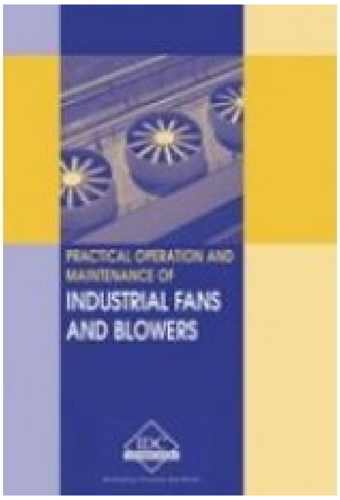
FN-E - Practical Operation and Maintenance of Industrial Fans and Blowers



Price: $65.95

Ex Tax: $59.95

Short Description

This manual explains the basic fundamentals of fans and blowers and their fundamental properties, operational characteristics with their behavior and operating curves for easy understanding.

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This manual explains the basic fundamentals of fans and blowers and their fundamental properties, operational characteristics with their behavior and operating curves for easy understanding.

Fans and fan drive technology is being used widely used in industrial and HVAC systems, cleanrooms and are greatly associated with properly designed ducting work, to avoid contaminations, to condition indoor air quality, temperature and humidity, not only in process but also for personnel comfort. A proper understanding of this technology is an excellent opportunity to reduce operating costs and improve overall efficiencies in your application.

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First Chapter
Basics Principles of Static and Dynamic Air Movement - Practical Operation and Maintenance of Industrial Fans and Blowers

1 Basics Principles of Static and Dynamic Air Movement

This chapter explains the various principles involved in static and dynamic air movement applicable to fans and blowers. It is important to understand these principles before we go on with fan engineering.

Learning objectives

At the end of this chapter, the participants will be able to understand

- Airflow principles in static air
- Airflow principles in dynamic air movement
- Application of these principles in fan engineering

1.1 Atmospheric pressure

Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of air above that surface at any given point in the Earth's atmosphere. The air pressure is highest close to earth, due to compression by the weight of the air above. Low pressure areas have less atmospheric mass above their location, whereas high pressure areas have more atmospheric mass above their location. The weight of a 1 m^2 column of air would be about 101 kN.

As the altitude increases, the atmospheric pressure decreases. This is shown in the table 1.1.

Table 1.1

Air pressure at elevations above sea level

Altitude above sea level		**Absolute barometer**		**Absolute atmospheric pressure**		
Feet	**Meter**	**Inch Hg**	**Mm Hg**	**Psia**	**Kg/cm^2**	**kPa**
0	0	29.92	760.0	14.696	1.033	101.33
500	153	29.38	746.3	14.43	1.015	99.49
1000	305	28.86	733.0	14.16	0.996	97.63

1500	458	28.33	719.6	13.91	0.978	95.91
2000	610	27.82	706.6	13.66	0.960	94.19
2500	763	27.32	693.9	13.41	0.943	92.46
3000	915	26.82	681.2	13.17	0.926	90.81
3500	1068	26.33	668.8	12.93	0.909	89.15
4000	1220	25.84	656.3	12.69	0.892	87.49
4500	1373	25.37	644.4	12.46	0.876	85.91
5000	1526	24.90	632.5	12.23	0.860	84.33

The air consists mainly of nitrogen (about 78 percent by volume) and oxygen (about 21 percent by volume) plus less than 1 percent of other gases. Air is a physical mixture (not a chemical compound) of these gases. Normally, air also contains some water vapor. This reduces the air density.

At average sea level, the standard atmospheric or barometric pressure is 760 mmHg (101.325 kPa or 1013.25 mbar or hPa). This standard atmosphere is defined at

Temperature = 20 °C, air density = 1.225 kg/m^3, altitude = sea level, and relative humidity = 20%.

According to National Aeronautics and Space administration (NASA), temperature, atmospheric pressure, and air density at various altitudes are as shown in the table:

The relationship between atmospheric pressure and the static pressure is to be understood in order to proceed with function of fans of different models and construction. The standard barometric pressure of 760 mmHg also can be expressed as 10332.275 mmWC.

Table 1.2

Temperature, density relationship with altitude

Altitude, m	**Temperatureº C**	**Atmospheric pressure, mmHg**	**Air density kg/m^3**
0	15.0	760	1.225
304.8	13.0	732.93	1.190
609.6	11.0	706.65	1.155
914.4	9.11	681.14	1.121
1219.2	7.11	656.38	1.087
1524	5.61	632.36	1.055

1828.8	3.11	609.05	1.023
2133.6	1.11	586.44	0.993
2438.4	-0.778	564.51	0.963
2743.2	-2.778	543.26	0.934
3048	-4.778	522.66	0.905
4572	-14.722	428.90	0.770
6096	-24.611	349.25	0.652
7620	-34.5	282.03	0.549
9144	-44.5	225.69	0.458
10668	-54.33	178.83	0.379

1.2 Static pressure

The definition of static pressure can be expressed in many ways:

- The pressure exerted by a liquid or gas, especially water or air, when they are not in motion or standstill
- The pressure measured in a static system is static pressure
- Static pressure is the difference in air pressure between the suction side and pressure side of the Fan or blower. Unit of measure is mmWC (millimeters of water column) or Pa (Pascal)

Static pressure is an important element in fan engineering. As the fan that circulates air through the system, it must be able to overcome the resistance to flow offered by the system components and pipe or duct work. Therefore, the static pressure must be strong enough to push the air through the system.

There are two phenomena to be understood in understanding the static pressure.

- The pressure is the same at all points along the same horizontal plane in the fluid and is independent of the shape of the container. (Hydrostatic paradox)
- The pressure increases with depth in the fluid and acts equally in all directions. The increase in pressure at a deeper depth is essentially the effect of the weight of the fluid above that depth. (Head pressure)

Figure 1.1

Hydrostatic paradox

The static pressure variations

The static pressure can be classified further as:

(a) Positive Static Pressure, when the airflow system operates above atmospheric pressure level

(b) Negative Static Pressure, when the airflow system operates below atmospheric pressure and is called Vacuum system.

The concept of positive and negative static pressure is explained below. A cylindrical vessel with a piston and u-tube manometer connected is illustrated in figure 1.2.

The static pressure air inside the vessel is measured by a U-Tube manometer. When there is no movement of piston, the U-tube will indicate zero pressure or atmospheric pressure. As the piston is moved down, the air volume below the piston is compressed, and the manometer will register a positive static pressure relative to the atmospheric pressure, where the atmospheric pressure level is considered zero pressure. This compressed air is then has potential energy, when released to expand to its original volume. If, on the other hand, the piston is raised, the air volume below the piston is expanded, and the manometer will register a negative static pressure relative to atmospheric pressure. This expanded air also has potential energy, when released to contract to its original volume. This explains the concept of positive and negative static pressure in stationary air.

Figure 1.2

Positive and Negative static pressure

It must be noted that the positive and negative static pressure concept exists both in moving air as well as in stationary air.

A fan blowing into a system (including such resistances as ducts, elbows, filters, dampers, and heating or cooling coils) produces positive static pressure, which is used to overcome the various resistances. A fan exhausting from a duct system produces negative static pressure, which again is used to overcome the resistance of the system.

The pressure in a static liquid can be easily calculated if the density of the liquid is known.

The absolute pressure at a depth H in a liquid is defined as:

Figure 1.3

Head pressure

$P_{\mathbf{absolute}} = P_{\mathbf{atmos}} + (? \text{ x } g \text{ x } H)$

Where:

P_{abs} is the absolute pressure at depth H.

P is the external pressure at the top of the liquid.(Atmospheric pressure), Pa

? is the density of the fluid, kg/m^3

g is the acceleration due to gravity (g = 9.81 m/sec2)

H is the depth at which the pressure is desired.,meters

1.3 Velocity pressure

The definition of Velocity pressure can be expressed as:

- The velocity pressure is regarded as the kinetic pressure per unit volume, that is necessary in order to cause a fluid to flow at a particular velocity and is measured in the direction flow and always positive.
- The velocity pressure corresponding to the average velocity at the fan outlet.

Velocity pressure taking density into consideration

$$P_v = \frac{(1/2 \text{ x } m \text{ x } V^2)}{\text{Volume}},$$

Mass

Here, --- ------------------- = Density

Volume

Therefore, the velocity pressure, P_v = ½ x ? x V^2

where p_v= Velocity pressure (Pa)

? = density of fluid (kg/m^3)

V= velocity (m/s)

Some common density at atmospheric pressure

Water-°C = 1000 kg/m^3

Air -20°C =1.2 kg/m^3

Velocity head , (V_h)be expressed as

½ V^2

V_h=-------------------

g

where V = velocity (m/s)

g = acceleration of gravity, 9.81 m/s

Air flowing through a straight, round duct or pipe of constant diameter has a velocity distribution, as shown in figure, with the maximum air velocity near the center and with zero velocity at the duct or pipe wall.

Figure 1.4

Air velocity

For small duct diameters of 150mm to 250 mm and for air velocities of 5 to 15 m/sec., the average velocity V is approximately equal to 91 percent of the maximum velocity at the center.

To find the average velocity in large ducts and for larger air velocities, a so-called Pitot tube traverse across the duct is taken.

Figure 1.5

Pitot tube traverse to measure average velocity

From the average velocity V, and the cross-sectional area of the duct, we can calculate the volume of air Q

$$Q = A \times V$$

Where, Q = Air volume, (m^3/sec)

A = Cross sectional area of duct (m^2)

V = Average velocity of air flow (m/sec)

Velocity pressure is the pressure we can feel when we hold our hand in the air stream. It represents kinetic energy.

1.4 Total pressure

In Bernoulli's principle, the total pressure is the sum of static pressure and velocity (dynamic) pressure .

$$P_{\text{Total}} = P_{\text{Static Pr.}} + P_{\text{Velocity Pr.}}$$

In fluid dynamics Bernoulli's principle states that for a non-viscous flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

Bernoulli's principle can be applied to various types of fluid flow, expressed as Bernoulli's equation. The Bernoulli equation also exists for different types of flow.

- The Bernoulli's equation for incompressible flows (liquid flows)
- The Bernoulli’s equation for compressible flows (gases) moving at low Mach numbers.

Bernoulli's principle is equivalent to the principle of conservation of energy. This states that in a steady flow the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy and potential energy remain constant.

Fluid particles are subject only to pressure and their own weight. If a fluid is flowing horizontally and along a section of a streamline, where the speed increases it can only be because the fluid on that section has moved from a region of higher pressure to a region of lower pressure; and if its speed decreases, it can only be because it has moved from a region of lower pressure to a region of higher pressure. Consequently, within a fluid flowing horizontally, the highest speed occurs where the pressure is lowest, and the lowest speed occurs where the pressure is highest.

Pressure and Head

The operation of a fan is often expressed in the terms of pressure

$P_{Total} = P_{Static\ Pr.} + P_{Velocity\ Pr. = Constant}$

where P_{Total} = Total pressure (Pa, N/m^2)

P_{Static} = Static pressure (Pa, N/m^2)

$P_{Velocity}$ = Velocity pressure (Pa, N/m^2)

Figure 1.6

Total head

The total head developed in a fan system

$P_{Total} = P_{s2} - P_{s1} + (V_2^2 - V_1^2)\ ?\ / 2$

1.5 Air flow through different sections

Airflow through a converging cone

When we water the garden, we always tend to quizze the hose at the tip to get a long jet of water. It means the water flow through the hose tip gains kinetic energy, by reducing the area of water flow. A similar condition exists when air flows through a converging cone, as shown in figure. The air volume Q is

$$Q = A \times V$$

Where Q = Air volume, in m^3/sec

A = Duct area, in m^2

V = Average air velocity, in m/sec.

As the airflow passes through the converging cone, the air volume, obviously will remain the same before and after the converging cone. This can be expressed as

$$Q_1 = Q_2 \quad \text{or} \quad A_1 \times V_1 = A_2 \times V_2$$

Figure 1.7

Airflow through a converging cone

This equation is called the principle of continuity (Bernoulli's principles) because the air volume continues to be the same before and after the point of constriction. As the air passes through the converging cone, it will accelerate from V_1 to a large air velocity V_2 because the area A_2 is smaller than the area A_1

This substantial increase in velocity pressure, will result in an increased kinetic energy which will be obtained at the expense of a decreased static pressure.

A converging cone past the scroll housing of a centrifugal fan usually works without any problem. However, on a converging cone past an axial flow fan causes an air spin past an axial-flow fan, even if it is a vaneaxial fan with guide vanes that are supposed to remove the air spin. If a little air spin remains past the fan, it is multiplied manifold as the air travels to a smaller duct diameter. As a result, at the smaller diameter, the revolutions per minute of the air spin becomes considerably larger.

Figure 1.8

Air spin phenomena in converging cone

Airflow through a diverging cone

A diverging cone, as shown in figure will produce a decreased air velocity past the cone, resulting in decreased kinetic energy.

Figure 1.9

Airflow through a diverging cone

About half of kinetic energy will be lost, mainly due to turbulence. The other half will be regained by an increase in static pressure, as stated by Bernoulli's theorem, provided that the cone angle is small, about 7 deg. While air normally flows from higher static pressure to lower static pressure, here is a case where the opposite takes place: air is flowing from lower static pressure to higher static pressure.

Airflow through a sharp edge orifice

When an air stream passing through a round duct of diameter D hits a sharp orifice with a hole of diameter d, a flow pattern will develop because the upstream airflow will approach the edge of the opening at an inward angle rather than in axial direction. Obviously, this angular velocity will continue past the orifice. This jet past the orifice will have a minimum diameter of about 0.6d, and this minimum diameter will occur at a distance of about 0.5d past the orifice, after this point, the airflow will gradually spread out again, but only after a distance of 3d past the orifice will the airflow fill the duct evenly as shown in figure This contraction of the air stream, shown is called "Vena Contracta" (contracted vein)

Figure 1.10

Airflow through a sharp edged orifice

Air flow through venturi inlet

A similar condition (although somewhat less extreme) exists when air flow enters a round duct without a venture inlet, as shown in figure 1.11. The reason why it is less extreme than in figure 1.10 is the upstream flow pattern. In figure 1.10, the approaching air is moving and in figure 1.11, it is hardly moving.

Figure 1.11

Airflow through a round duct without venturi inlet

Figure 1.12, shows the improved flow pattern obtained when the duct entrance is equipped with an inlet bell, also called a Venturi Inlet. This will reduce the duct resistance and increase the flow. For best results, the radius should be R =0.14D or more. If due to crowded conditions the radius has to be made smaller, the benefit will be reduced, but it will still be better than no venture at all.

A venture inlet is of particular importance at the entrance to an axial fan because without the venture inlet the blade tips would be starved for air. In a vaneaxial fan, where the blades are short (due to large hub), we can expect a flow increase of about 15 percent if a venture inlet (or an inlet duct) is used.

Figure 1.12

Airflow through a round duct with venturi inlet

Figure 1.13

Airflow through a vane-axial fan with venturi inlet

In a propeller fan, where the blades are longer (since there is no hub or only a small hub), a flow increase of about 12 % can be expected. Furthermore, the lack of a venture inlet (when no inlet duct is used) will result in an increase noise level because the blade tips will operate in extremely turbulent air.

In centrifugal fans without an inlet duct, a venture inlet will boost the flow by about 6%. This improvement here is somewhat less, for the following three reasons:

- The turbulent airflow here will hit the leading edges (not the blade tips), which are moving at lower velocities.
- Centrifugal fans are normally run at lower speeds than axial fans.
- The flow pattern is different in centrifugal fans. The airflow makes a 90 deg.turn before it hits the leading edges of the blades. The airflow ahead of the blades, therefore, contains some turbulence to begin with, and some additional turbulence, due to the lack of a venture inlet, therefore, is less harmful.

Airflow along a duct inside surface

The pattern of air passing through an elbow of rectangular cross section, is shown in figure 1.14. It is easy to understand that the airflow will tend to crowd on the inside of the outer wall, may be due to inertia of centrifugal force

The flow pattern of the air when the inner wall of the elbow has been removed (figure 1.14b). The outer wall still keeps the air from flowing straight, and the flow pattern is quite similar, possibly, the air will crowd a little more near the outer wall.

The flow pattern when the outer wall has been removed (figure 1.14c) and only the inner wall has been retained. The air still will not flow straight to the right, as one might expect. It will still attempt to adhere to the inner wall. It may not be 100% successful in this attempt, but let’s say it will be 70% successful. The reason is that a negative pressure will develop just outside the inner wall, and this negative pressure will tend to keep the airflow fairly close to the inner wall. Thus: A curved wall will try to keep an airflow on its outside attached to itself.

Figure 1.14

Airflow along a duct surface

1.6 Aerodynamic paradox

Normally, as we go along with the airflow through a duct system, the static pressure is highest upstream and gradually decreases from there. This is the reason why the air flows. The highest static pressure upstream forces the air through the duct, filters etc. Therefore, it seems hard to believe that the static pressure will increase as the air passes through a diverging cone. It seems contrary to common sense. It seems paradoxical.

Example-1

An example of a smooth sphere without any dimples is taken for explanation. A blower blows air through a funnel on a light weight sphere. When we hold the sphere by hand against the airflow, we assume that the sphere will be blown away. But to our surprise, the sphere is sucked inside the funnel. Due to high velocity of airflow on top of the sphere, the static pressure at that region reduced and the static pressure will be higher on bottom side side of the ball, which will ultimately lift the ball into the funnel. This is an example of aerodynamic paradox.

Figure 1.15

Light sphere and funnel experiment

Example-1

It consists of a circular plate A with a pipe B on top from the blower. Another thin, lightweight disc C is suspended about ½ in below A in such a way that it can easily move up. If we blow air into the pipe, we normally expect that the air stream will blow the lower disc C down. Actually, the lower disc will move up. This is contrary to the belief.

The air stream leaving the pipe will turn 90 deg. And move outward, since it has no other way to go. As it moves outward, the cross-sectional area becomes larger (as in a diverging cone), so the air velocity becomes smaller. As the air stream reaches the outside of the disks, the air velocity will be quite small, and the static pressure at that point will be close to the atmospheric pressure of the surrounding environment. However, where the cross-sectional area is much smaller, the velocity of the air flowing outward is larger, and the static pressure, therefore, is lower than the atmospheric pressure that pushes against the underside of the lower disk. As a result, the lower disk is lifted up against the upper plate.

This is shown in figure 1.16

Figure 1.16

A thin plate movement experiment.

The moment the lower disk touches the upper plate, the air stream is stopped, and the lower disk will drop again. The phenomenon, then will repeat itself.

Conclusion

As the airflow passes through a system of ducts, converging and diverging cones, etc., the velocity pressure (kinetic energy) may increase or decrease and the static pressure (potential energy) also may increase or decrease. These two pressures are mutually convertible. However, the total pressure (total energy), being the sum of velocity pressure and static pressure, will always decrease, since it is gradually used up by friction and turbulence as the air flow moves along a duct work.

1.7 Airfoils

An airfoil is a streamline shape, such as shown in figure Its main application is as the cross section of an airplane wing. Another application is as the cross section of a fan blade.

There are symmetric and asymmetric airfoils. The airfoils used in fan blades are asymmetric. The description of an airfoil is given below.

- The airfoil has a blunt leading edge and a pointed trailing edge. The distance from leading edge to trailing edge is called the “The airfoil chord”
- The airfoil has a convex upper surface, with a maximum upper camber of 13.3 % of c, occurring at about 36% of the chord c from the leading edge.
- The airfoil has a concave lower surface, with a maximum lower camber of 2.4 % of c, occurring at about 64% of the distance c from the leading edge.In some airfoils used in the fan blades, the lower surface is flat rather than concave.
- The airfoil has a baseline, from which the upper and lower cambers are

measured. The cambers are not profile thicknesses.

- The angle of attack ? is measured between the baseline and the relative air velocity.
- As the airfoil moves through the air (whether it is an airplane wing or a fan blade), it normally produces positive pressures on the lower surface of the airfoil and negative pressures (suction) on the upper surface. The suction pressures on the top surface are about twice as large as the positive pressures on the lower surface, but all these positive and negative pressures push and pull in approximately the same direction and reinforce each other.

The combination of these positive and negative pressures results in a force F, as shown in figure 1.17. The force F can be resolved into two components: a lift force L (perpendicular to the relative air velocity). The lift force L is the useful component. In the case of an axial fan blade, L (by reaction) deflects the air stream and produces the static pressure of the fan. The drag D is the resistance to the forward motion of the airfoil. It is the undesirable, power-consuming component. We therefore would like to use airfoil shapes that have not only a high lift L, but also a good lift-drag ratio L/D. As the angle of attack changes, lift, drag, and lift-drag ratio all change considerably, as will be seen in figure.

Figure 1.17

Airfoil design

Figure 1.18

Airfoil chord length

There are two important equations associated with airfoils are given below,

Lift coefficient, drag coefficient.

From the test data for lift L and drag D obtained from wind tunnel tests, we can calculate the corresponding coefficients as follows:

Lift coefficient $C_L = 844\ L / AV^2$

Drag coefficient $C_D = 844\ D / AV^2$

(For standard air density)

Where L and D are in Kilograms

A is the area of the tested airfoil plate in square meter

V is the relative air velocity in meters per second.

C_L and C_D are dimensionless coefficients.

From these formulas we note that $C_L / C_D = L / D$. In other words, the lift-drag ratio is also the ratio of the corresponding coefficients.