Figure 2-4. Elasticity of a modern aircraft wing aids when absorbing of stress for structural integrity and for passenger comfort.

are full of colored water. Even though they are different shapes and have different volumes of liquid, each one has a height of 231 inches. Because of this height, each one would exert a pressure on the bottom of 8.34 psi. The container on the left, with a surface area of 1 in^2, contains a volume of 231 in^3 (one gallon). One gallon of water weighs 8.34 lb, which is why the pressure on the bottom is 8.34 psi.

Still thinking about ***Figure 2-5***, if the pressure was measured half way down, it would be half of 8.34, or 4.17 psi. In other words, the pressure is adjustable by varying the height of the column. Pressure based on the column height of a fluid is known as static pressure. With liquids, such as gasoline, it is sometimes referred to as a head of pressure. For example, if a carburetor needs to have 2 psi supplied to its inlet (head of pressure), this could be accomplished by having the fuel tank positioned the appropriate number of inches higher than the carburetor.

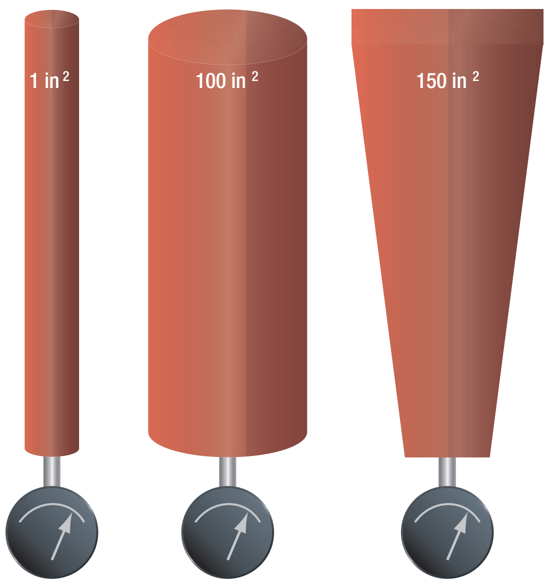

Figure 2-5. Fluid pressure based on column height.

As identified in the previous paragraph, pressure due to the height of a fluid column is known as static pressure. When a fluid is in motion, and its velocity is converted to pressure, that pressure is known as ram. When ram pressure and static pressure are added together, the result is known as total pressure. In the inlet of a gas turbine engine, for example, total pressure is often measured to provide a signal to the fuel metering device or to provide a signal to a gauge on the flight deck.

This same principle of pressure caused by a column of fluid applies to the earth's atmosphere. Air is a fluid that has weight. This weight causes atmospheric pressure. On a standard day at sea level, if a 1 square inch column of air extending to the top of the atmosphere is 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 equalize and the mercury will stabilize at a certain height in the tube. Under standard day atmospheric conditions, the air in a 1 square inch column extending to the top of the atmosphere weighs 14.7 lb. A 1 square inch column of mercury, 29.92 inches tall, also weighs 14.7 lb. That is why 14.7 psi is equal to 29.92 "Hg when referring to a barometric reading. ***Figure 2-6*** 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 pressure of the atmosphere is exerted against an thin metal aneroid connected to the pointer. Calibrations are made in thousands of feet rather than in psi or inches of mercury. For example, the standard pressure at sea level is 29.92 "Hg, or 14.7 psi. At 10 000 feet above sea level, standard pressure is 20.58 "Hg, or 10.10 psi. Altimeters are calibrated so that if the pressure exerted by the atmosphere is 10.10 psi, the altimeter will point to 10 000 ft. (***Figure 2-7***)

BUOYANCY

A solid body submerged in a liquid or a gas weighs less than when weighed in free space. This is because of the upward force, called buoyant force, which any fluid exerts on a body submerged in it. An object will float if this upward force of the fluid is greater than the weight of the object. Objects denser than the fluid, even though they sink readily, appear to lose a part of their weight when submerged. A person can lift a larger weight under water than he or she can possibly lift in the air.

The following experiment is illustrated in ***Figure 2-8***. The overflow can is filled to the spout with water. The heavy metal cube is first weighed in still air and weighs 10 lb. It is then weighed while completely submerged in the water and it weighs 3 lb. The difference between the two weights is the buoyant force of the water. As the cube is lowered into the overflow can, the water is caught in the catch bucket. The volume of water which overflows equals the volume of the cube. (The volume of irregular shaped objects can be measured by this method.) If this experiment is performed carefully, the weight of the water displaced by the metal cube exactly equals the buoyant force of the water, which the scale shows to be 7 lb.

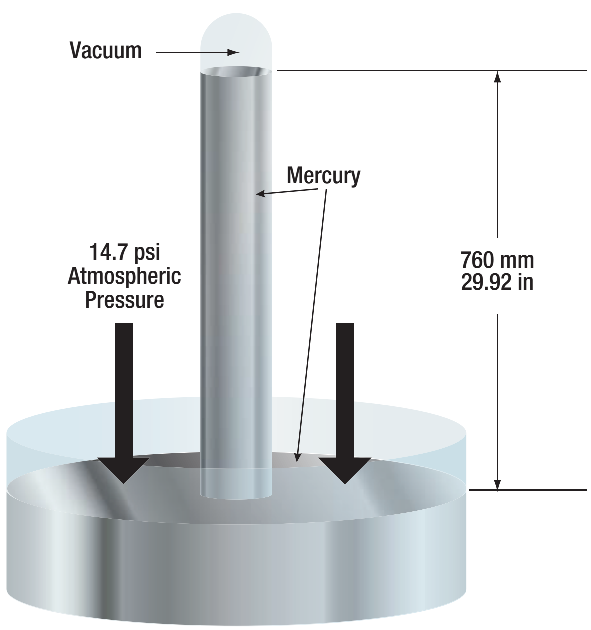

Figure 2-6. Atmospheric pressure as inches of mercury.

Figure 2-7. An airplane's altimeter is an aneroid barometer.

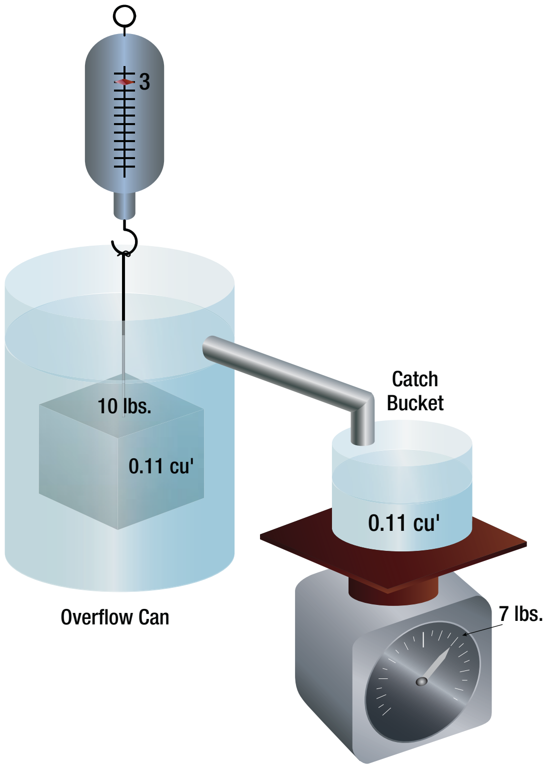

Figure 2-8. Example of buoyancy.

Archimedes (287–212 B.C.) performed similar experiments. As a result, he discovered that the buoyant force which a fluid exerts upon a submerged body is equal to the weight of the fluid the body displaces. This statement is referred to as Archimedes' principle. This principle applies to all fluids, gases as well as liquids. Just as water exerts a buoyant force on submerged objects, air exerts a buoyant force on objects submerged in it.

The amount of buoyant force available to an object can be calculated by using the following formula:

Buoyant Force = Volume of Object × Density of Fluid Displaced

If the buoyant force is more than the object weighs, the object will float. If the buoyant force is less than the object weighs, the object will sink. For the object that sinks, its measurable weight will be less by the weight of the displaced fluid.

Example: A 10-ft^3 object weighing 700 lbs is placed in pure water. Will the object float? If the object sinks, what is its measurable weight in the submerged condition? If the object floats, how many cubic feet of its volume is below the water line?

Buoyant Force = Volume of Object × Density of Fluid Displaced
= 10 (62.4)
= 624 lb

Because the buoyant force is less than the object weighs, the object will sink. The difference between the buoyant force and the object's weight will be its measurable weight, or 76 lb.

Two good examples of buoyancy are a helium filled airship and a seaplane on floats. An airship is able to float in the atmosphere and a seaplane is able to float on water. That means both have more buoyant force than weight. ***Figure 2-9*** is a DeHavilland Twin Otter seaplane, with a gross takeoff weight of 12 500 lb. At a minimum, the floats on this airplane must be large enough to displace a weight in water equal to the airplane's weight. Certification standards typically require that the floats must be 80 percent larger than the minimum needed to support the airplane.

For this airplane, the necessary size of the floats would be calculated as follows.

Divide the airplane weight by the density of water.

$$12\ 500 \div 62.4 = 200.3 \text{ ft}^3$$

Multiply this volume by 80%.

$$200.3 \times 80\% = 160.2 \text{ ft}^3$$

Add the two volumes together to get the total volume of the floats.

$$200.3 + 160.2 = 360.5 \text{ ft}^3$$


Figure 2-9. DeHavilland Twin Otter seaplane.

By looking at the DeHavilland Twin Otter in ***Figure 2-9***, it is obvious that much of the volume of the floats is out of the water. This is accomplished by making sure the floats have at least 80 percent more volume than the minimum necessary.

Some of the large Goodyear airships have a volume of 230 000 ft^3. Since the fluid they are submerged in is air, to find the buoyant force of the airship, the volume of the airship is multiplied by the density of air (.076 51 lb/ft^3). For this Goodyear airship, the buoyant force is 17 597 lb. ***Figure 2-10*** shows an inside view of the Goodyear airship.

The ballonets, are air chambers within the airship. Through the air scoop, air can be pumped into the ballonets or evacuated from the ballonets in order to control the weight of the airship. Controlling the weight of the airship controls how much positive or negative lift it has. Although the airship is classified as a lighter-than-air aircraft, it is in fact flown in a condition slightly heavier than air.

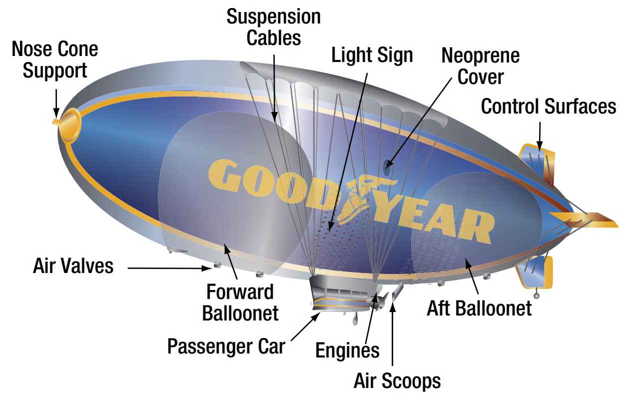

Figure 2-10. Inside view of the Goodyear airship.

2.2.2 - KINETICS

MOTION

The study of the relationship between the motion of bodies or objects and the forces acting on them is often called the study of "force and motion." In a more specific sense, the relationship between velocity, acceleration, and distance is known as kinematics.

LINEAR MOVEMENT

Motion may be defined as a continuing change of position or place, or as the process in which a body undergoes displacement. When an object is at different points in space at different times, that object is said to be in motion, and if the distance the object moves remains the same for a given period of time, the motion may be described as uniform. Thus, an object in uniform motion always has a constant speed.

SPEED AND VELOCITY

In everyday conversation, speed and velocity are often used as if they mean the same thing. In physics they have definite and distinct meanings. Speed refers to how fast an object is moving, or how far the object will travel in a specific time. The speed of an object tells nothing about the direction an object is moving. For example, if the information is supplied that an airplane leaves New York City and travels 8 hours at a speed of 150 mph, this information tells nothing about the direction in which the airplane is moving. At the end of 8 hours, it might be in Kansas City, or if it traveled in a circular route, it could be back in New York City.

Velocity is that quantity in physics which denotes both the speed of an object and the direction in which the object moves. Velocity can be defined as the rate of motion in a particular direction. Velocity is also described as being a vector quantity, a vector being a line of specific length, having an arrow on one end or the other. The length of the line indicates the number value and the arrow indicates the direction in which that number is acting.

Two velocity vectors, such as one representing the velocity of an airplane and one representing the velocity of the wind, can be added together in what is called vector analysis. ***Figure 2-11*** demonstrates this, with vectors "A" and "B" representing the velocity of the airplane and the wind, and vector "C" being the resultant. With no wind, the speed and direction of the airplane would be that shown by vector "A." When accounting for the wind direction and speed, the airplane ends up flying at the speed and direction shown by vector "C."

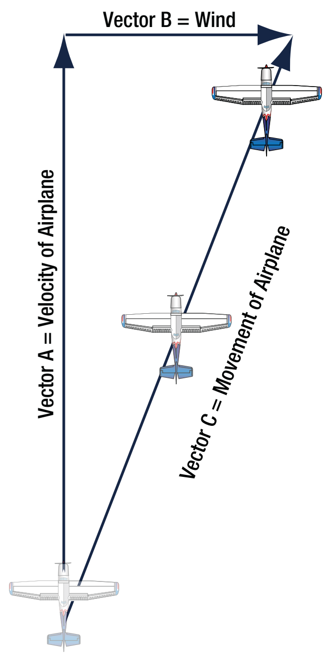

Figure 2-11. Vector analysis for airplane velocity and wind velocity.

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 (9.8mps/s). To calculate acceleration, the following formula is used.

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

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?

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

$$A = \frac{1\,200 - 400}{20}$$

A = 40 mph/s, or by multiplying by 1.467

A = 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 LAWS OF MOTION

First law

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.

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.

Second Law

When a force acts upon a body, the momentum of that body is changed. The rate of change of momentum is proportional to the applied force.

Bodies in motion have the property called momentum. A body that has great momentum has a strong tendency to remain in motion and is therefore hard to stop. For example, a train moving at even low velocity is difficult to stop because of its large mass. Newton's second law applies to this property. Based on Newton's second law, the formula for calculating thrust is derived, which states that force equals mass times acceleration (F = MA). Earlier in this chapter, it was determined that mass equals weight divided by gravity, and acceleration equals velocity final minus velocity initial divided by time. Putting all these concepts together, the formula for thrust is:

$$\text{Force} = \frac{\text{Weight (Velocity final – Velocity initial)}}{\text{Gravity (Time)}}$$

$$F = \frac{W\ (Vf - Vi)}{Gt}$$

Example: A turbojet engine is moving 150 lb of air per second through the engine. The air enters going 100 fps and leaves going 1 200 fps. How much thrust, in pounds, is the engine creating?

$$F = \frac{W\ (Vf - Vi)}{Gt}$$

$$F = \frac{150\ (1\,200 - 100)}{32.2\ (1)}$$

$$F = 5\,124 \text{ lb of thrust}$$

Third Law

For every action there is an equal and opposite reaction.

Newton's third law of motion is often called the law of action and reaction. This means that if a force is applied to an object, the object will supply a resistive force exactly equal to and in the opposite direction of the force applied. It is easy to see how this might apply to objects at rest. For example, as a man stands on the floor, the floor exerts a force against his feet exactly equal to his weight. But this law is also applicable when a force is applied to an object in motion.

Forces always occur in pairs. The term *acting force* means the force one body exerts on a second body, and *reacting force* means the force the second body exerts on the first.

When an aircraft propeller pushes a stream of air backward with a force of 500 lbs, the air pushes the blades forward with a force of 500 lbs. This forward force causes the aircraft to move forward. A turbofan engine exerts a force on the air entering the inlet duct, causing it to accelerate out the fan duct and the tailpipe. The air accelerating to the rear is the action, and the force inside the engine that makes it happen is the reaction, also called thrust.

ROTATIONAL MOVEMENT

Circular motion is the motion of an object along a curved path that has a constant radius. For example, if one end of a string is tied to an object and the other end is held in the hand, the object can be swung in a circle. The object is constantly deflected from a straight (linear) path by the pull exerted on the string, as shown in ***Figure 2-12***. When the weight is at point A, due to inertia it wants to keep moving in a straight line and end up at point B. Because of the force being exerted on the string, it is forced to move in a circular path and end up at point C.

The string exerts a centripetal force on the object, and the object exerts an equal but opposite force on the string, obeying Newton's third law of motion. The 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 2-12*** 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 2-12*** 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:

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

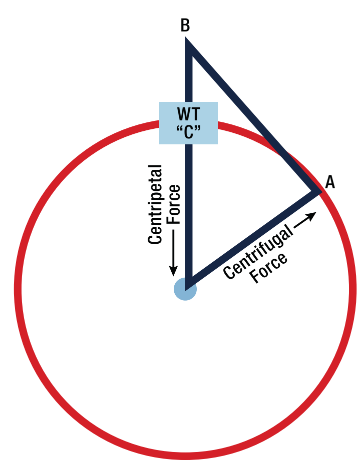

Figure 2-12. Circular motion.