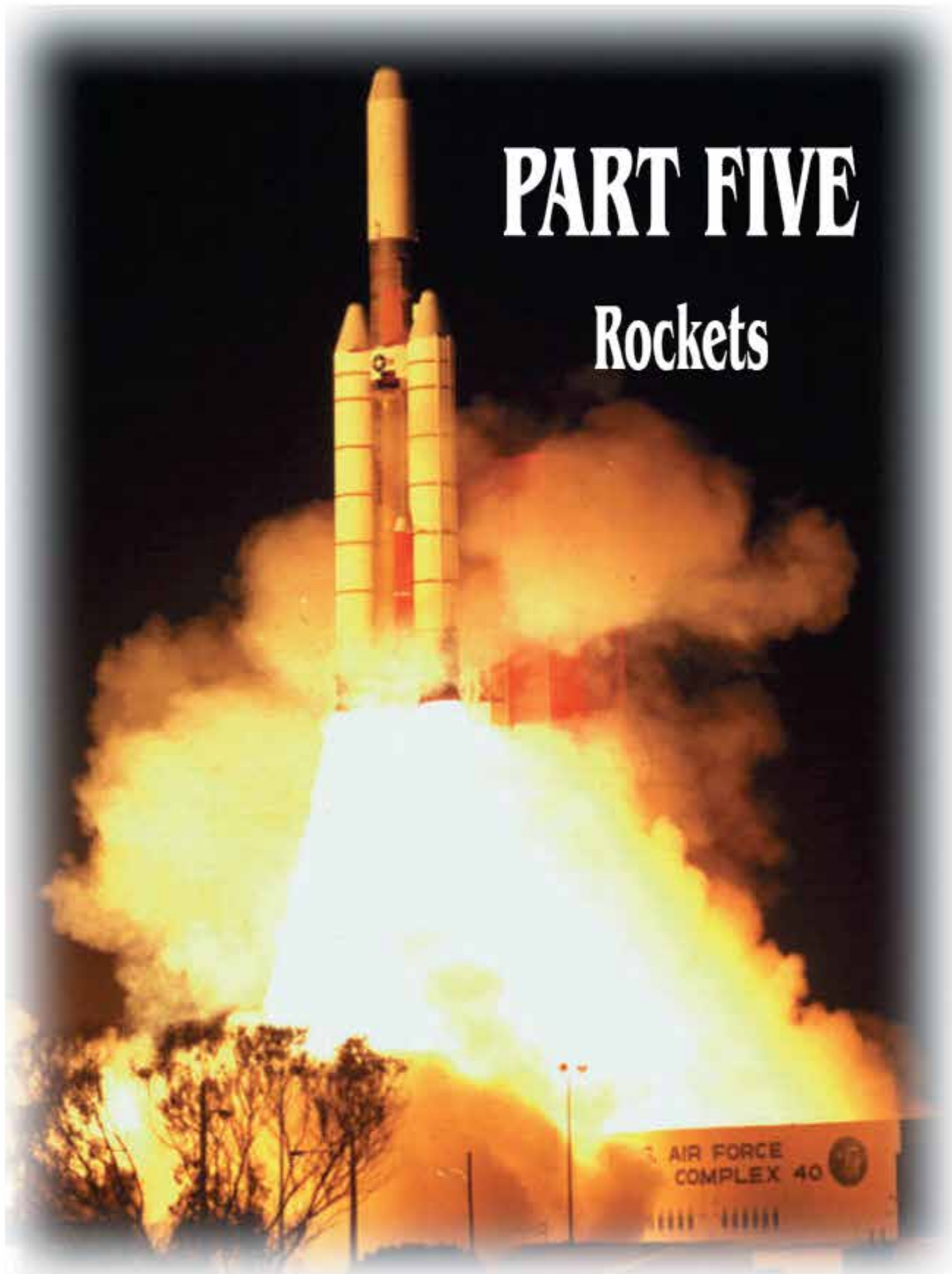


# PART FIVE

## Rockets





## Chapter 21

# ROCKET FUNDAMENTALS

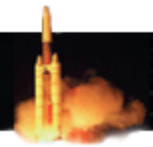
*There is an explanation for everything that a rocket does. The explanation is most always based on the laws of physics and the nature of rocket propellants. Experimentation is required to find out whether a new rocket will or will not work. Even today, with all the knowledge and expertise that exists in the field of rocketry, experimentation occasionally shows that certain ideas are not practical.*

*In this chapter, we will look back in time to the early developers and users of rocketry. We will review some of the physical laws that apply to rocketry, discuss selected chemicals and their combinations, and identify the rocket systems and their components. We also will look at the basics of rocket propellant efficiency.*



## Objectives

- Explain** why a rocket engine is called a reaction engine.
- Identify** the country that first used the rocket as a weapon.
- Compare** the rocketry advancements made by Eichstadt, Congreve and Hale.
- Name** the scientist who solved theoretically the means by which a rocket could escape the Earth's gravitational field.
- Describe** the primary innovation in rocketry developed by Dr. Goddard and Dr. Oberth.
- Explain** the difference between gravitation and gravity.
- Describe** the contributions of Galileo and Newton.
- Explain** Newton's law of universal gravitation.
- State** Newton's three laws of motion.
- Define** force, velocity, acceleration and momentum.
- Apply** Newton's three laws of motion to rocketry.
- Identify** two ways to increase the thrust of a rocket.
- State** the function of the combustion chamber, the throat, and nozzle in a rocket engine.
- Explain** which of Newton's laws of motion is most applicable to rocketry.
- Name** the four major systems of a rocket.
- Define** rocket payload.
- Describe** the four major systems of a rocket.
- List** the components of a rocket propulsion system.
- Identify** the three types of rocket propulsion systems.
- Name** the parts of a rocket guidance system.
- Name** four types of rocket guidance systems.
- Define** specific impulse.
- Define** density impulse.



## History of Rocketry

Rocketry is based on the propelling of a vehicle by a reactive force. The action of the rocket's exhaust gases produces a reaction, forcing the rocket in the opposite direction; therefore, a rocket engine, or motor, is a reaction engine. Jet engines, which power most airliners, are also reaction engines. However, there is a distinct difference between the two types of engines. A jet engine generates its reactive force by burning a mixture of air with a fuel; the rocket engine does not use air. The rocket carries everything it needs to generate a reactive force; this allows the rocket to operate in the atmosphere and in space.

Rocketry is not a new concept and was not born out of our efforts to explore space. As early as 1220, and perhaps even earlier, rockets were used by the Chinese, who were also the first to use the rocket as a weapon of war. In 1232, the Chinese used rocket "fire arrows" at the battle of Kai-feng Fu.

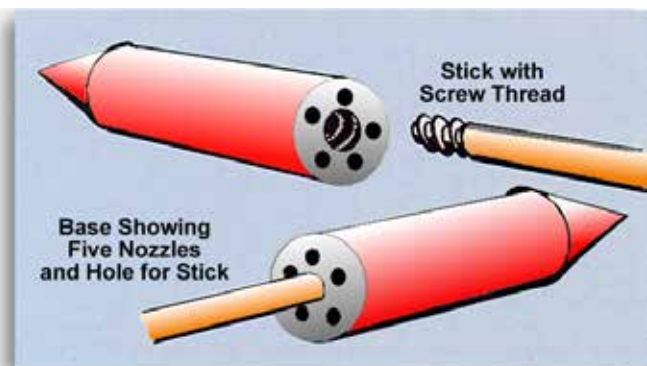
Much later, in 1405, a German engineer by the name of Konrad Kyeser von Eichstadt devised a rocket that was propelled by gunpowder. The French used rockets to defend Orleans against the British in 1429 and again at the siege of Pont-Andemer in 1449.

During the Thirty Year War (1618-1648), rockets weighing as much as 100 pounds were fired. These rockets exploded and sent small pieces of metal in all directions. In 1668, a German field artillery colonel, Christopher Friedrich von Geissler, experimented with rockets weighing over 100 pounds. By 1730, a series of successful flights had been made. Rockets saw extensive use in India when they were fired at the British in the battles of Seringapatam (1792 and 1799).

The news of India's success with rockets caused Colonel William Congreve, a British artillery expert, to experiment with rockets. He standardized the composition of gunpowder explosives, added flight-stabilizing guide sticks and built the first viable launching pad. He was able to increase the rocket range from approximately 300 yards to several thousand yards. Approximately 25,000 Congreve rockets were used in 1807 at the battle of Copenhagen.

In the War of 1812 between Britain and the United States, the British formed a rocket brigade. This brigade saw action in the Napoleonic Wars at Leipzig in 1813 and at Waterloo in 1815.

William Hale, an English engineer, solved the problem of stabilizing rockets in flight without a guiding stick. He used spin stabilization for his rockets, which were fitted with angled exhaust tubes that spun the projectile during flight.



Congreve's Rocket with Stabilizing Stick



Hale's Rocket



Even with improvements over the stick (skyrocket-type) stabilization, the rocket was seldom used for military purposes. Rockets of that time could not hit a specific target and, therefore, were not accurate enough for precision bombardment. For this reason, the rocket was replaced as a significant military weapon.

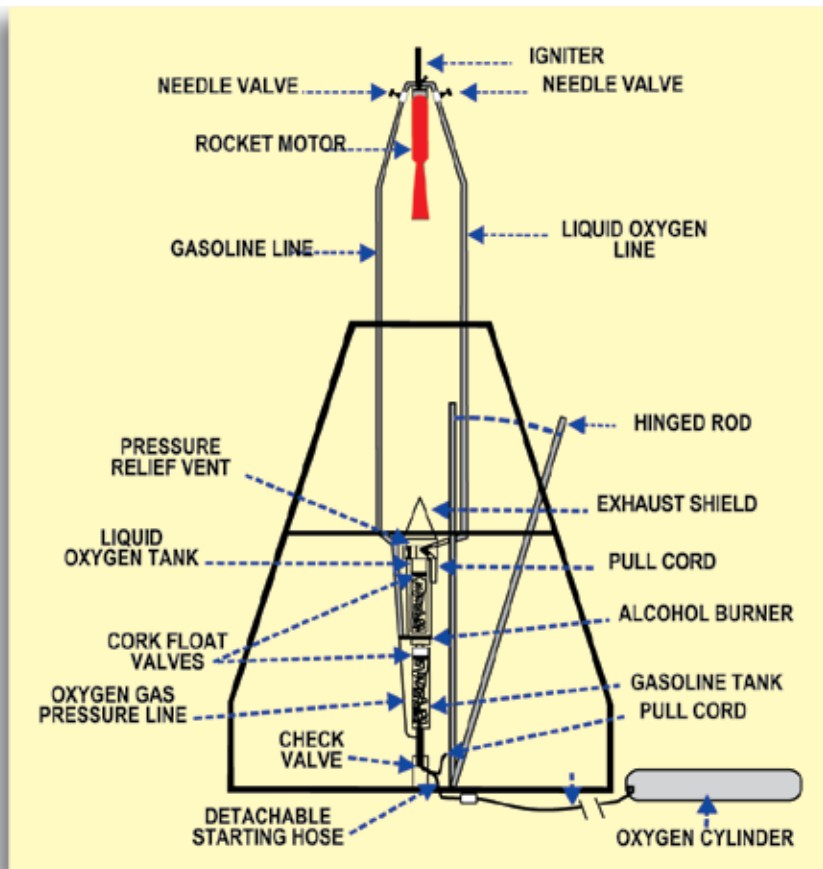
In 1903, Konstantin Eduardovich Tsiolkovsky, a Russian scientist, made the first computations for rocket flights into space. Although he never built a rocket, he designed several and solved theoretically how reaction engines could escape from and reenter the Earth's atmosphere.

In World War I, rockets were used to carry signal flares to light up the battlefield at night and to carry messages. Some rockets were used for the more typical military tasks against enemy airships and balloons. At least one World War I airplane was equipped with rockets. The rockets were placed in holding tubes attached to the biplane's wing struts. The rockets were ignited electrically.

The regeneration of interest in rocketry was brought about by the work of Dr. Robert H. Goddard in the United States and Dr. Hermann Oberth in Germany. Dr. Goddard, recognized as the "Father of Modern Rocketry," was the first scientist to use liquid propellants (liquid oxygen and gasoline) in a rocket. He also developed mechanisms for correcting deviations from planned flight paths.

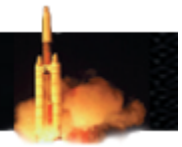


**Dr. Robert H. Goddard** built the first liquid-propellant rocket as pictured in the drawing to the right.



Dr. Oberth's work with liquid oxygen and alcohol propellants closely followed that of Dr. Goddard. These firsts in the use of the more powerful liquid propellants (as compared to solid propellants) took place in the 1920s.

While Dr. Goddard's work in liquid-propellant rocketry was strictly a private venture, rocketry in Germany had the attention and support of the government. As World War II drew near for the United States, Dr. Goddard's work was directed toward developing quick-takeoff propulsion units for US Navy



aircraft instead of rocket-powered launch vehicles for studies of the upper atmosphere and space. In Germany, however, rocketry went forward with the development of powerful engines for rockets. These rockets were ultimately known as the V-2 and more than a thousand fell on England as high-explosive “bombs.”

After World War II, both the United States and Russia acquired German personnel with rocketry expertise. These men formed the nucleus of the program that developed the powerful launch vehicles and space vehicles used today. Our modern rocketry, therefore, is the result of the expertise of Dr. Goddard, Dr. Oberth and others who developed the rocket as a weapon and eventually converted it to peaceful use.

## Newton's Laws

Rocket propulsion, flight and control are achieved by obeying or applying certain physical laws. These laws were discovered by Galileo (1564-1642) and Sir Isaac Newton (1642-1727).

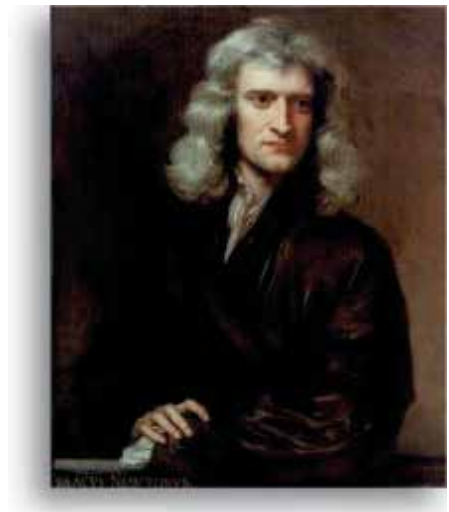
### Gravity

Gravitation is the term used to describe the force of attraction that exists between all matter within the universe. Why and exactly how this attraction force operates is unknown. However, it is in effect at all times, and a body of small mass attracts a body of large mass just as the large mass attracts the small mass. Stated in another way, mutual gravitation exists between all bodies regardless of size.

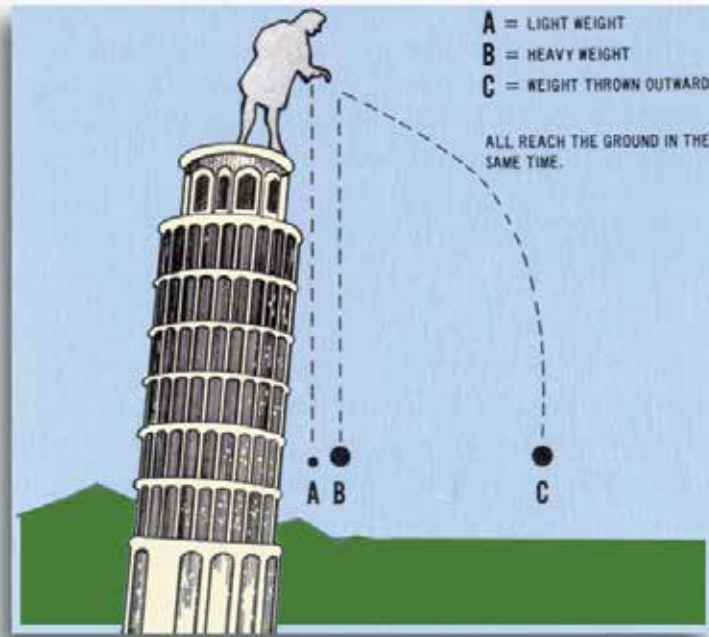
It can be theorized that when a pencil falls to the floor, the Earth attracts the pencil as the pencil attracts Earth. Theoretically, this is true; but, on the practical side, because the Earth has so much more mass than the pencil, the pencil will fall toward Earth while Earth doesn't move at all.

According to legend, Galileo experimented on gravity by dropping a solid iron ball from the Leaning Tower of Pisa. His experiments illustrated that objects of varying weight will strike the ground at the same time if they are released simultaneously and from the same height. From his theoretical work, Newton concluded that bodies in space (such as planets and their Moons) are attracted toward each other in a special way.

Bodies like Earth and the Moon are drawn toward each other by gravitation. The Moon is kept from crashing into Earth by the Moon's “forward” velocity (speed and direction), that creates the familiar centrifugal effect. Centrifugal effect, also identified by Newton, is the tendency of a rotating body to move away from its center of rotation. If it were not for gravity, the spinning Earth would come apart



Sir Isaac Newton



Galileo's Experiments at the Tower of Pisa

object to fly off into “space.” Slow the velocity and the object will fall. With this little experiment, the falling action is considered to be toward the center of gravity (your hand).

## **Newton's Law of Universal Gravitation**

Newton's law of universal gravitation defines the relationship of force, weight and mass. This law states that two bodies attract each other with a force directly proportional to their mass and inversely proportional to the square of the distance between them. This means that as either or both of the masses increase, the force increases, but that as the distance increases, the force decreases. This relationship may be expressed by the equation  $F = (GM_1M_2)/d^2$ , where  $F$  represents force in pounds,  $M_1$  and  $M_2$  are the masses of the two bodies in slugs (unit of mass accelerated at the rate of 1 foot per second per second when acted upon by a force of 1 pound weight),  $d$  is the distance between them, and  $G$  is a constant for all kinds of matter—the gravitational constant.

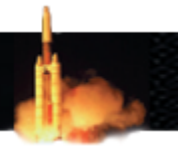
The gravitational force of a symmetric sphere acts as though its entire mass is concentrated at its center. The Earth approximates a symmetric sphere. Thus, the distance between the Earth's center and a body upon or near its surface is approximately equal to the Earth's radius. The mass of the Earth,  $M_1$ , remains constant. From these values the force of the Earth's gravity, which corresponds to the weight of the body  $M_2$ , is found to be 32.2 pounds-force for each unit of mass. This ratio is called the gravitational constant.

The weight of a body, that is, the attraction upon it by the force of the Earth's gravity, may be measured by using a spring scale. The apparent weight of a body depends upon the force exerted upon it by another larger body. The degree of force exerted depends upon the masses of both bodies. However, the mass of a body never changes. The mass of a body may be defined as the quantity of matter it contains.

Mass enables matter to occupy space. The mass of a body in kilograms can be obtained by dividing

because of the centrifugal force created by its rotation. Virtually the same effect exists with the Earth-Moon system. The Moon tries to fly off into space, but the gravitational attraction keeps it from doing so.

You can see the centrifugal effect by doing a simple experiment. Tie a string to an object and swing the object around and around. The object represents the Moon, your hand represents Earth's center of gravity, and the string represents gravitational attraction. If you swing the object steadily and with sufficient velocity, it will “circle the Earth” and exert a constant pulling on the string. Increase the swing (velocity) enough, the string (gravitation) will break and allow the



its weight in Newtons by the acceleration value of gravity at a specific position. At sea level a mass of one kilogram would weigh approximately 9.8 Newtons at 45° latitude on the Earth's surface.

The mass of a body in slugs can be obtained by dividing its weight in pounds by the acceleration value of gravity at a specific position. At sea level a mass of one slug would weigh 32.174 pounds at 45° latitude on the Earth's surface.

### Newton's Laws of Motion

Let's review Sir Isaac Newton's three laws of motion. The first states: **A body in a state of rest and a body in motion tend to remain at rest or in uniform motion unless acted upon by some outside force.** This really is an explanation of inertia, or the tendency of all things to remain in a fixed condition.

Newton used the term "force" (F) to define the cause of motion. You experience the application of force by exerting your muscles to move yourself or some object. Velocity (v) is the rate at which a body moves when a force is applied to it. It is expressed as a unit of velocity per unit of time, such as feet per second, and it implies a specific direction. The rate at which the velocity of a body increases is called positive acceleration. Acceleration (a) is expressed in unit of distance per unit of time, usually in feet per second per second. It occurs when a body is subjected to the application of a force over a continuing period of time. For example, the acceleration that results from the force of gravity upon a free-falling body is about 32.2 feet per second per second.

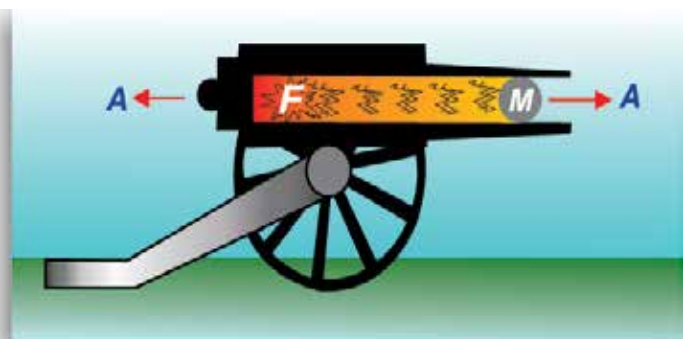


A Demonstration of Newton's First Law of Motion.

Momentum is defined as the product of mass and velocity. Newton found that the action of force on a body changes the body's momentum at a rate proportional to the force and the direction of the force. If the mass of a body remains constant, any change in momentum is reflected in a change of velocity.

For example, if a worker drops a brick from the fifth floor of a building, the brick will be accelerated by the force of gravity at the rate of 32.2 feet per second per second. The mass of the brick does not change; its velocity and momentum change at a rate proportional to the force of Earth's gravity.

The second law states: **The rate of change in the momentum of a body is proportional to the force acting upon the body and is in the direction of the force.**



A Demonstration of Newton's Second Law of Motion



Pushing away the fruit is a demonstration of Newton's Third Law of Motion

an object that she wants to discard. She pushes it away quickly with both of her hands. The object will float away in one direction, while she will float away in the opposite.

The third law states: **To every action, there is an equal and opposite reaction.** The term action means the motion that one body imparts on a second, and reaction means the motion that the second imparts on the first. If a book presses down on a table with a force of 2 pounds, then the table pushes back on the book with a force of 2 pounds. Gravity pulls the book down, and the table pushes it up. These two forces are equal and opposite, but both act on the same object. There is no unbalanced force acting on the book, and it remains at rest in accordance with Newton's first law.

Now imagine as astronaut floating in space. She is holding

## Application of Newton's Laws to Rocketry

We can relate Newton's three laws to rocketry as follows:



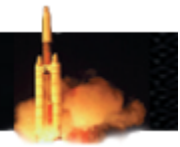
Rocket Launching the Space Shuttle

(1) The first law states simply that when launching a rocket vertically, the propulsion system must produce enough force (thrust) to overcome the inertia of the launch vehicle. Another way of expressing this is to say that the thrust (in pounds) must be greater than the weight of the rocket. As an example, the Saturn V rocket used to launch the Apollo spacecraft series weighed 6,000,000 pounds. In order for the Saturn V to be launched vertically, its engines had to produce more than 6,000,000 pounds of thrust. In fact, the engines of Saturn V produced 7,500,000 pounds of thrust.

(2) The second law is shown mathematically by the equation  $F \propto MA$  - where  $F$  represents force,  $M$  represents mass and  $A$  represents acceleration. The symbol  $\propto$  stands for "proportional to." What this formula says is that the amount of force required to accelerate a body depends on the mass of the body. The more mass, the more force is required to accelerate it.

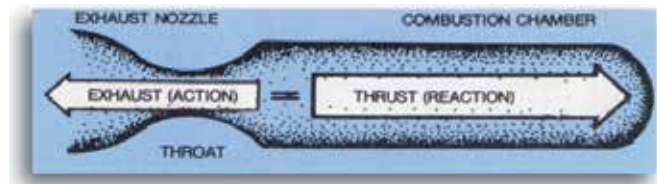
You may have seen on television or at the movies how slowly the older, large rockets lift-off their launch pads. At the moment of liftoff, the total mass (or weight) of the rocket is only slightly less than the force being produced by the





engines. However, every second the rocket's mass is being decreased by burning and expelling the rocket propellant as thrust. At the same time, the amount of force being produced remains constant. So, the force becomes increasingly greater than the dwindling mass, and this results in a rapid second-by-second acceleration until the propellant is used up.

(3) Newton's third law of motion is the heart of rocketry because the action of the rocket engine produces the forward motion of the total rocket. To relate this law of motion to a rocket, we must understand what is happening in a rocket engine. All chemical rockets develop thrust by burning fuel and expelling mass (exhaust particles) from their exhaust nozzles at a high velocity. The thrust (forward motion or push) produced is a reactive force acting in a direction opposite to the direction of the exhaust. Going back to Newton's second law ( $F = ma$ ), we see that there are two ways to increase the thrust (force)—either increase the mass of the exhaust or accelerate the exhaust particles to a higher velocity. When the rocket fuel burns in the combustion chamber, the gases produced are very hot and create a very high pressure inside the chamber. This high pressure forces the gases through the exhaust nozzle to the lower pressure outside the rocket. As these gases move out of the combustion chamber, they pass through the throat, which constricts (narrows) the exhaust and thereby increase its velocity. The "bell-shaped" nozzle allows the escaping exhaust to expand thereby lowering its pressure. This accomplishes two important things—it keeps the pressure in the nozzle lower than inside the combustion chamber and, at the same time, permits only rearward motion of the exhaust gas.

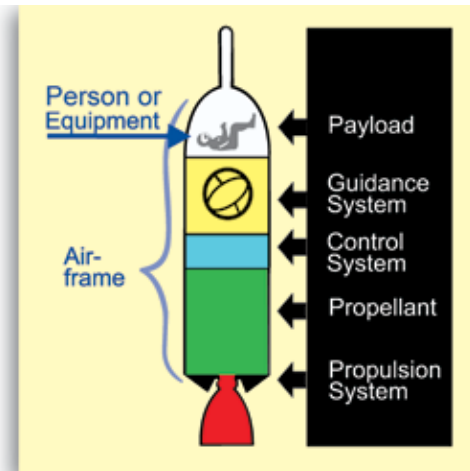


The Basic Rocket Engine or Motor

In the figure above, we can see what the aerospace engineer strives for in producing a powerful and efficient rocket engine—to create as high a pressure as possible in the combustion chamber and to design the throat and nozzle for maximum acceleration of exhaust particles.

## Rocket Systems

Modern rockets used for space applications consist of four major systems. The systems are known as: (1) the airframe system, (2) the propulsion system, (3) the guidance system, and (4) the control system. These systems exist to deliver whatever the rocket is carrying (payload). The payload of the three Saturn V rocket stages was the Apollo spacecraft consisting of the command module, the service module, and the lunar module. The rocket and payload arrangement on the return trip from the Moon was the service module rocket and the command



Major Systems of Rockets



module payload. Of course, the ultimate payload was the astronauts, materials and the data returned from the Moon.

Today, the payloads of large US rockets consist primarily of Earth satellites and deep space vehicles. Most military rockets have payloads of explosives, which are called missiles. These explosives can include nuclear and thermonuclear “bombs.” Of course, the payloads of the smallest military rockets are conventional-type explosives especially designed to destroy specific types of targets such as airplanes, tanks and hardened command posts. To clarify, a “rocket” is any device that uses rocket propulsion (which would include retro-rockets and braking rockets). A missile does not have to be rocket propelled, but usually is, and is typically thought of as a weapon which is directed at an enemy target. A launch vehicle is a rocket that takes a payload to high altitudes or outer space. Many early launch vehicles were converted military missiles, the Redstone, Atlas, and Titan are a few examples.

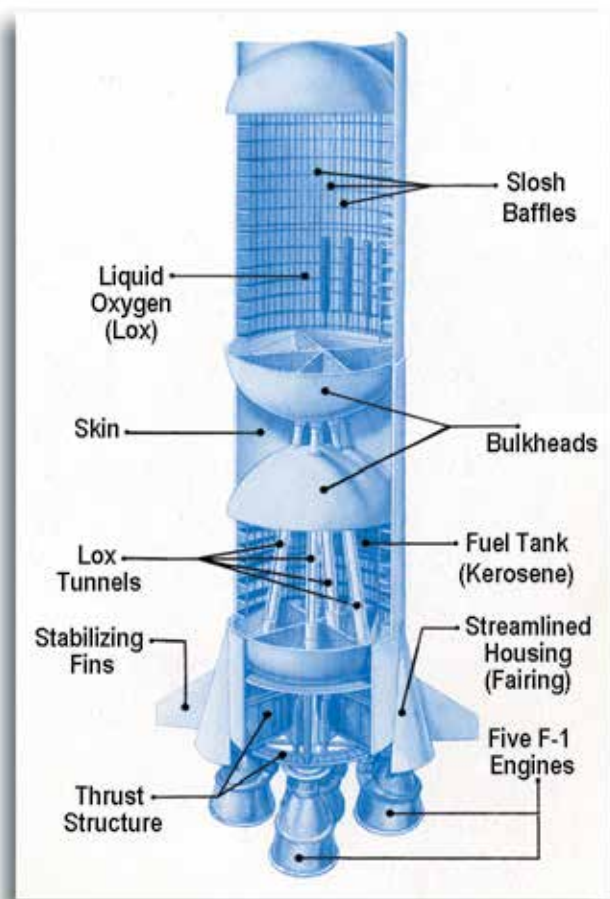
### **The Airframe System**

The airframe system of a rocket, like that of an aircraft, serves to contain the other systems and to provide the streamlined shape. The airframe must be structurally strong and capable of withstanding heat, stress and a great deal of vibration. At the same time, it must be as lightweight as possible. Every pound of weight saved in the airframe allows an additional pound of weight to be added to the payload.

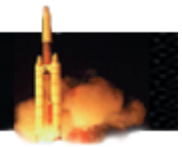
The Atlas missile was a prime example of how engineers design an airframe that was both strong and lightweight. The skin of this missile also served as the wall of the propellant tanks. This eliminated the need for separate internal tanks and provided great savings in weight. The skin of the Atlas was thinner than a dime and when it had no propellant aboard, it had to be pressurized to keep it from collapsing.

Precision is the watchword in making a rocket airframe. Techniques used to manufacture rocket airframe parts include machining, forging casting, spinning and extruding. To attain the required precision essential in building a rocket, the knowledge of the scientist and the skill of the technician are required to ensure the accuracy of each manufacturing technique—from the blueprint to the launch pad.

One of the most spectacular airframes ever constructed for a US rocket was that of the massive Saturn V launch vehicle. In its Apollo lunar (Moon)



**First Stage of the Saturn V Launch Vehicle**



flight configuration, the Saturn stood 363 feet tall. Of course, this included the payload of astronauts and the subvehicles that were delivered to the vicinity and surface of the Moon.

Saturn's first-stage airframe had a diameter of 33 feet and its length was 138 feet. This diagram shows the major components of the first stage's airframe. Beginning at the bottom was the thrust structure that contained the vehicle's five F-1 engines.

The thrust structure was a complex group of beams and braces made mainly of aluminum alloy plus some steel. Surrounding the thrust structure was a skin assembly that provided additional strength and better aerodynamics, lessening the effect of drag caused by the rocket pushing its way through the air.

Other aerodynamic features attached to the thrust structure included fairings and fins, as seen in the illustration. The fairings were drag reducers. The fins helped stabilize the rocket's flight while it was climbing rapidly through the atmosphere.

Fuel and oxidizer tanks made up the greater portion of the Saturn's first-stage airframe (this is true with all liquid-propellant rockets). The walls of these tanks formed a large part of the rocket's exterior surface or skin. Within each of the tanks were slosh baffles that added strength to the airframe, while serving another purpose. The other purpose was to stabilize the propellant's motion as the rocket vibrated and tilted in flight. Without such baffles, the liquid oxygen (oxidizer) and kerosene (fuel) would setup sloshing and swirling motions that would make the rocket uncontrollable.

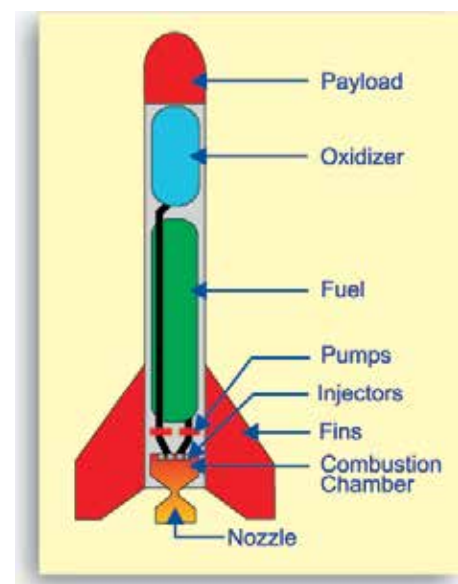
What is labeled skin in the figure is also known as the intertank structure. The interstage structure was similar and included that skin portion used to join the three rocket stages. While the propellant tank walls exposed to the airstream were smooth, the metal "skirts" forming the intertank and interstage structures were corrugated. This corrugation was necessary to give greater strength to a relatively thin part of the structure.

Although the airframes of all liquid-propellant rockets possess certain characteristics of the Saturn V's structure, there are differences. These differences depend on the size and purpose of the rocket. Again, in the design and construction of airframes for rockets, the primary objective is to build a structure that will withstand all anticipated stresses while using the least possible weight.

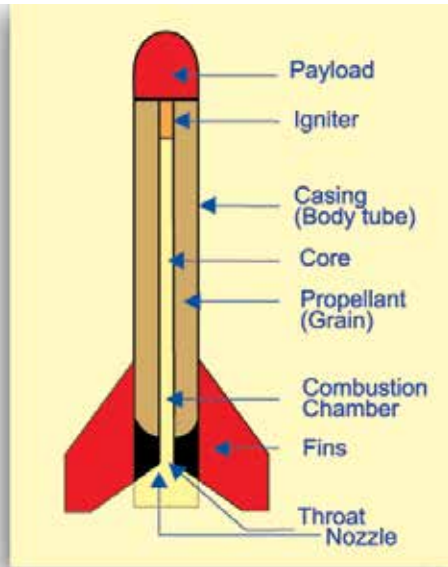
### **Propulsion System**

The rocket propulsion system includes the propellant used, the containers for the propellant, all plumbing that may be required to get the propellant from the containers to the engine, and the rocket engine itself. In other words, everything directly associated with propelling the rocket is part of the propulsion system.

From our previous discussion of the Saturn V's airframe, you can see that areas of the airframe may also serve as part of the propulsion system. Propellants are classified as liquid or as solid. Liquid propellants are carried in compartments separate from the combustion chamber. Solid propellants are carried in the



**Liquid Propulsion System Components**



**Solid Propulsion System Components**

combustion chamber. The two types of propellants lead to significant differences in engine structure and thrust control.

Propulsion systems used in rocketry may be generally classified as chemical, gas-heating and electric systems. Those considered chemical systems usually involve the mixing and burning of a chemical fuel and a chemical oxidizer to produce the hot, expanding gases needed to provide thrust. The gas-heating system design would use an external heat source to heat and cause the propellant to build the pressure necessary to provide thrust by exiting the exhaust nozzle at high velocity. Electric systems use magnetic fields and currents to propel matter in small amounts.

## **Guidance System**

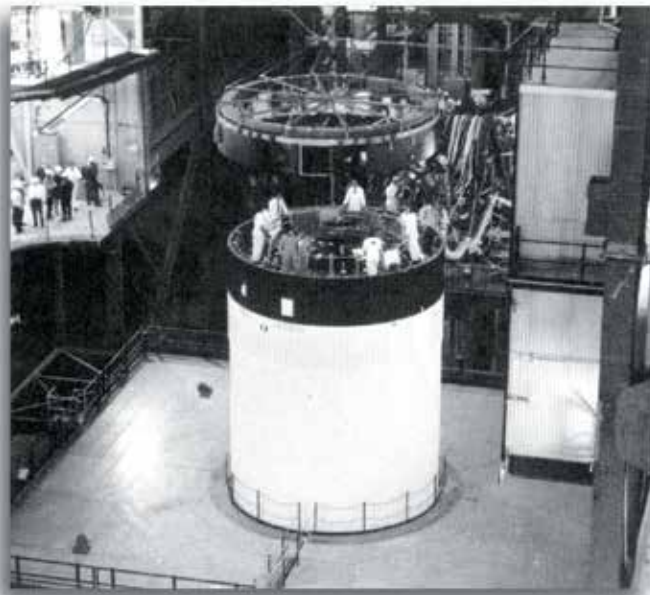
The “brain” of a large, sophisticated rocket is its guidance system. The guidance system is a self-contained electronic unit that employs a computer and an inertial platform and may also have a star-tracking unit for space navigation. The computer is programmed for the desired flight trajectory before launch. Of course, there is also a radio link between the rocket’s mission controllers and its guidance system. This link allows changes to be made in instructions to the rocket’s guidance system, and it also functions, more or less, as a direct control in the event the on-board guidance system experiences a partial malfunction.

In comparison to the rest of the rocket, the guidance system is exceptionally small. The miniaturization of electronics is the explanation for its small size. The electrical power needed flows through miniaturized circuits, and the wire connecting the various components is correspondingly lightweight.

Again, the Saturn V as an example, gives an idea of how relatively small a guidance system is in comparison to the rest of the rocket. This photograph shows the entire instrument unit being fitted atop the 22-foot-diameter third stage. The actual inertial guidance system was only a part of the total instrument unit.

The guidance system senses the rocket’s motion and this data is fed into the system’s computer. If the rocket is not flying according to the planned trajectory, impulses for correcting the trajectory are sent to the control system.

Coupled with an inertial guidance system may be an automatic celestial navigation unit,



**The Saturn V’s Instrument Unit**



or “star tracker.” However, a star tracker is justified only for spaceflight where it is exceptionally important to keep a spacecraft on the correct flight path.

Although rocketry is involved in making course corrections for the flight of spacecraft, we are hesitant to associate the star-tracker unit with the guidance system for rockets. The spacecraft itself is really the payload of a rocket launch vehicle whose guidance system initially placed the spacecraft on the correct flight path. Even so, a star-tracker unit can be linked to the primary guidance system of any rocket vehicle.

When we leave the larger, more sophisticated rockets and look at the smaller ones, we find there are several other types of guidance systems. These smaller rockets are within the area of military use; they are missiles. Of course, the largest of these missiles use the inertial guidance system too. These large missiles are capable of doing more than delivering a destructive device over intercontinental distances; they could be used (as some models have) as launch vehicles for spacecraft.

The smaller rocket missiles that have a guidance system usually are known as short-range missiles. Such missiles may be guided to their targets by the command of a human director. Other missiles’ guidance systems may require that they “home in” on the target that is radiating heat or light. Still other missiles are built to fly along a beam that is aimed at and kept on the target. These guidance systems, which are in addition to the inertial system, are the command system, the homing system and the beam-rider system.

### Control System

Again, we must think of the guidance system of a rocket as being its “brain.” It doesn’t matter if this “brain” is within the rocket as a self-contained unit (such as the inertial system) or mainly outside the rocket (such as a command system). Whatever the rocket’s guidance system dictates should be done to keep on the correct flight path must be carried out by another system—the control system.

While in the atmosphere, control systems for rockets can work much like those of an airplane. Once the rocket climbs to where the air is very thin, other methods need to be considered. One way to change the rocket’s flight path is to change the direction of the exhaust stream. Another way is to use small rockets along the side of the rocket near the nose and tail of the airframe to redirect the rocket. Variations or combinations of the systems control large and small rockets. (These same systems can also be used in the atmosphere.)

## Specific Impulse and Density Impulse

The effectiveness of either type of propellant is stated in terms of specific impulse or density impulse. The word impulse means thrust and is the measure of how much thrust will be obtained from a propellant.

Specific impulse ( $I_{sp}$ ) is the number of pounds of thrust delivered by consuming one pound of pro-



pellant (oxidizer/fuel mixture) in one second. If, for example, a pound of common black powder burns up in one second and produces 100 pounds of thrust, the specific impulse of this batch of powder is 100 seconds. Packing one pound of this powder into a rocket motor and igniting it would give our rocket a 100-pound kick that would last for one second. Now, how high or far our rocket travels depends on several factors; such as the total weight of the rocket and the design of the rocket motor.

Let's suppose we do not want to burn all this powder at one time. We do not need 100 pounds of thrust to lift our rocket because the entire rocket weighs only 2 pounds, including the black-powder propellant. What we want to do is spread the total thrust available over a longer period of time.

For instance, we would use a long-tube design for the motor. This would allow only a small portion of the powder's total surface to be exposed to the burning process. Let's say that this arrangement of the propellant extends the burning time to 10 seconds. In effect, we have divided our 100 pounds of thrust by 10, which gives us 10 pounds of thrust per second until the propellant is burned up.

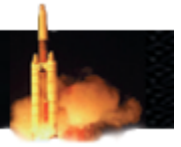
Taking this example to the extreme, if we could cause the same powder (propellant) to burn for 100 seconds, then we would have one pound of thrust per second. (However, our two-pound-weight would not move in the vertical direction.)

When you see the symbol  $I_{sp}$  and a number following it, you should remember that the number represents the seconds during which 1 pound of thrust could be provided by burning 1 pound of propellant. For example, if a propellant has an  $I_{sp}$  of 500, it means that burning 1 pound of this propellant will produce 1 pound of thrust for 500 seconds or 500 pounds of thrust for 1 second (or any of an infinite of variations, such as 1,000 pounds of thrust for 1/2 second, 2,000 pounds for 1/4 second, or 4,000 pounds for 1/8 second).

Specific impulse is not the only measure that is considered when choosing a propellant for a rocket. Density impulse is another measure of a propellant's thrust according to the volume involved. The propellants for the Saturn V's second stage are a good example. They were oxygen and hydrogen. This combination gives a specific impulse of 364 seconds. Yet, a pound of these propellants takes up a lot of space (volume) because of the relatively light density of hydrogen, even in liquid form.

The weight of the structure, or airframe, needed to contain this volume somewhat offsets the advantage of a high  $I_{sp}$ . The density impulse for oxygen/hydrogen is 90.

Another propellant composed of red fuming nitric acid (RFNA) as the oxidizer and aniline as the fuel has a specific impulse of 200 and a density impulse of 310. So why wasn't the RFNA/aniline propellant used for the Saturn V second stage? Very simply, the people managing the program had to consider many factors other than specific and density impulses. These factors included cost, ease and safety of handling the propellant, and stability of the propellant. The decision reached, therefore, was a compromise after considering all factors and all possible combinations of oxidizers and fuels.



## Key Terms and Concepts

- reaction engine
- Earth's gravitational field
- spin stabilization
- gravitation
- gravity
- Newton's law of universal gravitation
- Newton's three laws of motion
- force
- velocity
- acceleration
- momentum
- combustion chamber
- throat (of a rocket engine)
- nozzle (of a rocket engine)
- payload
- four major rocket systems—airframe, propulsion, guidance and control
- propulsion systems—chemical, gas-heating, electric
- guidance—inertial, command, homing, beam-rider
- specific impulse
- density impulse

## ? Test Your Knowledge ?

### SELECT THE CORRECT ANSWER

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1. (**Galileo / Newton**) conducted experiments from the Leaning Tower of Pisa.
2. (**Galileo / Newton**) proved that objects of varying weights strike the ground at the same time, if released at the same time.
3. The (**Germans / Chinese**) were the first to use a rocket as a weapon of war.
4. Dr. (**Oberth / Goddard**) is recognized as the "Father of Modern Rocketry."
5. Rockets were first attached to aircraft in (**World War I/ World War II**).



## MATCHING

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### 6. Match the scientist with his contribution:

- |                                |   |
|--------------------------------|---|
| a. Konrad Kyeser von Eichstadt | (1) Used spin stabilization for his rockets                 |
| b. Colonel William Congreve    | (2) Made first computations for rocket flight into space    |
| c. William Hale                | (3) Built the first viable launching pad                    |
| d. Konstantin Tsiolkovsky      | (4) Devised first rocket propelled by gunpowder             |
| e. Dr. Robert Goddard          | (5) Used more powerful liquid propellants                   |
| f. Dr. Hermann Oberth          | (6) Developed method to correct deviations from flight path |

### 7. Match the terms with their correct definitions

- |                 |   |
|-----------------|---|
| a. force        | (1) The product of mass and velocity        |
| b. acceleration | (2) The cause of motion                     |
| c. velocity     | (3) Application of force over time          |
| d. momentum     | (4) Rate a body moves when force is applied |

## MULTIPLE CHOICE

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8. Which is not a major system of modern rockets?
- The airframe
  - The payload
  - The propulsion
  - The guidance
  - The control
9. Which of the following doesn't apply to the airframe system?
- It provides a streamlined shape.
  - It contains the other systems.
  - It must be strong and heavyweight.
  - It must withstand heat, stress, and vibration.
10. Which is not a propulsion system used in rockets?
- Chemical
  - Gas heating
  - Nuclear
  - Electric
11. Which is not a part of the guidance system?
- A computer
  - An inertial platform
  - A star-tracking unit
  - Controls for the engine





**FILL IN THE BLANKS** \_\_\_\_\_

13. Newton identified \_\_\_\_\_ , which is the tendency of a rotating body to move away from its center of rotation.
14. Newton's \_\_\_\_\_ law of motion states a body at \_\_\_\_\_ and a body in \_\_\_\_\_ tend to remain in their respective states unless \_\_\_\_\_.
15. Newton's \_\_\_\_\_ law of motion states that for every action, there is a \_\_\_\_\_ .
16. Rockets were replaced as a significant military weapon when artillery developed \_\_\_\_\_.
17. Whatever the rocket is carrying is defined as the \_\_\_\_\_.
18. Propellants are classified as either \_\_\_\_\_ or \_\_\_\_\_.

**TRUE OR FALSE** \_\_\_\_\_

19. Mutual gravitation exists between all bodies, regardless of size.
20. After World War II, both the Soviets and Americans acquired German rocket experts.
21. The skin of the Atlas rocket was so thin that, if not fueled up, it had to be pressurized to keep from collapsing.
22. As with all solid fuel rockets, the Saturn V's first stage is made up mostly of fuel and oxidizer tanks.
23. The control system is the system of the rocket that equates to the "brain".
24. The homing system is a guidance system that missiles use to fly along a beam to their intended target.

**SHORT ANSWER** \_\_\_\_\_

25. Apply Newton's laws of motion to rocketry.
26. What is Newton's law of universal gravitation?
27. What are two ways to increase the thrust of a rocket?
28. Define specific impulse for propellants.