points of velocity change, the amount of conversion is seldom known, and therefore, most fan tables list only the static pressure available to overcome the system resistance.

According to the Standard Test Code[2], the efficiencies may be determined by the formulas:

Mechanical (total) Efficiency =

$$\frac{(\text{cfm}) \times \text{total pressure (inches water)}}{6356 \times \text{horsepower input}}$$

Static Efficiency =

$$\frac{(\text{cfm}) \times \text{static pressure (inches water)}}{6356 \times \text{horsepower input}}$$

Static pressure is used more often than total pressure, and likewise, static efficiency is used more than mechanical efficiency. However, where a high outlet velocity can be effectively utilized, the static efficiency fails to be a satisfactory measure of performance. 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.

The noise characteristics of a fan are also an important part of the fan performance, and must be evaluated for most fan installations. Fan noise is reported in terms of sound power level in eight octave bands. Noise levels of fan installations may be predicted by use of the sound power level values. The methods of calculation are explained in some detail in Chapter 14, Sound Control.

The technique of measuring the sound power level output of a fan has been reasonably well established and is explained in the Air Moving and Conditioning Association Bulletin 300.[3] A more detailed method is described in ASHRAE Standard 36–62, entitled *Measurement of Sound Power Radiated from Heating, Refrigerating, and Air Conditioning Equipment*.

FAN LAWS[4]

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 which are 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—Mixed 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 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 (at a stated 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[5] 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,[6] 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.

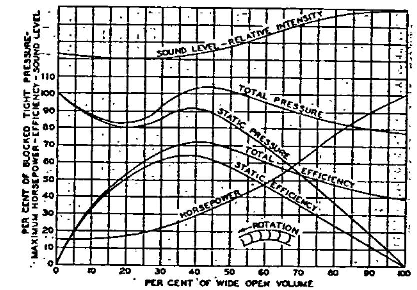

Fig. 2 . . . . Percentage Performance Curves of a Forward-Curved Blade Centrifugal Fan

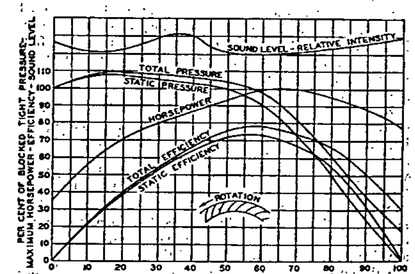

Fig. 3 . . . . Percentage Performance Curves of a Backward-Curved Blade Centrifugal Fan