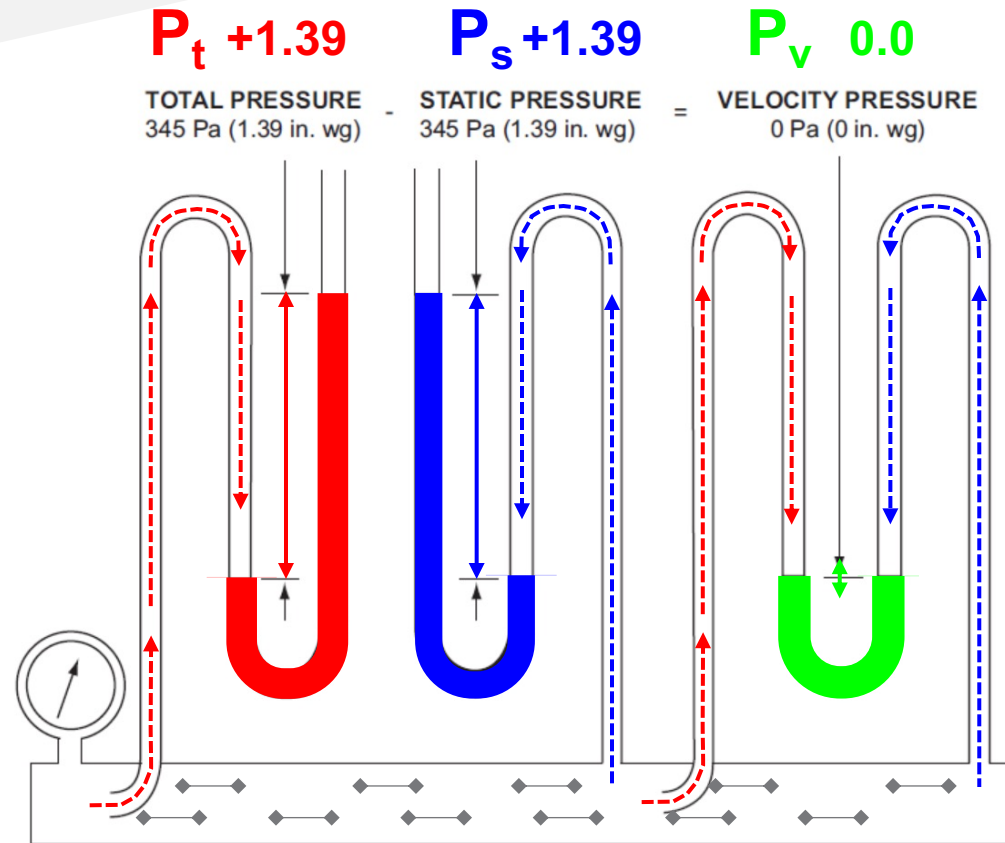
$$Q = V \cdot A \quad V = \frac{Q}{A} \quad A = \frac{Q}{V}$$

Measuring Pressures with Pitot-Static Tube

- Pitot tube is used to measure pressure
 - Used with a manometer (pressure meter) connected by flexible tubing.
 - Measured in the duct
 - Typical measurements:
 - Pascals (Pa)
 - Inches water (in. H₂O)
 - Millimeters water (mm H₂O)
 - **Total Pressure**
 - In the direction of airflow
 - **Static Pressure**
 - **Velocity Pressure**



Pressure in a Non-moving Airstream

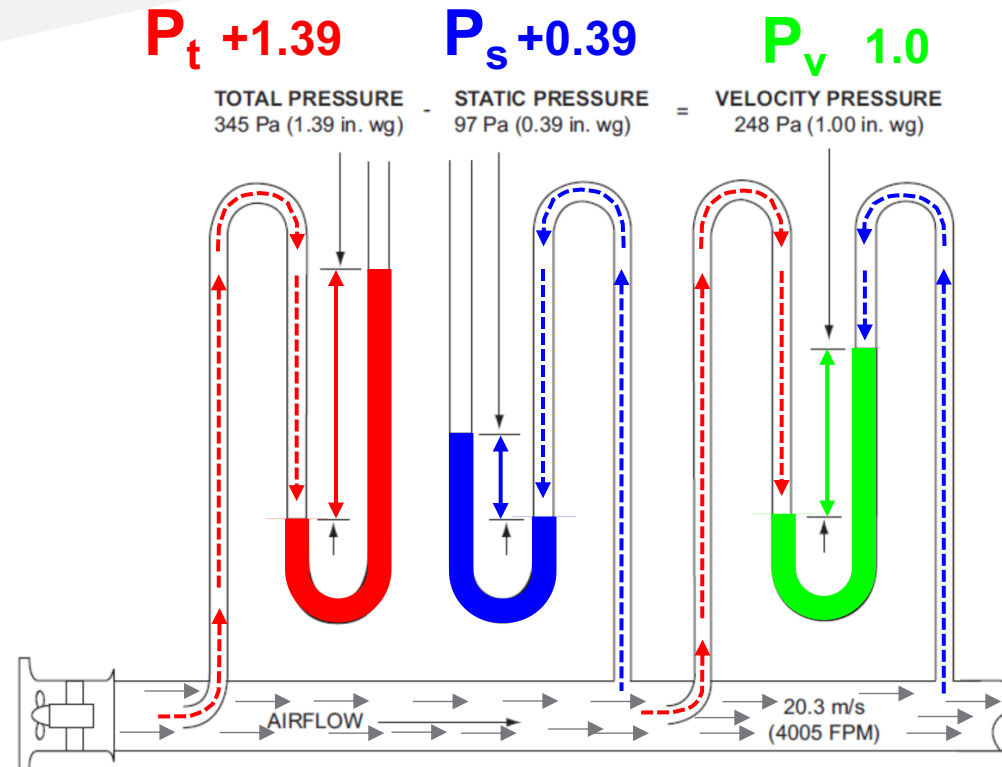


$$P_s + P_v = P_t$$
$$1.39 + 0.0 = 1.39$$

Reference AMCA 200 Air Systems
Figure 5A - Sealed System

The pressure in the seal length of duct is 345 Pa (1.39 in. wg) above atmospheric pressure. Since there is no airflow the velocity pressure is equal to zero. Total pressure equals static pressure.

Positive Pressure System

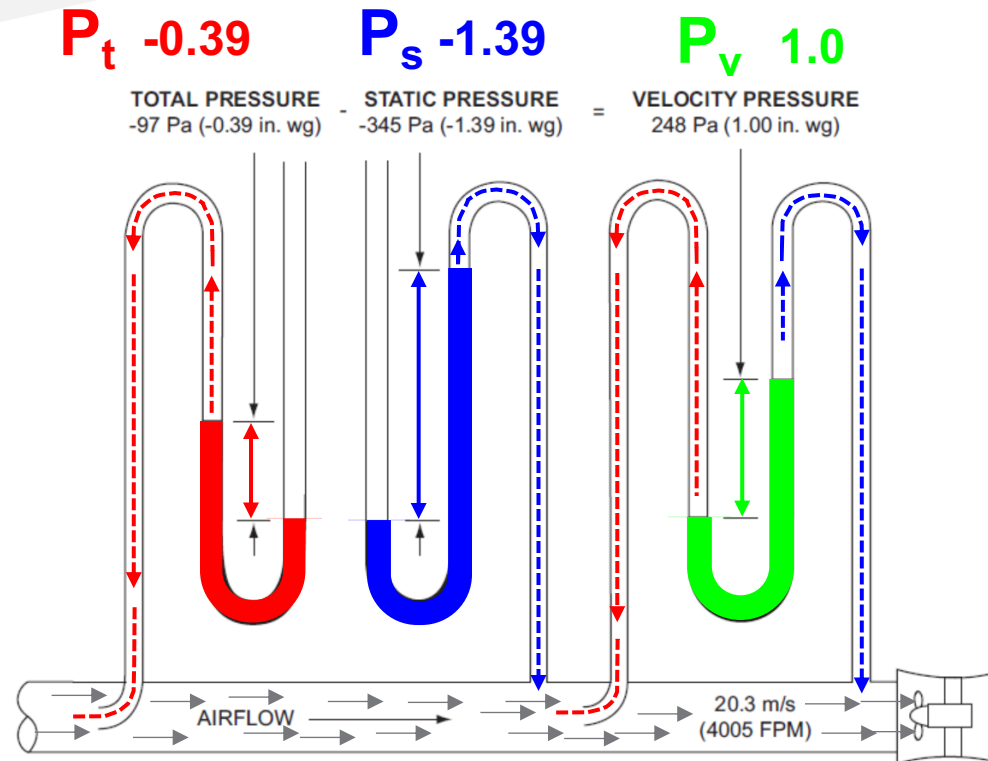


$$P_s + P_v = P_t$$
$$0.39 + 1.0 = 1.39$$

Reference AMCA 200 Air Systems
Figure 5B - Positive Pressure System

The duct open and a fan placed at one end blowing air through the duct, we find both static pressure and velocity pressure as illustrated by the water gauge. The total pressure is the sum of velocity pressure and static pressure.

Negative Pressure System

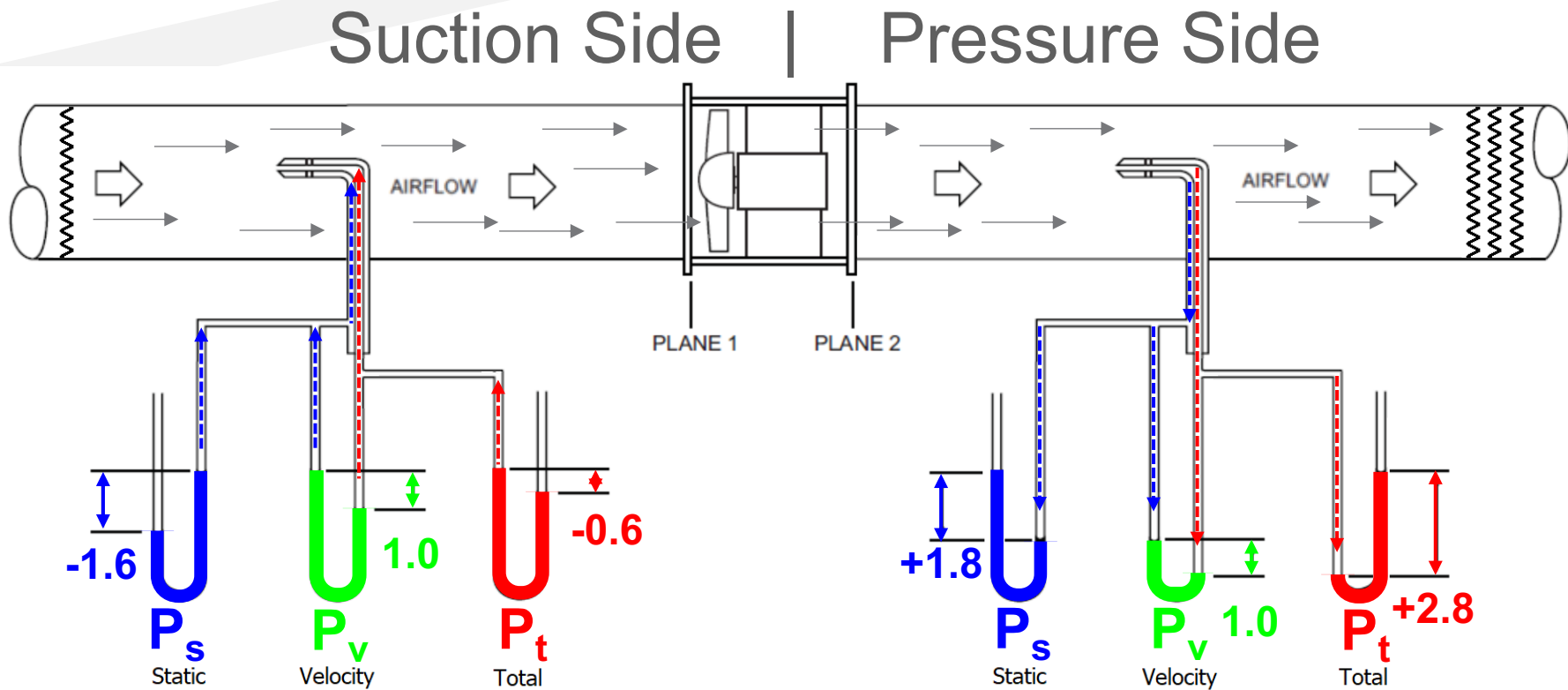


$$P_s + P_v = P_t$$
$$-1.39 + 1.0 = -0.39$$

Reference AMCA 200 Air Systems
Figure 5C - Negative Pressure System

The fan is placed at the end of the duct and draws air through the duct. In this case, the static pressure is below atmospheric pressure.

Pressures for Airflow in a Duct



$$P_s + P_v = P_t$$

$$-1.6 + 1.0 = -0.6 \text{ in. wg}$$

Pressure Below Atmosphere

$$P_s + P_v = P_t$$

$$1.8 + 1.0 = +2.8 \text{ in. wg}$$

Pressure Above Atmosphere

Reference Figure C.5 - Fan
Static Pressure for
Installation Type D: Ducted
Inlet, Ducted Outlet

Velocity Pressure and Velocity Calculation

Velocity Pressure Calculation

$$P_v = \left[\frac{V}{1097} \right]^2 \cdot \rho \quad \left(\text{in wg, f/m, } \frac{\text{lbm}}{\text{f}^3} \right)$$

$$P_v = \frac{V^2 \cdot \rho}{2} \quad (\text{Pa, m/s, kg/m}^3)$$

Velocity Calculation

$$V = \sqrt{\frac{P_v}{\rho}} \cdot 1097 \quad (\text{f/m, in wg, lbm/f}^3)$$

$$V = \sqrt{\frac{2 \cdot P_v}{\rho}} \quad (\text{m/s, Pa, kg/m}^3)$$

P_v = Velocity Pressure (in. wg or Pa)

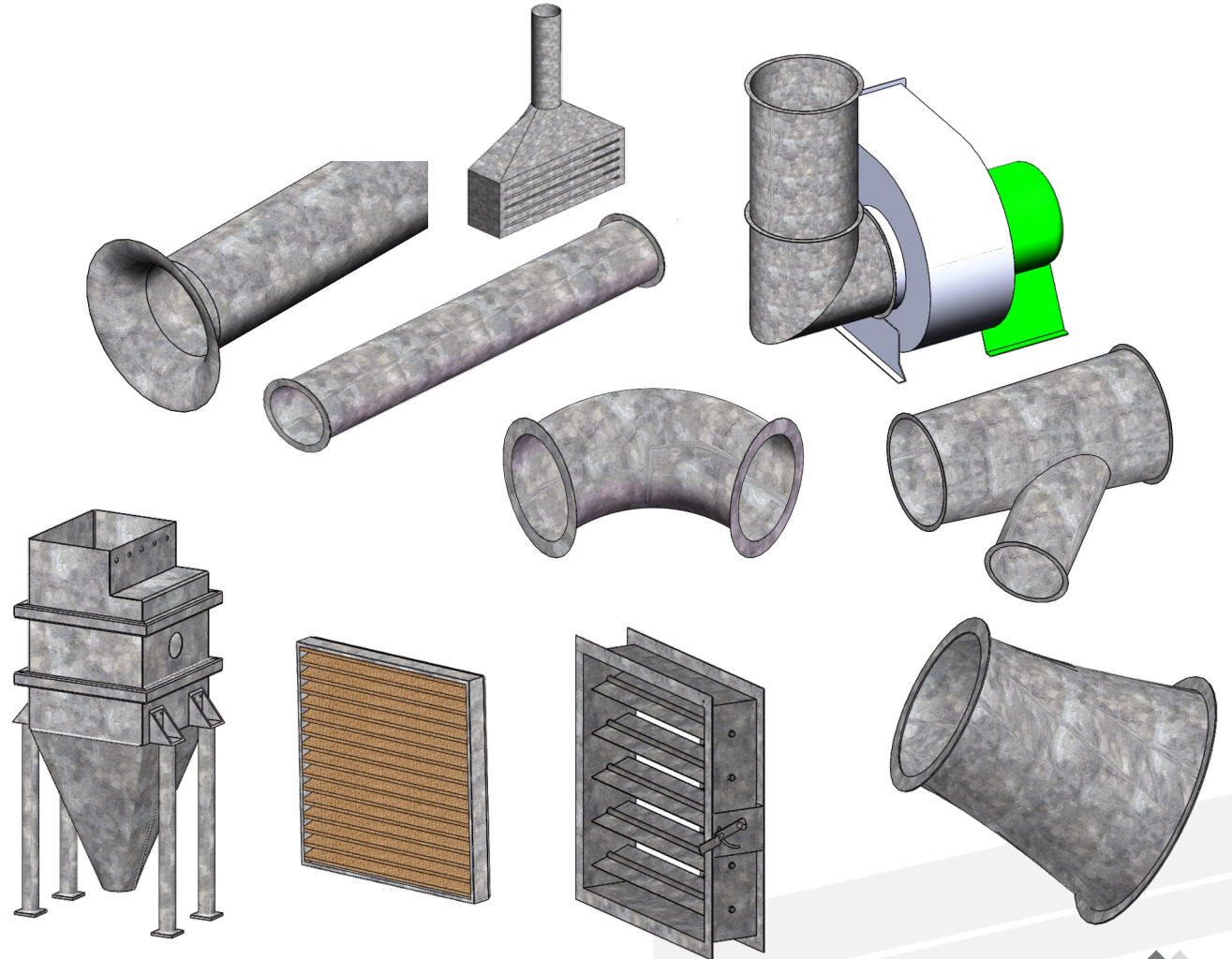
V = Velocity (f/m or m/s)

ρ = Gas Density (lbm/f³ or kg/m³)

$$Q = V \cdot A \quad V = \frac{Q}{A} \quad A = \frac{Q}{V}$$

Overview of System Losses

- Acceleration losses
- Friction losses
- Dynamic losses
- Component losses
 - Air Cleaning Devices
 - Dampers
 - Other
- System Effects
- Losses will be proportional to velocity pressure

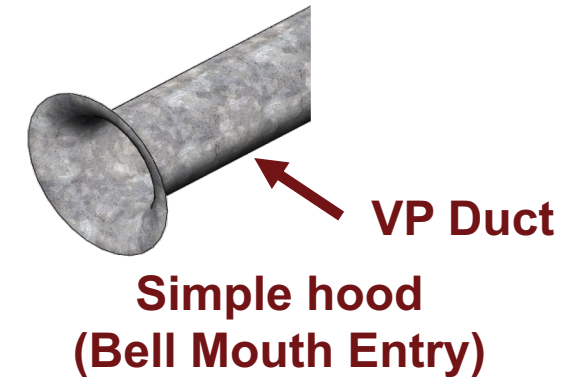







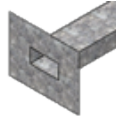


Losses are a Fraction(s) of Velocity Pressure

- The losses will be fraction(s) of the velocity pressure.
- The fraction(s) will be dependent on how much turbulence through the element.
- All elements have a friction loss.
- Increase in velocity will have pressure loss.
- Decrease in velocity will sometimes have a pressure gain.
- The flow must be accelerated into the duct system.
 - This is an additional loss to the loss for the inefficiency of the element.

$$\text{Duct Acceleration Loss} = 1 \cdot P_{v(\text{duct})}$$

$$\text{Element Loss} = F_{\text{element}} \cdot P_{v\text{element}}$$



Hood Entry Loss Coefficient			
Plain Duct End	Flanged Duct End	45° Cone Entry	Bell Mouth Entry
 $F_h=0.93$	 $F_h=0.56$ Conical	 45° 2X area $F_h=0.15$	 $F_h=0.04$
Sharp-Edged Orifice			
 $F_h=1.78$	 $F_h=0.64$ Rectangular	 45° 2X area $F_h=0.25$	 See Compound Hood
Hood Entry Loss = $F_h \cdot VP$		Compound Hood Entry Loss = $F_s \cdot VP + F_d \cdot VP$	

ASHRAE Duct Fitting Database App

- Application is available to calculate pressure losses for HVAC fittings.

ASHRAE DUCT FITTING DATABASE

Monday, July 11, 2022

Tel: +1 (847) 454-5420 Fax: ---

(CD11-1) Straight Duct

(Colebrook 1939)

INPUTS

Diameter (D, in.)	26.0
Length (L, ft)	300
Absolute Roughness (e, ft)	0.0003
Flow Rate (Q, cfm)	10,000

OUTPUTS

Velocity (V, fpm)	2,712
Vel Pres at Vo (Pv, in. wg)	0.46
Friction Factor (f)	0.0146
Pressure Loss (in. wg)	0.92

Help





HVAC ASHRAE

DFDB

ONLINE HELP

The HVAC ASHRAE Duct Fitting Database (DFDB) universal app for the iPhone and iPad allows you to perform pressure loss calculations for all 240+ supply, common, and return/exhaust ASHRAE fittings listed in the 2021 ASHRAE Handbook of Fundamentals.

< CD11

CD11-1

✂

User Inputs - CD11-1

Diameter (D, in.): 26.0

3.0 61.5 120.0

Length (L, ft): 300

1 501 1,000

Absolute Roughness (e, ft): 0.0003

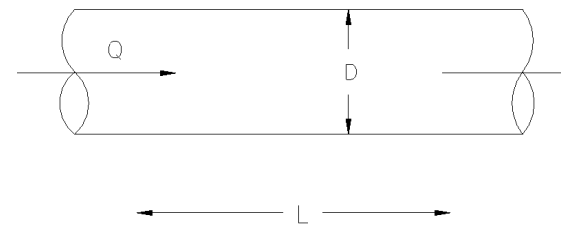
0.0001 0.0051 0.0100

Flow Rate (Q, cfm): 10,000

11 50,006 100,000

Summary Results - CD11-1

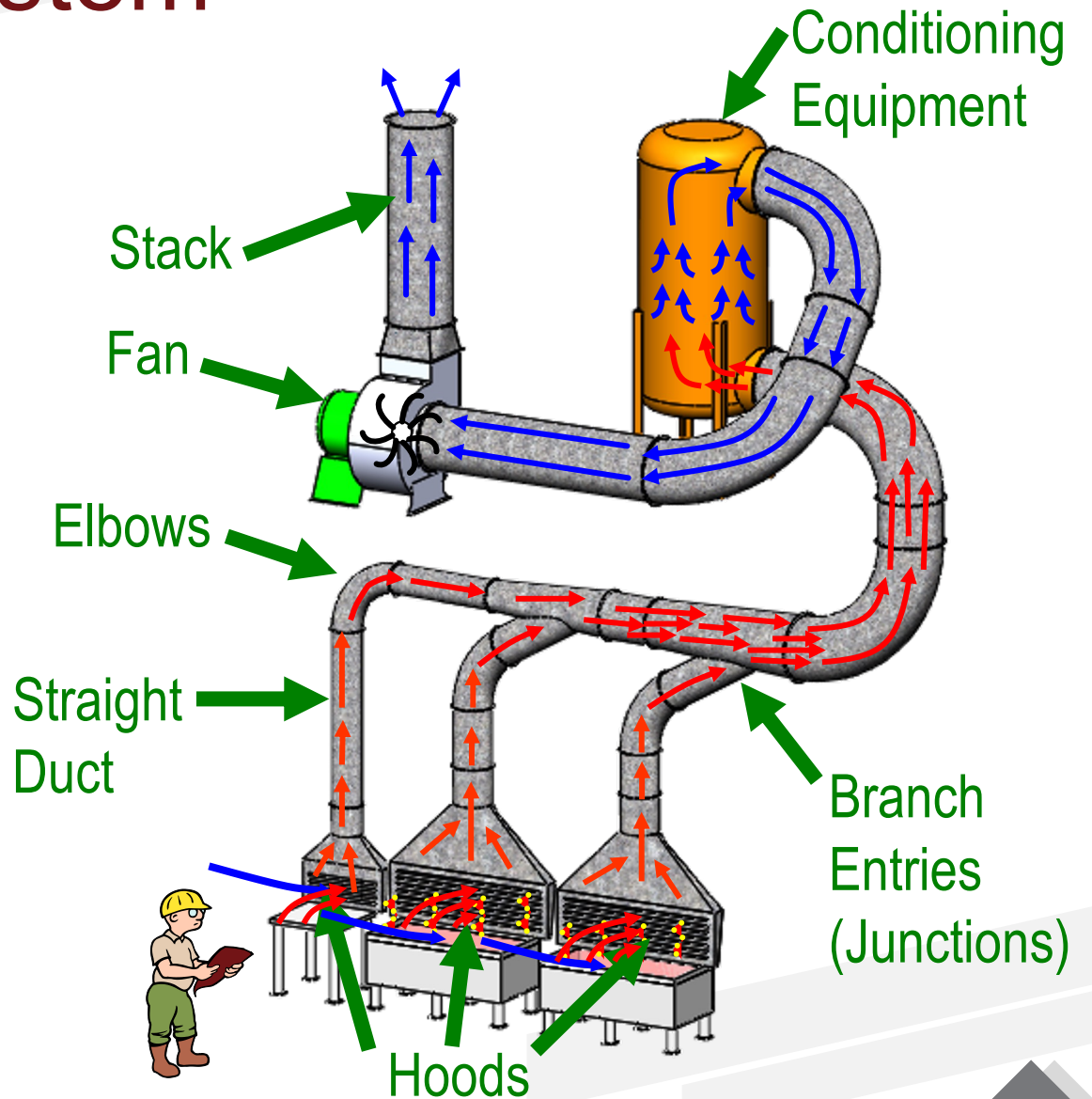
Pressure Loss (in. wg): 0.92



Pressure Losses the System

Where are the static pressure “losses” in this ventilation system?

- Hood entry losses due to:
 - Dynamic losses (turbulence)
 - Acceleration of the air and fumes into system
- Duct Friction
 - Duct losses (due to friction; measured centerline-to-centerline).
- Elbows
 - Dynamic losses (due to turning of the air stream)
- Branch Entries
 - Dynamic loss due to joining two airstreams together
- Pollution Control Equipment
- Fan
 - Adds energy to the system in the form of pressure
 - System Static Pressure (SSP)
- Discharge Duct (Stack)
- Dampers and other control devices (not shown)
- Duct expansions and contractions (not shown)



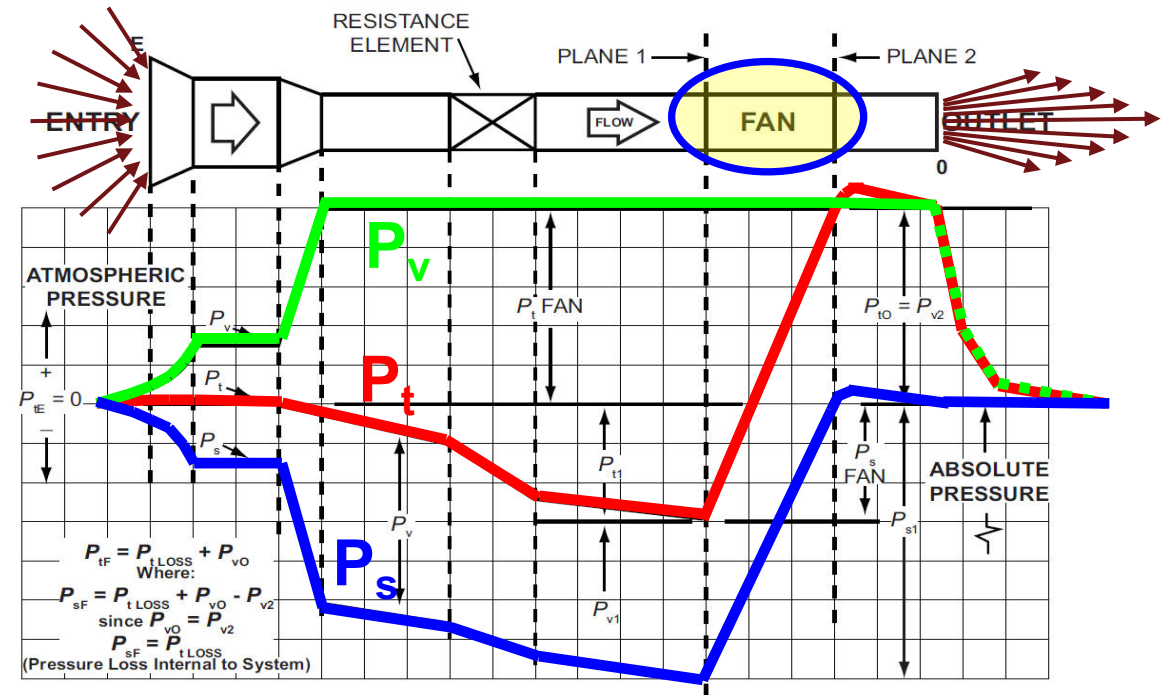
Pressures Through System

- The fan starts building pressure at the fan.
- Static pressure starts to increase
- The most negative point in the fan system will be the inlet of the fan.
- Velocity starts increasing
- Total pressure = static + velocity pressure.

$$P_t = P_s + P_v$$

P_v —
 P_t —
 P_s —

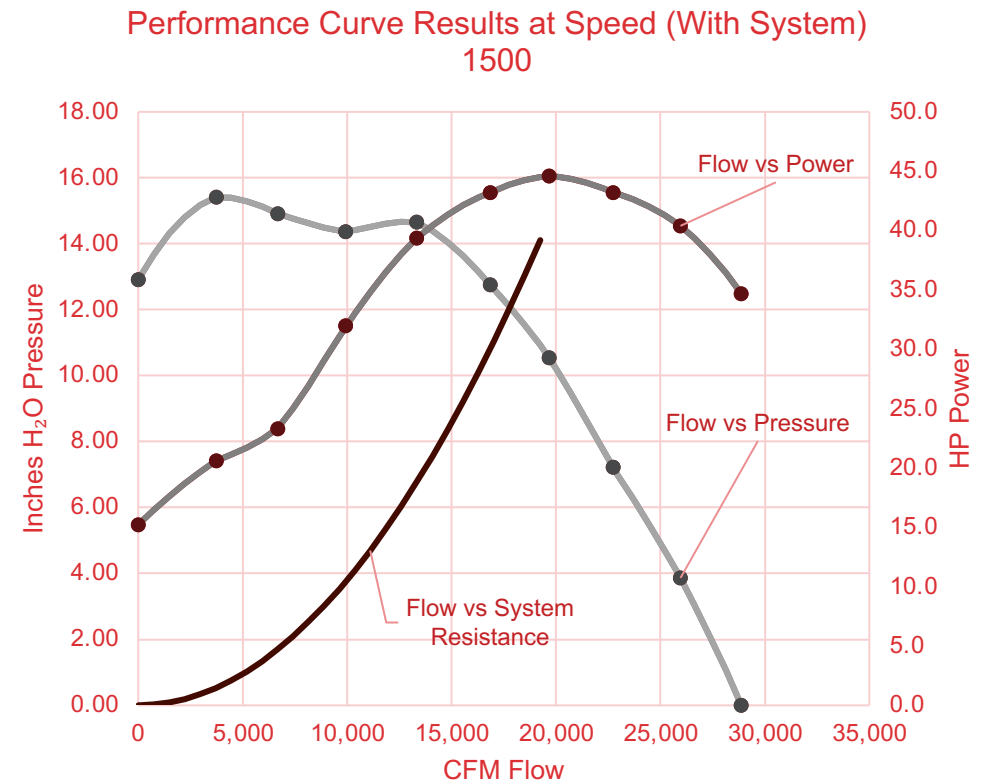
- Note the density and temperature at the fan inlet.
- The pressure on the fan outlet will be highest and be dissipated through the outlet side elements to the outlet of the fan system and discharge.



$$Fan_{SP} = SP_{out} - SP_{in} - VP_{in} @ \text{___CFM at ___Density and ___Temp.}$$

Fan & System Point of Operation

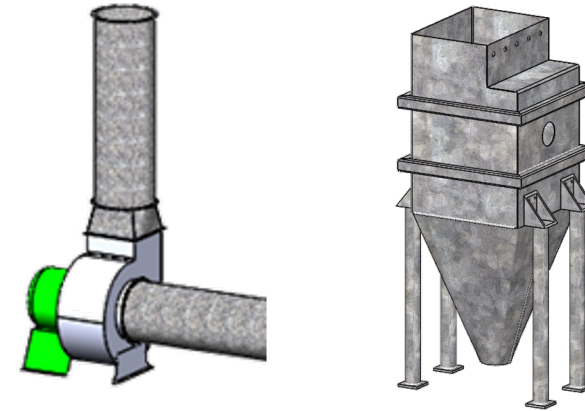
- Fan System Calculation
 - The flow and pressures for the entire system are calculated.
 - The pressure required to produce the flow will be cumulative up to the inlet of the fan plus the pressure requirement on the discharge side of the fan.
 - The flow from each inlet will combine in the duct system into the inlet of the fan.
- A fan provides the pressure to move the air through the system and the flow rate will reach a point of equilibrium (point of operation) when the pressure provided by the fan equals the pressure losses in the system at that flow rate.



$$Fan_{SP} = SP_{out} - SP_{in} - VP_{in} @ \text{___CFM at ___Density and ___Temp.}$$

Pressures in a Ventilation and Fan System Summary

- Fans have obvious and hidden hazards.
- The fan provides the differential pressure energy to the system to create airflow.
- Pressures in an air system are:
 - P_s – Static Pressure
 - P_t – Total Pressure ($P_t = P_s + P_v$)
 - P_v – Velocity Pressure (ΔP_s and P_t)
 - Pressures changing throughout system.
- Pressure Losses for all system elements should be considered.
 - Hoods, Ducts, Elbows, Junctions, Conditioning Equipment, Transitions, Discharges
 - Losses are fraction(s) of velocity pressure.
- Velocity through system can be calculated.
- Velocity pressure can be calculated.



$$\text{Element Loss} = F_{\text{element}} \cdot P_{v\text{element}}$$

$$Q = V \cdot A \quad V = \frac{Q}{A} \quad A = \frac{Q}{V}$$

$$P_v = \left[\frac{V}{1097} \right]^2 \cdot \rho \quad \left(\text{in wg, f/m, } \frac{\text{lbm}}{\text{ft}^3} \right)$$

$$P_v = \frac{V^2 \cdot \rho}{2} \quad (\text{Pa, m/s, kg/m}^3)$$

AMCA Technical Seminar

Introduction to Fans and Systems Topics

Date	Topics
Week 1	Fan and System Curves Pressure Considerations in Fan Systems Live introduction to online on-demand Simplified affinity laws Motors
Week2	Centrifugal & Axial Fan types Losses in Elbows and Ducts Fan-System Controls

Date	Topics
Week 3	Power and Efficiency of Fans System Effect Power and Efficiency of Fans Advanced Affinity Laws
Week 4	Fan Selection Certified Ratings Wrap up Review Final Questions

Resources

- **AMCA International:** www.amca.org
- **ANSI/AMCA Standards:** www.amca.org/store (available for purchase)
 - 210-16: Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating (ASHRAE 51-16)
- **AMCA Publications:** www.amca.org/store
 - 200-02 (R2011) – Air Systems
 - 201-02 (R2011) – Fans and Systems
 - 410-02 (R2009) – Recommended Safety Practices

Questions?

Contact Information

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**To receive PDH credit, you must complete
the post-course evaluation**

