

FAN LAWS AND SYSTEM CURVES

INTRODUCTION

The purpose of this Engineering Letter is to explain the basis and application of the rules used to predict fan performance in a given system. With a basic understanding of these rules, the performance of a fan can be quickly calculated for various conditions.

SYSTEM REQUIREMENTS

The three fundamental rules governing fan performance are commonly called the "fan laws." These rules are only valid within a fixed system with no change in the aerodynamics or airflow characteristics of the system. For the purpose of this discussion, a *system* is the combination of ductwork, hoods, filters, grills, collectors, etc., through which air is distributed. Therefore, these rules can also be referred to as "system laws."

VOLUME AND PRESSURE

The motion of any mass causes friction with its surroundings. The movement of air through a system causes friction between the air molecules and their surroundings (duct walls, filter media, etc.) and any other air molecules. Energy is required to overcome this friction, or resistance. The faster the air moves the greater the resistance to flow and the more energy is required to push or pull the air through the system.

This energy is stated in terms of pressure. The portion of the pressure that results in air velocity is described as velocity pressure (VP). The portion necessary to overcome friction in the air and in the system is described as static pressure (SP). The sum of the two is described as total pressure (TP).

The law of physics, for motion, is expressed algebraically as:

$$V = \sqrt{2gh} \quad \text{or} \quad V^2 = 2gh$$

where V = velocity of flow
g = force of gravity
h = pressure causing flow

As can be seen from the equation, the pressure necessary to cause flow is proportional to the square of the velocity. In a system, this means that SP will vary as the square of the change in velocity or volume expressed in cubic feet per minute (CFM). This makes it possible to predict all possible combinations of SP at the corresponding CFM given any one such calculated relationship of SP and CFM for a fixed system.

For example, a system is calculated to require a static pressure equal to 2" water gauge at an airflow rate of 1000 CFM. If it is desired to increase the flow to 1500 CFM without any physical change in the system, the required SP would be:

$$(1500 \div 1000)^2 \times 2" = 4.5" \text{ SP}$$

$$\left(\frac{\text{CFM new}}{\text{CFM old}}\right)^2 = \frac{\text{SP new}}{\text{SP old}}$$

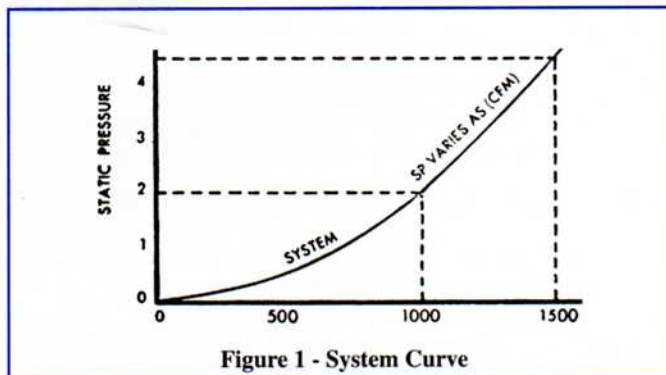


Figure 1 - System Curve

The same calculation using any number of varying CFM ratings would result in a plotted curve as shown in Figure 1.

Regardless of fan type, fan size, or volume of flow through a system, the relationship of CFM to SP will not change unless the system itself is altered in some way. SP always varies as the square of the change in CFM. The only exception to this rule is found in a laminar flow characteristic where VP is of far greater importance than SP. Such circumstances are not typical of fan systems.

FAN LAWS

In air movement systems, it is the fan wheel that does the work. In a sense, the fan wheel acts like a shovel. As it revolves, it discharges the same volume of air with each revolution. Working within a fixed system, a fan will discharge the same volume of air regardless of air density, (disregarding the effects of compression at high pressures).

If the fan RPM is increased, the fan will discharge a greater volume of air in exact proportion to the change in speed. This is the first "fan law."

1. CFM varies in direct proportion to change in RPM

$$\text{CFM (new)} = \frac{\text{RPM (new)}}{\text{RPM (old)}} \times \text{CFM (old)}$$

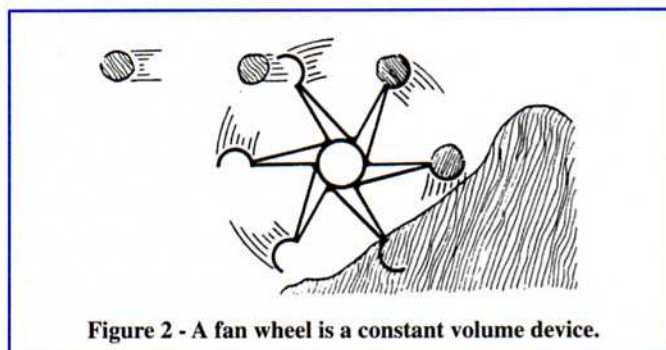


Figure 2 - A fan wheel is a constant volume device.

As shown earlier, in a system, the SP varies as the square of the change in CFM. Since CFM varies directly with RPM, RPM can be substituted for CFM in the system equation. Therefore, SP varies as the square of the change in RPM. This is the second "fan law."

2. SP varies in proportion to the change in (RPM)²

$$SP \text{ (new)} = \left(\frac{RPM \text{ (new)}}{RPM \text{ (old)}} \right)^2 \times SP \text{ (old)}$$

The efficiency of a fan is a function of its aerodynamic design and point of operation on its SP/CFM curve (see Figure 3). As the fan speed changes, this relative point of operation remains unchanged as long as the system remains unchanged. Thus, the fan brake horsepower varies proportionally as the cube of the change in RPM. This is the third "fan law."

3. BHP varies in proportion to the change in (RPM)³

$$BHP \text{ (new)} = \left(\frac{RPM \text{ (new)}}{RPM \text{ (old)}} \right)^3 \times BHP \text{ (old)}$$

It is important to remember that each of these "fan law" relationships takes place simultaneously and cannot be considered independently.

FAN CURVE AND SYSTEM CURVE

As stated previously, a system curve can be plotted to show all possible combinations of SP and CFM for a given fixed system. Any fan used on that system must operate somewhere on that system curve.

Fan performance is determined by laboratory testing and is presented graphically in the form of fan curves. Unless it is physically altered in some way, a fan must operate somewhere on its SP/CFM curve. The relative shape of that curve will not change, regardless of fan speed.

Because the fan and system can each only operate somewhere on their own respective curves, a fan used on a fixed system can only have one point of operation. The point of operation, as shown in Figure 3, is the intersection of the system curve and the fan SP/CFM curve.

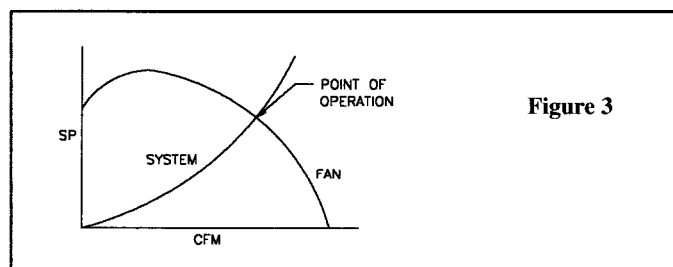


Figure 3

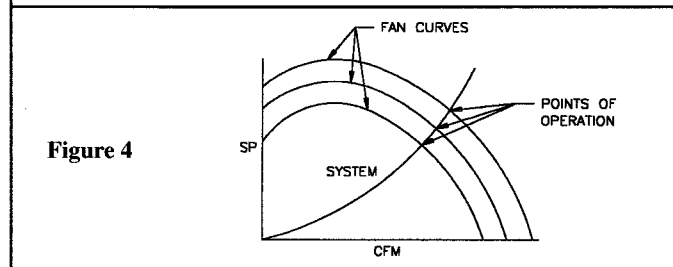


Figure 4

If the fan speed is increased or decreased, the point of operation will move up or down the existing system curve. This is shown in Figure 4.

The following are examples of how the fan curve can be used to calculate changes to flow and pressure requirements.

Example 1: A fan has been selected to deliver 35,530 CFM at 8" SP. The fan runs at 1230 RPM and requires 61.0 BHP.

After installation, it is desired to increase the output 20%. At what RPM must the fan run? What SP will be developed? What BHP is required?

1. CFM varies as RPM

$$(1230) (1.20) = 1476 \text{ RPM}$$

2. SP varies as (RPM)²

$$(1476/1230)^2 (8) = 11.52" \text{ SP}$$

3. BHP varies as (RPM)³

$$(1476/1230)^3 (61.0) = 105.4 \text{ BHP}$$

Example 2: A fan was originally installed to deliver 10,300 CFM at 2 1/4" SP and to run at 877 RPM, requiring 5.20 BHP.

After installation, it is found that the system only delivers 9,150 CFM at 2 1/2" SP and uses 4.70 BHP. This indicates the original calculations were in error, or that the system was not installed according to plan. What fan RPM and BHP will be necessary to develop the desired 10,300 CFM? What SP should have been figured?

1. CFM varies as RPM

$$(10,300/9,150) (877) = 987 \text{ RPM}$$

2. SP varies as (RPM)²

$$(987/877)^2 (2.50) = 3.17" \text{ SP}$$

3. BHP varies as (RPM)³

$$(987/877)^3 (4.70) = 6.70 \text{ BHP}$$

CONCLUSION

Use of the "fan laws" is based on a fixed system and a non-modified fan. Adding or deleting system components such as dampers, or incurring density changes, will create completely new system curves. Changing fan accessories such as inlet boxes, evases, or inlet dampers will alter the fan's performance curve from standard. These variables must be considered before the fan laws can be applied.

During the process of system design, the fan laws can be helpful in determining alternate performance criteria or in developing a minimum/maximum range. If "safety factors" are applied to system calculations, it should be recognized that a 10% factor on volume will result in an increase in horsepower of 33% according to the third fan law. An evaluation should be made weighing the necessity of the safety factor versus the cost penalty incurred.