Fan Laws II: Calculation and Application

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Fan Laws II: Calculation and Application

Purpose and Learning Objectives

The purpose of this presentation is to educate manufacturer's representatives, engineers, system designers, and fan specialists on the fan law calculations and their applications in the field.

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

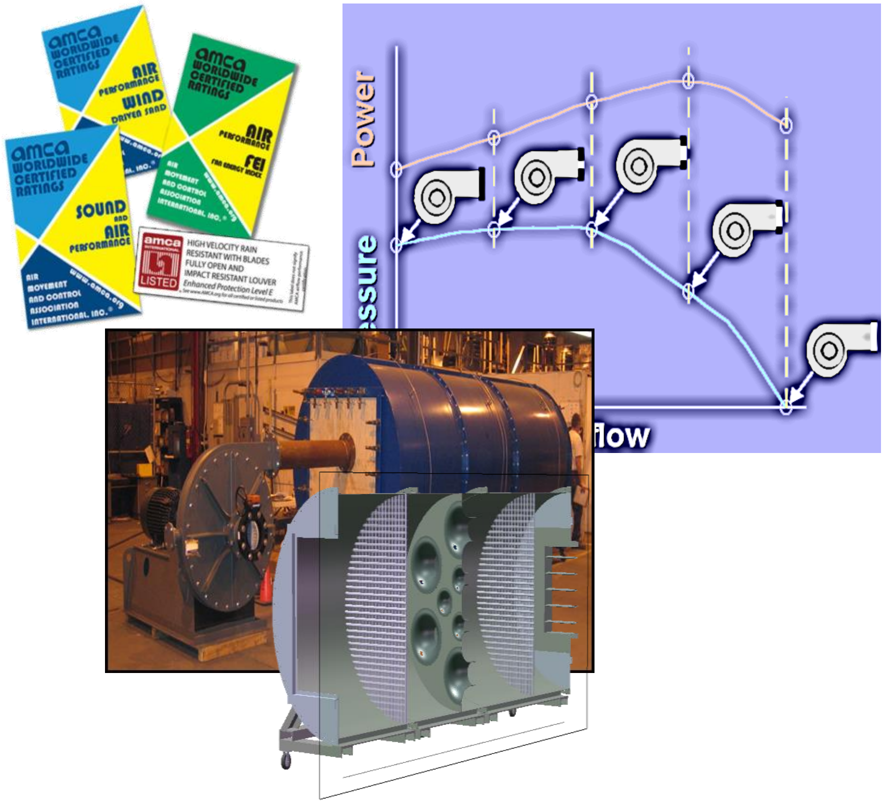
1. Identify the fan laws, testing, and ratings.
2. Explain the fan's role in an air system and interaction of fan and system.
3. Identify fan selection with system curve interaction.
4. Describe the impact of air density and RPM changes on fan performance.
5. Calculate variables for fan performance.

Fan Laws II: Calculation and Application Topics

- Fan ratings, testing, and fan laws.
- Air-fan system types and a fan's role in the system.
- Impact of air density on fan and system performance.
- Increase in air flow in a system using fan laws.
- Increase in power requirements using fan laws.

Fan Ratings

- **FAN** – A device that uses a power-driven rotating impeller to move air or gas.
- Fan Aerodynamic Performance Ratings
  - Airflow
  - Pressure (total or static)
  - Power
  - Speed
- The Fan Laws are used to calculate fan performance ratings.



Review of the Fan Laws

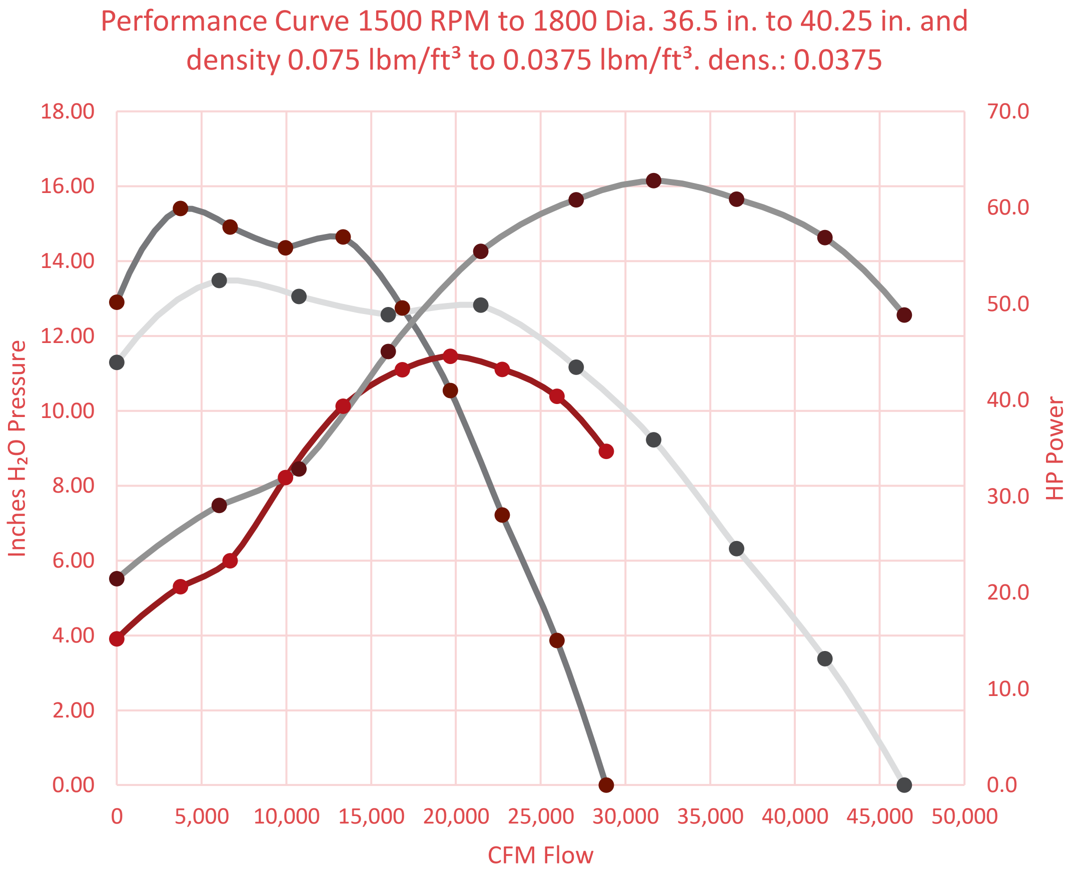
The Fan Laws are used to calculate fan performance at:

- Other Speeds, Densities, and Sizes

First Law: $CFM_2 = CFM_1 * \left[\frac{D_2}{D_1}\right]^3 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right]$

Second Law: $P_2 = P_1 * \left[\frac{D_2}{D_1}\right]^2 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$

Third Law: $HP_2 = HP_1 * \left[\frac{D_2}{D_1}\right]^5 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$



Fan Laws Calculations

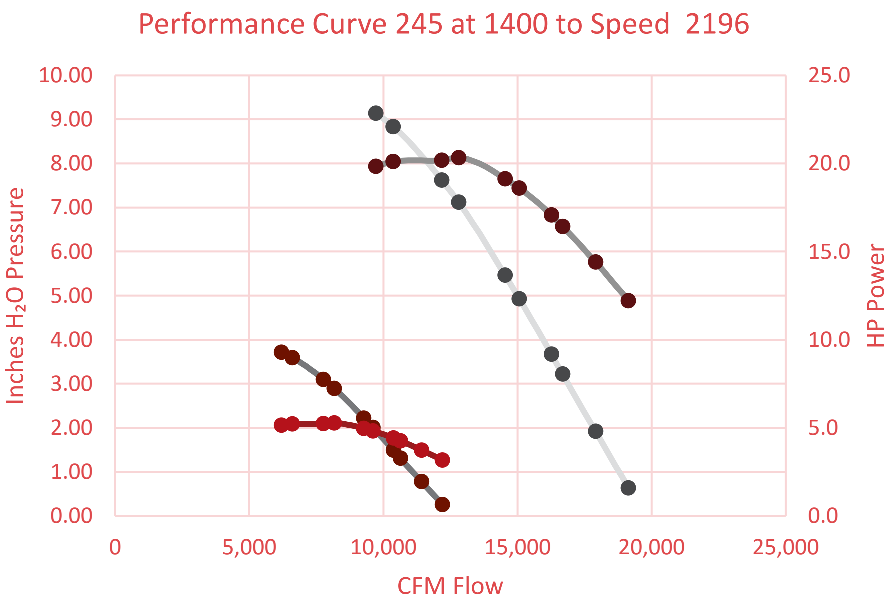
- Fan law calculations
  - Standardize the test data
    - 0.075 lbm/ft³ standard density
    - Normalize speed one RPM
  - Calculate new data points
    - New speeds
    - New sizes
    - Generate performance tables
    - Generate performance curves

https://www.pennbarry.com/file/9724/PennBarry_Plenum_Fans_Catalog_ESP.pdf

Performance Tables

Fan Performance Table Data:

- Fan size
- Various flow rates
- Various pressures
- Required RPM speed
- Required power
- Additional data



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Wheel Diameter = 24.50 in.	Tip Speed, FPM = 6.41 x RPM
Wheel Type = ESP	Maximum BHP = 1.96 x (RPM / 1000)^3

ESP - Performance Data

Efficient Silent Plenum Fan

CFM	3 1/2" SP		4" SP		4 1/2" SP		5" SP		5 1/2" SP		6" SP		6 1/2" SP		7" SP		7 1/2" SP		8" SP	
	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
7000	**1408**	**5.37**	**1479**	**6.17**	**1549**	**7.00**														
7400	**1432**	**5.67**	**1500**	**6.49**	**1567**	**7.34**	**1633**	**8.22**	**1698**	**9.12**										
7800	**1457**	**5.99**	**1524**	**6.83**	**1589**	**7.70**	**1652**	**8.60**	**1715**	**9.52**	**1776**	**10.47**								
8200	**1484**	**6.32**	**1549**	**7.19**	**1612**	**8.08**	**1673**	**9.00**	**1734**	**9.94**	**1793**	**10.91**	**1852**	**11.90**						
8600	**1513**	**6.67**	**1575**	**7.57**	**1636**	**8.48**	**1696**	**9.42**	**1755**	**10.38**	**1813**	**11.37**	**1870**	**12.38**	**1926**	**13.41**	**1981**	**14.47**		
9000	**1542**	**7.03**	**1603**	**7.96**	**1663**	**8.90**	**1721**	**9.86**	**1778**	**10.85**	**1834**	**11.85**	**1889**	**12.88**	**1944**	**13.94**	**1998**	**15.01**	**2051**	**16.11**
9600	1588	7.61	**1647**	**8.57**	**1704**	**9.55**	**1760**	**10.56**	**1815**	**11.58**	**1869**	**12.62**	**1922**	**13.68**	**1974**	**14.76**	**2026**	**15.87**	**2077**	**16.99**
10200	1636	8.22	1693	9.23	**1748**	**10.25**	**1802**	**11.29**	**1855**	**12.35**	**1907**	**13.43**	**1958**	**14.53**	**2008**	**15.64**	**2058**	**16.78**	**2107**	**17.93**
11000	1703	9.08	1757	10.15	1810	11.24	**1862**	**12.34**	**1912**	**13.45**	**1962**	**14.58**	**2011**	**15.73**	**2059**	**16.89**	**2106**	**18.08**	**2153**	**19.28**
11800	1771	10.01	1824	11.15	1874	12.30	1924	13.46	1973	14.63	**2020**	**15.82**	**2067**	**17.02**	**2113**	**18.23**	**2159**	**19.47**	**2203**	**20.72**
12600	1842	11.01	1892	12.21	1941	13.43	1989	14.65	2036	15.88	2082	17.13	**2127**	**18.39**	**2171**	**19.66**	**2215**	**20.95**	**2258**	**22.25**
13400	1914	12.08	1963	13.35	2010	14.63	2056	15.92	2102	17.21	2146	18.52	2189	19.84	2232	21.17	**2274**	**22.52**	**2316**	**23.88**
14200	1987	13.22	2034	14.56	2080	15.91	2125	17.26	2169	18.63	2212	20.00	2254	21.38	2296	22.77	2336	24.18	2377	25.59
15000	2061	14.45	2107	15.85	2152	17.27	2196	18.69	2238	20.12	2280	21.56	2321	23.01	2361	24.46	2401	25.93	2440	27.40
15800	2137	15.75	2182	17.23	2225	18.71	2268	20.20	2309	21.70	2350	23.21	2389	24.72	2429	26.24	2467	27.77	2505	29.31
16600	2213	17.14	2257	18.69	2299	20.24	2341	21.80	2381	23.37	2420	24.94	2459	26.52	2497	28.11	2535	29.71	2572	31.31
17400	2290	18.62	2333	20.24	2374	21.87	2414	23.50	2454	25.13	2492	26.77	2530	28.42	2567	30.08	2604	31.74	2640	33.41
18200	2368	20.20	2409	21.89	2450	23.58	2489	25.28	2528	26.99	2565	28.70	2602	30.42	2639	32.14	2674	33.87	2709	35.60
19200	2466	22.31	2506	24.09	2545	25.87	2584	27.66	2621	29.45	2658	31.25	2694	33.06	2729	34.86	2764	36.68		
20200	2564	24.58	2604	26.45	2642	28.32	2679	30.20	2716	32.08	2751	33.97								

Notes:
1) Performance shown is for Installation Type A: free inlet, free outlet.
2) Power rating (BHP) does not include belt drive losses.
3) Bold figures indicate range of maximum static efficiency.
4) Performance ratings do not include the effects of appurtenances in the airstream.
5) Ratings include the effect of a wall located 2" from the fan base.

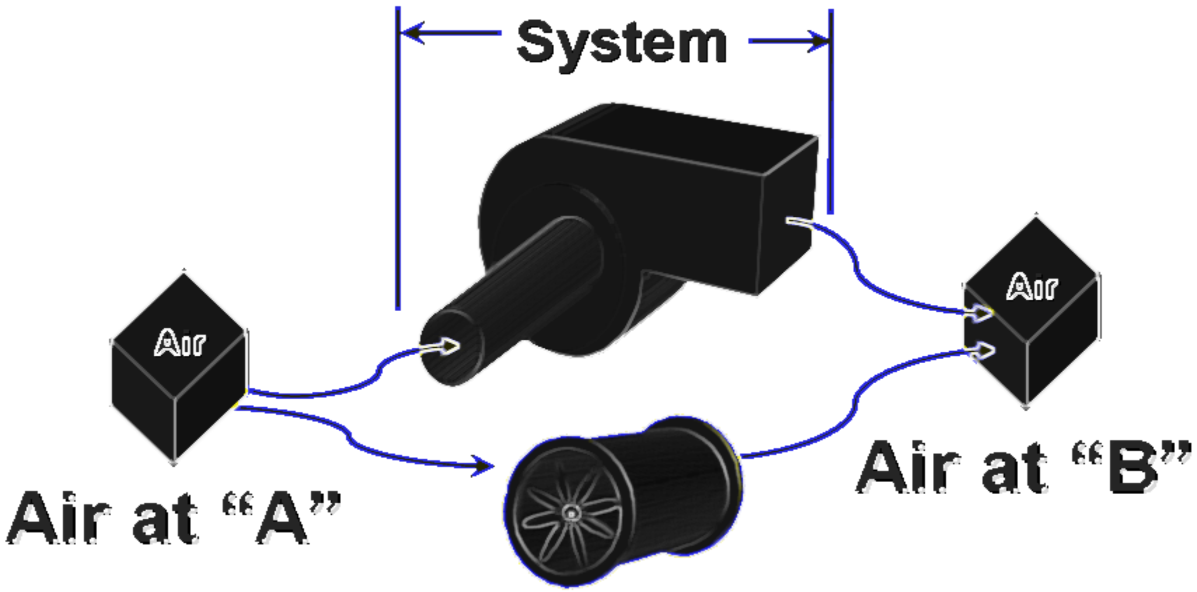
https://www.pennbarry.com/file/9724/PennBarry_Plenum_Fans_Catalog_ESP.pdf

Different Systems Flow and Pressure

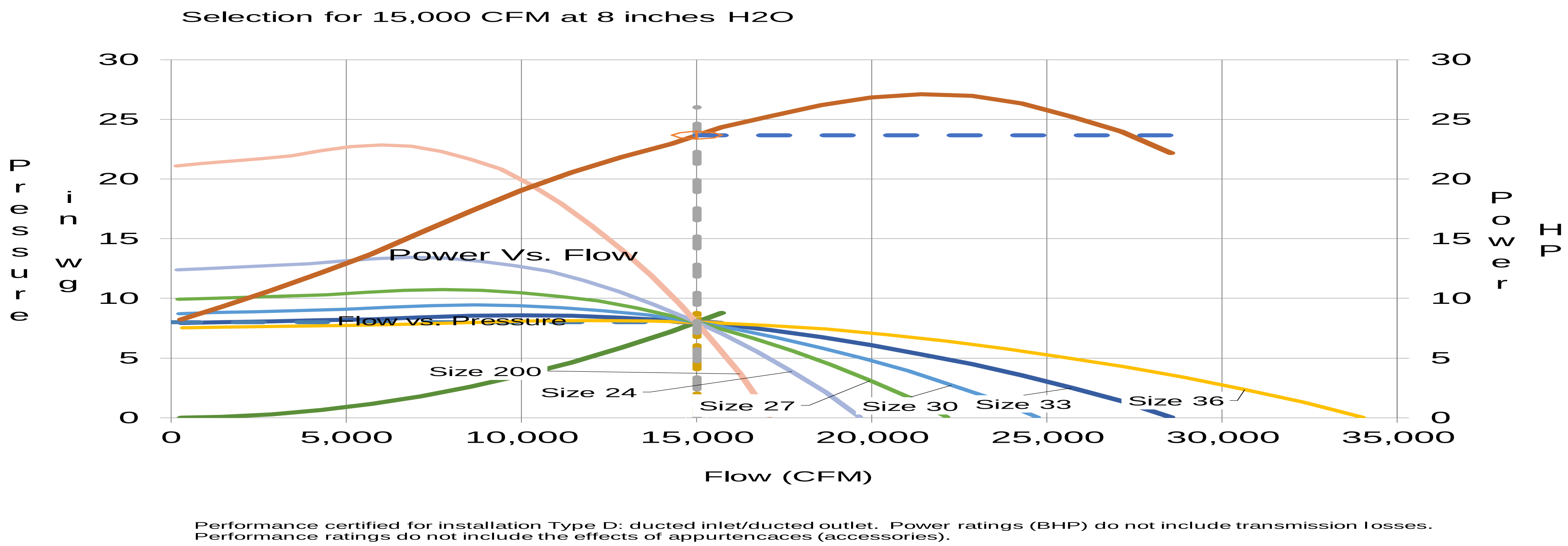
- HVAC - heating, ventilating and air conditioning
  - Indoor environmental air comfort
- General Ventilation
  - High Flow Low Pressure Systems
  - Dilution Air Systems
- LEV System (Local Exhaust Ventilation)
  - Combination of hoods, ducts, cleaning devices, fan, and stack to control contaminant or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

Fan's Role In Air System

- All air systems will have an airflow rate and to move that airflow will require differential pressure.
- The purpose of a fan is to supply an air system with energy (in the form of pressure) necessary to maintain airflow through the resistance of the system.



Fan Selection Choices



- Many fan sizes and types will provide the correct flow and pressure.

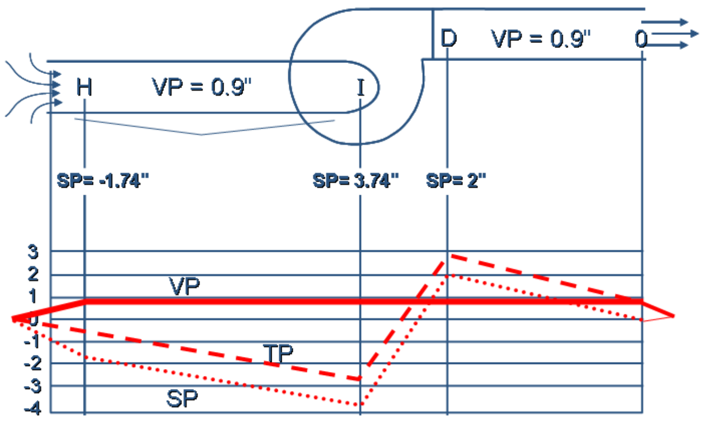
Fan Selection Choices

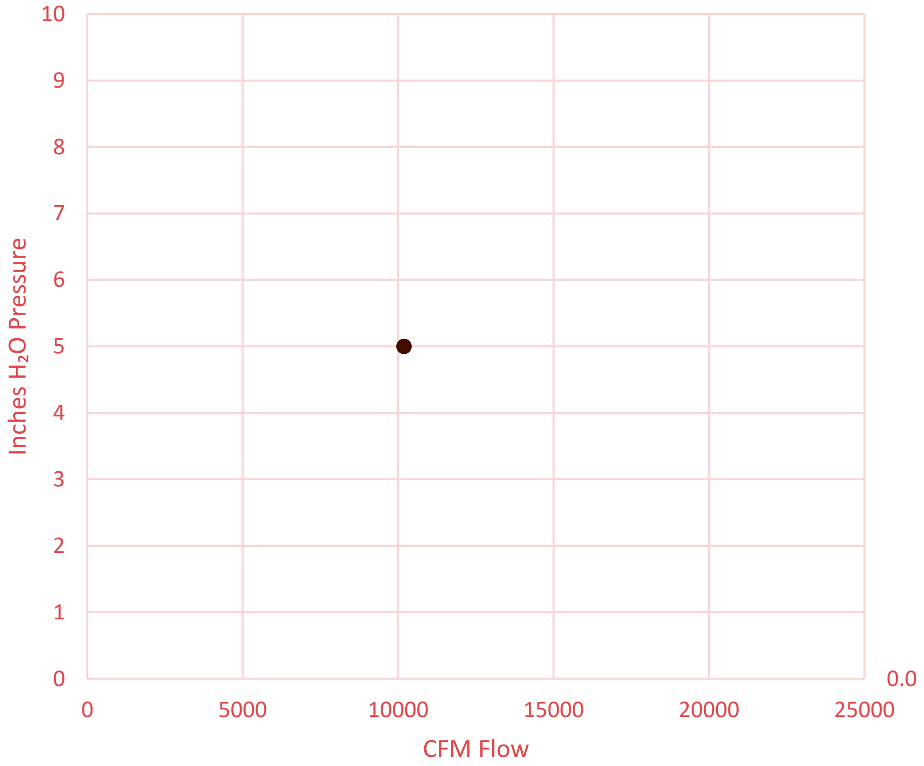
Size	Dia.	CFM	SP	RPM	BHP	Out. Vel.
Size: 200	20.00	15,000	8.0	3,700	41.1	6,472
Size: 245	24.50	15,000	8.0	2,315	29.2	4,313
Size: 275	27.50	15,000	8.0	1,844	25.8	3,423
Size: 300	30.00	15,000	8.0	1,586	24.2	2,876
Size: 330	33.00	15,000	8.0	1,375	23.7	2,377
Size: 365	36.50	15,000	8.0	1,211	24.4	1,943

- Size, Operating Point, Efficiency, Velocity, RPM, Noise all will impact choice.
- Other fan wheel types will also be available.
- Work with manufacturers and representatives to select.

Fan Selection

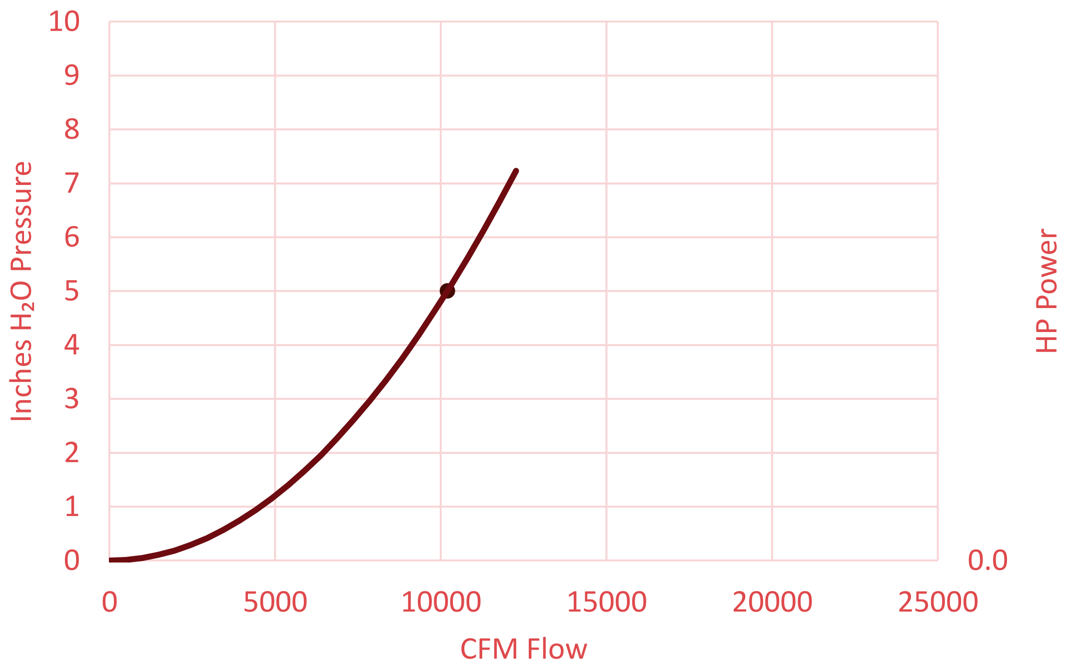
- System Calculation
  - SP is negative on the inlet, positive on the outlet
  - TP is negative on the inlet, positive on the outlet
  - VP is always positive
- System Requirement 10,200 CFM at 5-inch H_2O





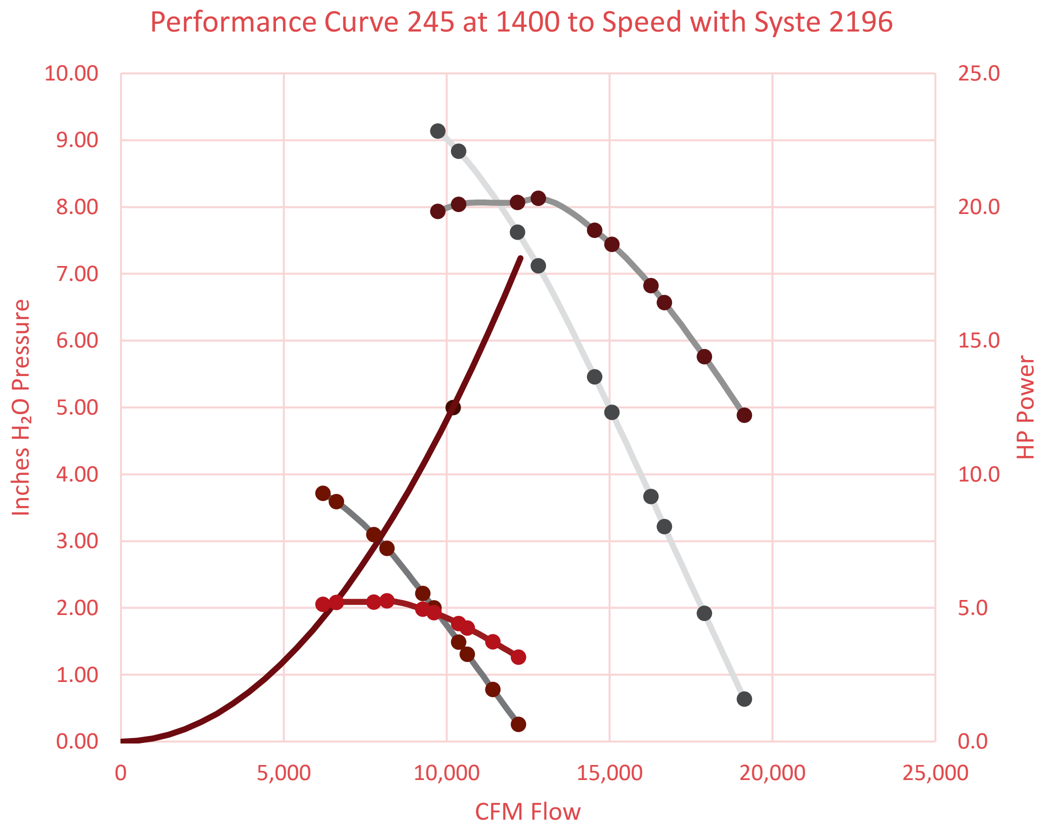
System Resistance Curve

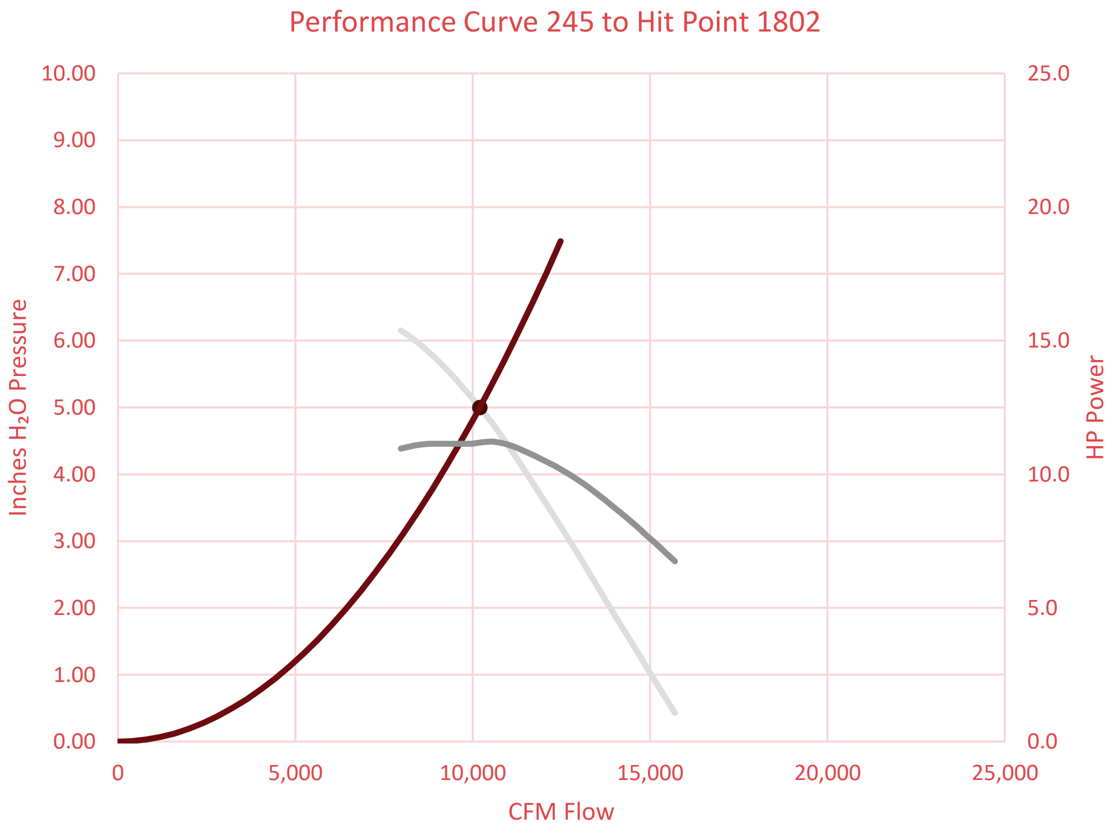
- System Calculation
  - Flow or Capacity (CFM)
  - Pressure Requirements (in wg)
- System Resistance Curve
  - System Affinity Law



$$SSP_2 = (SSP_1)\,(Q_2/Q_1)^2(df_2/df_1)$$

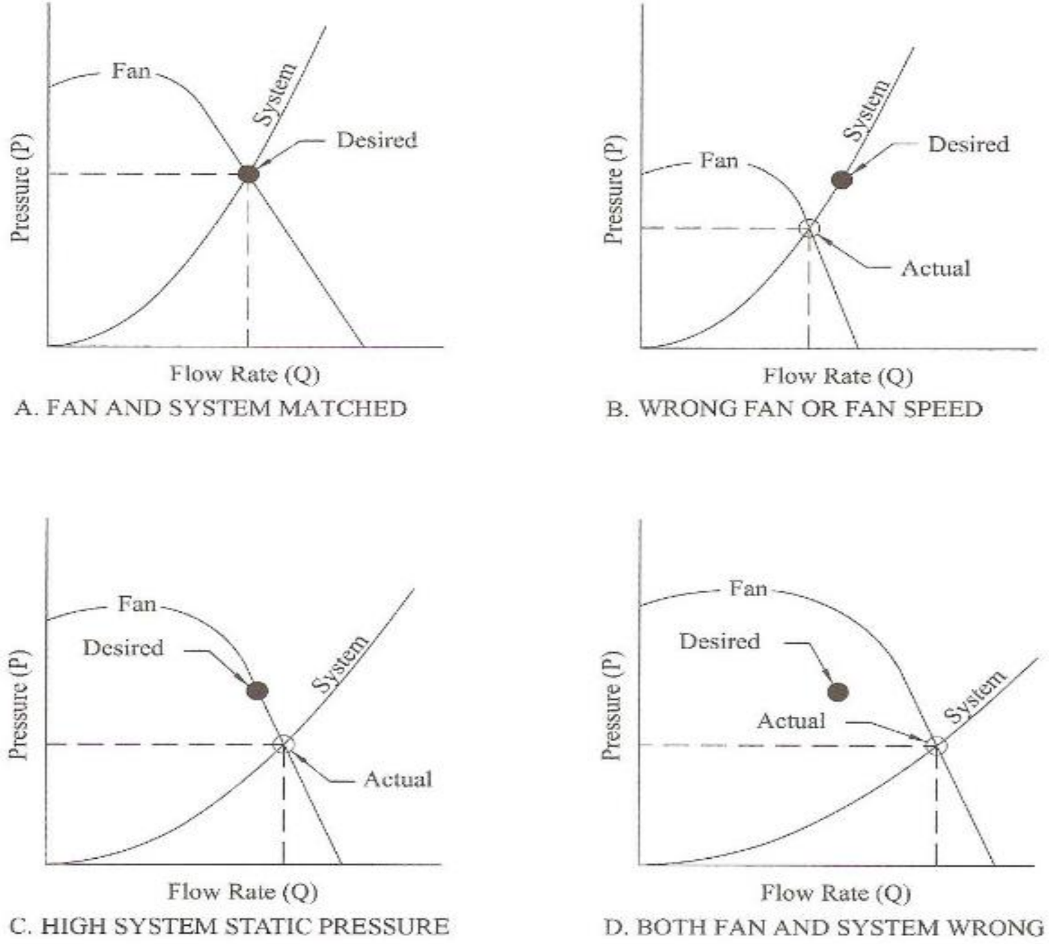
Fan Selection To Hit The Point





Flow, Pressure, Selection, Efficiency And System Interaction

- A properly calculated system and properly selected fan will deliver the correct flow at the desired pressure.
- When the flow or pressure is incorrect:
    - System resistance improperly calculated
    - Fan improperly selected
- Industrial Ventilation Fig 7-21, p 7-37



Basic Fan Laws

- Normalize data to standard conditions:
  - Average RPM
  - Standard Air Density of 0.075 lbm/ft³
- Flow is proportional to speed
- Pressure is proportional to:
  - The speed ratio squared
  - The density ratio
- Power is proportional to:
  - The speed ratio cubed
  - The density ratio
- K1/K2 - Gas compressibility affects the results.
  - For this introduction K1/K2 will be considered to be K1/K2 =1

$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right]$$

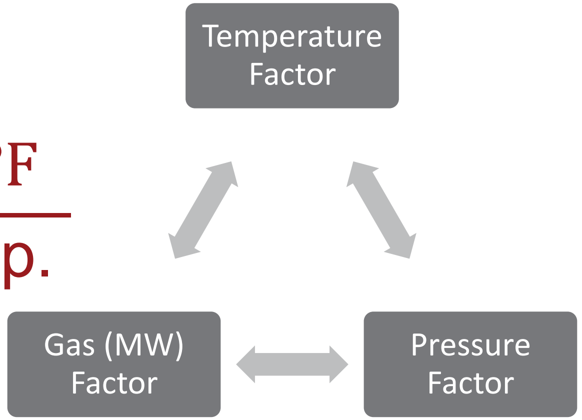
$$P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

$$HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Standard Air & Air Density

- Standard air is the reference gas for fan performance ratings.
  - Standard Density is 0.075 $^{lb.}/_{ft.^3}$ consisting of 78% Nitrogen (N_2), 21% Oxygen (O_2), 1% Argon (A), and other trace gases. At 70° F. Temp. and 29.92 in (Hg) barometer
- Humidity or water vapor reduces air density.
- Temperature increase reduces air density.

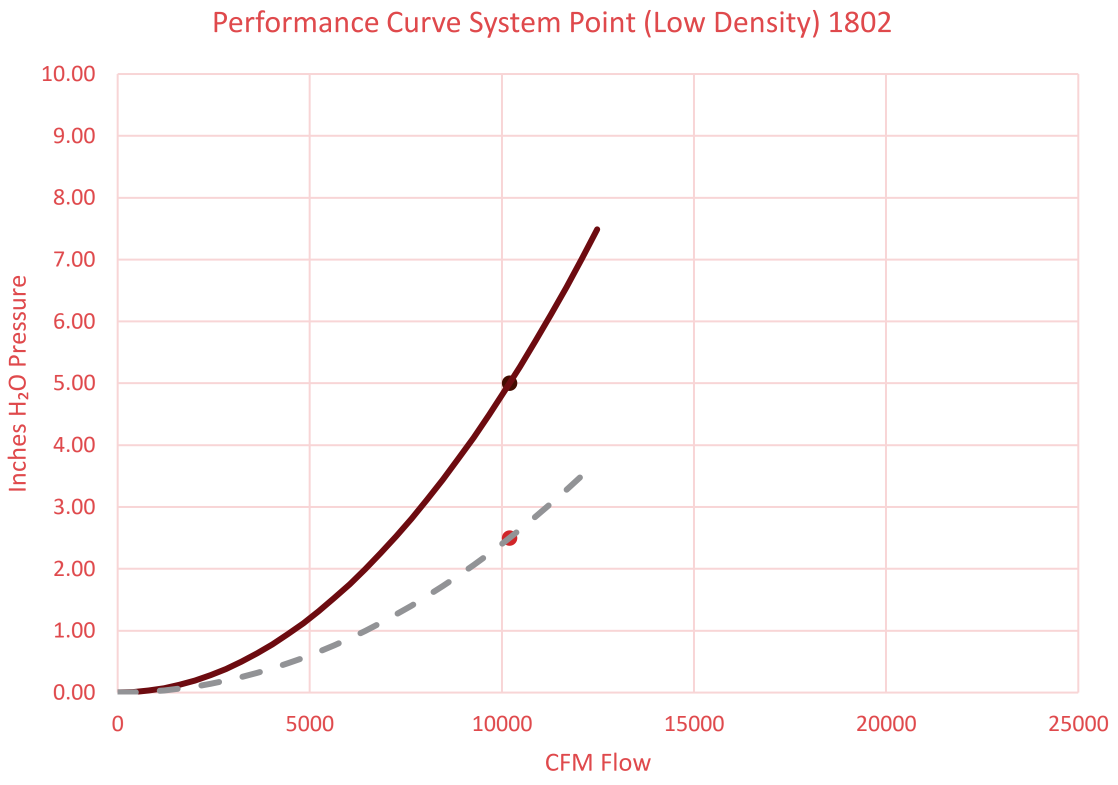
$$0.075\ \frac{\text{lbm}}{\text{ft}^3} \times \frac{\text{Abs. press.}}{29.92\ \text{in. Hg}} \times \frac{460°\text{F} + 70°\text{F}}{460°\text{F} + \text{Temp.}}$$



- Density effects fan and system performance.
- Density at a given temperature and barometric pressure can be calculated.

System Resistance Curve

- System Calculation
  - Flow or Capacity (CFM)
  - Pressure Requirements (in wg)
  - Resistance at standard density
- System Resistance Curve
- System Losses Plotted
- Resistance varies with density factor



$$SSP_2 = (SSP_1)\,(Q_2/Q_1)^2(\rho_2/\rho_1)$$

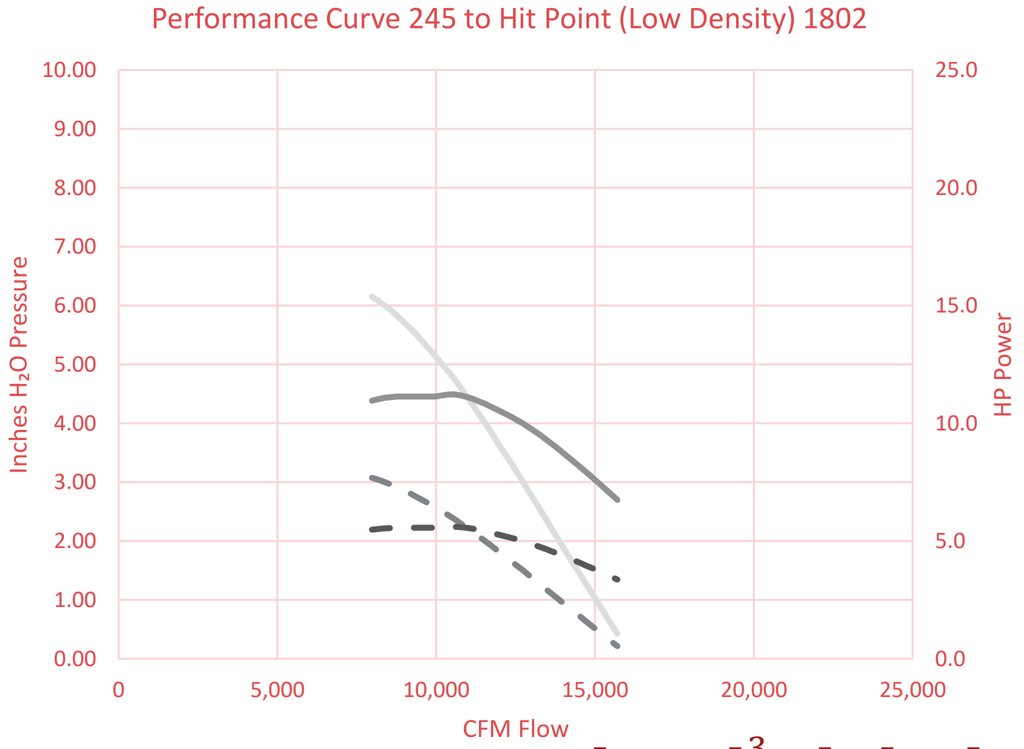
Changes In Air Density

- The Fan Laws can be used to calculate fan performance other gas densities:
  - Industrial Ventilation Section 7.4.3, p 7-35

Flow: $Q_2 = Q_1$

Pressure: $P_2 = P_1 \text{ x } (\rho_2/\rho_1)$

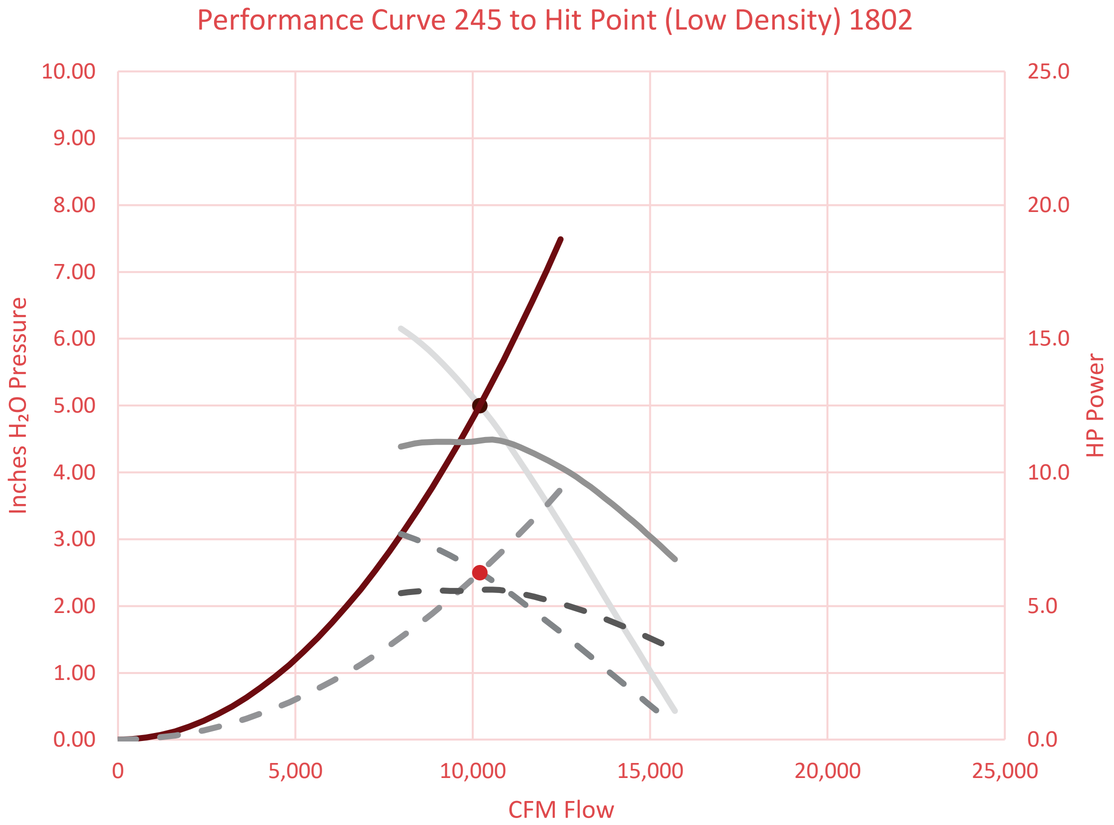
Power: $HP_2 = P_1 \ (\rho_2/\rho_1)$



$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right] \quad P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right] \quad HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Fan Selection

- Pressure produced by the fan is reduced with reduced density
- System resistance is reduced with reduced density
- Power required by the fan is reduced with reduced density



$$SSP_2 = (SSP_1)\,(Q_2/Q_1)^2(\rho_2/\rho_1)$$

$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right] \quad P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right] \quad HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Changes In Airflow

- The Fan Laws can be used to calculate fan performance for a specific operating point at different flows:
  - Industrial Ventilation Section 7.4.3, p 7-35
- Increase flow 20% ($Q_2 = Q_1 * 120\%$)

Flow & Speed: $RPM_2 = RPM_1 \text{ x } (Q_2/Q_1)$

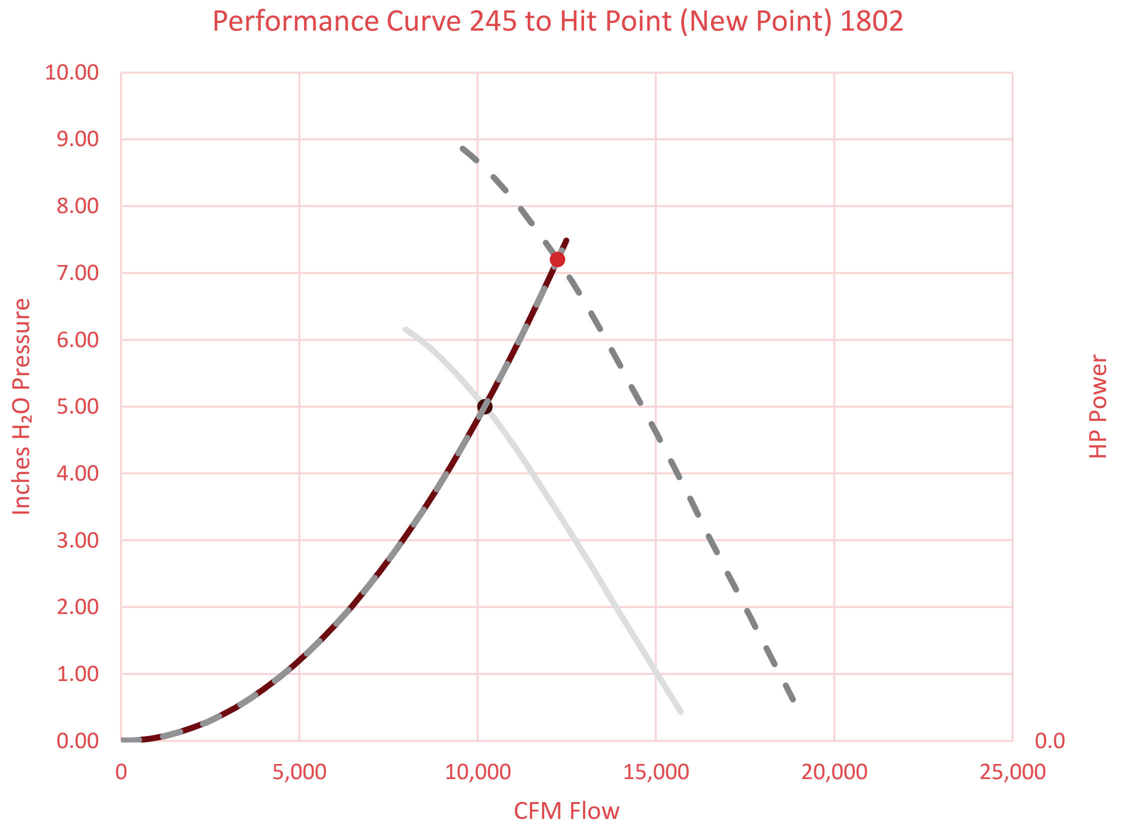
Pressure: $P_2 = P_1 \text{ x } (Q_2/Q_1)^2$

Power: $HP_2 = HP_1 \text{ x } (Q_2/Q_1)^3$

$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right]$ $P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$ $HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$

Fan Curve To Increase Flow

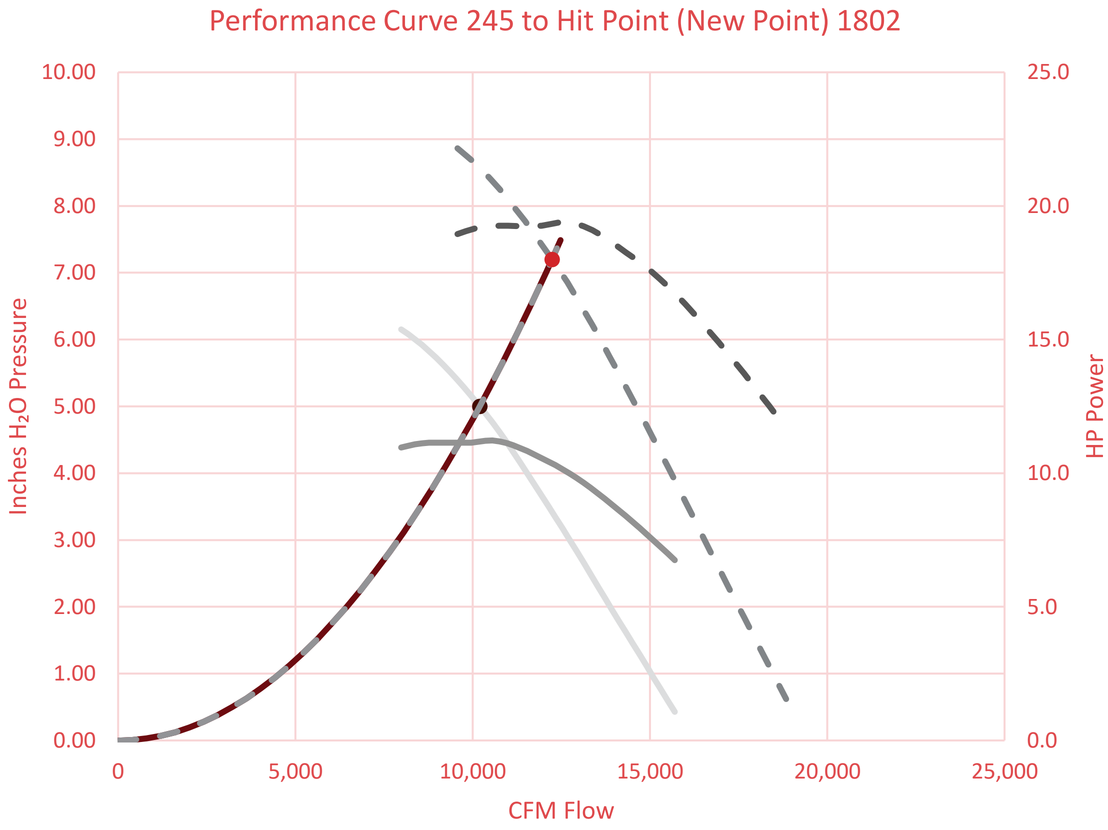
- Fan Laws used to generate Performance Curve at 120%:
  - Flow Increase:
    - 10,200 CFM @ 5.0 inch H_2O
    - 12,240 CFM @ 7.2 inch H_2O
  - Fan Pressure:
    - P α $(\Delta flow)^2$
  - Fan RPM:
    - RPM α Flow, Flow α RPM
    - 1802 RPM to 2162 RPM
  - Fan Power:
    - HP α $(\Delta RPM)^3$



$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right] \quad P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right] \quad HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Power Increase With Flow Increase

- Fan Laws used to generate Performance Curve at 120%:
  - Flow Increase:
    - 10,200 CFM @ 5.0 inch H_2O
    - 12,240 CFM @ 7.2 inch H_2O
  - Fan Pressure:
    - P α (Δflow)²
  - Fan Power:
    - Power α (ΔRPM)³
    - 120% Flow = 173% Power
    - 11.3 HP to 19.6 HP



$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right] \quad P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right] \quad HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Changes To Fully Load A Motor

- The Fan Laws can be used to calculate fan performance to fully load or unload a motor:

Power: $$RPM_C = RPM \text{ x } (\mathrm{PWR}_{\text{available}} / PWR_{\text{used}})^{1/3}$$

Flow: $$\mathrm{Q_C = Q\ x\ (RPM_c/RPM)}$$

Pressure: $$\mathrm{P_C = P\ x\ \ x\ (RPM_c/RPM)^2}$$

$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right] \quad P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right] \quad HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Power Increase To Increase Flow

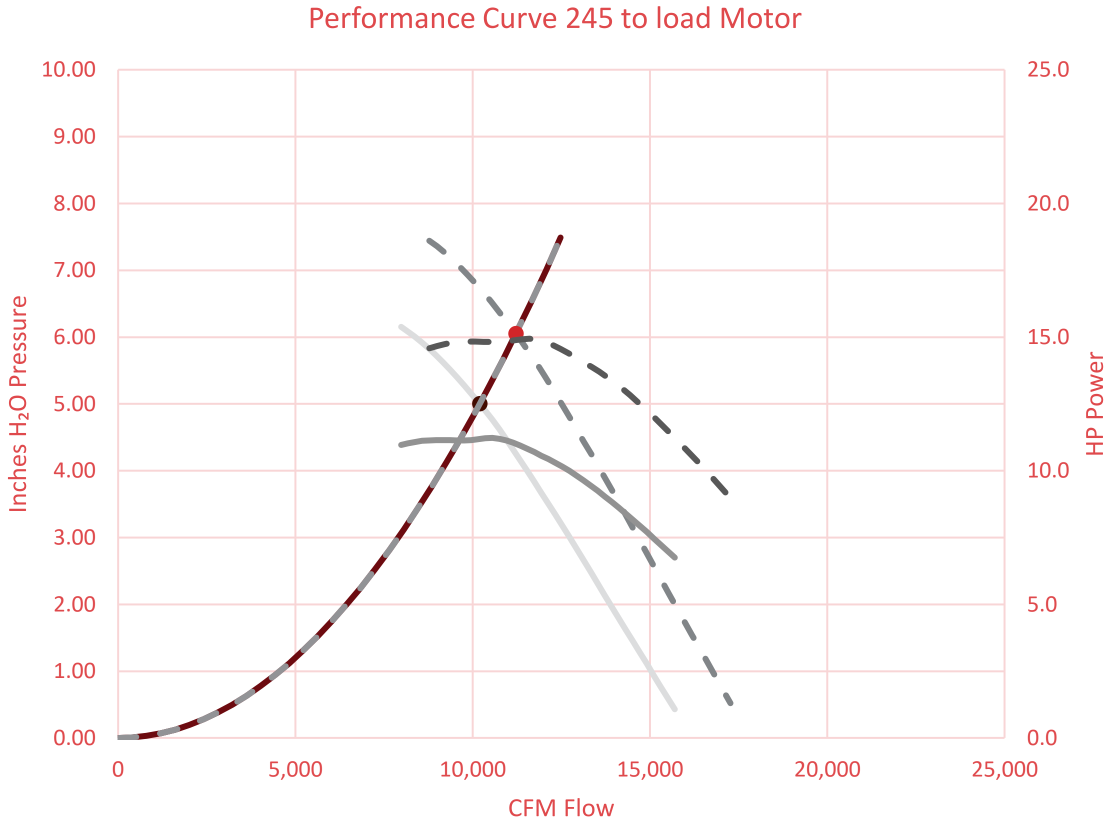
- Fully load motor to 15 HP
  - Power Increase 11.3 to 15 HP
  - Flow and pressure Increases:
    - 10,200 CFM @ 5.0 inch H_2O
    - 11,219 CFM @ 6.0 inch H_2O
  - Fan Power:
    - Power α $(\Delta RPM)^3$
    - 110% Flow = 133% Power

$$\mathrm{RPM_C} = \mathrm{RPM\ x\ (PWR_{available}/PWR_{used})^{1/3}}$$

$$\mathrm{RPM_C} = 1802\ \mathrm{x}\ (15.0/11.3)^{1/3}$$

$$\mathrm{RPM_C} = 1802\ \mathrm{x}\ 1.10$$

$$\mathrm{RPM_C} = 1982$$



$$CFM_2 = CFM_1 * \left[\frac{RPM_2}{RPM_1}\right] * \left[\frac{K_1}{K_2}\right] \quad P_2 = P_1 * \left[\frac{RPM_2}{RPM_1}\right]^2 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right] \quad HP_2 = HP_1 * \left[\frac{RPM_2}{RPM_1}\right]^3 * \left[\frac{\rho_2}{\rho_1}\right] * \left[\frac{K_1}{K_2}\right]$$

Fan Law Conclusion

- Fan laws are used to test and develop fan ratings.
  - AMCA certifies fan performance ratings and performance calculations.
- The fan's role in the system is to provide pressure energy into the air-fan system to maintain airflow.
- Fan selection should provide the required flow at the required pressure.
- Fan laws can be used to predict:
  - Fan performance and air system at different density conditions.
  - Fan performance and air system at different flow conditions.
  - Fan power requirement at different RPM, flow, and density conditions.

Resources

- **AMCA International**: *www.amca.org*
- **ANSI/AMCA Standards:** *www.amca.org/store* (available for purchase)
  - > 99-16: Standards Handbook
- **AMCA Publications**: *www.amca.org/store* (available for purchase)
  - > 201-02 (R2011) – Fans and Systems
- **ACGIH Publications:** *www.acgih.org* (available for purchase)
  - > Industrial Ventilation: A Manual of Recommended Practice for Design, 30th Edition
- **AMCA Certification**: *www.amca.org/certify*
- **AMCA Education Program**: *www.amca.org/educate*

Thank you for your time!

*To receive PDH credit for today's program, you **must** complete the online evaluation, which will be sent via email 1 hour after the conclusion of this session.*

PDH credits and participation certificates will be issued electronically within 30 days, once all attendance records are checked and online evaluations are received.

Attendees will receive an email at the address provided on your registration, listing the credit hours awarded and a link to a printable certificate of completion.

Questions?

NEXT PROGRAM

Join us for our next AMCA & O'Dell Associates Education Session:

- Thursday, October 14
- 10:00-11:00am ET
- ***Topic: Fundamentals of Air Flow***
- Presenter: Jason Meinke, Twin City Fan

>> For additional session details please contact Sarah Johnson, Marketing Manager, O'Dell Associates (sjohnson@odellassoc.com).