rotation will be quite a "curve ball artist" the golfer that cannot control the lateral motion of the club face striking the golf ball will impart an uncontrollable spin and have trouble with a "hook" or "slice."

While a rotating cylinder can produce a net lift from the circulatory flow, the method is relatively inefficient and only serves to point out the relationship between lift and circulation. An airfoil is capable of producing lift with relatively high efficiency and the process is illustrated in figure 1.8. If a symmetrical airfoil is placed at zero angle of attack to the airstream, the streamline pattern and pressure distribution give evidence of zero lift. However, if the airfoil is given a positive angle of attack, changes occur in the streamline pattern and pressure distribution similar to changes caused by the addition of circulation to the cylinder. The positive angle of attack causes increased velocity on the upper surface with an increase in upper surface suction while the decreased velocity on the lower surface causes a decrease in lower surface suction. Also, upwash is generated ahead of the airfoil, the forward stagnation point moves under the leading edge, and a downwash is evident aft of the airfoil. The pressure distribution on the airfoil now provides a net force perpendicular to the airstream—lift.

The generation of lift by an airfoil is dependent upon the airfoil being able to create circulation in the airstream and develop the lifting pressure distribution on the surface. In all cases, the generated lift will be the net force caused by the distribution of pressure over the upper and lower surfaces of the airfoil. At low angles of attack, suction pressures usually will exist on both upper and lower surfaces but the upper surface suction must be greater for positive lift. At high angles of attack near that for maximum lift, a positive pressure will exist on the lower surface but this will account for approximately one-third the net lift.

The effect of free stream density and velocity is a necessary consideration when studying the development of the various aerodynamic forces. Suppose that a particular shape of airfoil is fixed at a particular angle to the airstream. The *relative* velocity and pressure distribution will be determined by the shape of the airfoil and the angle to the airstream. The effect of varying the airfoil size, air density and airspeed is shown in figure 1.9. If the same airfoil shape is placed at the same angle to an airstream with twice as great a dynamic pressure the *magnitude* of the pressure distribution will be twice as great but the *relative* shape of the pressure distribution will be the same. With twice as great a pressure existing over the surface, all aerodynamic forces and moments will double. If a half-size airfoil is placed at the same angle to the original airstream, the magnitude of the pressure distribution is the same as the original airfoil and again the *relative* shape of the pressure distribution is identical. The same pressure acting on the half-size surface would reduce all aerodynamic forces to one-half that of the original. This similarity of flow patterns means that the stagnation point occurs at the same place, the peak suction pressure occurs at the same place, and the actual *magnitude* of the aerodynamic forces and moments depends upon the airstream dynamic pressure and the surface area. This concept is extremely important when attempting to separate and analyze the most important factors affecting the development of aerodynamic forces.

AIRFOIL TERMINOLOGY. Since the shape of an airfoil and the inclination to the airstream are so important in determining the pressure distribution, it is necessary to properly define the airfoil terminology. Figure 1.10 shows a typical airfoil and illustrates the various items of airfoil terminology

(1) The *chord line* is a straight line connecting the leading and trailing edges of the airfoil.