Fan Laws

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Basic Terms

- **CFM** - Cubic Feet per Minute, volume (amount) of air being moved
- **SP** - Static Pressure, resistance of air moving through a system, also the bursting pressure exerted on the duct sidewalls, measured as "wg (inches water gauge)
- **VP –** Velocity Pressure, pressure created by air moving due to its kinetic energy, measured as "wg
- **TP -** Total Pressure, the sum of **VP** and **SP**, measured as "wg

  TP=VP+SP
- **BHP** - Brake Horsepower, power required to rotate wheel/prop to achieve performance. Note that catalog BHP usually does not allow for drive losses, typically 2-5%.

Basic Terms

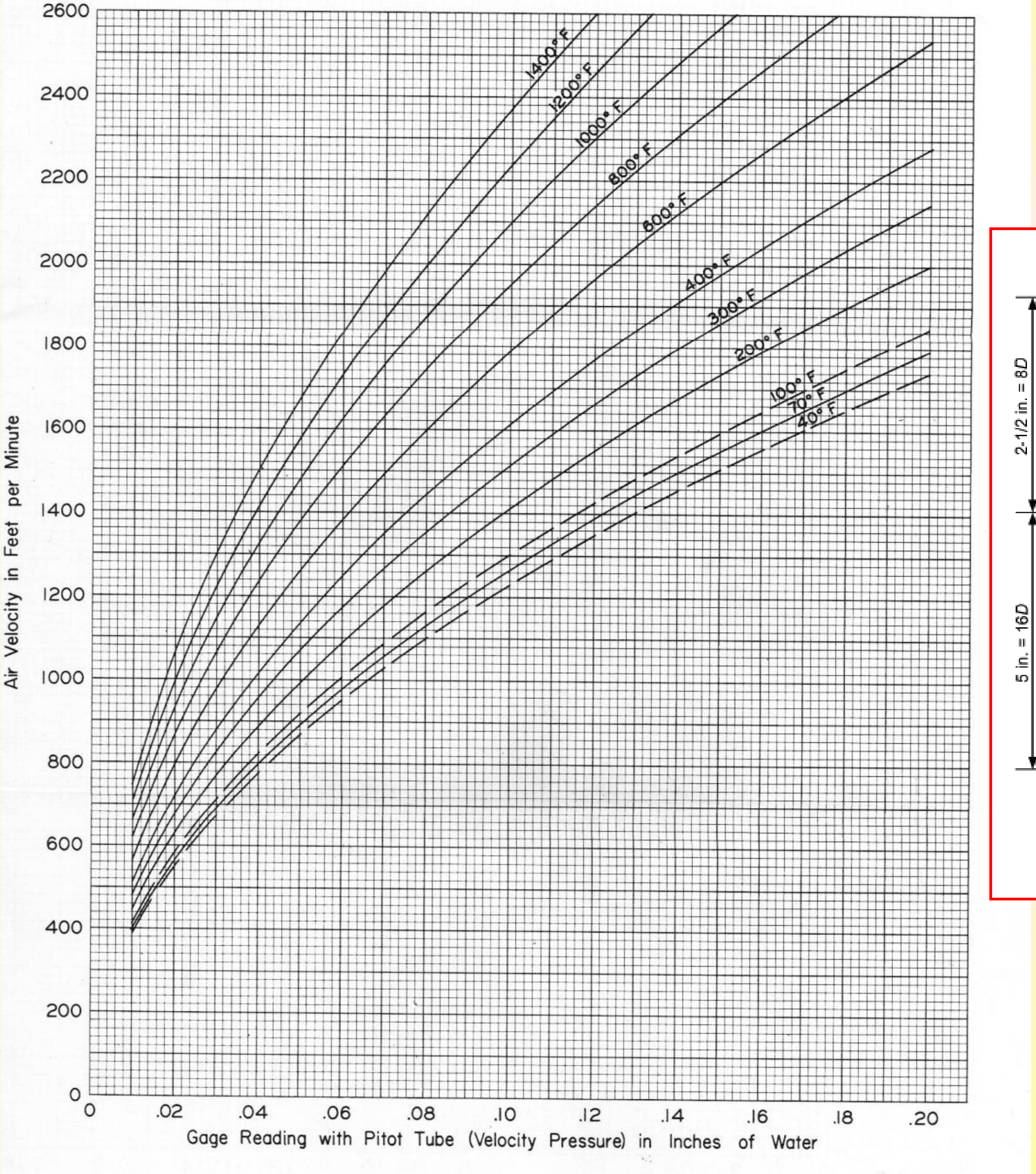
- **Sones** - AMCA subjective term of sound loudness, a linear number to compare noise, usually only of commercial fans
- **dB(A)** – Sound level reading on the A-weighted scale which adjusts sound meter response to approximate the human ear
- **NC** – Noise Criteria, background noise rating system based on the octave band sound pressure levels in the occupied space. Higher values represent higher background noise levels.

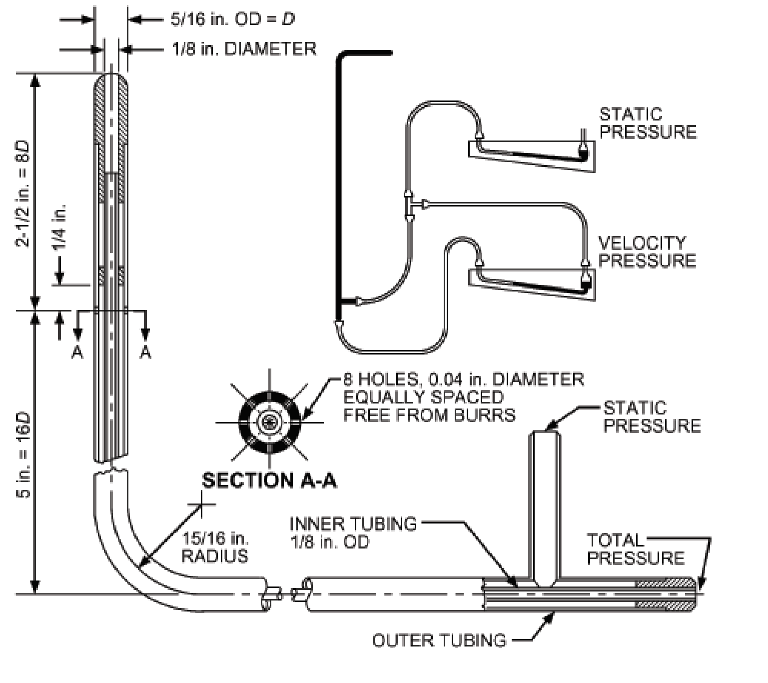
Sones to dB(A) Correlation:

$$dB(A)=33.2 \log_{10}(Sones)+28$$

Sones to dB(A) Conversion accuracy: **2 dB(A)**

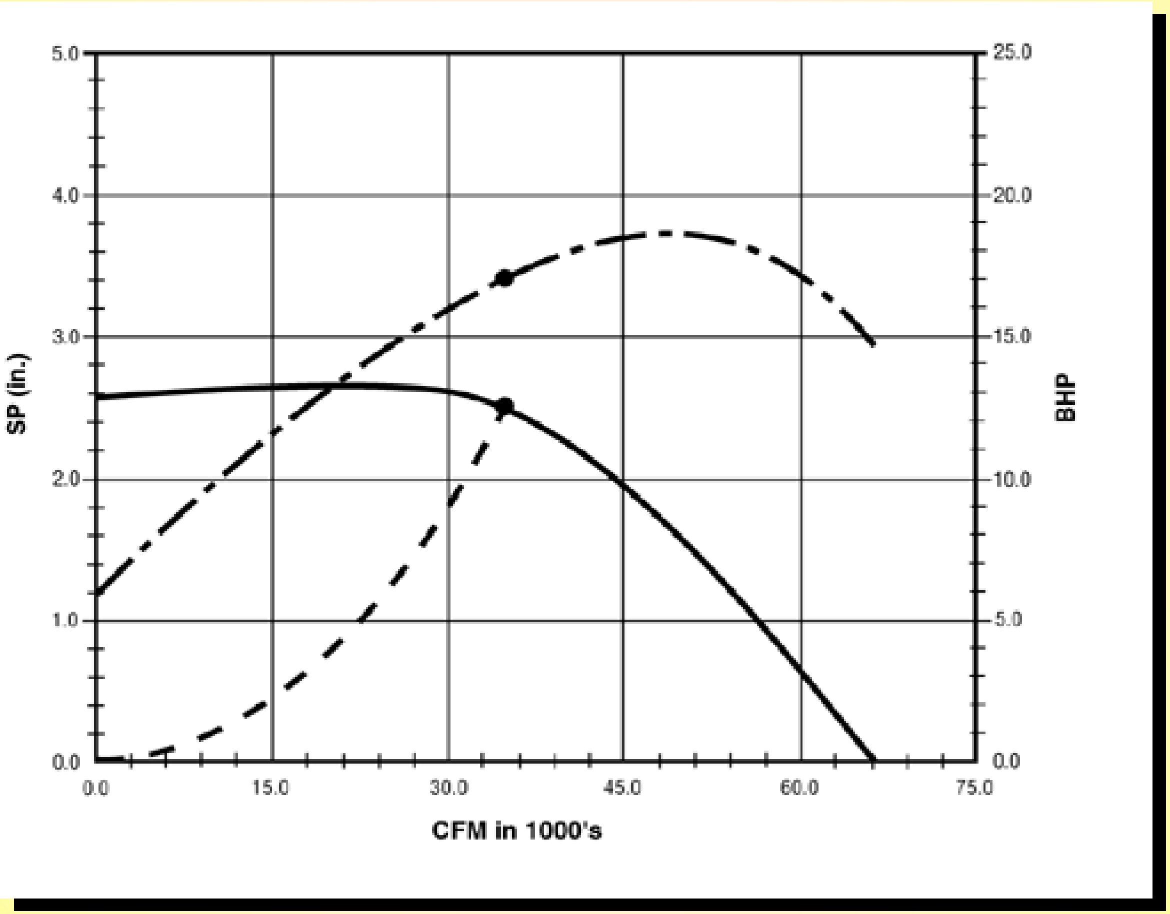
Air Velocity vs. Velocity Pressure





Standard Pitot Tube

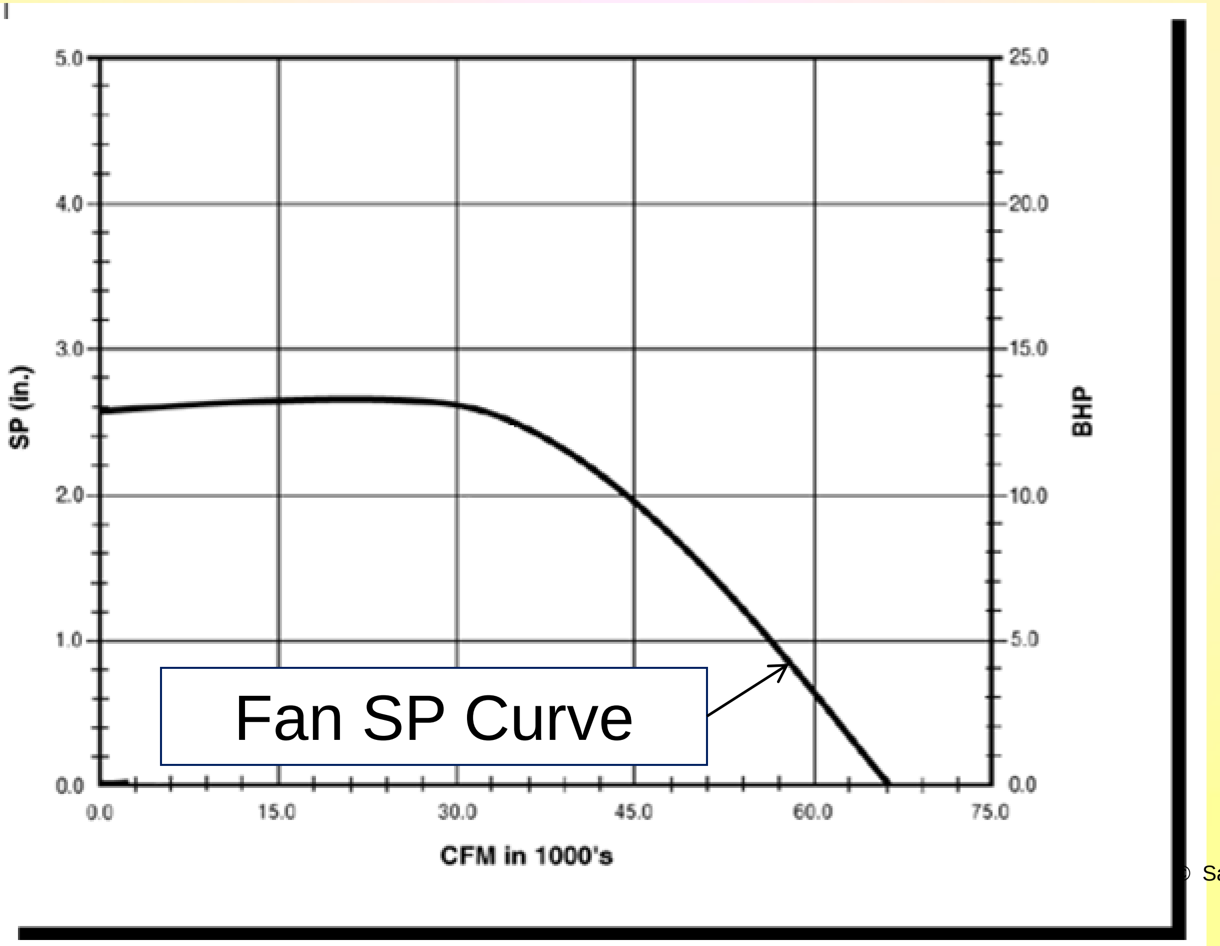
Fan Curves



5.0
4.0
3.0
2.0
1.0
0.0
SP (in.)
25.0
20.0
15.0
10.0
5.0
0.0
BHP
0.0
15.0
30.0
45.0
60.0
75.0
CFM in 1000's

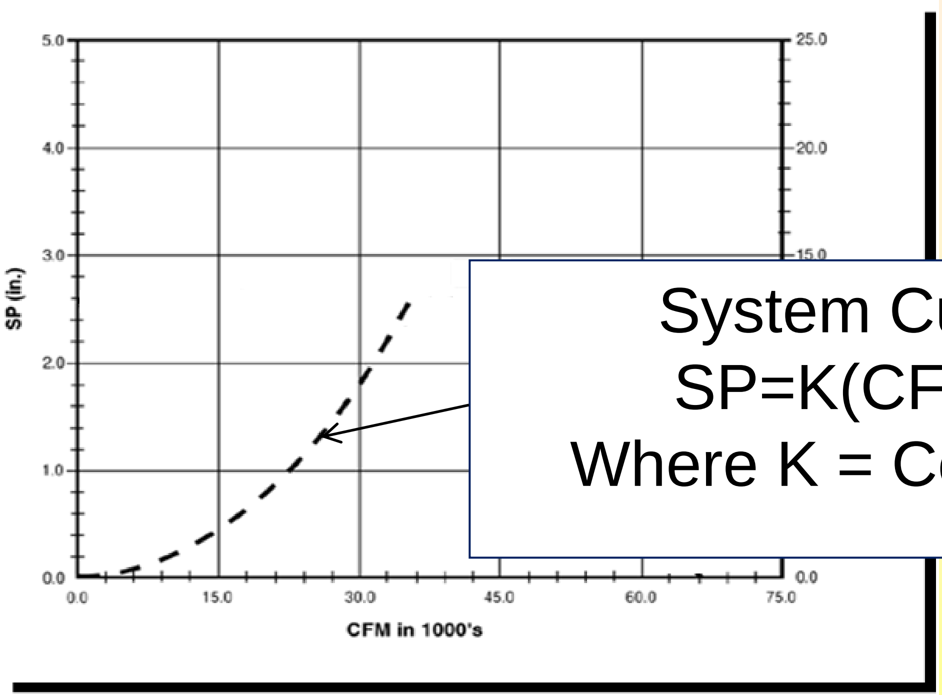
Fan Static Pressure Curve

- Shows performance of fan at constant RPM



System Curve

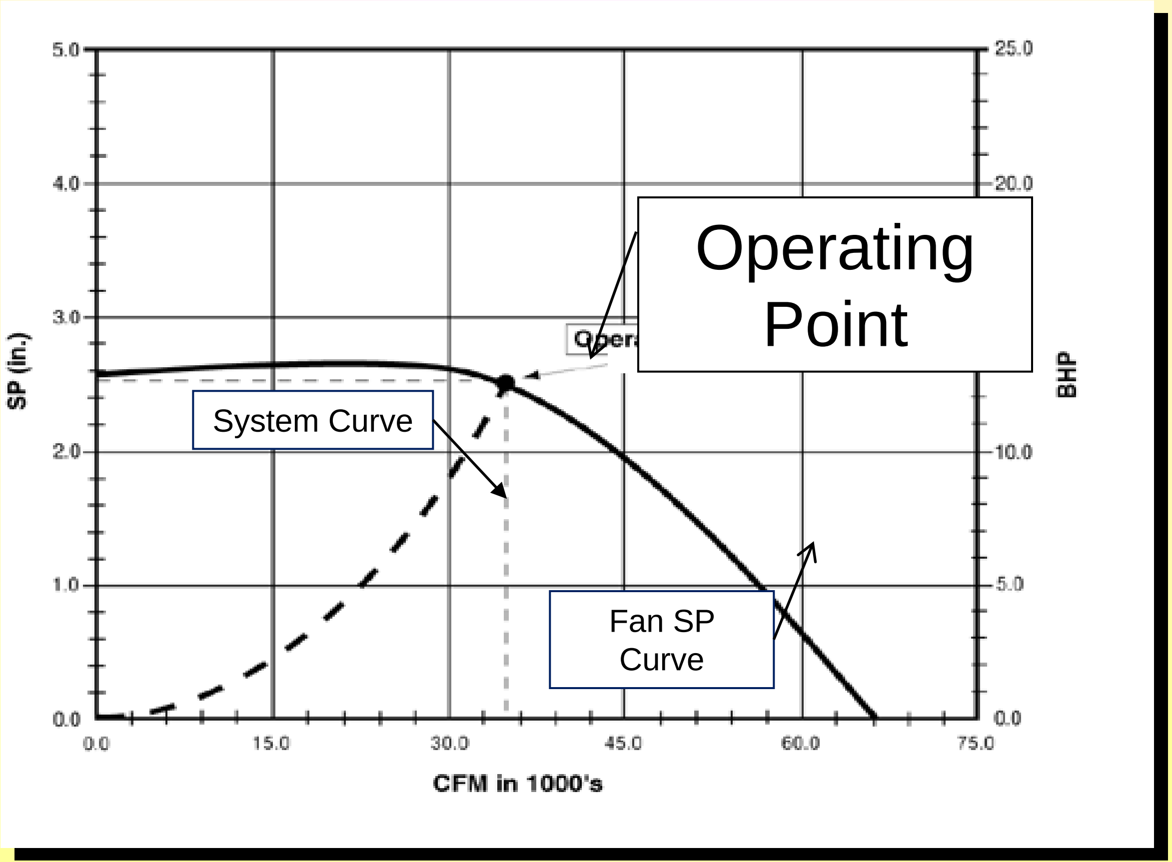
- Defines relationship of SP and airflow for a system
- Enables calculation of all possible operating points of the system



System Curve
$SP=K(CFM)^2$
Where K = Constant

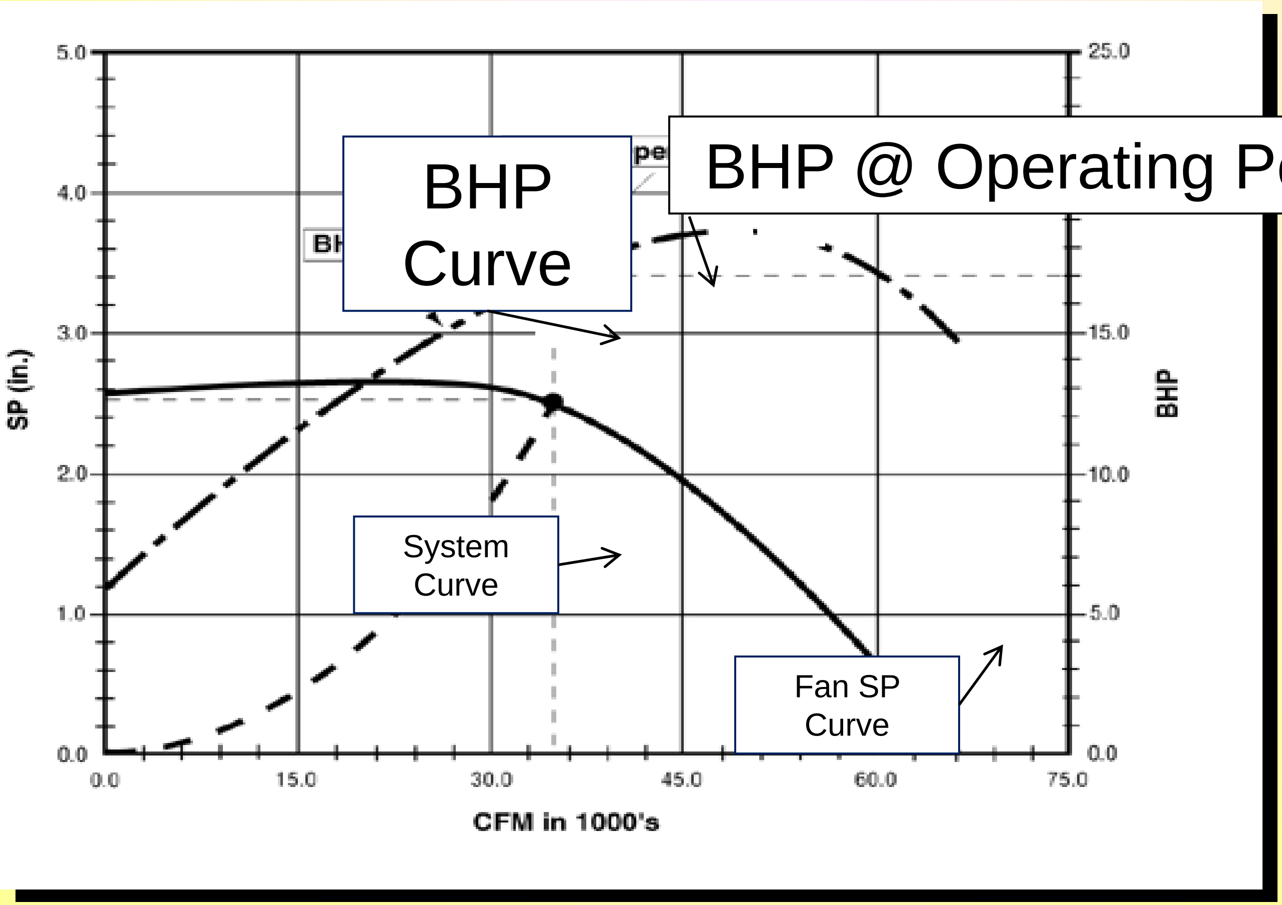
Operating Point

- Operating point is the intersection of the system and fan SP curves and indicates fan performance at given conditions

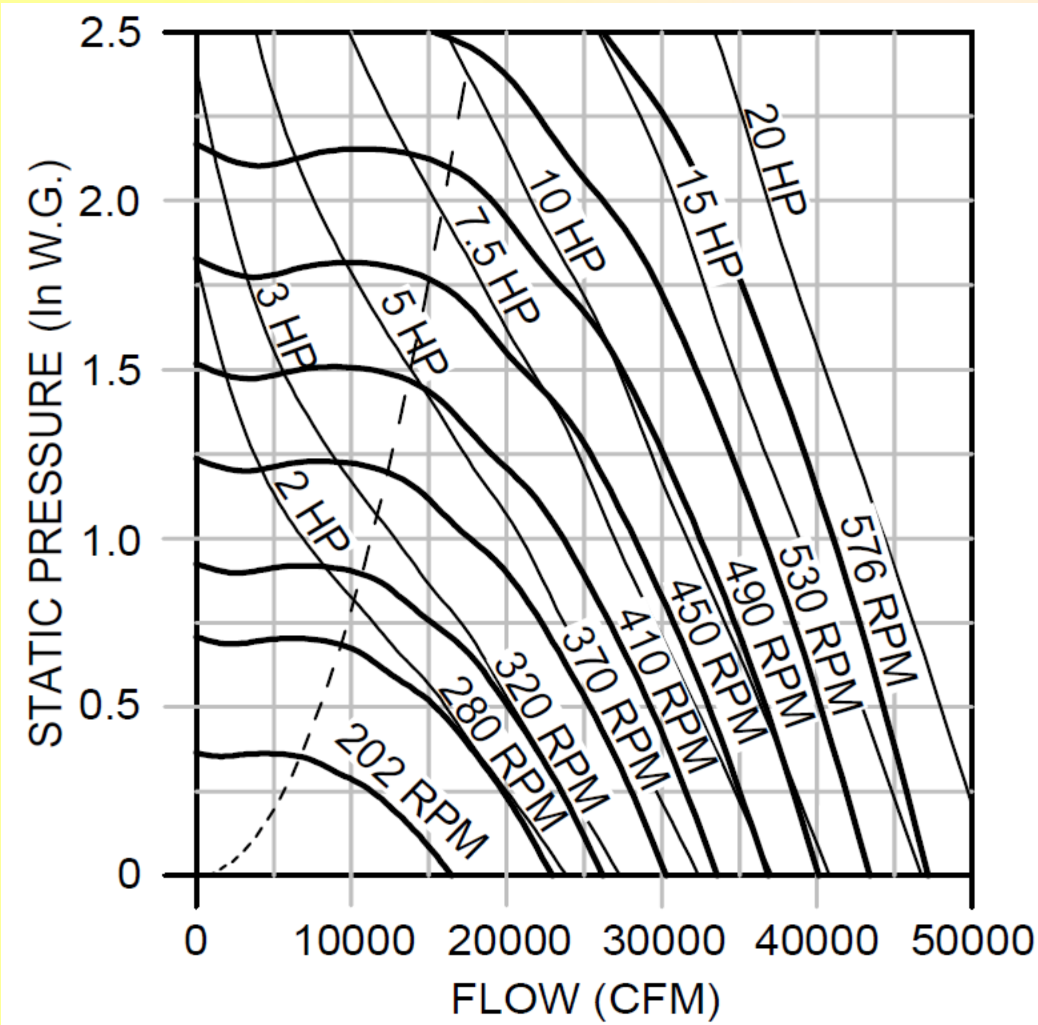


BHP Curve

- Plots horsepower requirements for points on fan curve



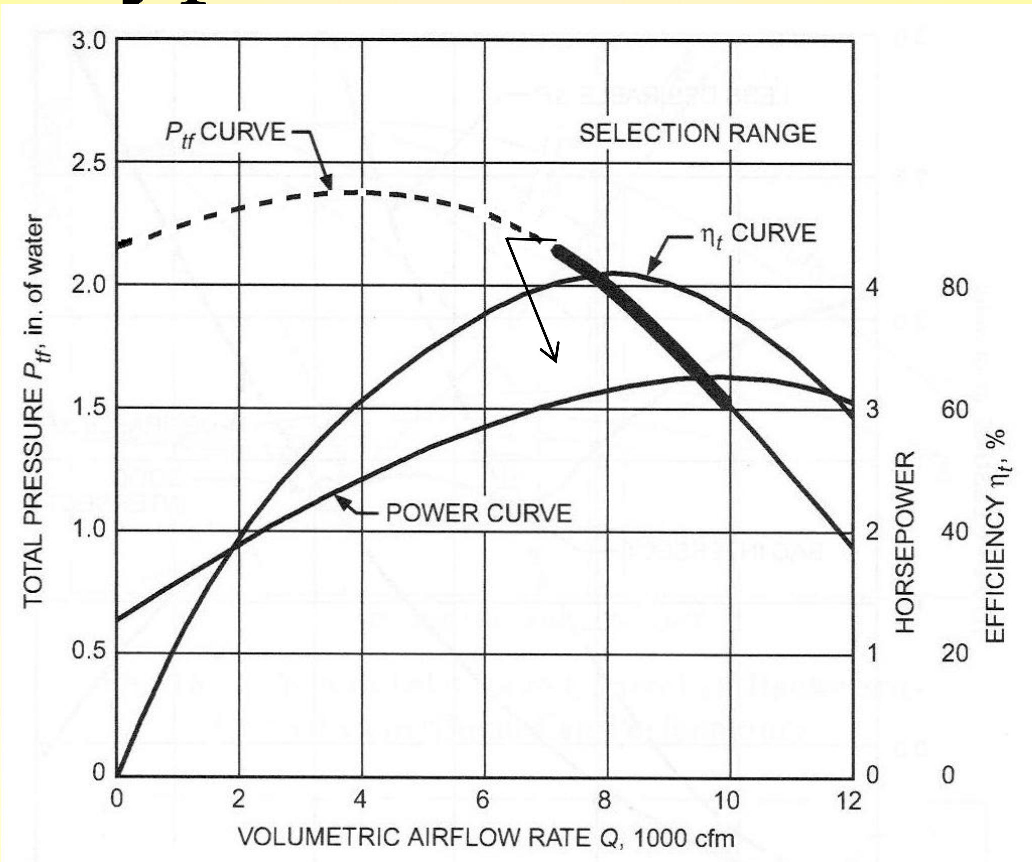
Fan Stall (Surge) Line



- - - - Stall Line

- Fan operation left of the stall line is unstable due to separation of airflow from the airfoils.
- Unstable fan operation is evidenced by decreased fan performance and increased fan noise and vibration

Typical Fan Curves



Curve shows performance of a fixed fan size running at a fixed speed.

Fan selections should be made as close to peak efficiency as possible and in stable region of fan curve

Fan Law Assumptions

- Constant Fan Aerodynamics and Fan Efficiency
- Constant Distribution System Configuration
- Constant Air/Gas Conditions, e.g., dry bulb, wet bulb, composition, density
- System effects have not severely changed fan performance from the cataloged performance
- Fan operating in stable region of fan curve

Simplified Fan Laws

$$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{CFM_2}{CFM_1} = \left(\frac{DIA_2}{DIA_1}\right)^3$$

$$\frac{P_2}{P_1} = \left(\frac{CFM_2}{CFM_1}\right)^2$$

$$\frac{HP_2}{HP_1} = \left(\frac{CFM_2}{CFM_1}\right)^3$$

$$\frac{P_2}{P_1} = \left(\frac{RPM_2}{RPM_1}\right)^2$$

$$\frac{HP_2}{HP_1} = \left(\frac{RPM_2}{RPM_1}\right)^3$$

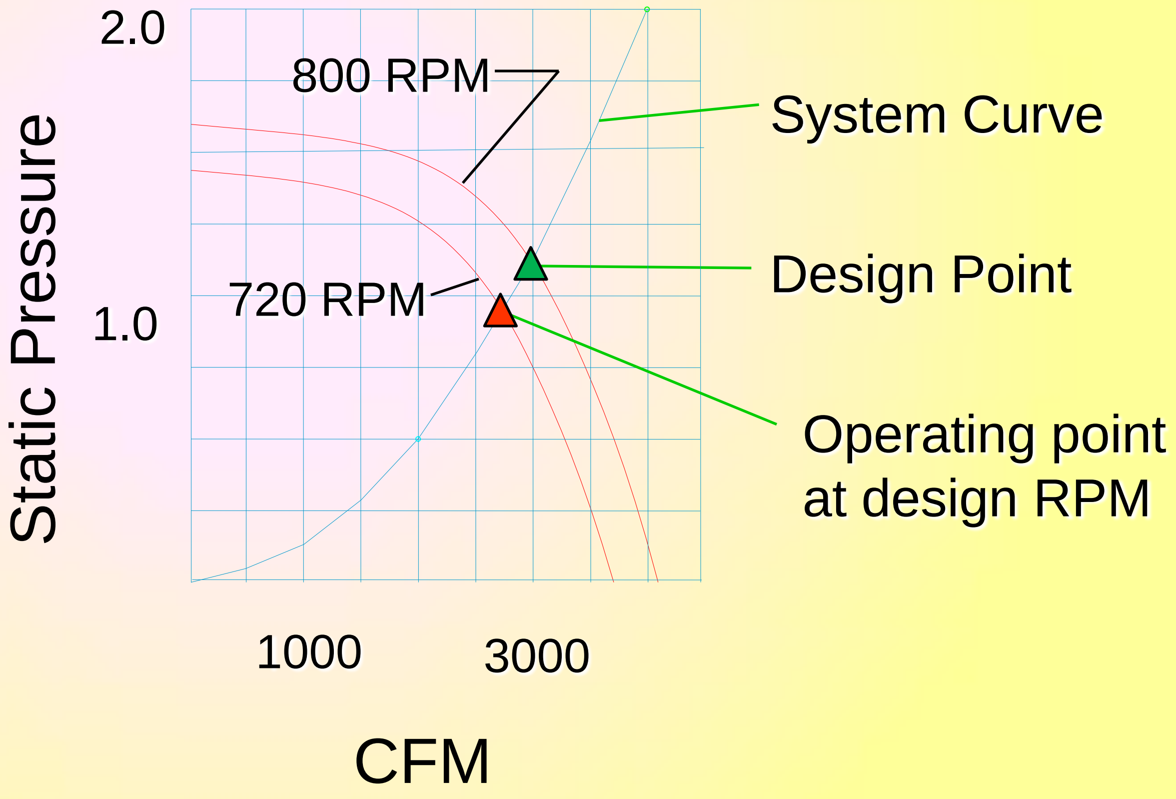
CFM_1=Original flow rate
CFM_2=New flow rate
DIA_1=Original wheel diameter
DIA_2=New wheel diameter
P_1=Original static pressure
P_2=New static pressure
RPM_1=Original fan speed
RPM_2=New fan speed
HP_1=Original brake horsepower required
HP_2=New brake horsepower required

Simplified fan laws assume constant gas density and temperature, motor and fan efficiency, and fan wheel aerodynamics. See 2008 ASHRAE HVAC Systems and Equipment Handbook Chapter 20 for additional information

Speed up the fan, what happens?

An 11% increase in RPM...

- yields an 11% increase in CFM
- produces a 23% increase in SP
- requires a 37% increase in HP



Fan Law Limitations

- Fan laws only apply to aerodynamically similar fans.
- The fan laws only apply over the stable portion of the fan curve, i.e., to the right of the fan stall line.
- A large change in performance between the original and new operating points may be over a large change in the slope of the fan curve and may produce misleading predictions from the fan laws.

System Effects
(or why fans don't operate as expected)

Causes:

- Non-uniform inlet flow: changes effective fan aerodynamics
- Swirl at the fan inlet: changes effective fan aerodynamics
- Improper outlet connection: causes higher than expected system pressure loss

System Effects: Consequences

- Alteration of fan performance
- Increased noise
- Increased fan and duct vibration
- Higher operating and maintenance costs

How to Minimize System Effects

Per AMCA:

- Provide minimum of 2.5 straight duct diameters at fan outlet before first elbow or offset
- Provide minimum of 3 to 5 straight duct diameters at fan inlet from last elbow or offset
- Avoid inlet swirl by installing turning vanes and large radius elbows upstream of fan inlet
- Install outlet duct elbow turning in same direction as airflow leaving fan wheel

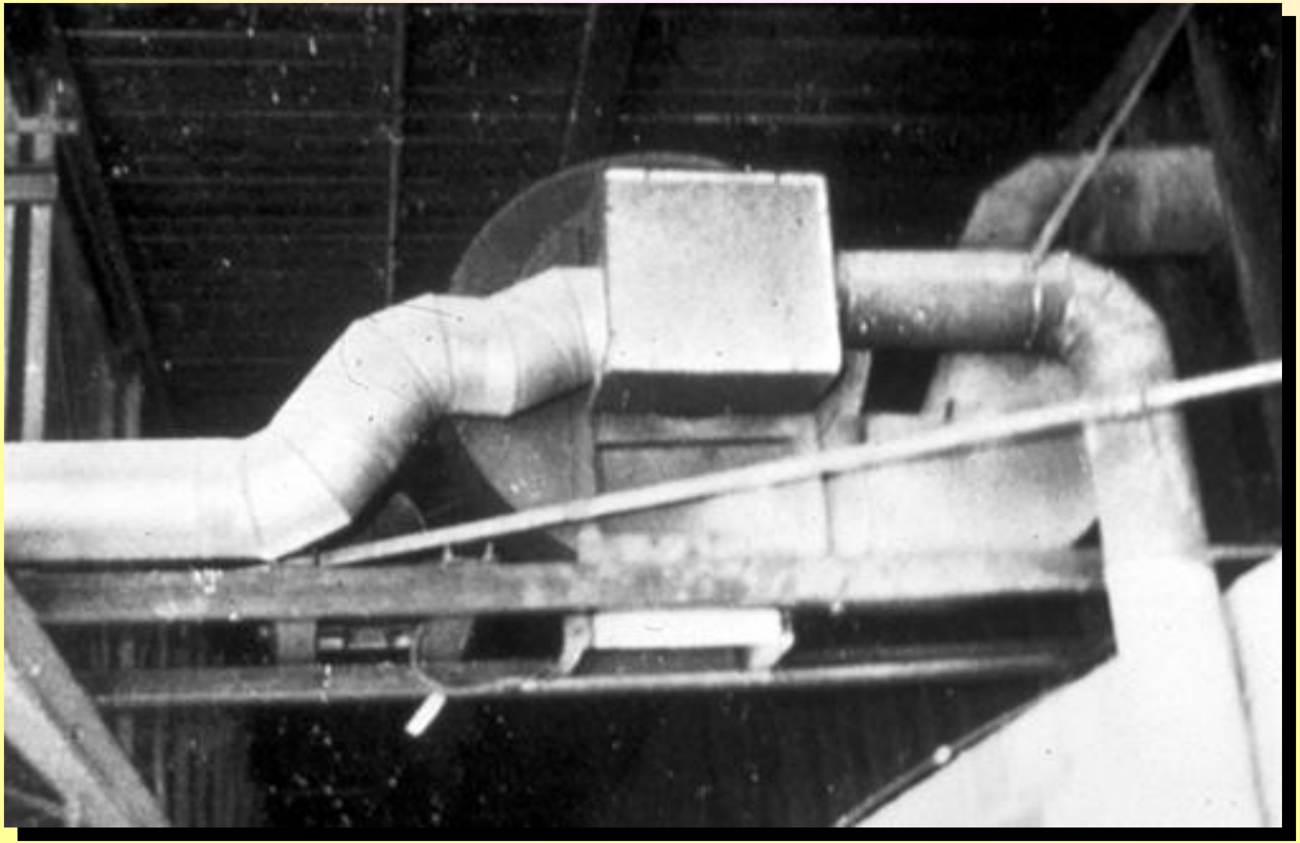
See 2009 ASHRAE Fundamentals Handbook chapter 21 for fan/system interface recommendations and calculating system effect factors and loss coefficients

System Effects - Examples

- Duct elbows too close to fan and discharge elbows turning opposite to fan wheel rotation

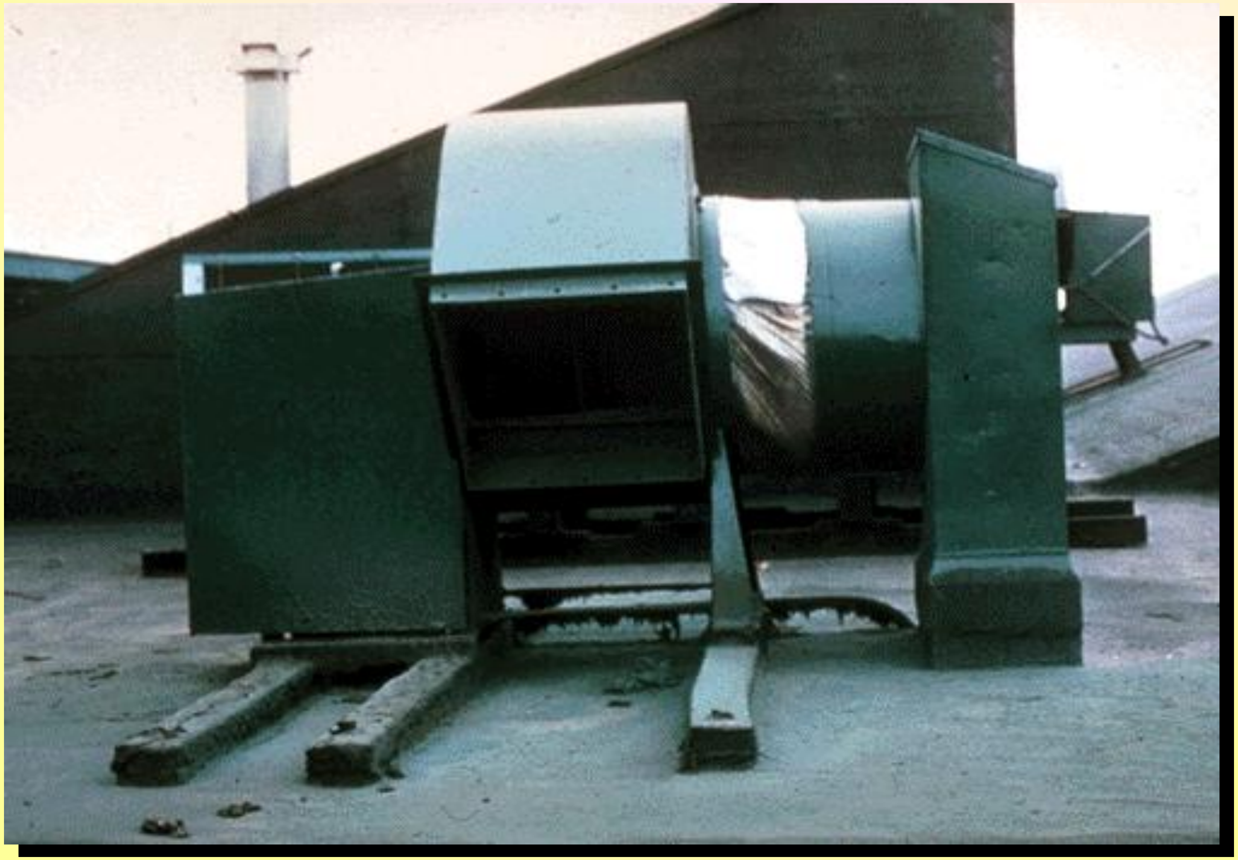
System Effects - Examples

- High loss inlet plenum without turning vanes: results in very high inlet pressure drop



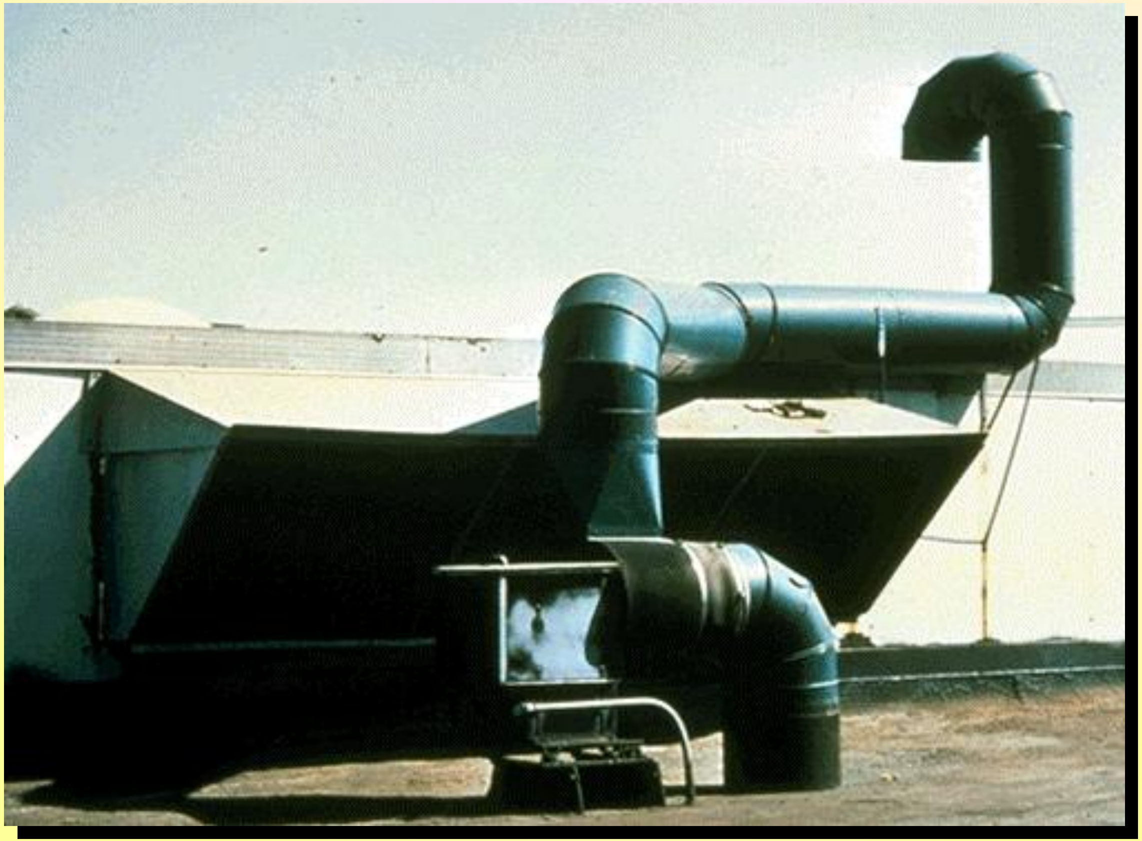
System Effects - Examples

- High loss inlet connection without turning vanes and the required minimum 3 to 5 duct diameter straight section: results in very high inlet pressure drop



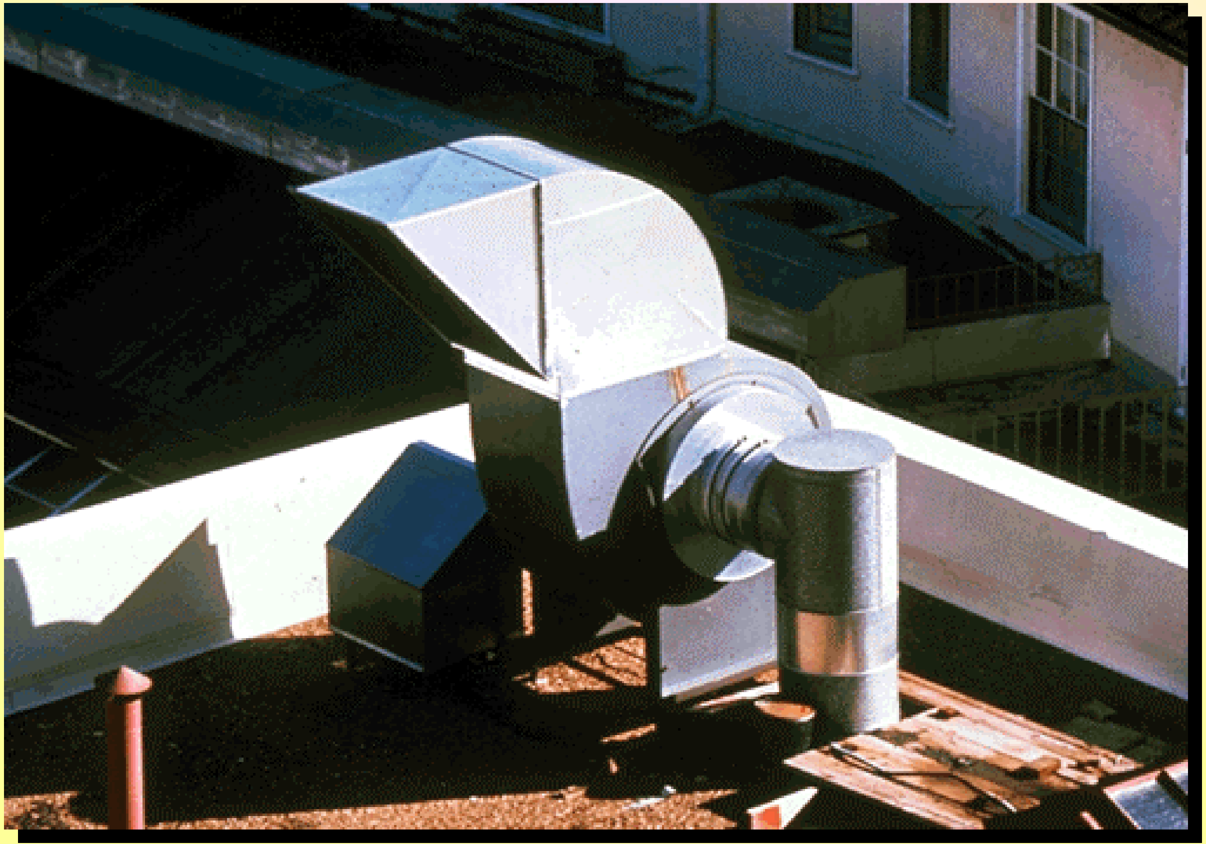
System Effects - Examples

- Short radius elbow close to inlet causes swirl & both inlet and outlet ducts result in high pressure losses

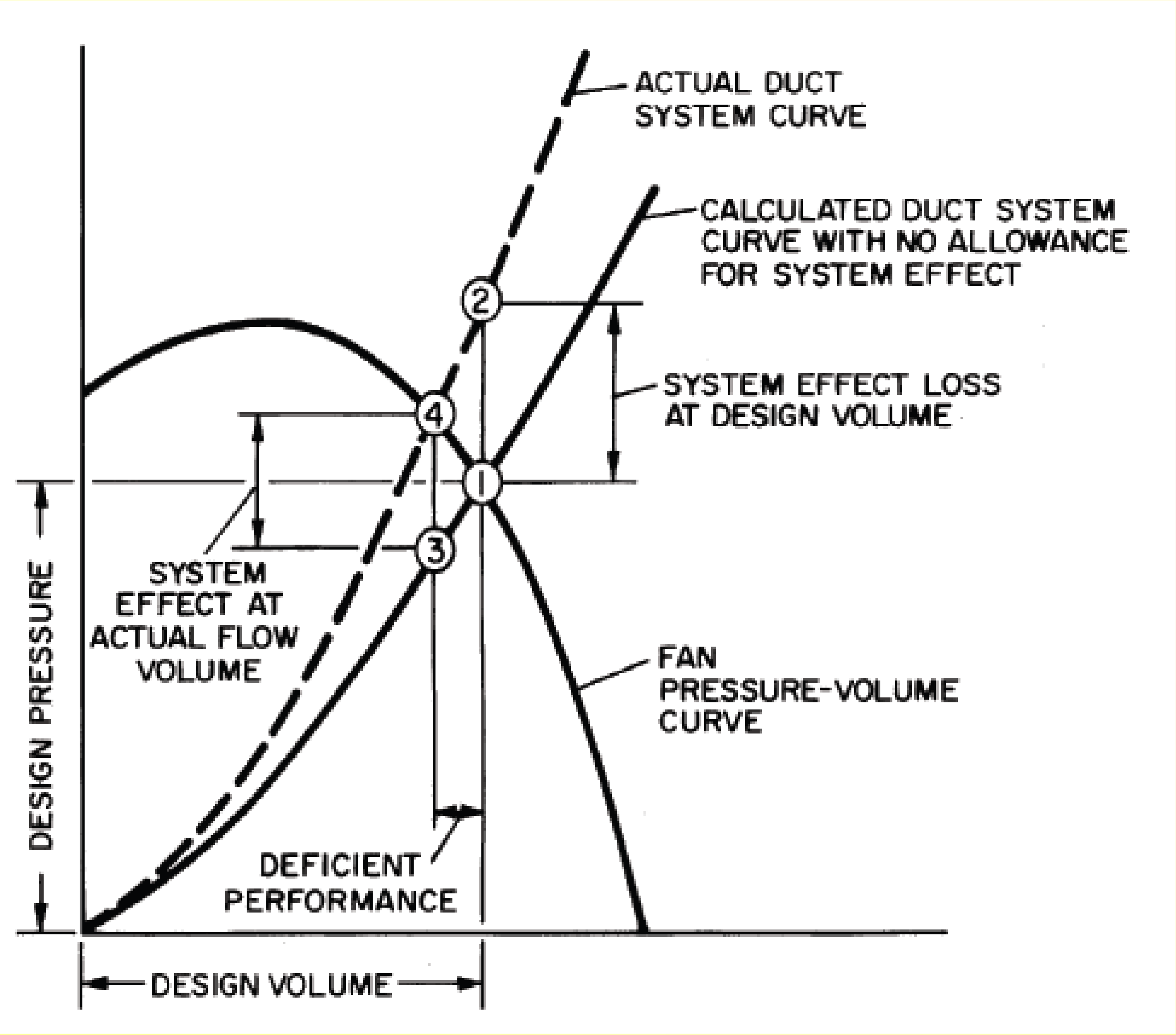


System Effects - Examples

- Duct elbows too close to fan and discharge elbows turning opposite to fan wheel rotation result in high pressure losses, fan performance shortfall, higher operating costs



System Effect



① Design selection point ignoring system effect

② Design CFM at adjusted pressure with fan modified to account for system effect

③ System operating point resulting from system effect

Consequences of 0.5” increase in Static Pressure due to System Effect on 10,000 CFM Fan with 1.5” SP Design Requirement:

- Fan speed increases from 838 RPM to 968 RPM (15.5% increase)
- Brake Horsepower increases from 4.1 to 6.3 (54% increase)

Common On-Site Errors Affecting Fan Law Calculations

- Direction of rotation, e.g., Backward Inclined centrifugal fan typically provides **1/3** of design airflow when operating in reverse direction
- Static pressure and airflow measurement errors- AMCA expects 2%-8% error in field static pressure measurements, but can be much greater with inexperienced personnel, inaccurate instrumentation, non-uniform/turbulent flow conditions at measurement station
- Improper fan belt tension

Conclusion

FAN LAWS ENABLE:

- Estimating any axial or centrifugal fan performance at revised condition that is on a section of the fan curve with similar slope to the original operating point
- Understanding fan performance shortfalls and how to correct them

As long as the true operating condition of the system is recognized and accounts for system effects

Questions?

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