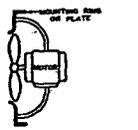
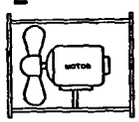
mechanical efficiency. However, where a high outlet velocity can be effectively utilized, the static efficiency fails to be a satisfactory measure of performance. Also when a fan operates against no resistance, the static efficiency becomes zero and is meaningless. Under such circumstances, many engineers prefer to use mechanical efficiency.

Sound developed by a fan is a characteristic which is becoming increasingly important. Unfortunately, no method has yet been devised for accurately measuring the sound actually discharged into a duct system. The ASHRAE Research Laboratory, in cooperation with the U. S. Navy, has a program underway seeking to find a method. Many manufacturers list the average sound (for various fan operating



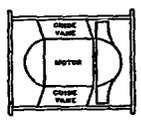
Propeller Fan

A propeller fan consists of a propeller or disc wheel within a mounting ring or plate.



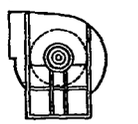
Tubeaxial Fan

A tubeaxial fan consists of an axial-flow wheel within a cylinder.



Vaneaxial Fan

A vaneaxial fan consists of an axial-flow wheel within a cylinder, combined with a set of air guide vanes located either before or after the wheel.



Centrifugal Fan

A centrifugal fan consists of a fan rotor or wheel within a scroll type of housing.

Fig. 1. . . . Names and Definitions of Types of Fans

conditions) measured at seven stations near the fan. These stations, as specified in the AMCA Test Code,[4] are located in a horizontal plane passing through the fan shaft, and are at a distance of one wheel diameter (but not less than 5 ft) from the fan. Such values are useful in comparing the relative sound generated by various types and sizes of fans under comparable operating conditions.

FAN LAWS[5]

The performances of fans of all types follow certain laws which are useful in predicting the effect upon performance of changes in the conditions of operation, the duty required of the installation, or the size of the equipment due to the space, power, or speed limitations. In the following laws, groups 1 to 6, Q = air volume and P = static, velocity, or total pressure. The laws pertaining to fan size apply only to fans geometrically similar, i.e., those in which all dimensions are proportional to some linear dimension denoted as size. If the size number is also linearly proportional, it may be used; otherwise, wheel diameter is commonly used as a size criterion.

1. Variation in Fan Speed:
   Constant Air Density—Constant System
   (a) Q: Varies as fan speed.
   (b) P: Varies as square of fan speed.
   (c) Power: Varies as cube of fan speed.

2. Variation in Fan Size:
   Constant Tip Speed—Constant Air Density
   Constant Fan Proportions—Fixed Point of Rating
   (a) Q: Varies as square of wheel diameter.
   (b) P: Remains constant.
   (c) RPM: Varies inversely as wheel diameter.
   (d) Power: Varies as square of wheel diameter.

3. Variation in Fan Size:
   At Constant RPM—Constant Air Density
   Constant Fan Proportions—Fixed Point of Rating
   (a) Q: Varies as cube of wheel diameter.
   (b) P: Varies as square of wheel diameter.
   (c) Tip Speed: Varies as wheel diameter.
   (d) Power: Varies as fifth power of diameter.

4. Variation in Air Density:
   Constant Volume—Constant System
   Fixed Fan Size—Constant Fan Speed
   (a) Q: Constant.
   (b) P: Varies as density.
   (c) Power: Varies as density.

5. Variation in Air Density:
   Constant Pressure—Constant System
   Fixed Fan Size—Variable Fan Speed
   (a) Q: Varies inversely as square root of density.
   (b) P: Constant.
   (c) RPM: Varies inversely as square root of density.
   (d) Power: Varies inversely as square root of density.

6. Variation in Air Density:
   Constant Weight of Air—Constant System
   Fixed Fan Size—Variable Fan Speed
   (a) Q: Varies inversely as density.
   (b) P: Varies inversely as density.
   (c) RPM: Varies inversely as density.
   (d) Power: Varies inversely as square of density.

Examples 1 to 4 illustrate the application of the preceding fan laws.

Example 1: A certain fan delivers 12,000 cfm at a static pressure of 1 in. of water when operating at a speed of 400 rpm and requires an input of 4 hp. If in the same installation 15,000 cfm are desired, what will be the speed, static pressure, and power?

$$\text{Speed} = 400 \times \frac{15{,}000}{12{,}000} = 500 \text{ rpm}$$

$$\text{Static pressure} = 1 \times \left(\frac{500}{400}\right)^2 = 1.56 \text{ in.}$$

$$\text{Power} = 4 \times \left(\frac{500}{400}\right)^3 = 7.81 \text{ hp}$$

Example 2: A certain fan delivers 12,000 cfm at 70 F and normal barometric pressure (density 0.075 lb per cubic foot) at a static pressure of 1 in. of water when operating at 400 rpm, and requires 4 hp. If the air temperature is increased to 200 F (density 0.0602 lb) and the speed of the fan remains the same, what will be the static pressure and power?

$$\text{Static pressure} = 1 \times \frac{0.0602}{0.075} = 0.80 \text{ in.}$$

$$\text{Power} = 4 \times \frac{0.0602}{0.075} = 3.20 \text{ hp}$$

Example 3: If the speed of the fan of *Example 2* is increased so as to produce a static pressure of 1 in. of water at at 200 F as at 70 F, what will be the speed, capacity, static power?

$$\text{Speed} = 400 \times \sqrt{\frac{0.075}{0.0602}} = 446 \text{ rpm}$$

$$\text{Capacity} = 12{,}000 \times \sqrt{\frac{0.075}{0.0602}}$$

$$= 13{,}392 \text{ cfm (measured at 200 F)}$$

$$\text{Power} = 4 \times \sqrt{\frac{0.075}{0.0602}} = 4.46 \text{ hp}$$

Example 4: If the speed of the fan of the previous examples is increased so as to deliver the same weight of air at 200 F as at 70 F, what will be the speed, capacity, static pressure, and power?

$$\text{Speed} = 400 \times \frac{0.075}{0.0602} = 498 \text{ rpm}$$

$$\text{Capacity} = 12{,}000 \times \frac{0.075}{0.0602} = 14{,}945 \text{ cfm (measured at 200 F)}$$

$$\text{Static pressure} = 1 \times \frac{0.075}{0.0602} = 1.25 \text{ in.}$$

$$\text{Power} = 4 \times \left(\frac{0.075}{0.0602}\right)^2 = 6.20 \text{ hp}$$

The fan laws stated may be combined to give other overall values. One useful combination is the product of Laws 1 and 3 which gives the following relations:

Capacity varies as the ratio of size cubed, times the ratio of the rpm.

Pressure varies as the ratio of size squared, times the ratio of the rpm squared.

Horsepower varies as the ratio of the size to fifth power, times the ratio of the rpm cubed.

Example 5: Assuming that a fan with a 36 in. diameter blast wheel will deliver 12,000 cfm at 70 F at 1 in. static pressure, requiring 4.0 brake hp when operating at 400 rpm, what is the capacity, pressure, and horsepower of a homologous fan having a 45 in. wheel at the same speed?

$$\text{Capacity} = \left(\frac{45}{36}\right)^3 \times \left(\frac{400}{400}\right) \times 12{,}000 = 23{,}400 \text{ cfm}$$

$$\text{Static pressure} = \left(\frac{45}{36}\right)^2 \times \left(\frac{400}{400}\right)^2 \times 1 = 1.56 \text{ in.}$$

$$\text{Horsepower} = \left(\frac{45}{36}\right)^5 \times \left(\frac{400}{400}\right)^3 \times 4 = 12.2 \text{ hp}$$

FAN PERFORMANCE CURVES

Fan performance curves are the graphical presentation (for constant speed and air density) of the relation of total pressure, static pressure, power input, and mechanical efficiency, and static efficiency, to actual volume, for the desired range of volumes. Figs. 2, 3 and 4 illustrate performance (sometimes called characteristic) curves of various types of fans.

Centrifugal fans[6] may be roughly divided into three classes: (1) those with the tip of the blades curved forward in the direction of rotation; (2) those with straight radial blades; and (3) those with the tip of the blades inclined backward away from direction of rotation. They are also characterized as slow speed, moderate speed, and high speed types, respectively, although the actual speed range of each may be wide and overlapping. The highest speed type may operate as high as 200 percent of the speed of the lowest speed type, to deliver the same volume of air at the same pressure. The differentiating curvature is always the tip of the blade, since the inlet edge, if inclined, is always curved forward to minimize the shock loss at entrance. Straight radial blades are most frequently found in pressure fans and material-handling fans.

Centrifugal fans produce pressure from two independent sources: (1) from the centrifugal force created by rotating the enclosed air column, and (2) from the kinetic energy imparted to the air by virtue of its velocity leaving the impeller. This velocity in turn is a combination of rotative velocity of the impeller and air speed relative to the impeller. When the blades tip forward, these two velocities are cumulative, and when backward, oppositional. Thus a fan with forward-curved blades depends less on centrifugal force for its pressure, and more on velocity pressure conversion in the scroll, with the result that it may run at relatively low speed. Conversely, a fan having backward-curved blades builds up more of its pressure by centrifugal force (a more efficient form of energy transfer) and less by velocity conversion and, therefore, must run at a higher speed. Likewise, a fan having forward-curved blades will produce the greatest capacity of any type of the same size when operating against no resistance.

Since the energy imparted to the air depends on the velocities,[7] and since the velocities are cumulative with a fan having forward-curved blades, the theoretical energy per pound of air rises rapidly with an increase of air delivery. With the velocities oppositional in the fan having backward-curved blades, the energy per pound of air may decrease, and in a fan having straight blades it is roughly constant. Thus the shape of the horsepower curve definitely identifies the blade angle.

Performance curves of a typical *forward-curved* blade centrifugal fan are shown in Fig. 2. The pressure rises from free delivery toward no delivery, with a characteristic drop at low capacities, because a large share of the pressure is being generated by conversion of velocity, which is small at low capacity. The maximum efficiency occurs at approximately maximum pressure. The horsepower curve reflects the increase in energy by rising rapidly from no delivery to free delivery. The sound is a minimum at maximum efficiency, and rises toward free delivery as the velocities increase.

Performance curves of a typical *backward-curved* blade centrifugal fan are shown in Fig. 3. The pressure is constantly rising from free delivery nearly to point of no de-