FAN PERFORMANCE - THE SYSTEM EFFECT

INTRODUCTION

Fans are typically tested and rated in prescribed test configurations defined by the Air Movement and Control Association. This is done to ensure standardized procedures and ratings so that system designers can make realistic choices among various manufacturers. Beyond the routine system resistance calculations, the location of some common components and their proximity to the fan inlet or outlet can create additional immeasurable losses commonly called *System Efect*. These losses, if not eliminated or minimized, will necessitate fan speed and horsepower increases to compensate for the performance deficiencies. This Letter will outline some of the common causes for these deficiencies and provide useful guidelines for more efficient and predictable air-handling systems.

SYSTEM DESIGN

The term *system* refers to the path through which air is pushed and/or pulled. Since it can be any combination of ducts, coils, filters, etc., through which air flows, a system can range in complexity. The system can be as simple as exhausting air through an opening in the wall of a building, or as involved as a multi-zoned system with varying flows and densities. The calculations for determining the performance requirements are discussed in Engineering Letter 1. The effects of the system design on the actual performance capability of a fan represent separate and equally important considerations.

In the typical process of system design, the performance requirements are calculated and then used to select the appropriate fan. However, in many cases the effects of the relationship between the system components and the fan are not considered in the calculation or selection process. For example, the resistance of a given size elbow at a given flow can be easily determined using the equivalent length calculation method. However, if that elbow is located at the fan inlet or outlet, further immeasurable losses will be imposed in addition to the simple loss through the elbow itself. Most importantly, these losses cannot be measured or even detected with field instruments because they are, in fact, a destruction of the fan performance characteristics.

Standardized testing and rating methods for fans have been established by the Air Movement and Control Association, (AMCA). The test methods are described in AMCA Standard 210, titled Test Code for Air Moving Devices. Specifying fan equipment tested and rated in strict accordance with AMCA Standard 210 is the best way to ensure accurate fan performance. However, the system effects that alter or limit the ultimate performance remain the most frequent causes of field performance problems.

The four most common causes of system-induced performance deficiencies:

1. Eccentric flow into the fan inlet.
2. Spinning flow into the fan inlet.
3. Improper ductwork at the fan outlet.
4. Obstructions at the fan inlet or outlet.

ECCENTRIC FLOW

Fans perform correctly when air flows straight into the inlet. Air should be drawn into the fan inlet with an evenly distributed velocity profile. As shown in Figure 1, this allows all portions of the fan wheel to handle an equal air load.

If the air is not drawn into the fan inlet evenly, performance deficiencies will result from the combined effects of turbulence and uneven air distribution. This is illustrated in Figure 2, where an elbow is installed directly on the fan inlet.

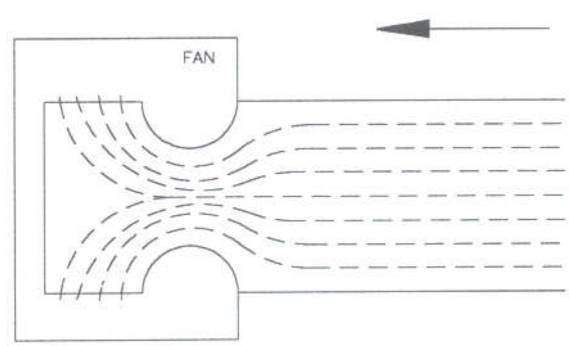

Figure 1 – Even Air Loading

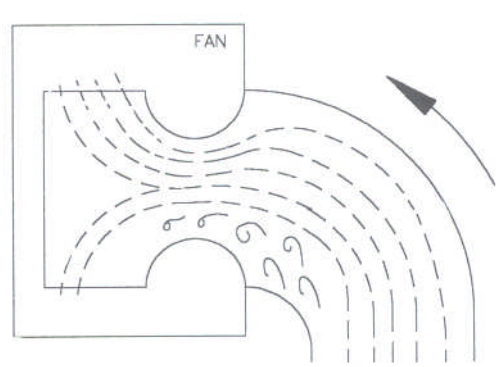

Figure 2 – Uneven Air Loading

When the system attempts to change the direction of flow, the air hugs the outside of the inlet elbow entering the fan. This causes uneven, turbulent airflow into the fan. Another common cause of non-uniform flow into the fan inlet is a poorly designed inlet box, such as the one shown in Figure 3. It is important to remember that air has mass.

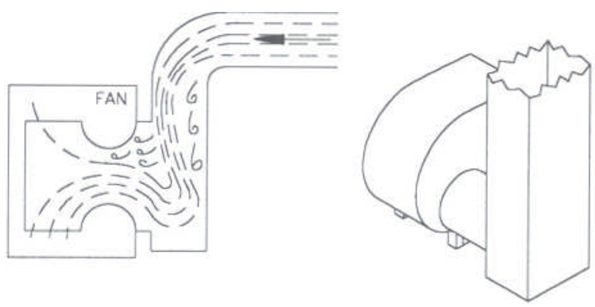

Figure 3 – Poorly Designed Inlet Box

SPINNING FLOW

Unintentionally spinning air into the fan inlet can have the same effect on performance as the intentional pre-spin produced by a vortex-type inlet damper.

The direction air is flowing when it enters the fan wheel is very important. In order to produce its rated capacity, the fan works on the air by changing its direction and accelerating its velocity. If the air is spinning in the same direction as the wheel rotation, the fan capacity will be diminished. If the air is spinning in the opposite direction of the wheel rotation, the brake horsepower and noise of the fan will increase. The static pressure of the fan may also increase slightly, but far less than indicated by the increased power consumption.

The evaluation and control of pre-spinning flow is more difficult than eccentric flow because of the variety of system connections or components that can contribute to pre-spin. Also, spinning often occurs in combination with eccentric flow such as the case with the inlet box shown in Figure 4.

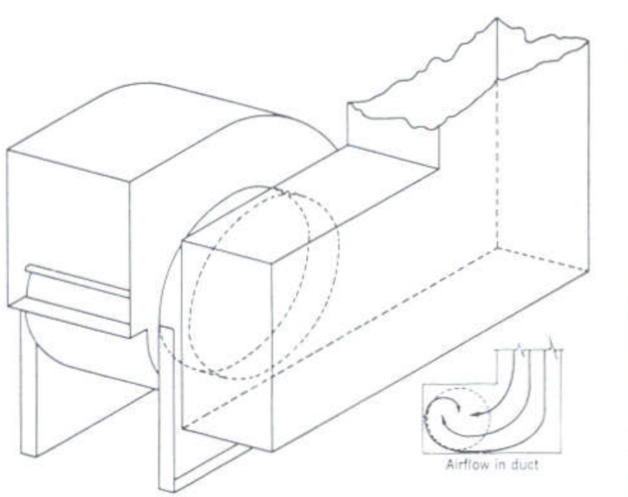

Figure 4 – Eccentric Flow with Pre-Spin

Pre-spinning flow can result from any number of common situations. Two elbows in close proximity to one another can force the air to make consecutive turns in perpendicular planes to form a corkscrew effect. As shown in Figure 5, air converging tangentially into the main duct or plenum can create an obvious spinning effect.

Pre-spinning flow can also be induced by such common air cleaning devices as a venturi scrubber or a cyclone as seen in Figure 6. In these cases, it is often the very function of the air cleaning device to create a spinning effect.

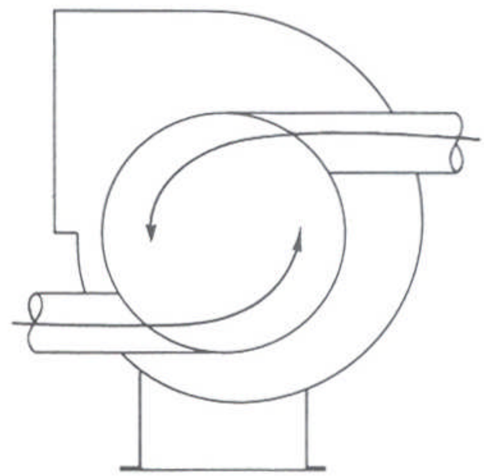

Figure 5 – Spinning Effect

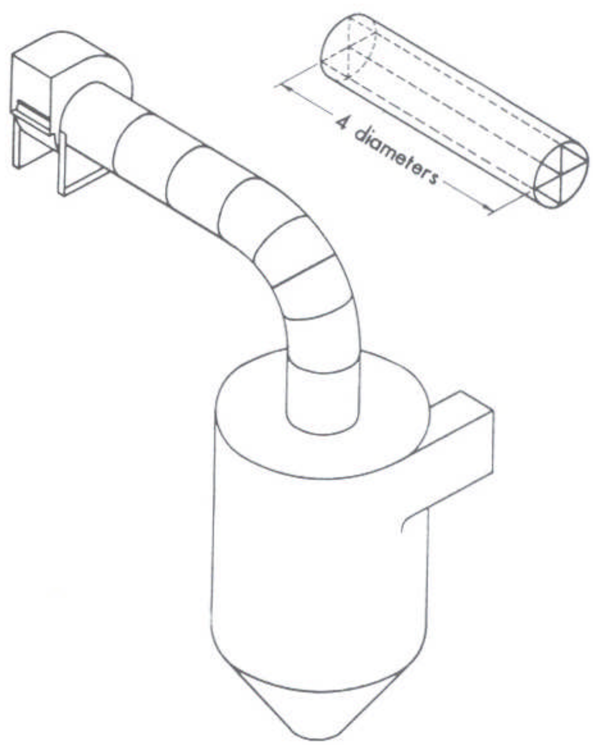

Figure 6 - Fan/Cyclone System

CORRECTING BAD INLET CONNECTIONS

The ideal fan inlet connection creates neither eccentric nor spinning flow. Where an inlet duct is required, the best connection is a long straight duct with straightening vanes. However, it is usually necessary to adapt the system to the available space. When space becomes the limiting factor, two choices are available:

1. Install corrective devices in the duct.
2. Increase fan speed to compensate.

The first choice is preferable, but the second is often necessary. In many cases, the corrective devices themselves will represent some resistance to flow. A combination of both choices could be necessary to correct extreme field performance problems.

If the fan and system are properly matched, their common point of operation should fall within the recommended range on the fan static-pressure curve. Figure 7 illustrates the recommended range for backwardly-inclined fans. A deleterious system effect could move the point of operation to the left on the pressure curve. This would force the fan to operate at an unstable point. The same situation can occur with any of the basic fan types that exhibit unstable flow characteristics as discussed in Engineering Letter 3. When this happens there are three options: alter the system to allow greater flow without increasing resistance significantly, replace the fan with a smaller one, or replace the fan with one that has a stable curve.

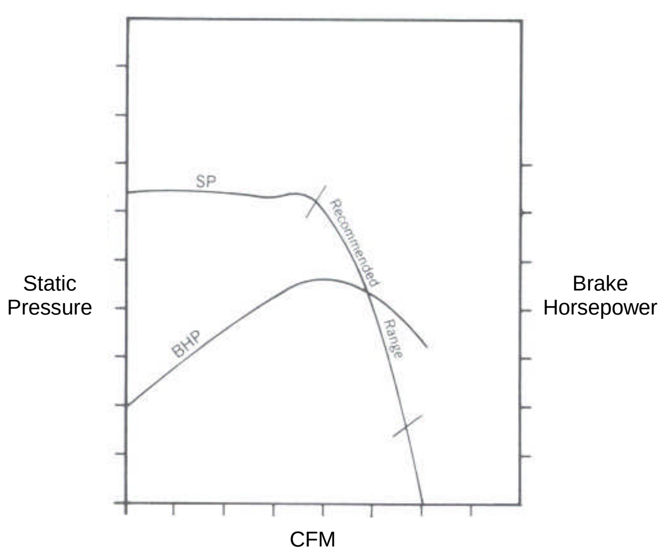

Figure 7 - Static Pressure Curve for Backwardly-Inclined Fan

Simple or complex turning vanes, such as those shown in Figure 8, can be used to minimize the effects of both eccentric and/or spinning flow. The egg-crate straightener, such as the one shown in Figure 6, can be used in the available space to stop pre-spin and improve fan inlet conditions.

Most of the inlet connections illustrated, with or without corrective devices, can produce losses in performance. These losses would be difficult, if not impossible, to predict. Even the inlet box shown in Figure 8, with all the turning vanes installed, could still easily represent losses of 10% to 15% of the required flow.

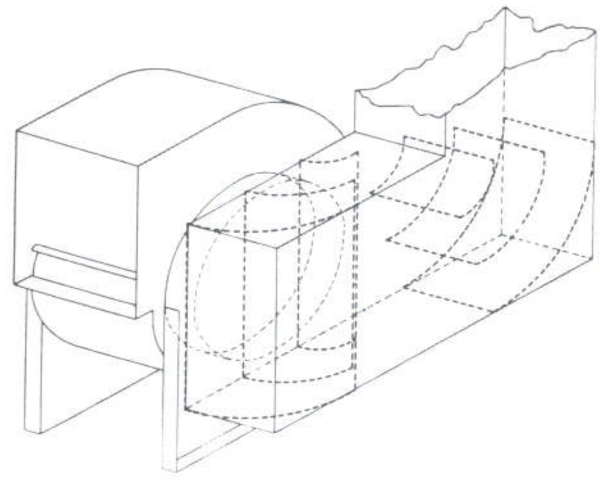

Figure 8 – Turning Vanes

To overcome these losses, the fan speed must be increased to the speed shown in the fan's rating table at the required volume and a pressure 21% greater than originally calculated:

$$(110\% \div 100\%)^2 = 1.21$$

Of course the fan's speed should never be increased beyond the cataloged maximum safe speed!

It is important to note that the increased resistance will not be observed on the system. The pressure increase is only for the purpose of selecting the fan to compensate for the losses associated with the particular system effect.

The fan laws cannot be applied selectively, only simultaneously. According to the fan laws, if the fan speed is increased 10% for a given system, the flow through the system will increase 10%, the system resistance will increase 21%, and the fan BHP will increase 33%. This represents an obvious waste of energy due to an often avoidable system-related deficiency. In most cases, such a change would require the purchase of a larger motor as well as a new drive. If the fan is a direct-connected arrangement, limited to one fixed motor speed, the solution becomes even more expensive. These considerations and horsepower penalties apply to all the major causes of system-induced performance deficiencies.

If the available space dictates the need for a turn into the fan inlet, a standardized inlet-box design, with predictable losses, should be used whenever possible.

DISCHARGE DUCTWORK

The connection made to a fan outlet can affect fan performance. An outlet duct ranging in length from 21/2 to 6 fan wheel diameters, depending on velocity, is necessary to allow the fan to develop its full rated pressure. If the outlet duct is omitted completely, a static pressure loss equal to one half the outlet velocity pressure will result. The system resistance calculation should include this loss as additional required static pressure.

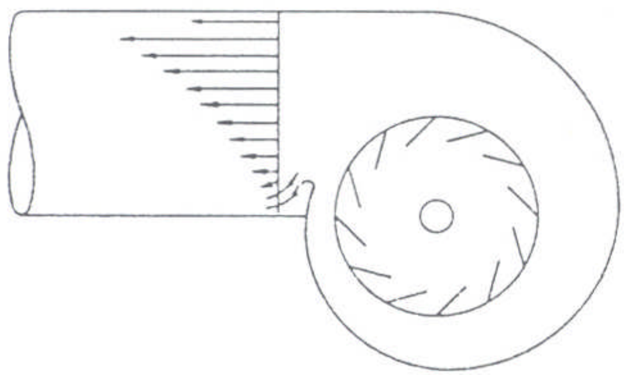

Figure 9 - Velocity Profile at Fan Outlet

Air is not discharged from a fan with a uniform velocity profile. The main reason for this is the fact that air has weight and is thrown to the outside of the scroll. Figure 9 shows a typical velocity profile.

In a duct with a uniform cross-section, the average velocity will be the same at all points along the duct. However, where velocity distribution changes (such as the duct adjacent to the fan outlet) the velocities are not typically the same.

Since velocity pressure is proportional to velocity squared, the average velocity pressure at the fan outlet will be higher than the average downstream. Since total pressure will be virtually the same, the static pressure cannot be fully developed until some point 21/2 to 6 duct diameters downstream.

Although duct turns directly at the fan outlet should be avoided, there are times when they cannot. In such cases, the turns should follow the same direction as the wheel rotation. Turns made in the opposite direction of wheel rotation (such as those shown in Figure 10) can have a pressure drop beyond normal system calculations. Usually the drop is between .5 to 1.5 fan outlet velocity pressures.

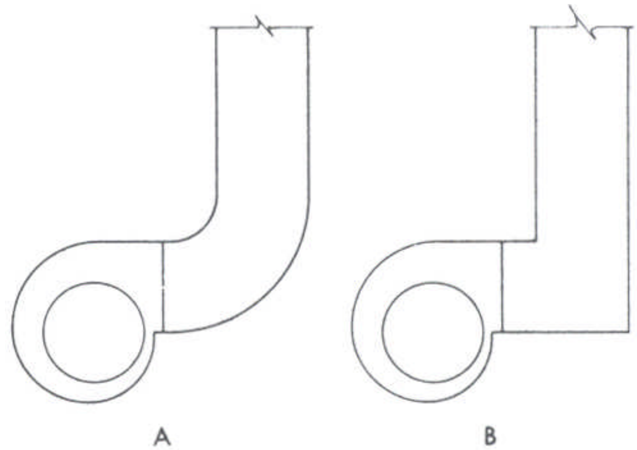

Figure 10 - Poor Fan Outlet Connections

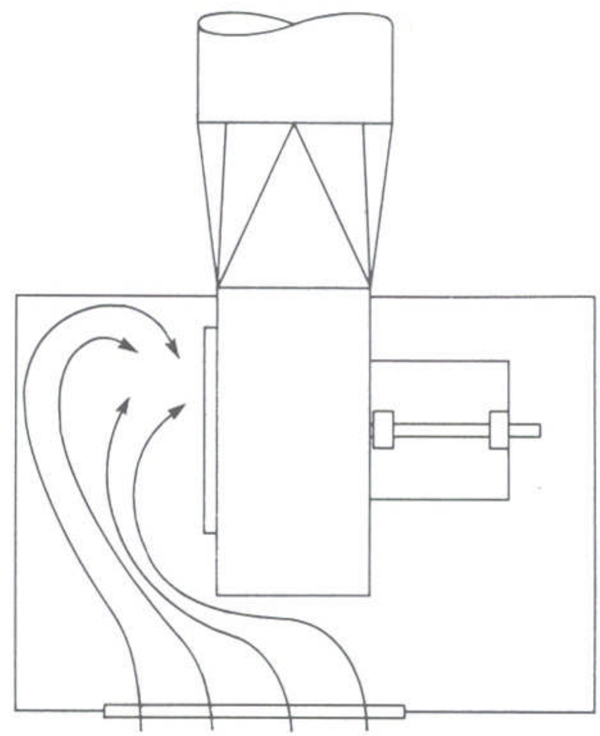

Figure 11 - Plenum System

INLET OR OUTLET OBSTRUCTIONS

System obstructions can be as obvious as the cone-shaped stack cap which can have a pressure drop as high as one velocity pressure, or as subtle as the installation of a large fan sheave directly in front of the inlet on an Arrangement 3, double-width, double-inlet fan.

One of the most common situations is to place a fan inside a plenum or near some obstruction and fail to account for the effects on the airflow to the fan inlet. The installation shown in Figure 11 is typical of the sort of non-uniform flow that could result in additional losses beyond the normal system calculation. These losses will increase as the velocity increases or as the distance between the obstruction and the fan inlet decreases.

CONCLUSION

AMCA Publication 201 - Fans and Systems, presents an in-depth discussion of system effect and provides methods for estimating losses associated with many common situations.

If system effect situations cannot be avoided, their impact on performance should be estimated and added to the calculated system resistance prior to sizing or selecting the fan. Ignoring the system effect could lead to difficult field performance problems later. It could be that the installed fan does not have the necessary speed reserve, or the motor is not of sufficient brake horsepower. The cost of correcting such a field performance problem could escalate rapidly.

System designers need to carefully consider the system effect values presented in AMCA Publication 201. By accurately defining the true performance requirements of fans in installed systems, field performance problems can be reduced significantly.