requires consideration when dealing with any moving mechanism.

In experiments relating to friction, measurement of the applied forces reveals that there are three kinds of friction. One force is required to start a body moving, while another is required to keep the body moving at constant speed. Also, after a body is in motion, a definitely larger force is required to keep it sliding than to keep it rolling.

Thus, the three kinds of friction may be classified as: (1) starting (static) friction, (2) sliding friction, and (3) rolling friction.

Static Friction

When an attempt is made to slide a heavy object along a surface, the object must first be broken loose or started. Once in motion, it slides more easily. The "breaking loose" force is, of course, proportional to the weight of the body. The force necessary to start the body moving slowly is designated "F," and "F'" is the normal force pressing the body against the surface (usually its weight). Since the nature of the surfaces rubbing against each other is important, they must be considered. The nature of the surfaces is indicated by the coefficient of starting friction which is designated by the letter "k." This coefficient can be established for various materials and is often published in tabular form. Thus, when the load (weight of the object) is known, starting friction can be calculated by using the following formula:

$$F = kF'$$

For example, if the coefficient of sliding friction of a smooth iron block on a smooth, horizontal surface is 0.3, the force required to start a 10 lb block would be 3 lb; a 40-lb block, 12 lb.

Starting friction for objects equipped with wheels and roller bearings is much smaller than that for sliding objects. Nevertheless, a locomotive would have difficulty getting a long train of cars in motion all at one time. Therefore, the couples between the cars are purposely made to have a few inches of play. When starting the train, the engineer backs the engine until all the cars are pushed together. Then, with a quick start forward the first car is set in motion. This technique is employed to overcome the static friction of each wheel (as well as the inertia of each car). It would be impossible for the engine to start all of the cars at the same instant, for static friction, which is the resistance of being set in motion, would be greater than the force exerted by the engine. Once the cars are in motion, however, static friction is greatly reduced and a smaller force is required to keep the train in motion than was required to start it.

Sliding Friction

Sliding friction is the resistance to motion offered by an object sliding over a surface. It pertains to friction produced after the object has been set in motion, and is always less than starting friction. The amount of sliding resistance is dependent on the nature of the surface of the object, the surface over which it slides, and the normal force between the object and the surface. This resistive force may be computed by using the following formula.

$$F = mN$$

In the formula above, "F" is the resistive force due to friction expressed in pounds; "N" is the force exerted on or by the object perpendicular (normal) to the surface over which it slides; and "m" (mu) is the coefficient of sliding friction. On a horizontal surface, N is equal to the weight of the object in pounds. The area of the sliding object exposed to the sliding surface has no effect on the results. A block of wood, for example, will not slide any easier on one of the broad sides than it will on a narrow side, (assuming all sides have the same smoothness). Therefore, area does not enter into the equation above.

Rolling Friction

Resistance to motion is greatly reduced if an object is mounted on wheels or rollers. The force of friction for objects mounted on wheels or rollers is called rolling friction. This force may be computed by the same equation used in computing sliding friction, but the values of "m" will be much smaller. For example, the value of "m" for rubber tires on concrete or macadam is about 0.02. The value of "m" for roller bearings is very small, usually ranging from 0.001 to 0.003 and is often disregarded.

Example: *An aircraft with a gross weight of 79,600 lb is towed over a concrete ramp. What force must be exerted by the towing vehicle to keep the airplane rolling after once set in motion?*

$$\begin{aligned} F &= mN \\ &= 0.02 \text{ mu} \times 79{,}600 \text{ lb} \\ &= 1{,}592 \text{ lb} \end{aligned}$$

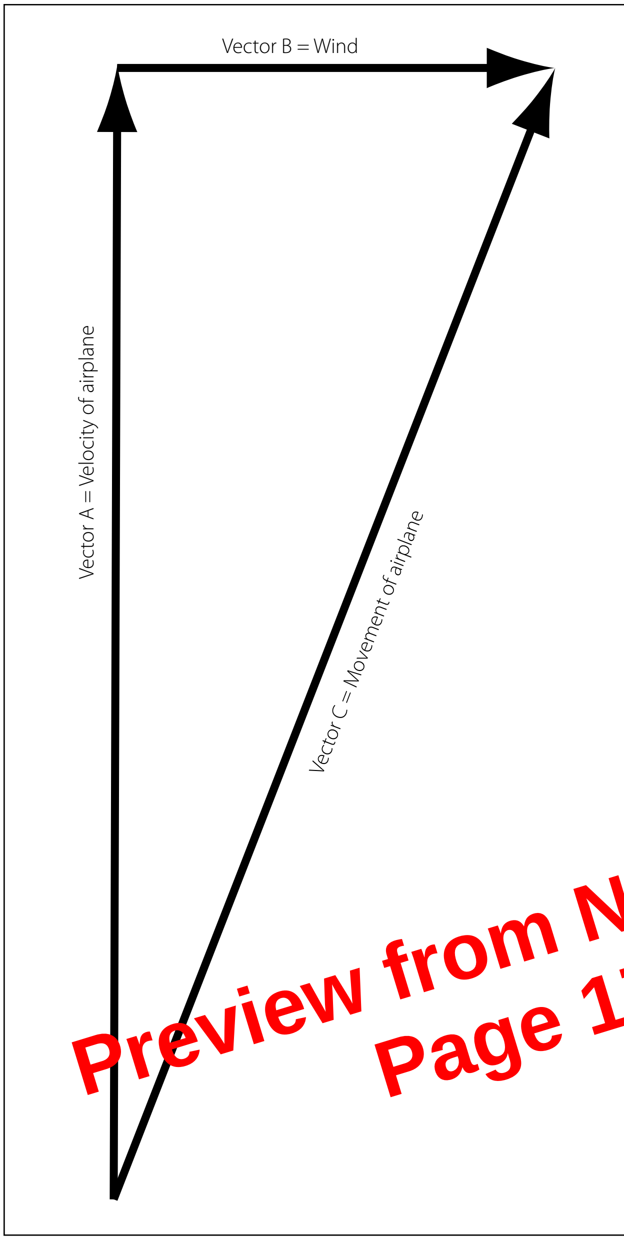

Figure 3-25. Vector analysis for airplane velocity and wind velocity.

Imagine that an airplane is flying in a circular pattern at a constant speed. Because of the circular pattern, the airplane is constantly changing direction, which means the airplane is constantly changing velocity. The reason for this is the fact that velocity includes direction.

To calculate the speed of an object, the distance it travels is divided by the elapsed time. If the distance is measured in miles and the time in hours, the units of speed will be miles per hour (mph). If the distance is measured in feet and the time in seconds, the units of speed will be feet per second (fps). To convert mph to fps, multiply by 1.467. Velocity is calculated the same way, the only difference being it must be recalculated every time the direction changes.

Acceleration

Acceleration is defined as the rate of change of velocity. If the velocity of an object is increased from 20 mph to 30 mph, the object has been accelerated. If the increase in velocity is 10 mph in 5 seconds, the rate of change in velocity is 10 mph in 5 seconds, or 2 mph per second. If this were multiplied by 1.467, it could also be expressed as an acceleration of 2.93 feet per second per second (fps/s). By comparison, the acceleration due to gravity is 32.2 fps/s.

To calculate acceleration, the following formula is used.

$$\text{Acceleration (A)} = \frac{\text{Velocity Final (Vf)} - \text{Velocity Initial (Vi)}}{\text{Time (t)}}$$

Example: *An Air Force F-15 fighter is cruising at 400 mph. The pilot advances the throttles to full afterburner and accelerates to 1,200 mph in 20 seconds. What is the average acceleration in mph/s and fps/s?*

$$A = \frac{Vf - Vi}{t}$$

$$A = \frac{1200 - 400}{20}$$

$A = 40\ ^{mph}\!/_{s}$, or by multiplying by 1.467, $58.7\ ^{fps}\!/_{s}$

In the example just shown, the acceleration was found to be 58.7 fps/s. Since 32.2 fps/s is equal to the acceleration due to gravity, divide the F-15's acceleration by 32.2 to find out how many G forces the pilot is experiencing. In this case, it would be 1.82 Gs.

Newton's Law of Motion

First Law

When a magician snatches a tablecloth from a table and leaves a full setting of dishes undisturbed, he is not displaying a mystic art; he is demonstrating the principle of inertia. Inertia is responsible for the discomfort felt when an airplane is brought to a sudden halt in the parking area and the passengers are thrown forward in their seats. Inertia is a property of matter. This property of matter is described by Newton's first law of motion, which states:

Objects at rest tend to remain at rest and objects in motion tend to remain in motion at the same speed and in the same direction, unless acted on by an external force.

force that is equal to centripetal force, but acting in an opposite direction, is called centrifugal force.

Centripetal force is always directly proportional to the mass of the object in circular motion. Thus, if the mass of the object in Figure 3-26 is doubled, the pull on the string must be doubled to keep the object in its circular path, provided the speed of the object remains constant.

Centripetal force is inversely proportional to the radius of the circle in which an object travels. If the string in Figure 3-26 is shortened and the speed remains constant, the pull on the string must be increased since the radius is decreased, and the string must pull the object from its linear path more rapidly. Using the same reasoning, the pull on the string must be increased if the object is swung more rapidly in its orbit. Centripetal force is thus directly proportional to the square of the velocity of the object. The formula for centripetal force is:

$$\text{Centripetal Force} = \text{Mass (Velocity}^2) \div \text{Radius}$$

For the formula above, mass would typically be converted to weight divided by gravity, velocity would be in feet per second, and the radius would be in feet.

Example: *What would the centripetal force be if a 10 pound weight was moving in a 3-ft radius circular path at a velocity of 500 fps?*

$$\begin{aligned}\text{Centripetal Force} &= \text{Mass (Velocity}^2) \div \text{Radius}\\ \text{Centripetal Force} &= 10\ (500^2) \div 32.2\ (3)\\ &= 25{,}880 \text{ lb}\end{aligned}$$

In the condition identified in the example, the object acts like it weighs 2,588 times more than it actually does. It can also be said that the object is experiencing 2,588 Gs (force of gravity). The fan blades in a large turbofan engine, when the engine is operating at maximum rpm, are experiencing many thousands of Gs for the same reason.

Heat

Heat is a form of energy. It is produced only by the conversion of one of the other forms of energy. Heat may also be defined as the total kinetic energy of the molecules of any substance.

Some forms of energy which can be converted into heat energy are as follows:

- *Mechanical Energy.* This includes all methods of producing increased motion of molecules such as friction, impact of bodies, or compression of gases.
- *Electrical Energy.* Electrical energy is converted to heat energy when an electric current flows through any form of resistance such as an electric iron, electric light, or an electric blanket.
- *Chemical Energy.* Most forms of chemical reaction convert stored potential energy into heat. Some examples are the explosive effects of gunpowder, the burning of oil or wood, and the combining of oxygen and grease.
- *Radiant Energy.* Electromagnetic waves of certain frequencies produce heat when they are absorbed by the bodies they strike such as x-rays, light rays, and infrared rays.
- *Nuclear Energy.* Energy stored in the nucleus of atoms is released during the process of nuclear fission in a nuclear reactor or atomic explosion.
- *The Sun.* All heat energy can be directly or indirectly traced to the nuclear reactions occurring in the sun.

When a gas is compressed, work is done and the gas becomes warm or hot. Conversely, when a gas under high pressure is allowed to expand, the expanding gas becomes cool. In the first case, work was converted into energy in the form of heat; in the second case heat energy was expended. Since heat is given off or absorbed, there must be a relationship between heat energy and work. Also, when two surfaces are rubbed together, the friction develops heat. However, work was required to cause the heat, and by experimentation, it has been shown that the work required and the amount of heat produced by friction are proportional. Thus, heat can be regarded as a form of energy.

According to this theory of heat as a form of energy, the molecules, atoms, and electrons in all bodies are in a continual state of motion. In a hot body, these small particles possess relatively large amounts of kinetic energy, but in cooler bodies they have less. Because the small particles are given motion, and hence kinetic energy, work must be done to slide one body over the other. Mechanical energy apparently is transformed, and what we know as heat is really kinetic energy of the small molecular subdivisions of matter.

Heat Energy Units

Two different units are used to express quantities of heat energy. They are the calorie and the BTU. One calorie is equal to the amount of heat required to change the temperature of 1 gram of water 1 degree Centigrade.

called its specific heat capacity, to increase the temperature of a unit of its mass 1°C. The specific heat of a substance is the ratio of its specific heat capacity to the specific heat capacity of water. Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the English and the metric systems.

It is fortunate that water has a high specific heat capacity. The larger bodies of water on the earth keep the air and solid matter on or near the surface of the earth at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature falls below that of such bodies of water, they give off large quantities of heat. This process keeps the atmospheric temperature at the surface of the earth from changing rapidly.

The specific heat values of some common materials are listed in Figure 3-30.

Temperature

Temperature is a dominant factor affecting the physical properties of fluids. It is of particular concern when calculating changes in the state of gases.

The four temperature scales used extensively are the Centigrade, the Fahrenheit, the absolute or Kelvin, and the Rankine scales. The Centigrade scale is constructed by using the freezing and boiling points of water, under standard conditions, as fixed points of zero and 100, respectively, with 100 equal divisions between. The Fahrenheit scale uses 32° as the freezing point of water and 212° as the boiling point, and has 180 equal divisions between. The absolute or Kelvin scale is constructed with its zero point established as minus 273°C, meaning 273° below the freezing point of water. The relationships of the other fixed points of the scales are shown in Figure 3-31.

When working with temperatures, always make sure which system of measurement is being used and know how to convert from one to another. The conversion formulas are as follows:

Degrees Fahrenheit = (1.8 × Degrees Celsius) + 32
Degrees Celsius = (Degrees Fahrenheit – 32) × $\frac{5}{9}$
Degrees Kelvin = Degrees Celsius + 273
Degrees Rankine = Degrees Fahrenheit + 460

For purposes of calculations, the Rankine scale is commonly used to convert Fahrenheit to absolute. For Fahrenheit readings above zero, 460° is added. Thus, 72°F equals 460° plus 72°, or 532° absolute. If the Fahrenheit reading is below zero, it is subtracted from 460°. Thus −40°F equals 460° minus 40°, or 420° absolute. It should be stressed that the Rankine scale does not indicate absolute temperature readings in accordance with the Kelvin scale, but these conversions may be used for the calculations of changes in the state of gases.

The Kelvin and Centigrade scales are used more extensively in scientific work; therefore, some technical manuals may use these scales in giving directions and operating instructions. The Fahrenheit scale is commonly used in the United States, and most people are familiar with it. Therefore, the Fahrenheit scale is used in most areas of this book.

Material	Specific Heat
Lead	0.031
Mercury	0.033
Brass	0.094
Copper	0.095
Iron or Steel	0.113
Glass	0.195
Alcohol	0.547
Aluminum	0.712
Water	1.000

Figure 3-30. Specific heat value for various substances.

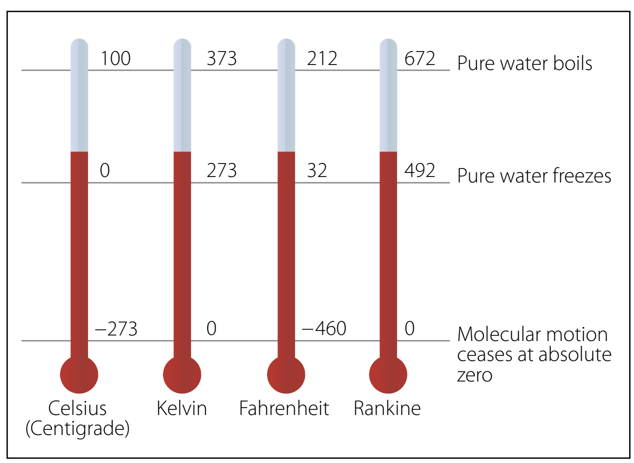

Figure 3-31. Comparison of temperature scales.

Part of understanding Pascal's law and hydraulics involves utilizing formulas, and recognizing the relationship between the individual variables. Before the numbers are plugged into the formulas, it is often possible to analyze the variables in the system and come to a realization about what is happening. For example, look at the variables in Figure 3-45 and notice that the output piston is 20 times larger than the input piston (5 in^2 compared to ¼ in^2). That comparison tells us that the output force will be 20 times greater than the input force, and also that the output piston will only move 1/20 as far. Without doing any formula based calculations, we can conclude that the hydraulic system in question has a mechanical advantage of 20.

Bernoulli's Principle

Bernoulli's principle was originally stated to explain the action of a liquid flowing through the varying cross-sectional areas of tubes. In Figure 3-46 a tube is shown in which the cross-sectional area gradually decreases to a minimum diameter in its center section. A tube constructed in this manner is called a "venturi," or "venturi tube." Where the cross-sectional area is decreasing, the passageway is referred to as a converging duct. As the passageway starts to spread out, it is referred to as a diverging duct.

As a liquid (fluid) flows through the venturi tube, the gauges at points "A," "B," and "C" are positioned to register the velocity and the static pressure of the liquid. The venturi in Figure 3-46 can be used to illustrate Bernoulli's principle, which states that: The static pressure of a fluid (liquid or gas) decreases at points where the velocity of the fluid increases, provided no energy is added to nor taken away from the fluid. The velocity of the air is kinetic energy and the static pressure of the air is potential energy.

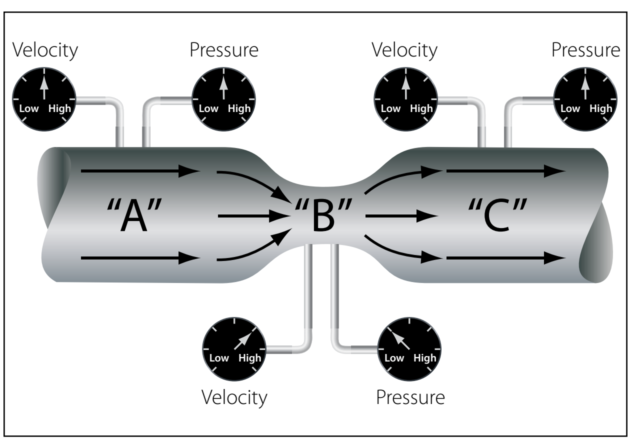

Figure 3-46. Bernoulli's principle and a venturi.

In the wide section of the venturi (points A and C of Figure 3-46), the liquid moves at low velocity, producing a high static pressure, as indicated by the pressure gauge. As the tube narrows in the center, it must contain the same volume of fluid as the two end areas. In this narrow section, the liquid moves at a higher velocity, producing a lower pressure than that at points A and C, as indicated by the velocity gauge reading high and the pressure gauge reading low. A good application for the use of the venturi principle is in a float-type carburetor. As the air flows through the carburetor on its way to the engine, it goes through a venturi, where the static pressure is reduced. The fuel in the carburetor, which is under a higher pressure, flows into the lower pressure venturi area and mixes with the air.

Bernoulli's principle is extremely important in understanding how some of the systems used in aviation work, including how the wing of an airplane generates lift or why the inlet duct of a turbine engine on a subsonic airplane is diverging in shape. The wing on a slow moving airplane has a curved top surface and a relatively flat bottom surface. The curved top surface acts like half of the converging shaped middle of a venturi. As the air flows over the top of the wing, the air speeds up, and its static pressure decreases. The static pressure on the bottom of the wing is now greater than the pressure on the top, and this pressure difference creates the lift on the wing. Bernoulli's principle and the concept of lift on a wing is covered in greater depth in "Aircraft Theory of Flight" located in this chapter.

Sound

Sound has been defined as a series of disturbances in matter that the human ear can detect. This definition can also be applied to disturbances which are beyond the range of human hearing. There are three elements which are necessary for the transmission and reception of sound. These are the source, a medium for carrying the sound, and the detector. Anything which moves back and forth (vibrates) and disturbs the medium around it may be considered a sound source.

An example of the production and transmission of sound is the ring of a bell. When the bell is struck and begins to vibrate, the particles of the medium (the surrounding air) in contact with the bell also vibrate. The vibrational disturbance is transmitted from one particle of the medium to the next, and the vibrations travel in a "wave" through the medium until they reach the ear. The eardrum, acting as detector, is set in motion by the vibrating particles of air, and the brain interprets atmosphere, would be broiled on the side facing the sun and frozen on the other.

The atmosphere is divided into concentric layers or levels. Transition through these layers is gradual and without sharply defined boundaries. However, one boundary, the tropopause, exists between the first and second layer. The tropopause is defined as the point in the atmosphere at which the decrease in temperature (with increasing altitude) abruptly ceases. The four atmosphere layers are the troposphere, stratosphere, ionosphere, and the exosphere. The upper portion of the stratosphere is often called the chemosphere or ozonosphere, and the exosphere is also known as the mesosphere.

The troposphere extends from the earth's surface to about 35,000 ft at middle latitudes, but varies from 28,000 ft at the poles to about 54,000 ft at the equator. The troposphere is characterized by large changes in temperature and humidity and by generally turbulent conditions. Nearly all cloud formations are within the troposphere. Approximately three-fourths of the total weight of the atmosphere is within the troposphere. The stratosphere extends from the upper limits of the troposphere (and the tropopause) to an average altitude of 60 miles.

The ionosphere ranges from the 50 mile level to a level of 300 to 600 miles. Little is known about the characteristics of the ionosphere, but it is thought that many electrical phenomena occur there. Basically, this layer is characterized by the presence of ions and free electrons, and the ionization seems to increase with altitude and in successive layers.

The exosphere (or mesosphere) is the outer layer of the atmosphere. It begins at an altitude of 600 miles and extends to the limits of the atmosphere. In this layer, the temperature is fairly constant at 2,500° Kelvin, and propagation of sound is thought to be impossible due to lack of molecular substance.

Atmospheric Pressure

The human body is under pressure, since it exists at the bottom of a sea of air. This pressure is due to the weight of the atmosphere. On a standard day at sea level, if a 1-in^2 column of air extending to the top of the atmosphere was weighed, it would weigh 14.7 lb. That is why standard day atmospheric pressure is said to be 14.7 pounds per square inch (14.7 psi).

Since atmospheric pressure at any altitude is due to the weight of air above it, pressure decreases with increased altitude. Obviously, the total weight of air above an area at 15,000 ft would be less than the total weight of the air above an area at 10,000 ft.

Atmospheric pressure is often measured by a mercury barometer. A glass tube somewhat over 30 inches in length is sealed at one end and then filled with mercury. It is then inverted and the open end placed in a dish of mercury. Immediately, the mercury level in the inverted tube will drop a short distance, leaving a small volume of mercury vapor at nearly zero absolute pressure in the tube just above the top of the liquid mercury column. Gravity acting on the mercury in the tube will try to make the mercury run out. Atmospheric pressure pushing down on the mercury in the open container tries to make the mercury stay in the tube. At some point these two forces (gravity and atmospheric pressure) will equilibrate and the mercury will stabilize at a certain height in the tube. Under standard day atmospheric conditions, the air in a 1-in^2 column extending to the top of the atmosphere would weigh 14.7 lb. A 1-in^2 column of mercury, 29.92 inches tall, would also weigh 14.7 lb. That is why 14.7 psi is equal to 29.92 "Hg. Figure 3-50 demonstrates this point.

A second means of measuring atmospheric pressure is with an aneroid barometer. This mechanical instrument is a much better choice than a mercury barometer for use on airplanes. Aneroid barometers (altimeters) are used to indicate altitude in flight. The calibrations are made in thousands of feet rather than in psi or inches of mercury. For example, the standard pressure at sea

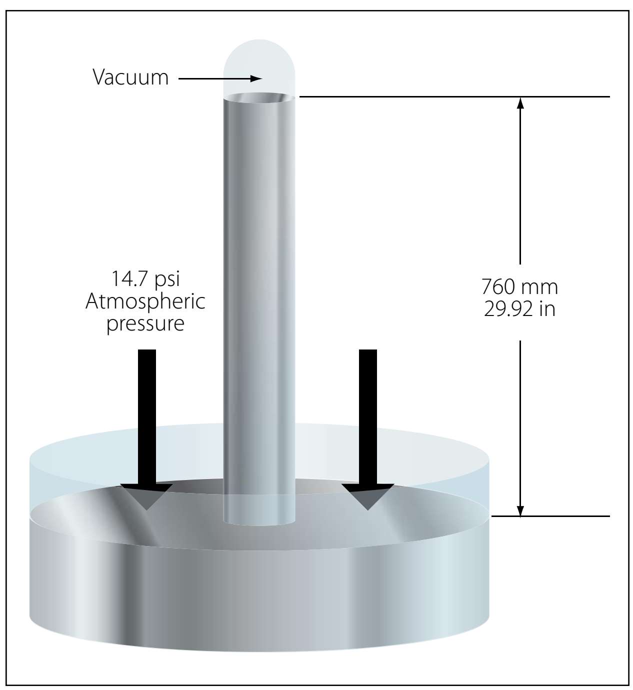

Figure 3-50. Atmospheric pressure as inches of mercury.

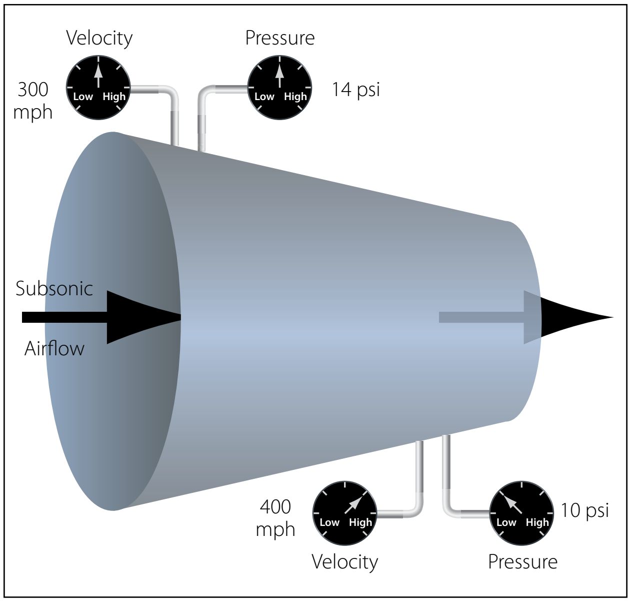

Figure 3-54. Bernoulli's principle and a converging duct.

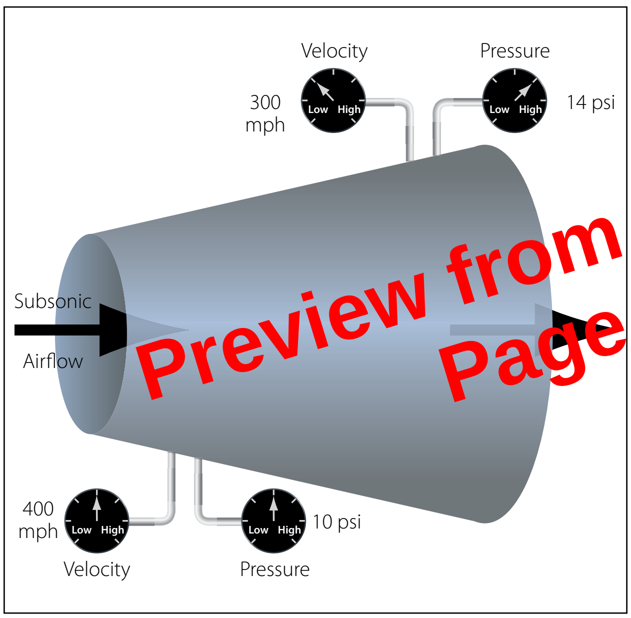

Figure 3-55. Bernoulli's principle and a diverging duct.

been lost in velocity (kinetic energy) is gained in static pressure (potential energy).

In the discussion of Bernoulli's principle earlier in this chapter, a venturi was shown in Figure 3-46. In Figure 3-56, a venturi is shown again, only this time a wing is shown tucked up into the recess where the venturi's converging shape is. There are two arrows showing airflow. The large arrow shows airflow within the venturi, and the small arrow shows airflow on the outside heading toward the leading edge of the wing.

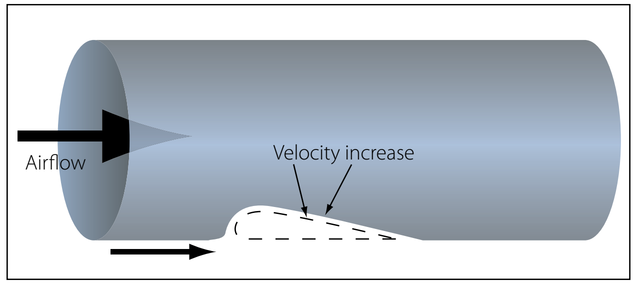

Figure 3-56. Venturi with a superimposed wing.

In the converging part of the venturi, velocity would increase and static pressure would decrease. The same thing would happen to the air flowing around the wing, with the velocity over the top increasing and static pressure decreasing.

In Figure 3-56, the air reaching the leading edge of the wing separates into two separate flows. Some of the air goes over the top of the wing and some travels along the bottom. The air going over the top, because of the curvature, has farther to travel. With a greater distance to travel, the air going over the top must move at a greater velocity. The higher velocity on the top causes the static pressure on the top to be less than it is on the bottom, and this difference in static pressures is what creates lift.

For the wing shown in Figure 3-56, imagine it is 5 ft wide and 15 ft long, for a surface area of 75 ft^2 (10,800 in^2). If the difference in static pressure between the top and bottom is 0.1 psi, there will be $\frac{1}{10}$ lb of lift for each square inch of surface area. Since there are 10,800 in^2 of surface area, there would be 1,080 lb of lift (0.1 × 10,800).

Lift and Newton's Third Law

Newton's third law identifies that for every force there is an equal and opposite reacting force. In addition to Bernoulli's principle, Newton's third law can also be used to explain the lift being created by a wing. As the air travels around a wing and leaves the trailing edge, the air is forced to move in a downward direction. Since a force is required to make something change direction, there must be an equal and opposite reacting force. In this case, the reacting force is what we call lift. In order to calculate lift based on Newton's third law, Newton's second law and the formula "Force = Mass × Acceleration" would be used. The mass would be the weight of air flowing over the wing every second, and the acceleration would be the change in velocity the wing imparts to the air.

The lift on the wing as described by Bernoulli's principle, and lift on the wing as described by Newton's third law, are not separate or independent of each other. They are just two different ways to describe the same thing, namely the lift on a wing.

Airfoils

An airfoil is any device that creates a force, based on Bernoulli's principles or Newton's laws, when air is caused to flow over the surface of the device. An airfoil can be the wing of an airplane, the blade of a propeller, the rotor blade of a helicopter, or the fan blade of a turbofan engine. The wing of an airplane moves through the air because the airplane is in motion, and generates lift by the process previously described. By comparison, a propeller blade, helicopter rotor blade, or turbofan engine fan blade rotates through the air. These rotating blades could be referred to as rotating wings, as is common with helicopters when they are called rotary wing aircraft. The rotating wing can be viewed as a device that creates lift, or just as correctly, it can be viewed as a device that creates thrust.

In Figure 3-57 an airfoil (wing) is shown, with some of the terminology that is used to describe a wing. The terms and their meaning are as follows:

Camber

The camber of a wing is the curvature which is present on top and bottom surfaces. The camber on the top is much more pronounced, unless the wing is a symmetrical airfoil, which has the same camber top and bottom. The bottom of the wing, more often than not, is relatively flat. The increased camber on top is what causes the velocity of the air to increase and the static pressure to decrease. The bottom of the wing has less velocity and more static pressure, which is why the wing generates lift.

Chord Line

The chord line is an imaginary straight line running from the wing's leading edge to its trailing edge. The angle between the chord line and the longitudinal axis of the airplane is known as the angle of incidence.

Relative Wind

Whatever direction the airplane is flying, the relative wind is in the opposite direction. If the airplane is flying due north, and someone in the airplane is not shielded from the elements, that person will feel like the wind is coming directly from the south.

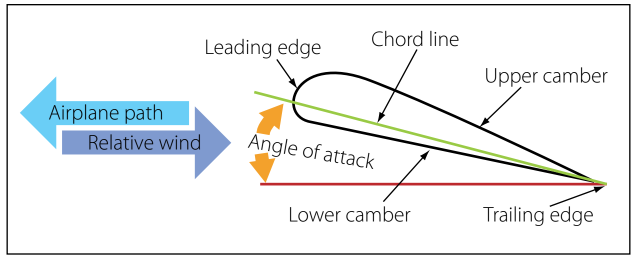

Figure 3-57. Wing terminology.

Angle of Attack

The angle between the chord line and the relative wind is the angle of attack. As the angle of attack increases, the lift on the wing increases. If the angle of attack becomes too great, the airflow can separate from the wing and the lift will be destroyed. When this occurs, a condition known as a stall takes place.

There are a number of different shapes, known as planforms, that a wing can have. A wing in the shape of a rectangle is very common on small general aviation airplanes. An elliptical shape or tapered wing can also be used, but these do not have as desirable a stall characteristic. For airplanes that operate at high subsonic speeds, sweptback wings are common, and for supersonic flight, a delta shape might be used.

The aspect ratio of a wing is the relationship between its span (wingtip to wingtip measurement) and the chord of the wing. If a wing has a long span and a very narrow chord, it is said to have a high aspect ratio. A higher aspect ratio produces less drag for a given flight speed, and is typically found on glider type aircraft.

The angle of incidence of a wing is the angle formed by the intersection of the wing chord line and the horizontal plane passing through the longitudinal axis of the aircraft. Many airplanes are designed with a greater angle of incidence at the root of the wing than at the tip, and this is referred to as washout. This feature causes the inboard part of the wing to stall before the outboard part, which helps maintain aileron control during the initial stages of a wing stall.

Boundary Layer Airflow

The boundary layer is a very thin layer of air lying over the surface of the wing and, for that matter, all other surfaces of the airplane. Because air has viscosity, this layer of air tends to adhere to the wing. As the wing moves forward through the air, the boundary layer at first flows smoothly over the streamlined shape of the airfoil. Here the flow is called the laminar layer.

Balance Tab

On some airplanes, the force needed to move the flight controls can be excessive. In these cases, a balance tab can be used to generate a force that assists in the movement of the flight control. Just the opposite of anti-servo tabs, balance tabs move in the opposite direction of the flight control's trailing edge, providing a force that helps the flight control move.

Servo Tab

On large airplanes, because the force needed to move the flight controls is beyond the capability of the pilot, hydraulic actuators are used to provide the necessary force. In the event of a hydraulic system malfunction or failure, some of these airplanes have servo tabs on the trailing edge of the primary flight controls. When the control wheel is pulled back in an attempt to move the elevator, the servo tab moves and creates enough aerodynamic force to move the elevator. The servo tab is acting like a balance tab, but rather than assisting the normal force that moves the elevator, it becomes the sole force that makes the elevator move. Like the balance tab, the servo tab moves in the opposite direction of the flight control's trailing edge. The Boeing 727 has servo tabs that back up the hydraulic system in the event of a failure. During normal flight, the servo tabs act like balance tabs. [Figure 3-73]

Supplemental Lift-Modifying Devices

If the wing of an airplane was designed to produce the maximum lift possible at low airspeeds to accommodate takeoffs and landings, it would not be suited for higher speed flight because of the enormous amount of drag it would produce. To give the wing the ability to produce maximum low speed lift without being drag prohibitive, retractable high lift devices, such as flaps and slats, are utilized.

Flaps

The most often used lift-modifying device, for small airplanes and large, is the wing flap. Flaps can be installed on the leading edge or trailing edge, with the leading edge versions used only on larger airplanes. Flaps change the camber of the wing, and they increase both the lift and the drag for any given angle of attack. The four different types of flaps in use are the plain, split, slotted, and Fowler. [Figure 3-72]

Plain flaps attach to the trailing edge of the wing, inboard of the ailerons, and form part of the wing's overall surface. When deployed downward, they increase the effective camber of the wing and the wing's chord line. Both of these factors cause the wing to create more lift and more drag.

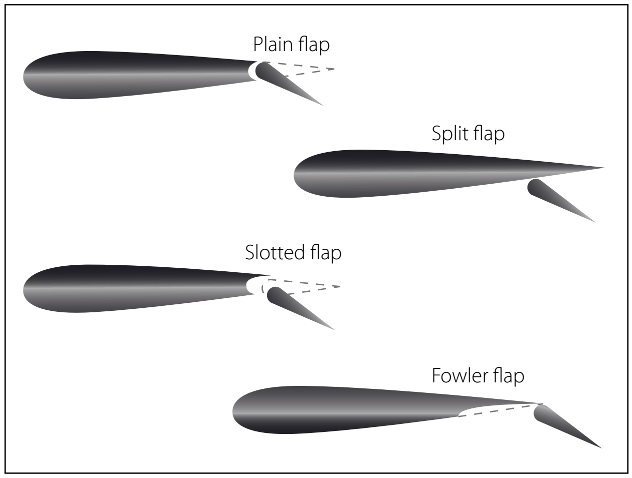

Figure 3-72. Four types of wing flaps.

The split flap attaches to the bottom of the wing, and deploys downward without changing the top surface of the wing. This type of flap creates more drag than the plain flap because of the increase in turbulence.

The slotted flap is similar to the plain flap, except when it deploys, the leading edge drops down a small amount. By having the leading edge drop down slightly, a slot opens up, which lets some of the high pressure air on the bottom of the wing flow over the top of the flap. This additional airflow over the top of the flap produces additional lift.

The Fowler flap attaches to the back of the wing using a track and roller system. When it deploys, it moves aft in addition to deflecting downward. This increases the total wing area, in addition to increasing the wing camber and chord line. This type of flap is the most effective of the four types, and it is the type used on commercial airliners and business jets.

Leading Edge Slots

Leading edge slots are ducts or passages in the leading edge of a wing that allow high pressure air from the bottom of the wing to flow to the top of the wing. This ducted air flows over the top of the wing at a high velocity and helps keep the boundary layer air from becoming turbulent and separating from the wing. Slots are often placed on the part of the wing ahead of the ailerons, so during a wing stall, the inboard part of the wing stalls first and the ailerons remain effective.

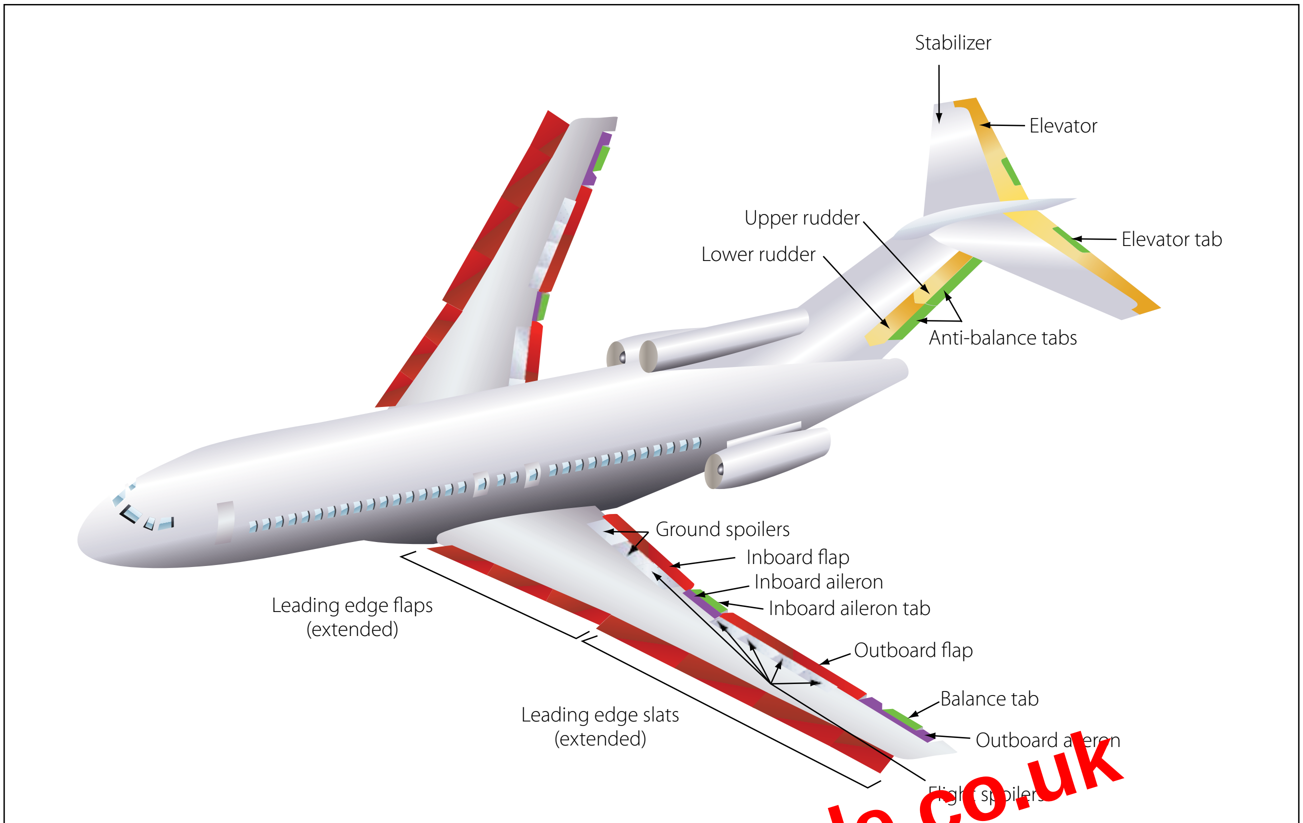

Figure 3-73. Boeing 727 flight controls.

Leading Edge Slats

Leading edge slats serve the same purpose as slots, the difference being that slats are movable and can be retracted when not needed. On some airplanes, leading edge slats have been automatic in operation, deploying in response to the aerodynamic forces that come into play during a high angle of attack. On most of today's commercial airliners, the leading edge slats deploy when the trailing edge flaps are lowered.

The flight controls of a large commercial airliner are shown in Figure 3-73. The controls by color are as follows:

1. All aerodynamic tabs are shown in green.
2. All leading and trailing edge high lift devices are shown in red (leading edge flaps and slats, trailing edge inboard and outboard flaps).
3. The tail mounted primary flight controls are in yellow (rudder and elevator).
4. The wing mounted primary flight controls are in purple (inboard and outboard aileron).

High Speed Aerodynamics

Compressibility Effects

When air is flowing at subsonic speed, it acts like an incompressible fluid. As discussed earlier in this chapter, when air at subsonic speed flows through a diverging shaped passage, the velocity decreases and the static pressure rises, but the density of the air does not change. In a converging shaped passage, subsonic air speeds up and its static pressure decreases. When supersonic air flows through a converging passage, its velocity decreases and its pressure and density both increase. [Figure 3-74] At supersonic flow, air acts like a compressible fluid. Because air behaves differently

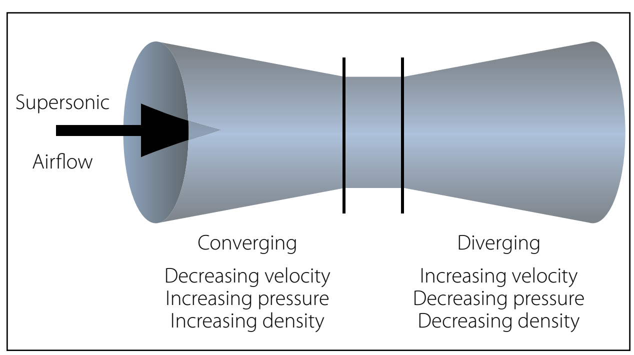

Figure 3-74. Supersonic airflow through a venturi.