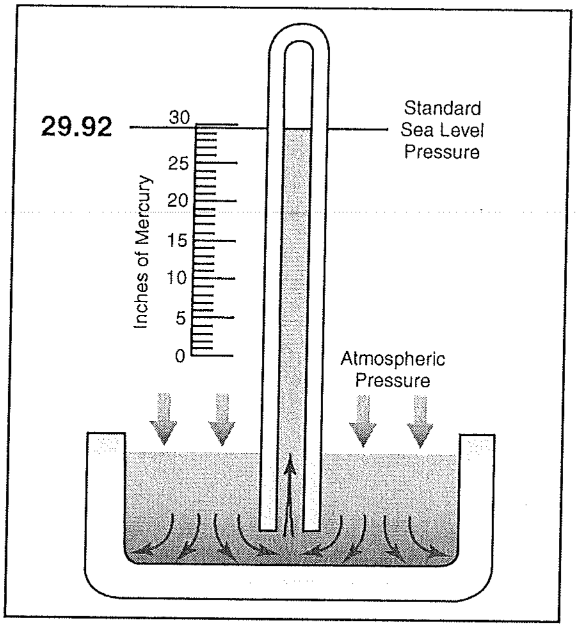

Figure 2-1. Standard sea level pressure.

mercury—but as its thickness is limited, the higher the altitude, the less air there is above. For this reason, the weight of the atmosphere at 18,000 feet is only one-half what it is at sea level. [Figure 2-1]

ATMOSPHERIC PRESSURE

Though there are various kinds of pressure, this discussion is mainly concerned with atmospheric pressure. It is one of the basic factors in weather changes, helps to lift the airplane, and actuates some of the important flight instruments in the airplane. These instruments are the altimeter, the airspeed indicator, the rate-of-climb indicator, and the manifold pressure gauge.

Though air is very light, it has mass and is affected by the attraction of gravity. Therefore, like any other substance, it has weight, and because of its weight, it has force. Since it is a fluid substance, this force is exerted equally in all directions, and its effect on bodies within the air is called pressure. Under standard conditions at sea level, the average pressure exerted on the human body by the weight of the atmosphere around it is approximately 14.7 lb./in. The density of air has significant effects on the airplane's capability. As air becomes less dense, it reduces (1) power because the engine takes in less air, (2) thrust because the propeller is less efficient in thin air, and (3) lift because the thin air exerts less force on the airfoils.

EFFECTS OF PRESSURE ON DENSITY

Since air is a gas, it can be compressed or expanded. When air is compressed, a greater amount of air can occupy a given volume. Conversely, when pressure on a given volume of air is decreased, the air expands and occupies a greater space. That is, the original column of air at a lower pressure contains a smaller mass of air. In other words, the density is decreased. In fact, density is directly proportional to pressure. If the pressure is doubled, the density is doubled, and if the pressure is lowered, so is the density. This statement is true, only at a constant temperature.

EFFECT OF TEMPERATURE ON DENSITY

The effect of increasing the temperature of a substance is to decrease its density. Conversely, decreasing the temperature has the effect of increasing the density. Thus, the density of air varies inversely as the absolute temperature varies. This statement is true, only at a constant pressure.

In the atmosphere, both temperature and pressure decrease with altitude, and have conflicting effects upon density. However, the fairly rapid drop in pressure as altitude is increased usually has the dominating effect. Hence, density can be expected to decrease with altitude.

EFFECT OF HUMIDITY ON DENSITY

The preceding paragraphs have assumed that the air was perfectly dry. In reality, it is never completely dry. The small amount of water vapor suspended in the atmosphere may be almost negligible under certain conditions, but in other conditions humidity may become an important factor in the performance of an airplane. Water vapor is lighter than air; consequently, moist air is lighter than dry air. It is lightest or least dense when, in a given set of conditions, it contains the maximum amount of water vapor. The higher the temperature, the greater amount of water vapor the air can hold. When comparing two separate air masses, the first warm and moist (both qualities tending to lighten the air) and the second cold and dry (both qualities making it heavier), the first necessarily must be less dense than the second. Pressure, temperature, and humidity have a great influence on airplane performance, because of their effect upon density.

NEWTON'S LAWS OF MOTION AND FORCE — Inicia.

In the 17th century, a philosopher and mathematician, Sir Isaac Newton, propounded three basic laws of motion. It is certain that he did not have the airplane in mind when he did so, but almost everything known about motion goes back to his three simple laws. These laws, named after Newton, are as follows:

Newton's first law states, in part, that: A body at rest tends to remain at rest, and a body in motion tends to remain moving at the same speed and in the same direction.

This simply means that, in nature, nothing starts or stops moving until some outside force causes it to do so. An airplane at rest on the ramp will remain at rest unless a force strong enough to overcome its inertia is applied. Once it is moving, however, its inertia keeps it moving, subject to the various other forces acting on it. These forces may add to its motion, slow it down, or change its direction.

Newton's second law implies that: When a body is acted upon by a constant force, its resulting acceleration is inversely proportional to the mass of the body and is directly proportional to the applied force.

What is being dealt with here are the factors involved in overcoming Newton's First Law of Inertia. It covers both changes in direction and speed, including starting up from rest (positive acceleration) and coming to a stop (negative acceleration, or deceleration).

Newton's third law states that: Whenever one body exerts a force on another, the second body always exerts on the first, a force that is equal in magnitude but opposite in direction.

The recoil of a gun as it is fired is a graphic example of Newton's third law. The champion swimmer who pushes against the side of the pool during the turnaround, or the infant learning to walk—both would fail but for the phenomena expressed in this law. In an airplane, the propeller moves and pushes back the air; consequently, the air pushes the propeller (and thus the airplane) in the opposite direction—forward. In a jet airplane, the engine pushes a blast of hot gases backward; the force of equal and opposite reaction pushes against the engine and forces the airplane forward. The movement of all vehicles is a graphic illustration of Newton's third law.

MAGNUS EFFECT

The explanation of lift can best be explained by looking at a cylinder rotating in an airstream. The local velocity near the cylinder is composed of the airstream velocity and the cylinder's rotational velocity, which decreases with distance from the cylinder. On a cylinder, which is rotating in such a way that the top surface area is rotating in the same direction as the airflow, the local velocity at the surface is high on top and low on the bottom.

As shown in figure 2-2, at point "A," a stagnation point exists where the airstream line that impinges on the surface splits; some air goes over and some under. Another stagnation point exists at "B," where the two

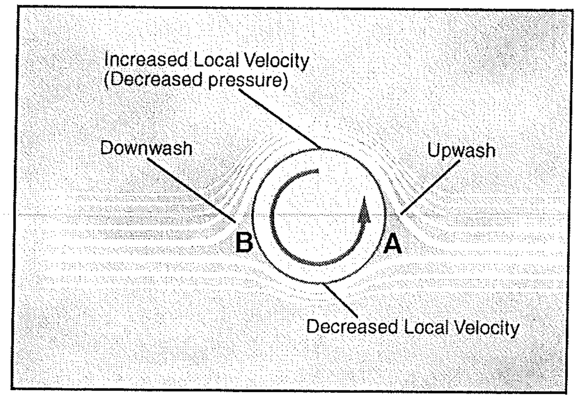

Figure 2-2. Magnus Effect is a lifting force produced when a rotating cylinder produces a pressure differential. This is the same effect that makes a baseball curve or a golf ball slice.

airstreams rejoin and resume at identical velocities. We now have upwash ahead of the rotating cylinder and downwash at the rear.

The difference in surface velocity accounts for a difference in pressure, with the pressure being lower on the top than the bottom. This low pressure area produces an upward force known as the "Magnus Effect." This mechanically induced circulation illustrates the relationship between circulation and lift.

An airfoil with a positive angle of attack develops air circulation as its sharp trailing edge forces the rear stagnation point to be aft of the trailing edge, while the front stagnation point is below the leading edge. [Figure 2-3]

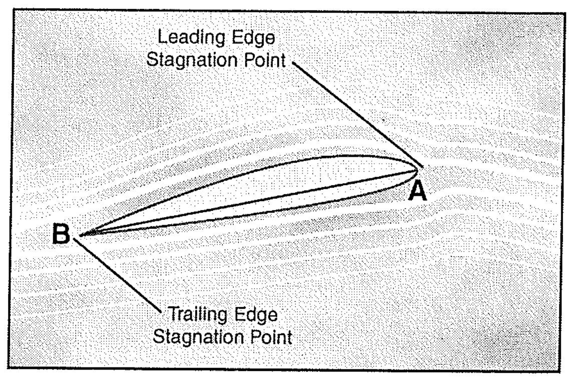

Figure 2-3. Air circulation around an airfoil occurs when the front stagnation point is below the leading edge and the aft stagnation point is beyond the trailing edge.

BERNOULLI'S PRINCIPLE OF PRESSURE

A half century after Sir Newton presented his laws, Mr. Daniel Bernoulli, a Swiss mathematician, explained how the pressure of a moving fluid (liquid or gas) varies with its speed of motion. Specifically, he stated that an increase in the speed of movement or flow would cause a decrease in the fluid's pressure. This is exactly what happens to air passing over the curved top of the airplane wing.

An appropriate analogy can be made with water flowing through a garden hose. Water moving through a hose of constant diameter exerts a uniform pressure on the hose; but if the diameter of a section of the hose is increased or decreased, it is certain to change the pressure of the water at that point. Suppose the hose was pinched, thereby constricting the area through which the water flows. Assuming that the same volume of water flows through the constricted portion of the hose in the same period of time as before the hose was pinched, it follows that the speed of flow must increase at that point.

Therefore, if a portion of the hose is constricted, it not only increases the speed of the flow, but also decreases the pressure at that point. Like results could be achieved if streamlined solids (airfoils) were introduced at the same point in the hose. This same principle is the basis for the measurement of airspeed (fluid flow) and for analyzing the airfoil's ability to produce lift.

A practical application of Bernoulli's theorem is the venturi tube. The venturi tube has an air inlet which narrows to a throat (constricted point) and an outlet section which increases in diameter toward the rear. The diameter of the outlet is the same as that of the inlet. At the throat, the airflow speeds up and the pressure decreases; at the outlet, the airflow slows and the pressure increases. [Figure 2-4]

If air is recognized as a body and it is accepted that it must follow the above laws, one can begin to see how and why an airplane wing develops lift as it moves through the air.

AIRFOIL DESIGN

In the sections devoted to Newton's and Bernoulli's discoveries, it has already been discussed in general terms the question of how an airplane wing can sustain flight when the airplane is heavier than air. Perhaps the explanation can best be reduced to its most elementary concept by stating that lift (flight) is simply the result of fluid flow (air) about an airfoil—or in everyday language, the result of moving an airfoil (wing), by whatever means, through the air.

Since it is the airfoil which harnesses the force developed by its movement through the air, a discussion and explanation of this structure, as well as some of the material presented in previous discussions on Newton's and Bernoulli's laws, will be presented.

An airfoil is a structure designed to obtain reaction upon its surface from the air through which it moves or that moves past such a structure. Air acts in various ways when submitted to different pressures and velocities; but this discussion will be confined to the parts of an airplane that a pilot is most concerned with in flight—namely, the airfoils designed to produce lift. By looking at a typical airfoil profile, such as the cross section of a wing, one can see several obvious characteristics of design. [Figure 2-5] Notice that there is a difference in the curvatures of the upper and lower surfaces of the airfoil (the curvature is called camber). The camber of the upper surface is more pronounced than that of the lower surface, which is somewhat flat in most instances.

In figure 2-5, note that the two extremities of the airfoil profile also differ in appearance. The end which faces forward in flight is called the leading edge, and is rounded; while the other end, the trailing edge, is quite narrow and tapered. * - [illegible]

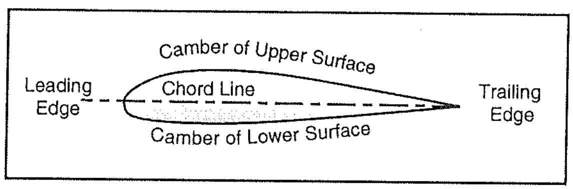

Figure 2-5. Typical airfoil section.

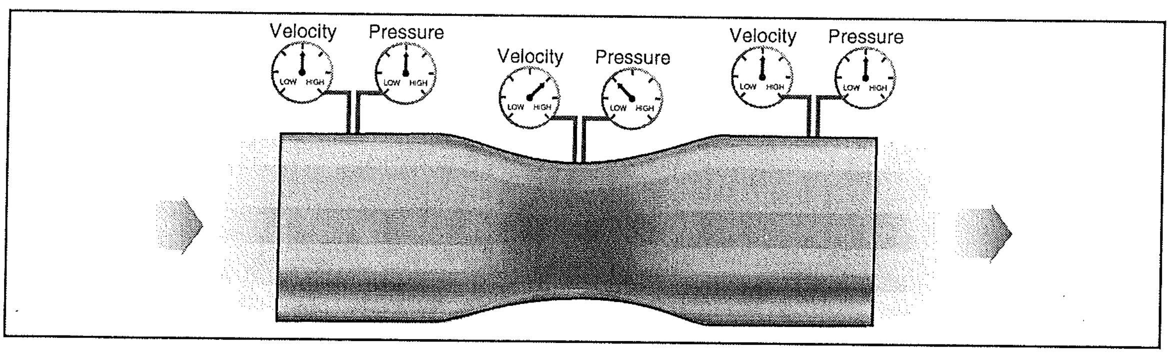

Figure 2-4. Air pressure decreases in a venturi.