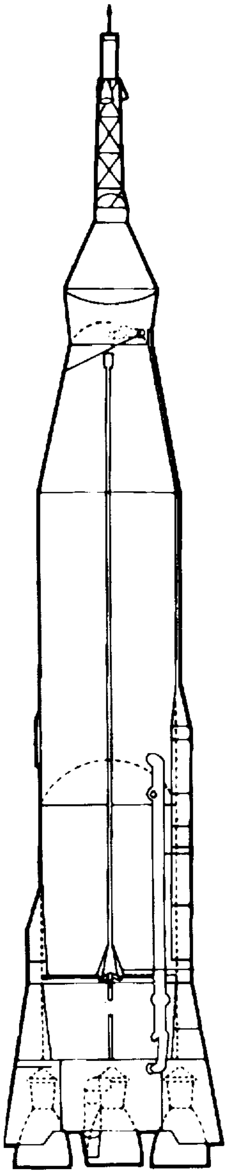
National Aeronautics and
Space Administration

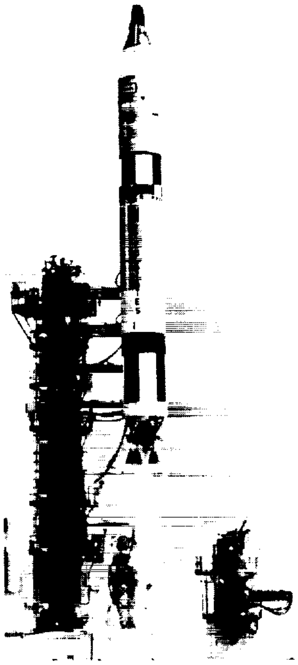
Office of Education and
Human Resources
Education Division

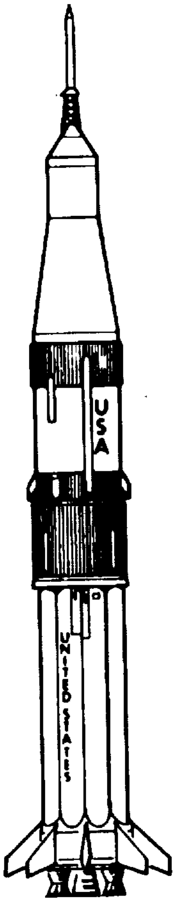
Educational Product	
Teachers	Grades 2-6

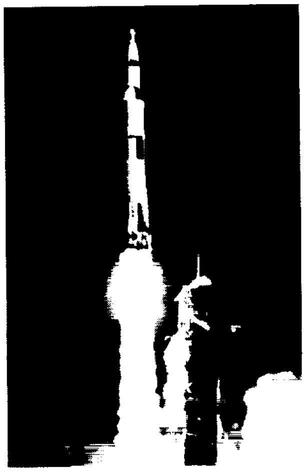
ROCKETS

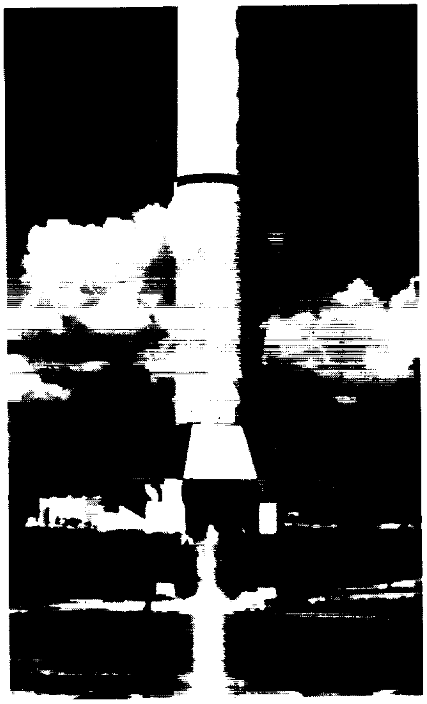
Physical Science Teacher's Guide With Activities











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How To Use This Guide

Rockets are the oldest form of self-contained vehicles in existence. Early rockets were in use more than two thousand years ago. Over a long and exciting history, rockets have evolved from simple tubes filled with black powder into mighty vehicles capable of launching a spacecraft out into the galaxy. Few experiences can compare with the excitement and thrill of watching a rocket-powered vehicle, such as the Space Shuttle, thunder into space. Dreams of rocket flight to distant worlds fire the imagination of both children and adults.

With some simple and inexpensive materials, you can mount an exciting and productive physical science unit about rockets for children, even if you don't know much about rockets yourself. The unit also has applications for art, chemistry, history, mathematics, and technology education. The many activities contained in this teaching guide emphasize hands-on involvement. It contains background information about the history of rockets and basic rocket science to make you an "expert."

The guide begins with background information sections on the history of rocketry, scientific principles, and practical rocketry. The sections on scientific principles and practical rocketry are based on Isaac Newton's Three Laws of Motion. These laws explain why rockets work and how to make them more efficient.

The background sections are followed with a series of physical science activities that demonstrate the basic science of rocketry. Each activity is designed to be simple and take advantage of inexpensive materials. Construction diagrams, material and tools lists, and instructions are included. A brief discussion elaborates on the concepts covered in the activities and is followed with teaching notes and discussion questions.

Because many of the activities and demonstrations apply to more than one subject area, a matrix chart has been included on this page to assist in identifying opportunities for extended learning experiences. The chart identifies these subject areas by activity and demonstration title. In addition, many of the student activities encourage student problem-solving and cooperative learning. For example, students can use problem-solving to come up with ways to attach fins in the Bottle Rocket activity. Cooperative learning is a necessity in the Altitude Tracking and Balloon Staging activities.

The length of time involved for each activity and demonstration will vary according to its degree of difficulty and the development level of the students. Generally, demonstrations will take just a few minutes to complete. With the exception of the Altitude Tracking activity, most activities can be completed in less than an hour.

The guide concludes with a glossary of terms, suggested reading list, NASA educational resources, and an evaluation questionnaire with a mailer.

A Note on Measurement

In developing this guide, metric units of measurement were employed. In a few exceptions, notably within the "materials needed" lists, English units have been listed. In the United States, metric-sized parts such as screws and wood stock are not as accessible as their English equivalents. Therefore, English units have been used to facilitate obtaining required materials.

Activities and Demonstrations by Subject Area and Relationship to Newton's Laws of Motion

	Chemistry	History	Mathematics	Physical Science	Technology Education	Newton's Laws of Motion			Page
						1	2	3	
Hero Engines		●		●	●	●	●	●	21
Rocket Pinwheel				●		●	●	●	23
Rocket Car			●	●	●	●	●	●	24
Water Rocket			●	●		●	●	●	25
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Newton Car			●	●	●	●	●	●	29
Antacid Tablet Race	●		●	●			●		31
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Pencil "Rocket"				●	●	●	●	●	33
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Altitude Tracking			●		●				36

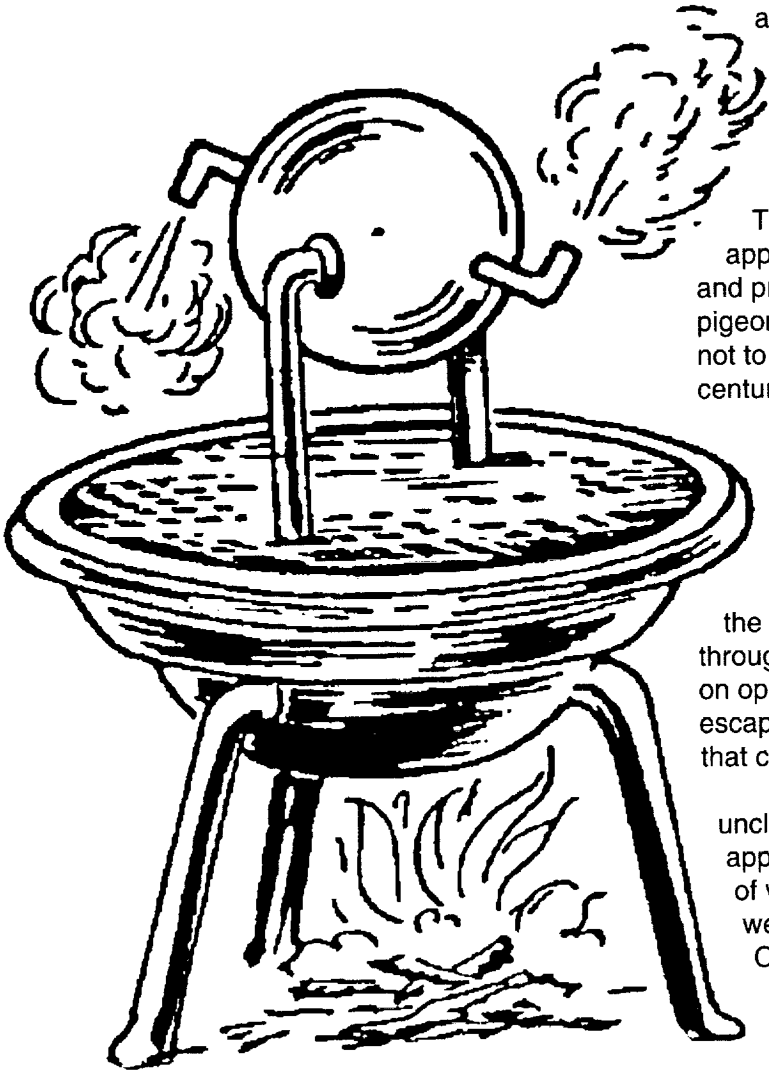
Brief History of Rockets

Today's rockets are remarkable collections of human ingenuity. NASA's Space Shuttle, for example, is one of the most complex flying machines ever invented. It stands upright on a launch pad, lifts off as a rocket, orbits Earth as a spacecraft, and returns to Earth as a gliding airplane. The Space Shuttle is a true spaceship. In a few years it will be joined by other spaceships. The European Space Agency is building the *Hermes* and Japan is building the *HOPE*. Still later may come aerospace planes that will take off from runways as airplanes, fly into space, and return as airplanes.

The rockets and spaceships of today and the spaceships of the future have their roots in the science and technology of the past. They are natural outgrowths of literally thousands of years of experimentation and research on rockets and rocket propulsion.

One of the first devices to successfully employ the principles essential to rocket flight was a wooden bird. In the writings of Aulus Gellius, a Roman, there is a story of a Greek named Archytas who lived in the city of Tarentum, now a part of southern Italy. Somewhere around the year 400 B.C., Archytas mystified and amused the citizens of Tarentum by flying a pigeon made of wood. It appears that the bird was suspended on wires and propelled along by escaping steam. The pigeon used the action-reaction principle that was not to be stated as a scientific law until the 17th century.

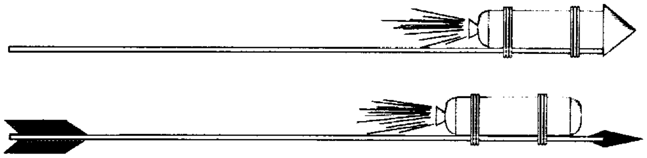
About three hundred years after the pigeon, another Greek, Hero of Alexandria, invented a similar rocket-like device called an *aeolipile*. It, too, used steam as a propulsive gas. Hero mounted a sphere on top of a water kettle. A fire below the kettle turned the water into steam, and the gas traveled through pipes to the sphere. Two L-shaped tubes on opposite sides of the sphere allowed the gas to escape, and in doing so gave a thrust to the sphere that caused it to rotate.



Hero Engine

Just when the first true rockets appeared is unclear. Stories of early rocket like devices appear sporadically through the historical records of various cultures. Perhaps the first true rockets were accidents. In the first century A.D., the Chinese were reported to have had a simple form of gunpowder made from saltpeter, sulfur, and charcoal dust. It was used mostly for fireworks in religious and other festive celebrations. Bamboo tubes were filled with the mixture and tossed into fires to create explosions during religious festivals. It is entirely possible that some of those tubes failed to explode and instead skittered out of the fires, propelled by the gases and sparks produced by the burning gunpowder.

It is certain that the Chinese began to experiment with the gunpowder-filled tubes. At some point, bamboo tubes were attached to arrows and launched with bows. Soon it was discovered that these gunpowder tubes could launch themselves just by the power produced from the escaping gas. The true rocket was born.



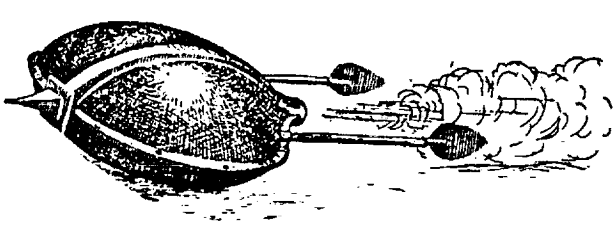
Chinese Fire-Arrows

The first date we know true rockets were used was the year 1232. At this time, the Chinese and the Mongols were at war with each other. During the battle of Kai-Keng, the Chinese repelled the Mongol invaders by a barrage of "arrows of flying fire." These fire-arrows were a simple form of a solid-propellant rocket. A tube, capped at one end, was filled with gunpowder. The other end was left open and the tube was attached to a long stick. When the powder was ignited, the rapid burning of the powder produced fire, smoke, and gas that escaped out the open end and produced a thrust. The stick acted as a simple guidance system that kept the rocket headed in one general direction as it flew through the air. It is not clear how effective these arrows of flying fire were as weapons of destruction, but their psychological effects on the Mongols must have been formidable.

Chinese soldier launches fire-arrow

Following the battle of Kai-Keng, the Mongols produced rockets of their own and may have been responsible for the spread of rockets to Europe. All through the 13th to the 15th centuries there were reports of many rocket experiments. In England, a monk named Roger Bacon worked on improved forms of gunpowder that greatly increased the range of rockets. In France, Jean Froissart found that more accurate flights could be achieved by launching rockets through tubes. Froissart's idea was the forerunner of the modern bazooka. Joanes de Fontana of Italy designed a surface-running rocket-powered torpedo for setting enemy ships on fire.

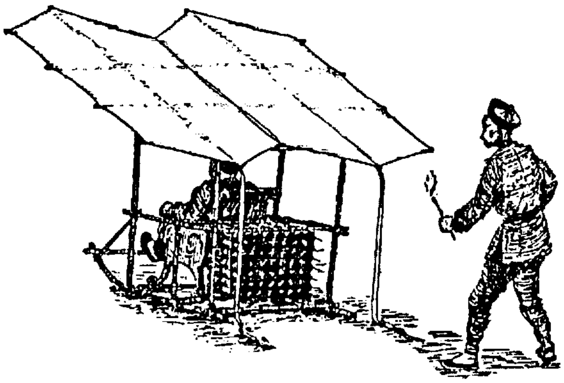
By the 16th century rockets fell into a time of disuse as weapons of war, though they were still used for fireworks displays, and a German fireworks maker, Johann Schmidlap, invented the "step rocket," a multi-staged vehicle for lifting fireworks to higher altitudes. A large sky rocket (first stage) carried a smaller sky rocket (second stage). When the large rocket burned out, the smaller one continued to a higher altitude before showering the sky with glowing cinders. Schmidlap's idea is basic to all rockets today that go into outer space.



Surface-Running Torpedo

Nearly all uses of rockets up to this time were for warfare or fireworks, but there is an interesting old Chinese legend that reported the use of rockets as a means of transportation. With the help of many assistants, a lesser-known Chinese official named Wan-Hu assembled a rocket-powered flying chair. Attached to the chair were two large kites, and fixed to the kites were forty-seven fire-arrow rockets.

On the day of the flight, Wan-Hu sat himself on the chair and gave the command to light the rockets. Forty-seven rocket assistants, each armed with torches, rushed forward to light the fuses. In a moment, there was a tremendous roar accompanied by billowing clouds of smoke. When the smoke cleared, Wan-Hu and his flying chair were gone. No one knows for sure what happened to Wan-Hu, but it is probable that if the event really did take place, Wan-Hu and his chair were blown to pieces. Fire-arrows were as apt to explode as to fly.



Legendary Chinese official Wan Hu braces himself for "liftoff"

Rocketry Becomes a Science

During the latter part of the 17th century, the scientific foundations for modern rocketry were laid by the great English scientist Sir Isaac Newton (1642-1727). Newton organized his understanding of physical motion into three scientific laws. The laws explain how rockets work and why they are able to work in the vacuum of outer space. (Newton's three laws of motion will be explained in detail later.)

Newton's laws soon began to have a practical impact on the design of rockets. About 1720, a Dutch professor, Willem Gravesande, built model cars propelled by jets of steam. Rocket experimenters in Germany and Russia began working with rockets with a mass of more than 45 kilograms. Some of these rockets were so powerful that their escaping exhaust flames bored deep holes in the ground even before lift-off.

During the end of the 18th century and early into the 19th, rockets experienced a brief revival as a weapon of war. The success of Indian rocket barrages against the British in 1792 and again in 1799 caught the interest of an artillery expert, Colonel William Congreve. Congreve set out to design rockets for use by the British military.

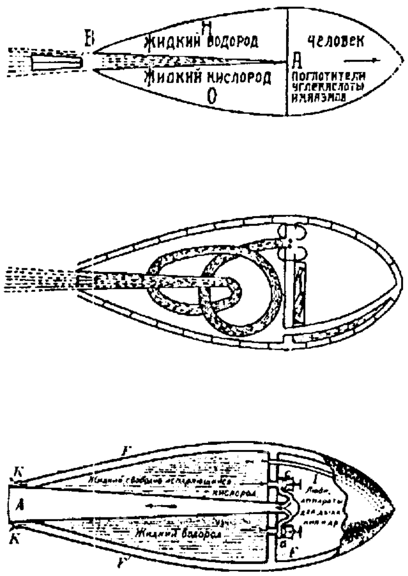
The Congreve rockets were highly successful in battle. Used by British ships to pound Fort McHenry in the War of 1812, they inspired Francis Scott Key to write "the rockets' red glare," words in his poem that later became *The Star-Spangled Banner.*

Even with Congreve's work, the accuracy of rockets still had not improved much from the early days. The devastating nature of war rockets was not their accuracy or power, but their numbers. During a typical siege, thousands of them might be fired at the enemy. All over the world, rocket researchers experimented with ways to improve accuracy. An Englishman, William Hale, developed a technique called spin stabilization. In this method, the escaping exhaust gases struck small vanes at the bottom of the rocket, causing it to spin much as a bullet does in flight. Variations of the principle are still used today.

Rockets continued to be used with success in battles all over the European continent. However, in a war with Prussia, the Austrian rocket brigades met their match against newly designed artillery pieces. Breech-loading cannon with rifled barrels and exploding warheads were far more effective weapons of war than the best rockets. Once again, rockets were relegated to peacetime uses.

Modern Rocketry Begins

In 1898, a Russian schoolteacher, Konstantin Tsiolkovsky (1857-1935), proposed the idea of space exploration by rocket. In a report he published in 1903, Tsiolkovsky suggested the use of liquid propellants for rockets in order to achieve greater range. Tsiolkovsky stated that the speed and range of a rocket were limited only by the exhaust velocity of escaping gases. For his ideas, careful research, and great vision, Tsiolkovsky has been called the father of modern astronautics.

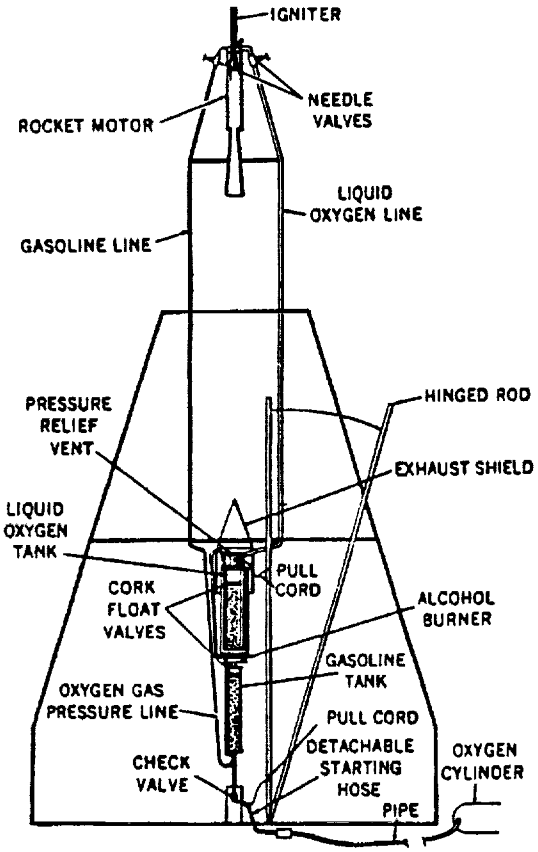


Tsiolkovsky Rocket Designs

Early in the 20th century, an American, Robert H. Goddard (1882-1945), conducted practical experiments in rocketry. He had become interested in a way of achieving higher altitudes than were possible for lighter-than-air balloons. He published a pamphlet in 1919 entitled *A Method of Reaching Extreme Altitudes.* It was a mathematical analysis of what is today called the meteorological sounding rocket.

In his pamphlet, Goddard reached several conclusions important to rocketry. From his tests, he stated that a rocket operates with greater efficiency in a vacuum than in air. At the time, most people mistakenly believed that air was needed for a rocket to push against and a *New York Times* newspaper editorial of the day mocked Goddard's lack of the "basic physics ladled out daily in our high schools." Goddard also stated that multistage or step rockets were the answer to achieving high altitudes and that the velocity needed to escape Earth's gravity could be achieved in this way.

Goddard's earliest experiments were with solid-propellant rockets. In 1915, he began to try various types of solid fuels and to measure the exhaust velocities of the burning gases.



Dr. Goddard's 1926 Rocket

While working on solid-propellant rockets, Goddard became convinced that a rocket could be propelled better by liquid fuel. No one had ever built a successful liquid-propellant rocket before. It was a much more difficult task than building solid-propellant rockets. Fuel and oxygen tanks, turbines, and combustion chambers would be needed. In spite of the difficulties, Goddard achieved the first successful flight with a liquid-propellant rocket on March 16, 1926. Fueled by liquid oxygen and gasoline, the rocket flew for only two and a half seconds, climbed 12.5 meters, and landed 56 meters away in a cabbage patch. By today's standards, the flight was unimpressive, but like the first powered airplane flight by the Wright brothers in 1903, Goddard's gasoline rocket was the forerunner of a whole new era in rocket flight.

Goddard's experiments in liquid-propellant rockets continued for many years. His rockets became bigger and flew higher. He developed a gyroscope system for flight control and a payload compartment for scientific instruments. Parachute recovery systems were employed to return rockets and instruments safely. Goddard, for his achievements, has been called the father of modern rocketry.

A third great space pioneer, Hermann Oberth (1894-1989) of Germany, published a book in 1923 about rocket travel into outer space. His writings were important. Because of them, many small rocket societies sprang up around the world. In Germany, the formation of one such society, the Verein fur Raumschiffahrt (Society for Space Travel), led to the development of the V-2 rocket, which was used against London during World War II. In 1937, German engineers and scientists, including Oberth, assembled in Peenemunde on the shores of the Baltic Sea. There the most advanced rocket of its time would be built and flown under the directorship of Wernher von Braun.

The V-2 rocket (in Germany called the A-4) was small by comparison to today's rockets. It achieved its great thrust by burning a mixture of liquid oxygen and alcohol at a rate of about one ton every seven seconds. Once launched, the V-2 was a formidable weapon that could devastate whole city blocks.

Fortunately for London and the Allied forces, the V-2 came too late in the war to change its outcome. Nevertheless, by war's end, German rocket scientists and engineers had already laid plans for advanced missiles capable of spanning the Atlantic Ocean and landing in the United States. These missiles would have had winged upper stages but very small payload capacities.

With the fall of Germany, many unused V-2 rockets and components were captured by the Allies. Many German rocket scientists came to the United States. Others went to the Soviet Union. The German scientists, including Wernher von Braun, were amazed at the progress Goddard had made.

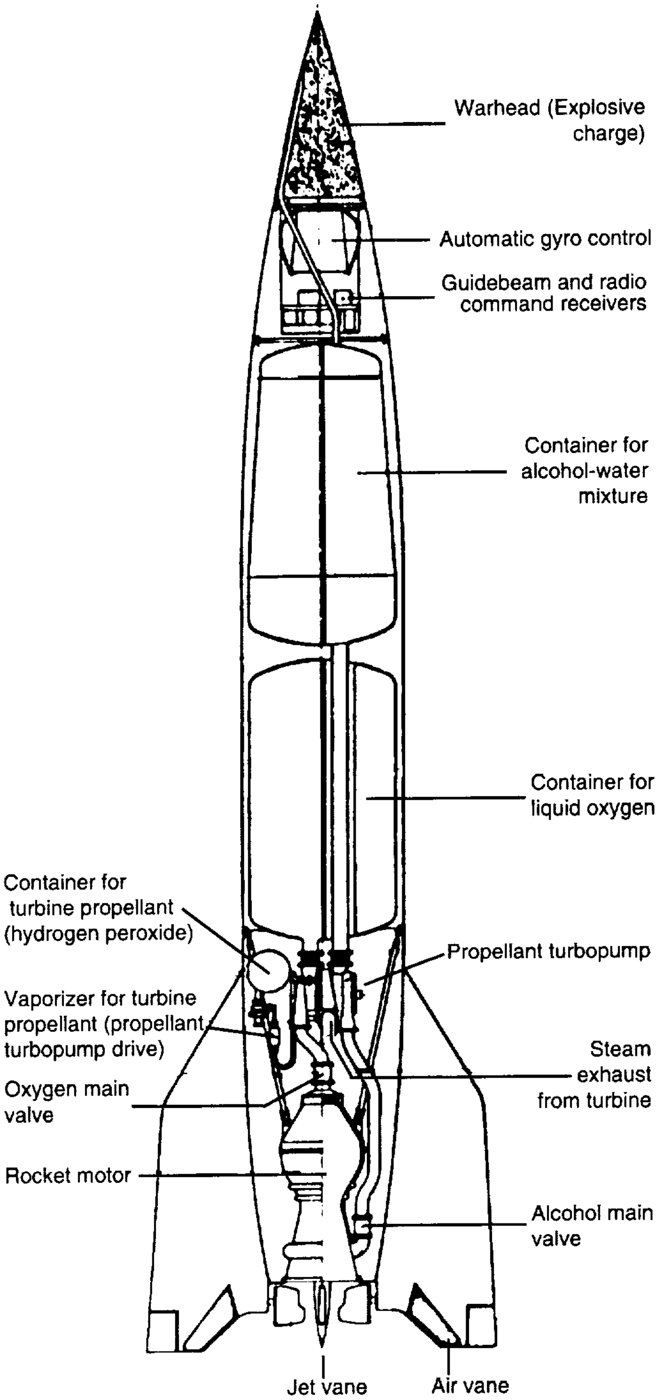
Both the United States and the Soviet Union realized the potential of rocketry as a military weapon and began a variety of experimental programs. At first, the United States began a program with high-altitude atmospheric sounding rockets, one of Goddard's early ideas. Later, a variety of medium- and long-range intercontinental ballistic missiles were developed. These became the starting point of the U.S. space program. Missiles such as the Redstone, Atlas, and Titan would eventually launch astronauts into space.

On October 4, 1957, the world was stunned by the news of an Earth-orbiting artificial satellite launched by the Soviet Union. Called *Sputnik I,* the satellite was the first successful entry in a race for space between the two superpower nations. Less than a month later, the Soviets followed with the launch of a satellite carrying a dog named Laika on board. Laika survived in space for seven days before being put to sleep before the oxygen supply ran out.

A few months after the first *Sputnik,* the United States followed the Soviet Union with a satellite of its own. *Explorer I* was launched by the U.S. Army on January 31, 1958. In October of that year, the United States formally organized its space program by creating the National Aeronautics and Space Administration (NASA). NASA became a civilian agency with the goal of peaceful exploration of space for the benefit of all humankind.

Soon, many people and machines were being launched into space. Astronauts orbited Earth and landed on the Moon. Robot spacecraft traveled to the planets. Space was suddenly opened up to exploration and commercial exploitation. Satellites enabled scientists to investigate our world, forecast the weather, and to communicate instantaneously around the globe. As the demand for more and larger payloads increased, a wide array of powerful and versatile rockets had to be built.

Since the earliest days of discovery and experimentation, rockets have evolved from simple gunpowder devices into giant vehicles capable of traveling into outer space. Rockets have opened the universe to direct exploration by humankind.

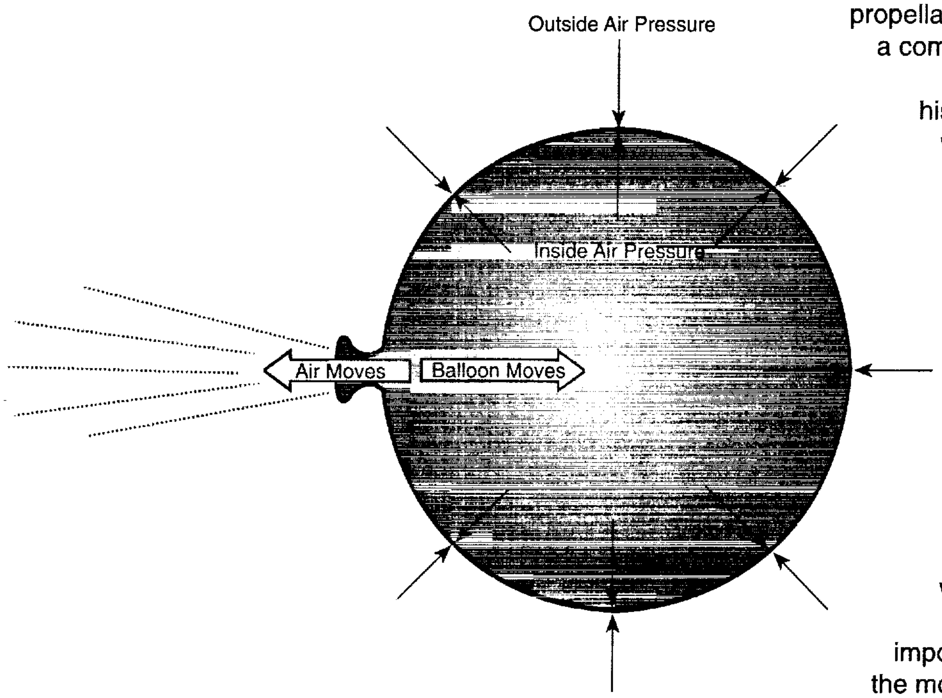


German V-2 (A-4) Missile

Rocket Principles

A rocket in its simplest form is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and in doing so provides a thrust that propels the rocket in the opposite direction. A good example of this is a balloon. Air inside a balloon is compressed by the balloon's rubber walls. The air pushes back so that the inward and outward pressing forces are balanced. When the nozzle is released, air escapes through it and the balloon is propelled in the opposite direction.

When we think of rockets, we rarely think of balloons. Instead, our attention is drawn to the giant vehicles that carry satellites into orbit and spacecraft to the Moon and planets. Nevertheless, there is a strong similarity between the two. The only significant difference is the way the pressurized gas is produced. With space rockets, the gas is produced by burning propellants that can be solid or liquid in form or a combination of the two.



One of the interesting facts about the historical development of rockets is that while rockets and rocket-powered devices have been in use for more than two thousand years, it has been only in the last three hundred years that rocket experimenters have had a scientific basis for understanding how they work.

The science of rocketry began with the publishing of a book in 1687 by the great English scientist Sir Isaac Newton. His book, entitled *Philosophiae Naturalis Principia Mathematica,* described physical principles in nature. Today, Newton's work is usually just called the *Principia.* In the *Principia*, Newton stated three important scientific principles that govern the motion of all objects, whether on Earth or in space. Knowing these principles, now called Newton's Laws of Motion, rocketeers have been able to construct the modern giant rockets of the 20th century such as the Saturn V and the Space Shuttle. Here now, in simple form, are Newton's Laws of Motion.

1. Objects at rest will stay at rest and objects in motion will stay in motion in a straight line unless acted upon by an unbalanced force.
2. Force is equal to mass times acceleration.
3. For every action there is always an opposite and equal reaction.

As will be explained shortly, all three laws are really simple statements of how things move. But with them, precise determinations of rocket performance can be made.

Newton's First Law

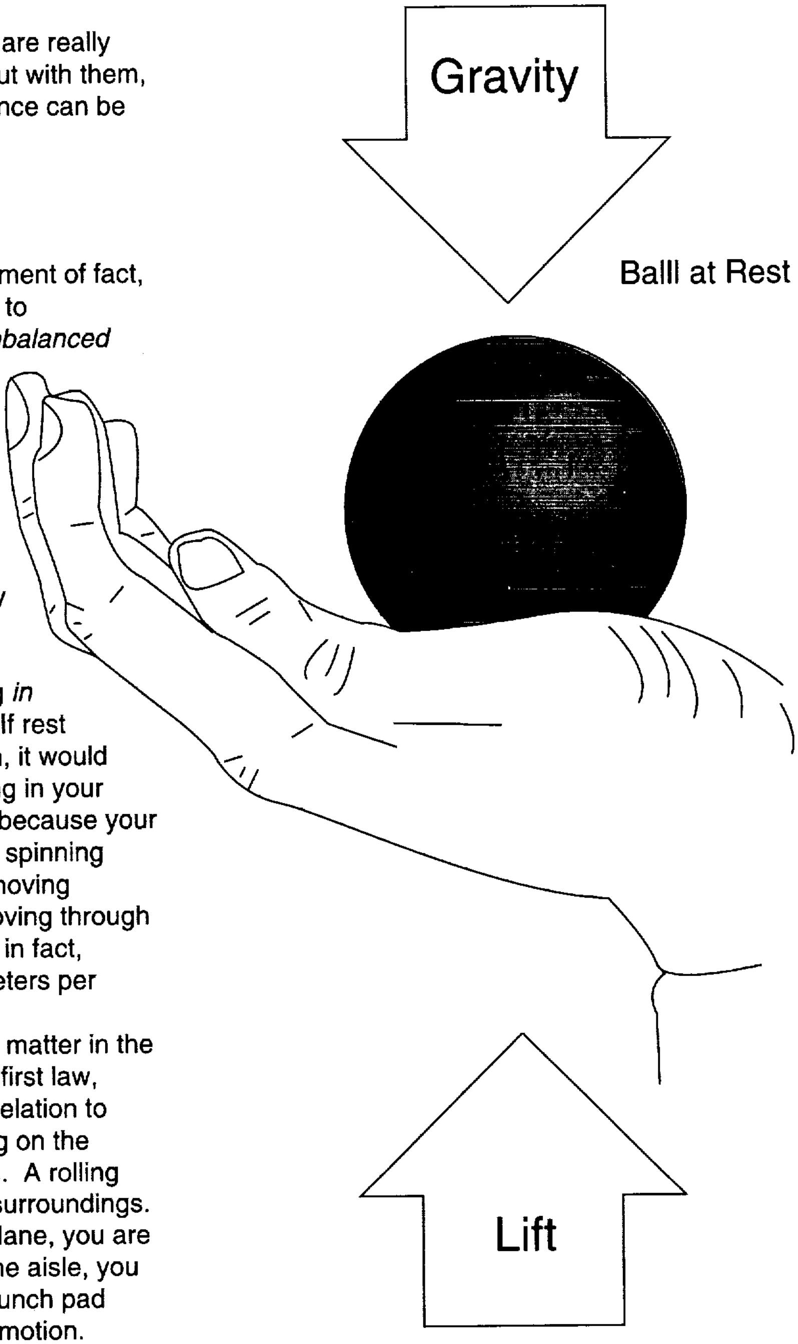
This law of motion is just an obvious statement of fact, but to know what it means, it is necessary to understand the terms *rest, motion,* and *unbalanced force.*

Rest and motion can be thought of as being opposite to each other. Rest is the state of an object when it is not changing position in relation to its surroundings. If you are sitting still in a chair, you can be said to be at rest. This term, however, is relative. Your chair may actually be one of many seats on a speeding airplane. The important thing to remember here is that you are not moving *in relation to your immediate surroundings.* If rest were defined as a total absence of motion, it would not exist in nature. Even if you were sitting in your chair at home, you would still be moving, because your chair is actually sitting on the surface of a spinning planet that is orbiting a star. The star is moving through a rotating galaxy that is, itself, moving through the universe. While sitting "still," you are, in fact, traveling at a speed of hundreds of kilometers per second.

Motion is also a relative term. All matter in the universe is moving all the time, but in the first law, motion here means changing position in relation to surroundings. A ball is at rest if it is sitting on the ground. The ball is in motion if it is rolling. A rolling ball changes its position in relation to its surroundings. When you are sitting on a chair in an airplane, you are at rest, but if you get up and walk down the aisle, you are in motion. A rocket blasting off the launch pad changes from a state of rest to a state of motion.

The third term important to understanding this law is unbalanced force. If you hold a ball in your hand and keep it still, the ball is at rest. All the time the ball is held there though, it is being acted upon by forces. The force of gravity is trying to pull the ball downward, while at the same time your hand is pushing against the ball to hold it up. The forces acting on the ball are balanced. Let the ball go, or move your hand upward, and the forces become unbalanced. The ball then changes from a state of rest to a state of motion.

In rocket flight, forces become balanced and unbalanced all the time. A rocket on the launch pad is balanced. The surface of the pad pushes the rocket up while gravity tries to pull it down. As the engines are ignited, the thrust from the rocket unbalances the forces, and the rocket travels upward. Later, when the rocket runs out of fuel, it slows down, stops at the highest point of its flight, then falls back to Earth.



Objects in space also react to forces. A spacecraft moving through the solar system is in constant motion. The spacecraft will travel in a straight line if the forces on it are in balance. This happens only when the spacecraft is very far from any large gravity source such as Earth or the other planets and their moons. If the spacecraft comes near a large body in space, the gravity of that body will unbalance the forces and curve the path of the spacecraft. This happens, in particular, when a satellite is sent by a rocket on a path that is parallel to Earth's surface. If the rocket shoots the spacecraft fast enough, the spacecraft will orbit Earth. As long as another unbalanced force, such as friction with gas molecules in orbit or the firing of a rocket engine in the opposite direction from its movement, does not slow the spacecraft, it will orbit Earth forever.

Now that the three major terms of this first law have been explained, it is possible to restate this law. If an object, such as a rocket, is at rest, it takes an unbalanced force to make it move. If the object is already moving, it takes an unbalanced force, to stop it, change its direction from a straight line path, or alter its speed.

Newton's Third Law

For the time being, we will skip the second law and go directly to the third. This law states that every action has an equal and opposite reaction. If you have ever stepped off a small boat that has not been properly tied to a pier, you will know exactly what this law means.

A rocket can lift off from a launch pad only when it expels gas out of its engine. The rocket pushes on the gas, and the gas in turn pushes on the rocket. The whole process is very similar to riding a skateboard. Imagine that a skateboard and rider are in a state of rest (not moving). The rider jumps off the skateboard. In the third law, the jumping is called an *action*. The skateboard responds to that action by traveling some distance in the opposite direction. The skateboard's opposite motion is called a *reaction*. When the distance traveled by the rider and the skateboard are compared, it would appear that the skateboard has had a much greater reaction than the action of the rider. This is not the case. The reason the skateboard has traveled farther is that it has less mass than the rider. This concept will be better explained in a discussion of the second law.

With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the mass of the rocket. In space, however, even tiny thrusts will cause the rocket to change direction.

One of the most commonly asked questions about rockets is how they can work in space where there is no air for them to push against. The answer to this question comes from the third law. Imagine the skateboard again. On the ground, the only part air plays in the motions of the rider and the skateboard is to slow them down. Moving through the air causes friction, or as scientists call it, *drag.* The surrounding air impedes the action-reaction.

As a result rockets actually work better in space than they do in air. As the exhaust gas leaves the rocket engine it must push away the surrounding air; this uses up some of the energy of the rocket. In space, the exhaust gases can escape freely.

Newton's Second Law

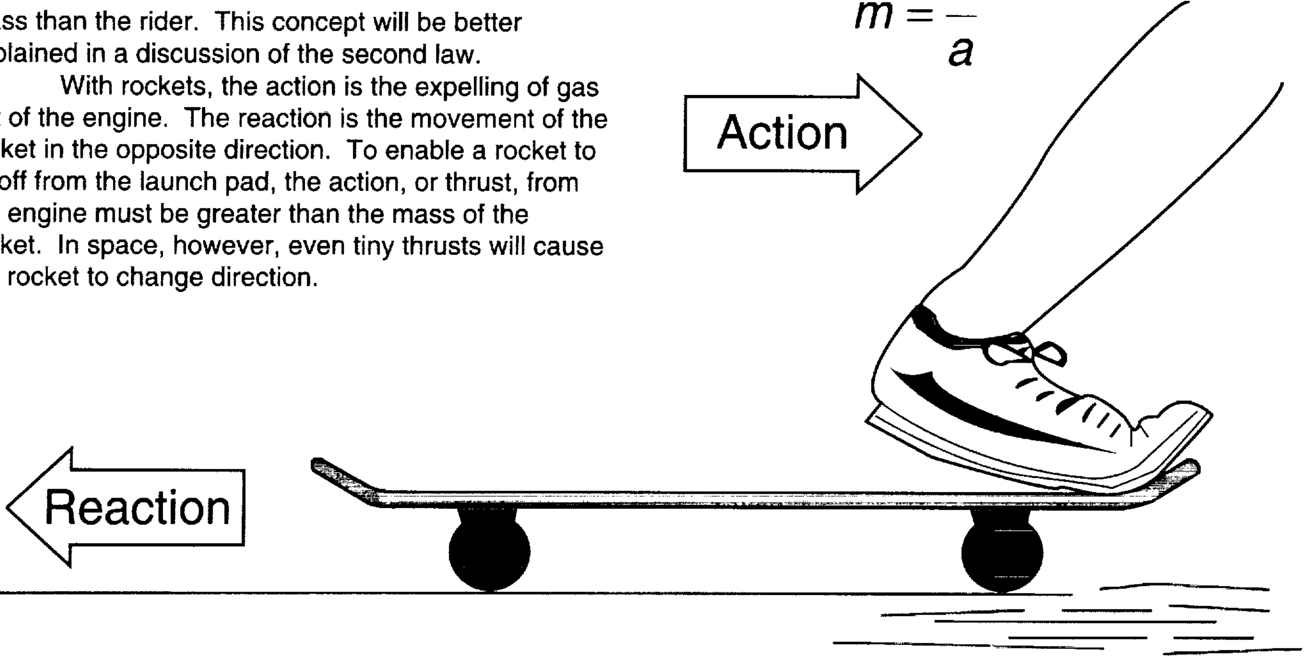
This law of motion is essentially a statement of a mathematical equation. The three parts of the equation are mass (m), acceleration (a), and force (f). Using letters to symbolize each part, the equation can be written as follows:

$$f = ma$$

By using simple algebra, we can also write the equation two other ways:

$$a = \frac{f}{m}$$

$$m = \frac{f}{a}$$



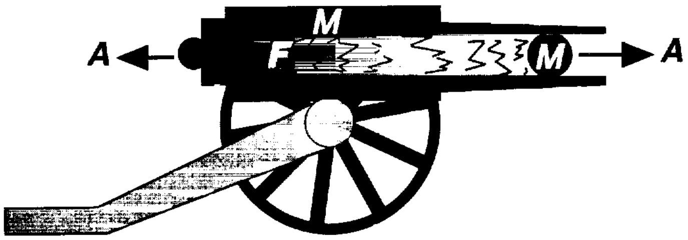
The first version of the equation is the one most commonly referred to when talking about Newton's second law. It reads: force equals mass times acceleration. To explain this law, we will use an old style cannon as an example.

When the cannon is fired, an explosion propels a cannon ball out the open end of the barrel. It flies a kilometer or two to its target. At the same time the cannon itself is pushed backward a meter or two. This is action and reaction at work (third law). The force acting on the cannon and the ball is the same. What happens to the cannon and the ball is determined by the second law. Look at the two equations below.

$$f = m_{(cannon)} a_{(cannon)}$$

$$f = m_{(ball)} a_{(ball)}$$

The first equation refers to the cannon and the second to the cannon ball. In the first equation, the mass is the cannon itself and the acceleration is the movement of the cannon. In the second equation the mass is the cannon ball and the acceleration is its movement.



Because the force (exploding gun powder) is the same for the two equations, the equations can be combined and rewritten below.

$$m_{(cannon)} a_{(cannon)} = m_{(ball)} a_{(ball)}$$

In order to keep the two sides of the equations equal, the accelerations vary with mass. In other words, the cannon has a large mass and a small acceleration. The cannon ball has a small mass and a large acceleration.

Let's apply this principle to a rocket. Replace the mass of the cannon ball with the mass of the gases being ejected out of the rocket engine. Replace the mass of the cannon with the mass of the rocket moving in the other direction. Force is the pressure created by the controlled explosion taking place inside the rocket's engines. That pressure accelerates the gas one way and the rocket the other.

Some interesting things happen with rockets that don't happen with the cannon and ball in this example. With the cannon and cannon ball, the thrust lasts for just a moment. The thrust for the rocket continues as long as its engines are firing. Furthermore, the mass of the rocket changes during flight. Its mass is the sum of all its parts. Rocket parts includes engines, propellant tanks, payload, control system, and propellants. By far, the largest part of the rocket's mass is its propellants. But that amount constantly changes as the engines fire. That means that the rocket's mass gets smaller during flight. In order for the left side of our equation to remain in balance with the right side, acceleration of the rocket has to increase as its mass decreases. That is why a rocket starts off moving slowly and goes faster and faster as it climbs into space.

Newton's second law of motion is especially useful when designing efficient rockets. To enable a rocket to climb into low Earth orbit, it is necessary to achieve a speed, in excess of 28,000 km per hour. A speed of over 40,250 km per hour, called *escape velocity*, enables a rocket to leave Earth and travel out into deep space. Attaining space flight speeds requires the rocket engine to achieve the greatest action force possible in the shortest time. In other words, the engine must burn a large mass of fuel and push the resulting gas out of the engine as rapidly as possible. Ways of doing this will be described in the next chapter.

Newton's second law of motion can be restated in the following way: the greater the mass of rocket fuel burned, and the faster the gas produced can escape the engine, the greater the thrust of the rocket.

Putting Newton's Laws of Motion Together

An unbalanced force must be exerted for a rocket to lift off from a launch pad or for a craft in space to change speed or direction (first law). The amount of thrust (force) produced by a rocket engine will be determined by the mass of rocket fuel that is burned and how fast the gas escapes the rocket (second law). The reaction, or motion, of the rocket is equal to and in the opposite direction of the action, or thrust, from the engine (third law).

Practical Rocketry

The first rockets ever built, the fire-arrows of the Chinese, were not very reliable. Many just exploded on launching. Others flew on erratic courses and landed in the wrong place. Being a rocketeer in the days of the fire-arrows must have been an exciting, but also a highly dangerous activity.

Today, rockets are much more reliable. They fly on precise courses and are capable of going fast enough to escape the gravitational pull of Earth. Modern rockets are also more efficient today because we have an understanding of the scientific principles behind rocketry. Our understanding has led us to develop a wide variety of advanced rocket hardware and devise new propellants that can be used for longer trips and more powerful takeoffs.

Rocket Engines and Their Propellants

Most rockets today operate with either solid or liquid propellants. The word *propellant* does not mean simply fuel, as you might think; it means both *fuel* and *oxidizer*. The fuel is the chemical rockets burn but, for burning to take place, an oxidizer (oxygen) must be present. Jet engines draw oxygen into their engines from the surrounding air. Rockets do not have the luxury that jet planes have; they must carry oxygen with them into space, where there is no air.

Solid rocket propellants, which are dry to the touch, contain both the fuel and oxidizer combined together in the chemical itself. Usually the fuel is a mixture of hydrogen compounds and carbon and the oxidizer is made up of oxygen compounds. Liquid propellants, which are often gases that have been chilled until they turn into liquids, are kept in separate containers, one for the fuel and the other for the oxidizer. Then, when the engine fires, the fuel and oxidizer are mixed together in the engine.

A *solid-propellant rocket* has the simplest form of engine. It has a *nozzle*, a *case*, *insulation*, propellant, and an *igniter*. The case of the engine is usually a relatively thin metal that is lined with insulation to keep the propellant from burning through. The propellant itself is packed inside the insulation layer.

Many solid-propellant rocket engines feature a hollow core that runs through the propellant. Rockets that do not have the hollow core must be ignited at the lower end of the propellants and burning proceeds gradually from one end of the rocket to the other. In all cases, only the surface of the propellant burns. However, to get higher thrust, the hollow core is used. This increases the surface of the propellants available for burning. The propellants burn from the inside out at a much higher rate, and the gases produced escape the engine at much higher speeds. This gives a greater thrust. Some propellant cores are star shaped to increase the burning surface even more.

To fire solid propellants, many kinds of igniters can be used. Fire-arrows were ignited by fuses, but sometimes these ignited too quickly and burned the rocketeer. A far safer and more reliable form of ignition used today is one that employs electricity. An electric current, coming through wires from some distance away, heats up a special wire inside the rocket. The wire raises the temperature of the propellant it is in contact with to the combustion point.

Other igniters are more advanced than the hot wire device. Some are encased in a chemical that ignites first, which then ignites the propellants. Still other igniters, especially those for large rockets, are rocket engines themselves. The small engine inside the hollow core blasts a stream of flames and hot gas down from the top of the core and ignites the entire surface area of the propellants in a fraction of a second.

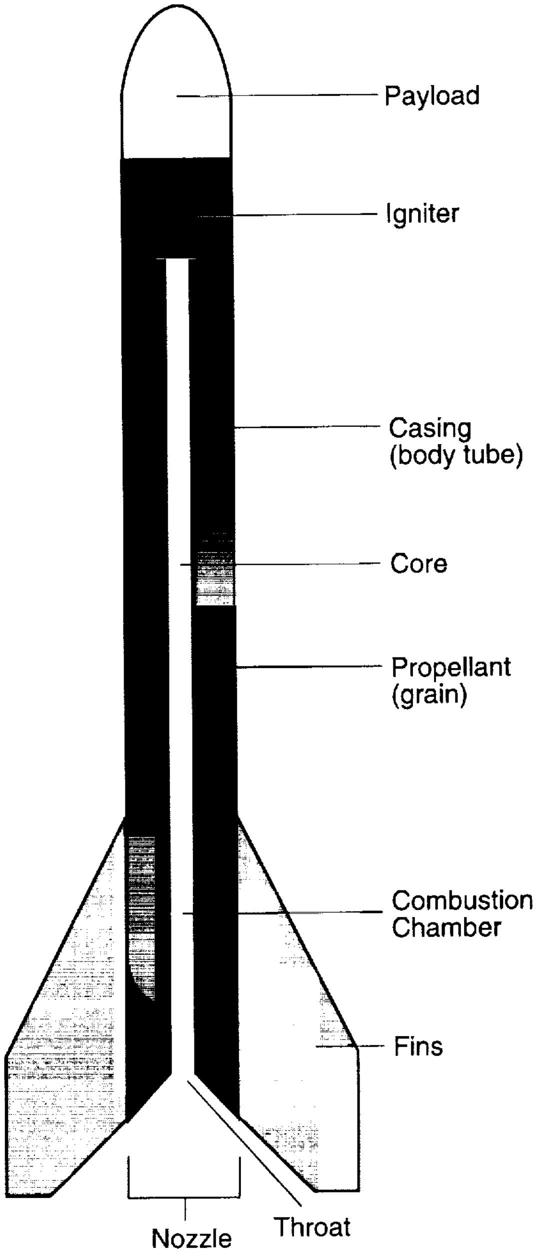
The nozzle in a solid-propellant engine is an opening at the back of the rocket that permits the hot expanding gases to escape. The narrow part of the nozzle is the *throat*. Just beyond the throat is the exit cone.

The purpose of the nozzle is to increase the acceleration of the gases as they leave the rocket and thereby maximize the thrust. It does this by cutting down the opening through which the gases can escape. To see how this works, you can experiment with a garden hose that has a spray nozzle attachment. This kind of nozzle does not have an exit cone, but that does not matter in the experiment. The important point about the nozzle is that the size of the opening can be varied.

Start with the opening at its widest point. Watch how far the water squirts and feel the thrust produced by the departing water. Now reduce the diameter of the opening, and again note the distance the water squirts and feel the thrust. Rocket nozzles work the same way.

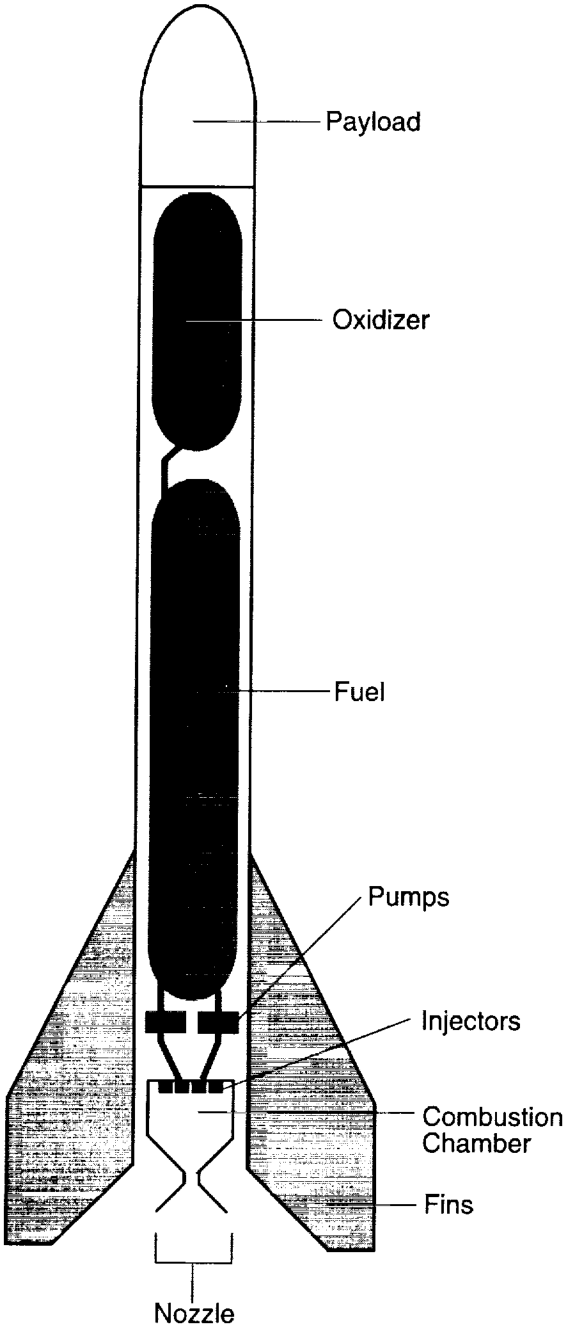
As with the inside of the rocket case, insulation is needed to protect the nozzle from the hot gases. The usual insulation is one that gradually erodes as the gas passes through. Small pieces of the insulation get very hot and break away from the nozzle. As they are blown away, heat is carried away with them.

The other main kind of rocket engine is one that uses liquid propellants. This is a much more complicated engine, as is evidenced by the fact that solid rocket engines were used for at least seven hundred years before the first successful liquid engine was tested. Liquid propellants have separate storage tanks—one for the fuel and one for the oxidizer. They also have *pumps*, a *combustion chamber*, and a nozzle.



Solid Propellant Rocket

The fuel of a liquid-propellant rocket is usually kerosene or liquid hydrogen; the oxidizer is usually liquid oxygen. They are combined inside a cavity called the combustion chamber. Here the propellants burn and build up high temperatures and pressures, and the expanding gas escapes through the nozzle at the lower end. To get the most power from the propellants, they must be mixed as completely as possible. Small *injectors* (nozzles) on the roof of the chamber spray and mix the propellants at the same time. Because the chamber operates under high



Liquid Propellant Rocket

pressures, the propellants need to be forced inside. Powerful, lightweight turbine pumps between the propellant tanks and combustion chambers take care of this job.

With any rocket, and especially with liquid-propellant rockets, weight is an important factor. In general, the heavier the rocket, the more the thrust needed to get it off the ground. Because of the pumps and fuel lines, liquid engines are much heavier than solid engines.

One especially good method of reducing the weight of liquid engines is to make the exit cone of the nozzle out of very lightweight metals. However, the extremely hot, fast-moving gases that pass through the cone would quickly melt thin metal. Therefore, a cooling system is needed. A highly effective though complex cooling system that is used with some liquid engines takes advantage of the low temperature of liquid hydrogen. Hydrogen becomes a liquid when it is chilled to -253°C. Before injecting the hydrogen into the combustion chamber, it is first circulated through small tubes that lace the walls of the exit cone. In a cutaway view, the exit cone wall looks like the edge of corrugated cardboard. The hydrogen in the tubes absorbs the excess heat entering the cone walls and prevents it from melting the walls away. It also makes the hydrogen more energetic because of the heat it picks up. We call this kind of cooling system *regenerative cooling.*

Engine Thrust Control

Controlling the thrust of an engine is very important to launching payloads (cargoes) into orbit. Too much thrust or thrust at the wrong time can cause a satellite to be placed in the wrong orbit or set too far out into space to be useful. Too little thrust can cause the satellite to fall back to Earth.

Liquid-propellant engines control the thrust by varying the amount of propellant that enters the combustion chamber. A computer in the rocket's guidance system determines the amount of thrust that is needed and controls the propellant flow rate. On more complicated flights, such as going to the Moon, the engines must be started and stopped several times. Liquid engines do this by simply starting or stopping the flow of propellants into the combustion chamber.

Solid-propellant rockets are not as easy to control as liquid rockets. Once started, the propellants burn until they are gone. They are very difficult to stop or slow down part way into the burn. Sometimes fire extinguishers are built into the engine to stop the rocket in flight. But using them is a tricky procedure and doesn't always work. Some solid-fuel engines have hatches on their sides that can be cut loose by remote control to release the chamber pressure and terminate thrust.

The burn rate of solid propellants is carefully planned in advance. The hollow core running the length of the propellants can be made into a star shape. At first, there is a very large surface available for burning, but as the points of the star burn away, the surface area is reduced. For a time, less of the propellant burns, and this reduces thrust. The *Space Shuttle* uses this technique to reduce vibrations early in its flight into orbit.

NOTE: Although most rockets used by governments and research organizations are very reliable, there is still great danger associated with the building and firing of rocket engines. Individuals interested in rocketry should ***never*** attempt to build their own engines. Even the simplest-looking rocket engines are very complex. Case-wall bursting strength, propellant packing density, nozzle design, and propellant chemistry are all design problems beyond the scope of most amateurs. Many home-built rocket engines have exploded in the faces of their builders with tragic consequences.

Stability and Control Systems

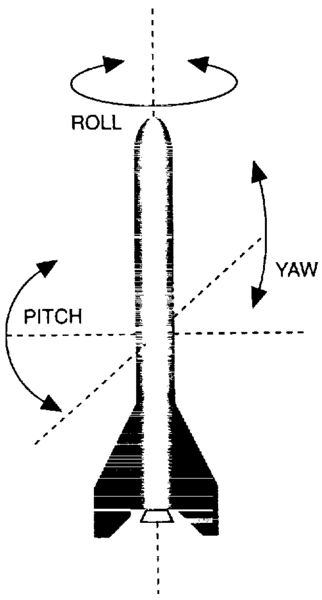
Building an efficient rocket engine is only part of the problem in producing a successful rocket. The rocket must also be stable in flight. A stable rocket is one that flies in a smooth, uniform direction. An unstable rocket flies along an erratic path, sometimes tumbling or changing direction. Unstable rockets are dangerous because it is not possible to predict where they will go. They may even turn upside down and suddenly head back directly to the launch pad.

Making a rocket stable requires some form of control system. Controls can be either active or passive. The difference between these and how they work will be explained later. It is first important to understand what makes a rocket stable or unstable.

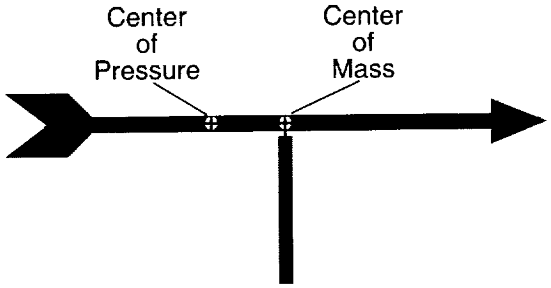
All matter, regardless of size, mass, or shape, has a point inside called the *center of mass* (CM). The center of mass is the exact spot where all of the mass of that object is perfectly balanced. You can easily find the center of mass of an object such as a ruler by balancing the object on your finger. If the material used to make the ruler is of uniform thickness and density, the center of mass should be at the halfway point between one end of the stick and the other. If the ruler were made of wood, and a heavy nail were driven into one of its ends, the center of mass would no longer be in the middle. The balance point would then be nearer the end with the nail.

The center of mass is important in rocket flight because it is around this point that an unstable rocket tumbles. As a matter of fact, any object in flight tends to tumble. Throw a stick, and it tumbles end over end. Throw a ball, and it spins in flight. The act of spinning or tumbling is a way of becoming stabilized in flight. A Frisbee will go where you want it to only if you throw it with a deliberate spin. Try throwing a Frisbee without spinning it. If you succeed, you will see that the Frisbee flies in an erratic path and falls far short of its mark.

In flight, spinning or tumbling takes place around one or more of three axes. They are called *roll, pitch,* and *yaw.* The point where all three of these axes intersect is the center of mass. For rocket flight, the pitch and yaw axes are the most important because any movement in either of these two directions can cause the rocket to go off course. The roll axis is the least important because movement along this axis will not affect the flight path. In fact, a rolling motion will help stabilize the rocket in the same way a properly passed football is stabilized by rolling (spiraling) it in flight. Although a poorly passed football may still fly to its mark even if it tumbles rather than rolls, a rocket will not. The action-reaction energy of a football pass will be completely expended by the thrower the moment the ball leaves the hand. With rockets, thrust from the engine is still being produced while the rocket is in flight. Unstable motions about the pitch and yaw axes will cause the rocket to leave the planned course. To prevent this, a control system is needed to prevent or at least minimize unstable motions.



In addition to center of mass, there is another important center inside the rocket that affects its flight. This is the *center of pressure* (CP). The center of pressure exists only when air is flowing past the moving rocket. This flowing air, rubbing and pushing against the outer surface of the rocket, can cause it to begin moving around one of its three axes. Think for a moment of a weather vane. A weather vane is an arrow-like stick that is mounted on a rooftop and used for telling wind direction. The arrow is attached to a vertical rod that acts as a pivot point. The arrow is balanced so that the center of mass is right at the pivot point. When the wind blows, the arrow turns, and the head of the arrow points into the on-coming wind. The tail of the arrow points in the downwind direction.



The reason that the weather vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail than the head, and therefore the tail is pushed away. There is a point on the arrow where the surface area is the same on one side as the other. This spot is called the center of pressure. The center of pressure is not in the same place as the center of mass. If it were, then neither end of the arrow would be favored by the wind and the arrow would not point. The center of pressure is between the center of mass and the tail end of the arrow. This means that the tail end has more surface area than the head end.

It is extremely important that the center of pressure in a rocket be located toward the tail and the center of mass be located toward the nose. If they are in the same place or very near each other, then the rocket will be unstable in flight. The rocket will then try to rotate about the center of mass in the pitch and yaw axes, producing a dangerous situation. With the center of pressure located in the right place, the rocket will remain stable.

Control systems for rockets are intended to keep a rocket stable in flight and to steer it. Small rockets usually require only a stabilizing control system. Large rockets, such as the ones that launch satellites into orbit, require a system that not only stabilizes the rocket, but also enable it to change course while in flight.

Controls on rockets can either be active or passive. *Passive controls* are fixed devices that keep rockets stabilized by their very presence on the rocket's exterior. *Active controls* can be moved while the rocket is in flight to stabilize and steer the craft.

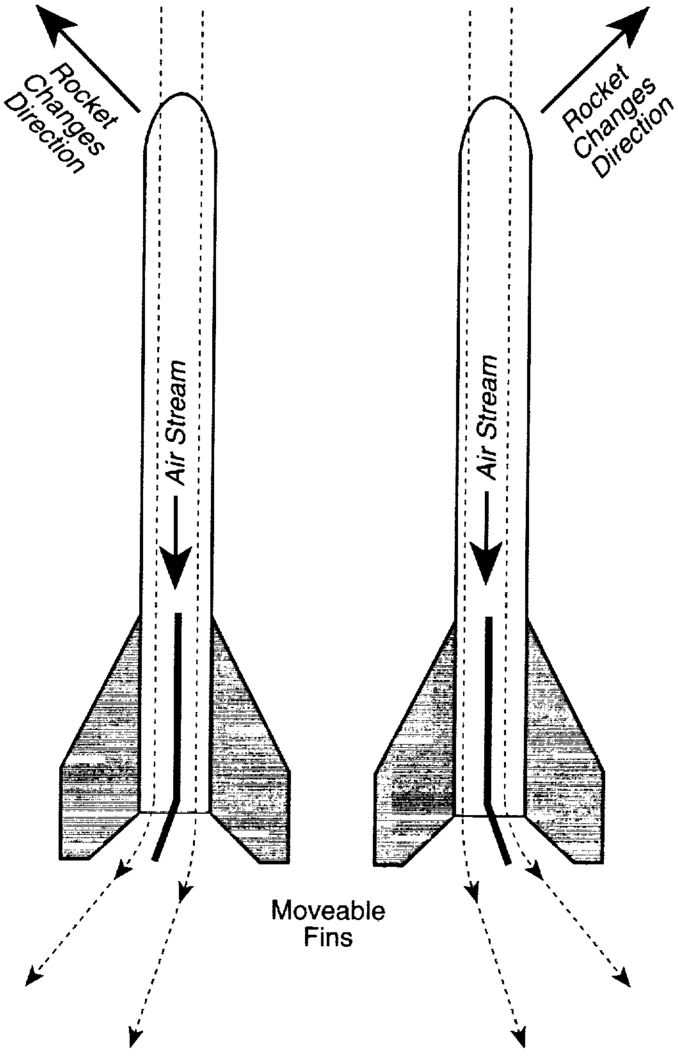
The simplest of all passive controls is a stick. The Chinese fire-arrows were simple rockets mounted on the ends of sticks. The stick kept the center of pressure behind the center of mass. In spite of this, fire-arrows were notoriously inaccurate. Before the center of pressure could take effect, air had to be flowing past the rocket. While still on the ground and immobile, the arrow might lurch and fire the wrong way.

Years later, the accuracy of fire-arrows was improved considerably by mounting them in a trough aimed in the proper direction. The trough guided the arrow in the right direction until it was moving fast enough to be stable on its own.

As will be explained in the next section, the weight of the rocket is a critical factor in performance and range. The fire-arrow stick added too much dead weight to the rocket, and therefore limited its range considerably.

An important improvement in rocketry came with the replacement of sticks by clusters of lightweight fins mounted around the lower end near the nozzle. Fins could be made out of lightweight materials and be streamlined in shape. They gave rockets a dartlike appearance. The large surface area of the fins easily kept the center of pressure behind the center of mass. Some experimenters even bent the lower tips of the fins in a pinwheel fashion to promote rapid spinning in flight. With these "spin fins," rockets become much more stable in flight. But this design also produces more drag and limits the rocket's range.

With the start of modern rocketry in the 20th century, new ways were sought to improve rocket stability and at the same time reduce overall rocket weight. The answer to this was the development of active controls. Active control systems included *vanes, movable fins, canards, gimbaled nozzles, vernier rockets, fuel injection*, and *attitude-control rockets*. Tilting fins and canards are quite similar to each other in appearance. The only real difference between them is their location on the rockets. Canards are mounted on the front end of the rocket while the tilting fins are at the rear. In flight, the fins and canards tilt like rudders to deflect the air flow and cause the rocket to change course. Motion sensors on

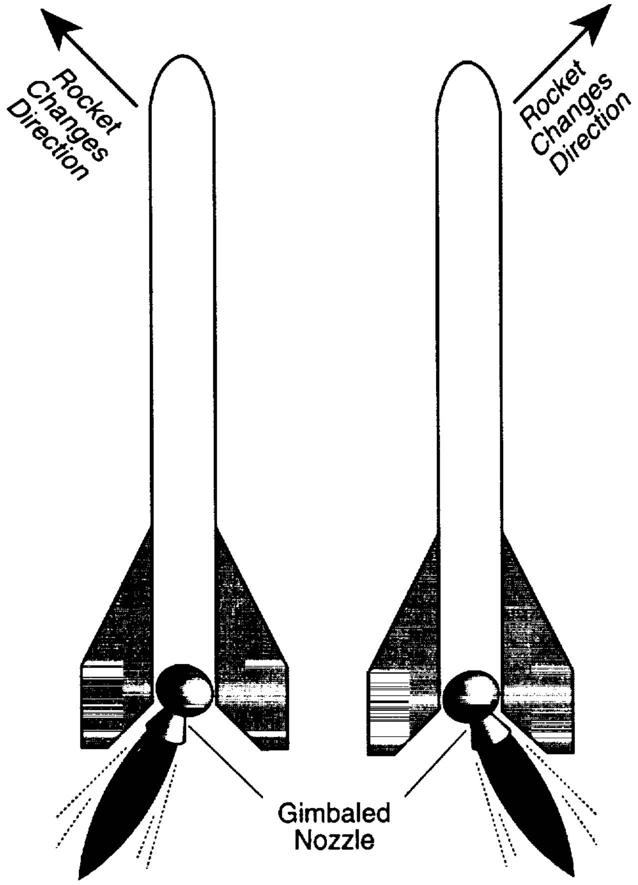


the rocket detect unplanned directional changes, and corrections can be made by slight tilting of the fins and canards. The advantage of these two devices is size and weight. They are smaller and lighter and produce less drag than the large fins.

Other active control systems can eliminate fins and canards altogether. By tilting the angle at which the exhaust gas leaves the rocket engine, course changes can be made in flight. Several techniques can be used for changing exhaust direction.

Vanes are small finlike devices that are placed inside the exhaust of the rocket engine. Tilting the vanes deflects the exhaust, and by action-reaction the rocket responds by pointing the opposite way.

Another method for changing the exhaust direction is to gimbal the nozzle. A gimbaled nozzle is one that is able to sway while exhaust gases are passing through it. By tilting the engine nozzle in the proper direction, the rocket responds by changing course.



Vernier rockets can also be used to change direction. These are small rockets mounted on the outside of the large engine. When needed they fire, producing the desired course change.

In space, only by spinning the rocket along the roll axis or by using active controls involving the engine exhaust can the rocket be stabilized or have its direction changed. Without air, fins and canards have nothing to work upon. (Science fiction movies showing rockets in space with wings and fins are long on fiction and short on science.) The most common kinds of active control used in space are attitude-control rockets. Small clusters of engines are mounted all around the vehicle. By firing the right combination of these small rockets, the vehicle can be turned in any direction. As soon as they are aimed properly, the main engines fire, sending the rocket off in the new direction.

Mass

There is another important factor affecting the performance of a rocket. The mass of a rocket can make the difference between a successful flight and just wallowing around on the launch pad. As a basic principle of rocket flight, it can be said that for a rocket to leave the ground, the engine must produce a thrust that is greater than the total mass of the vehicle. It is obvious that a rocket with a lot of unnecessary mass will not be as efficient as one that is trimmed to just the bare essentials.

For an ideal rocket, the total mass of the vehicle should be distributed following this general formula:

> Of the total mass, 91 percent should be propellants; 3 percent should be tanks, engines, fins, etc.; and 6 percent can be the payload.

Payloads may be satellites, astronauts, or spacecraft that will travel to other planets or moons.

In determining the effectiveness of a rocket design, rocketeers speak in terms of mass fraction (MF). The mass of the propellants of the rocket divided by the total mass of the rocket gives mass fraction:

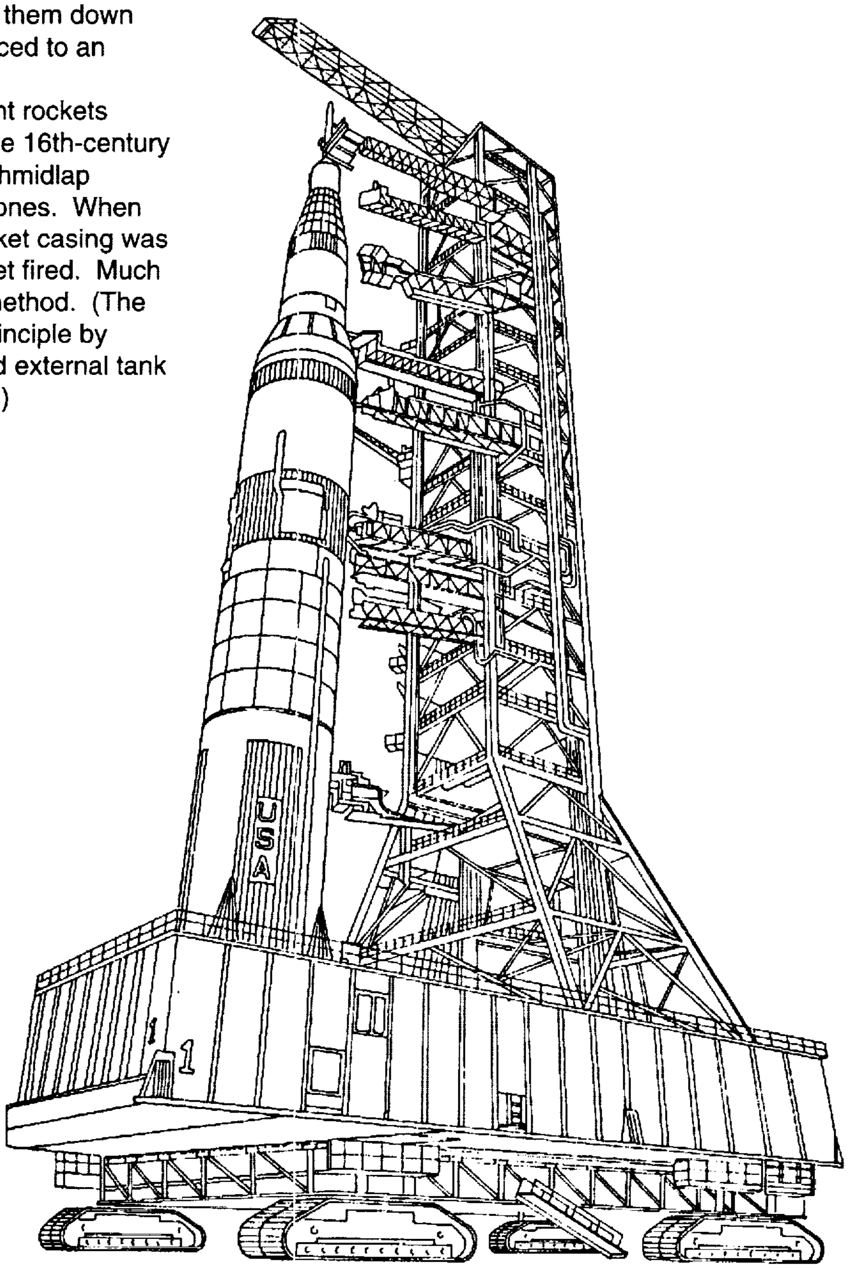
$$MF = \frac{mass\ \ of\ \ propellants}{total\ \ mass}$$

The mass fraction of the ideal rocket given above is 0.91. From the mass fraction formula one might think that an MF of 1.0 is perfect, but then the entire rocket would be nothing more than a lump of propellants that would simply ignite into a fireball. The larger the MF number, the less payload the rocket can carry; the smaller the MF number, the less its range becomes. An MF number of 0.91 is a good balance between payload-carrying capability and range. The Space Shuttle has an MF of approximately 0.82. The MF varies between the different orbiters in the Space Shuttle fleet and with the different payload weights of each mission.

Large rockets, able to carry a spacecraft into space, have serious weight problems. To reach space and proper orbital velocities, a great deal of propellant is needed; therefore, the tanks, engines, and associated hardware become larger. Up to a point, bigger rockets fly farther than smaller rockets, but when they become too large their structures weigh them down too much, and the mass fraction is reduced to an impossible number.

A solution to the problem of giant rockets weighing too much can be credited to the 16th-century fireworks maker Johann Schmidlap. Schmidlap attached small rockets to the top of big ones. When the large rocket was exhausted, the rocket casing was dropped behind and the remaining rocket fired. Much higher altitudes were achieved by this method. (The Space Shuttle follows the step rocket principle by dropping off its solid rocket boosters and external tank when they are exhausted of propellants.)

The rockets used by Schmidlap were called step rockets. Today this technique of building a rocket is called *staging.* Thanks to staging, it has become possible not only to reach outer space but the Moon and other planets too.



Saturn V rocket being transported to the launch pad

Activities and Demonstrations

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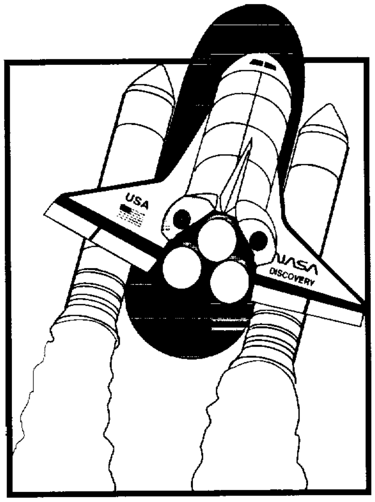


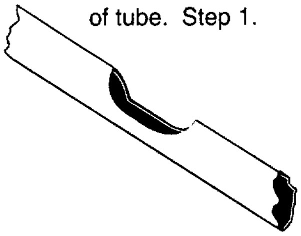
Hero Engines

Objective: To demonstrate Newton's Third Law of Motion using the action force of expanding steam or falling water.

Description: This activity provides plans for constructing and using two versions (teacher demonstration model and student model) of a working Hero engine.

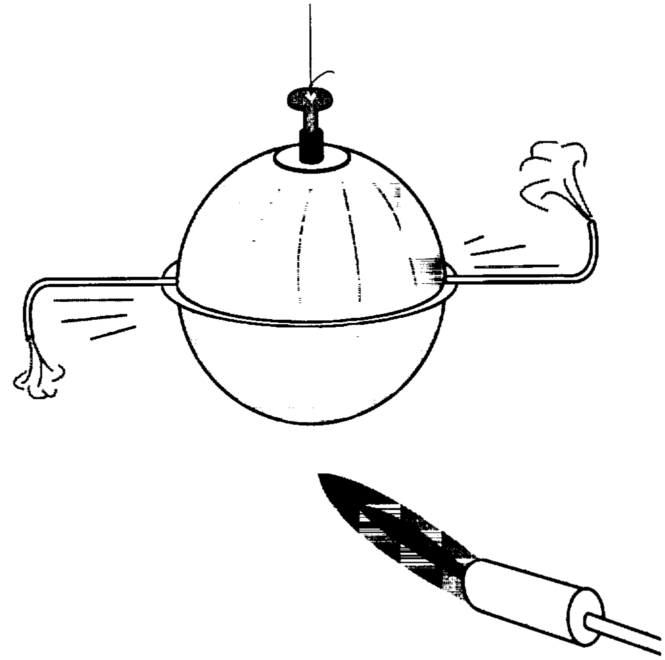
Procedure: Making a Steam-Powered Hero Engine (Teacher Model)

1. File the middle of the brass tube until a notch is produced. Do not file the tube in half.
2. Using the ice pick or drill, bore two small holes on opposite sides of the float at its middle. The holes should be just large enough to pass the tube straight through the float.
3. With the tube positioned so that equal lengths protrude through the float, heat the contact points of the float and tube with the propane torch. Touch the end of the solder to the heated area so that it melts and seals both joints.
4. Drill a water access hole through the threaded connector at the top of the float.
5. Using the torch again, heat the protruding tubes about one inch from each end. With pliers, carefully bend the tube tips in opposite directions. Bend the tubes slowly so they do not crimp.
6. Drill a small hole through the flat part of the thumb screw for attaching the fish line and swivel. Twist the thumb screw into the threaded connector of the float in step 4 and attach the line and swivel.


File notch in middle of tube. Step 1.

Procedure: Using the Steam-Powered Hero Engine

1. Place a small amount of water (about 10 to 20 ml) into the float. The precise amount is not important. The float can be filled through the top if you drilled an access hole or through the tubes by partially immersing the engine in a bowl of water with one tube submerged and the other out of the water.



2. Suspend the engine and heat its bottom with the torch. In a minute or two, the engine should begin spinning. Be careful not to operate the engine too long because it probably will not be exactly balanced and may wobble violently. If it begins to wobble, remove the heat.

Materials and Tools: (Teacher Model)

Copper toilet tank float (available from full-line hardware stores)
Thumb screw, 1/4 inch
Brass tube, 3/16 I.D., 12 in. (from hobby shops)
Solder
Fishing line
Ice pick or drill
Metal file
Propane torch

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Caution: The steam-powered Hero engine should be operated by adults only. Wear eye protection. Be sure to confirm that the tubes are not obstructed in any way before heating. Test them by blowing through one like a straw. If air flows out the other tube, the engine is safe to use.

Procedure: Making and Using the Soda Pop Can Hero Engine (Student Model)

1. Lay the can on its side and using the nail or ice pick carefully punch four equally spaced, small holes just above and around the bottom rim. Then, before removing the punching tool from each hole, push the tool to the right (parallel to the rim) so that the holes all slant in the same direction.
2. Bend the can's opener lever straight up and tie a short length of fishing line to it.
3. Immerse the can in water until it is filled. Pull the can out by the fishing line. As water streams out, the can will start spinning.

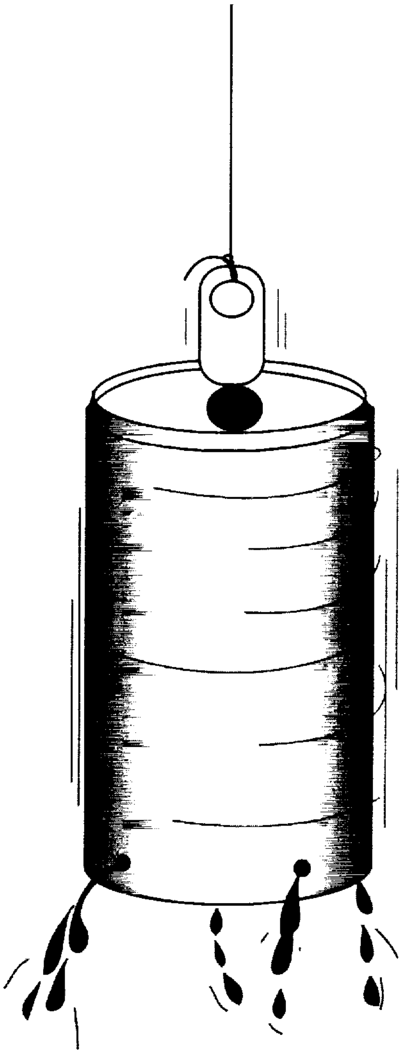
Discussion:

The Hero engine was invented by Hero of Alexandria in the first century B.C. Refer to the historical text at the beginning of this guide for information about the engine and other early rocket-powered devices.

The principle behind the Hero engine is simple. Steam from the boiling water inside the float pressurizes the metal sphere (float). The steam rapidly escapes through the L-shaped tubes producing an action-reaction force that causes the sphere to spin in the opposite direction. The action-reaction principle of the Hero engine is the same that is used to propel airplanes and rockets.

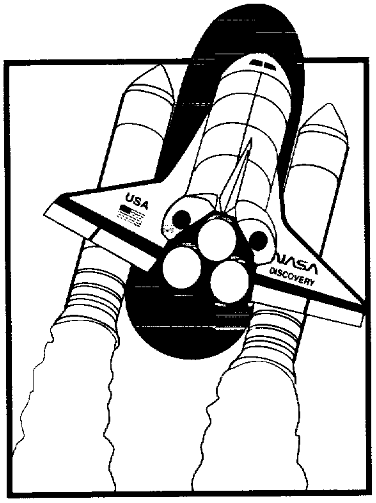
Teaching Notes and Questions:

- Because of the steam produced with the first Hero engine. Only the teacher should operate it. The second engine design is safe for all students to use.
- Is there any difference in the efficiency (rate of rotation) of the soda pop engines and the number and diameter of the holes? If there are differences, how can they be explained using Newton's Second Law of Motion?
- What happens if the holes slant in different directions?
- What happens when the holes are spaced unevenly or at different heights?
- Be sure to recycle the soda pop cans at the end of the activity.



Materials and Tools: (Student Model)

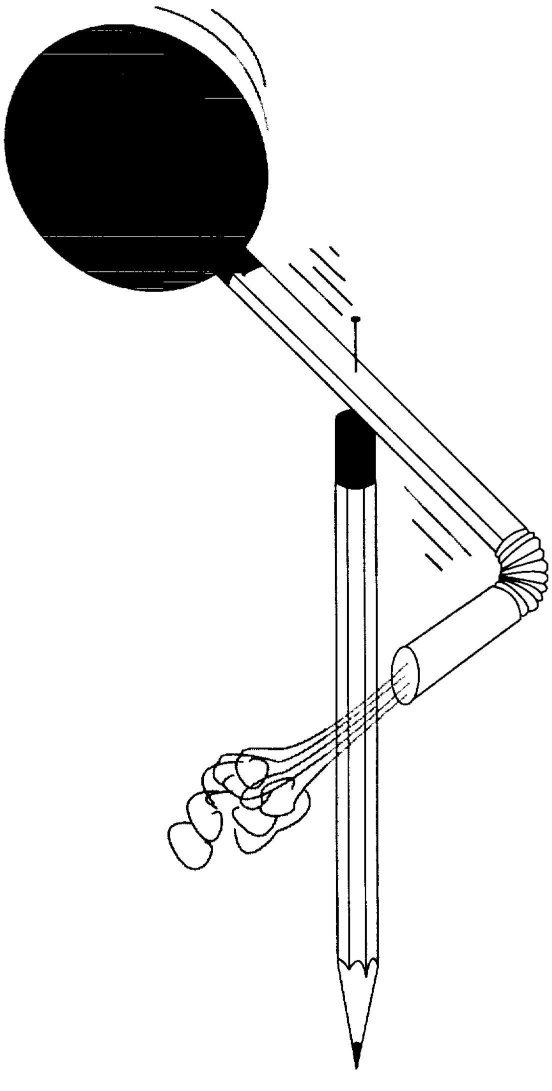
Empty soda pop can with the opener lever still attached
Nail or ice pick
Fishing line
Bucket or tub of water



Rocket Pinwheel

Objective: To demonstrate Newton's Third Law of Motion using air escaping from a balloon as the action force.

Description: In this activity, students construct a balloon-powered pinwheel that spins from the force of air escaping through a plastic straw.



Method:

1. Inflate the balloon to stretch it out.
2. Slip the nozzle end of the balloon over the end of the straw farthest away from the flexible bend. Use a short piece of plastic tape to seal the balloon to the straw. The balloon should inflate when you blow through the straw.
3. Bend the opposite end of the straw at a right angle.
4. Lay the straw and balloon on an outstretched finger to find the balance point. Push the pin through the straw at the balance point, into the pencil eraser, and into the wood itself.
5. Spin the straw a few times to loosen up the hole the pin made.
6. Inflate the balloon and let go of the straw.

Discussion:

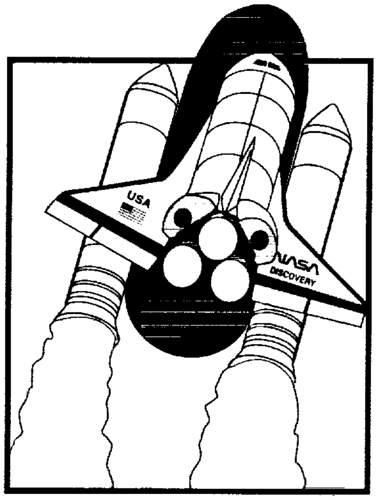
The balloon-powered pinwheel spins because of the action-reaction principle described in Newton's Third Law of Motion. The air, traveling around the bend in the straw, imparts a reaction force at a right angle to the straw. The result is that the balloon and straw spin around the pin in the opposite direction.

Teaching Notes and Questions:

- This activity can be done by every student; however, younger students may need assistance in inserting the pin into the wood of the pencil.
- Some toy and variety stores sell an inexpensive balloon-powered helicopter. The device has three small plastic wings through which air passes and is released in a right angle direction at each blade tip. Try to obtain one or more of these toys for comparison with the balloon pinwheel. The toy is marketed under the name of *Whistle Balloon Helicopter*. One of these helicopters was used by astronauts on the STS-54 Space Shuttle mission during the Physics of Toys live lesson. Refer to the reference list at the end of this guide for information on obtaining a videotape that demonstrates this toy's performance in microgravity.

Materials:

Wooden pencil with an eraser on one end
Straight pin
Round party balloon
Flexible soda straw
Plastic tape



Rocket Car

Objective: Newton's Third Law of Motion is demonstrated with escaping air as the action force.

Description: In this activity, students construct a balloon-powered rocket car that rolls across the floor because air is forced to escape through a plastic straw.

Procedure:

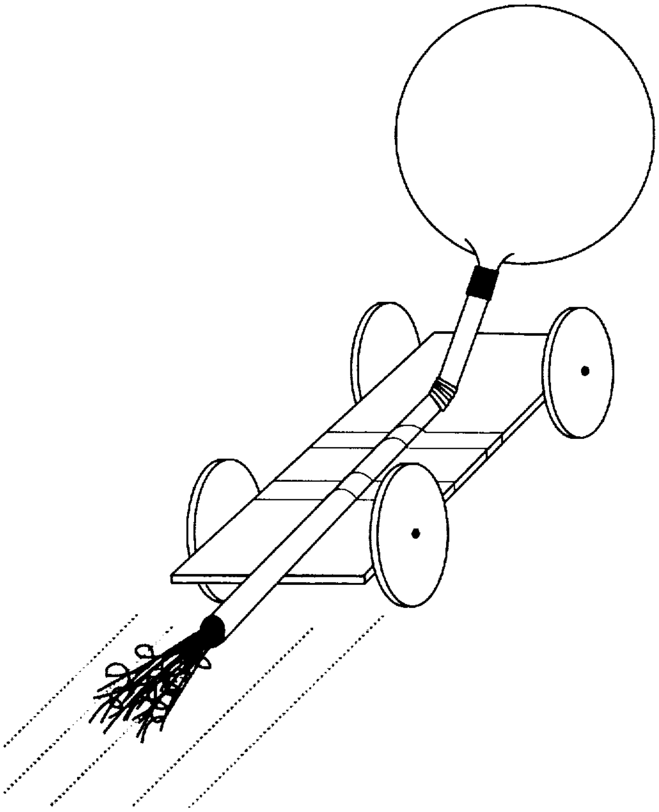
1. Using the ruler, marker, and drawing compass, draw a rectangle about 7.5 cm by 18 cm and four circles 7.5 cm in diameter on the flat surface of the meat tray. Cut out each piece.
2. Inflate the balloon a few times to stretch it. Slip the nozzle over the end of the flexi-straw nearest the bend. Secure the nozzle to the straw with tape and seal it tight so that the balloon can be inflated by blowing through the straw.
3. Tape the straw to the car as shown in the picture.
4. Push one pin into the center of each circle and then into the edge of the rectangle as shown in the picture. The pins become axles for the wheels. Do not push the pins in snugly because the wheels have to rotate freely. It is okay if the wheels wobble.
5. Inflate the balloon and pinch the straw to hold in the air. Set the car on a smooth surface and release the straw.

Discussion:

The rocket car is propelled along the floor according to the principle stated in Isaac Newton's Third Law of Motion. The escaping air is the action and the movement of the car in the opposite direction is the reaction. The car's wheels reduce friction and provide some stability to the car's motion. A well-designed and constructed car will travel several meters in a straight line across a smooth floor.

Teaching Notes and Questions:

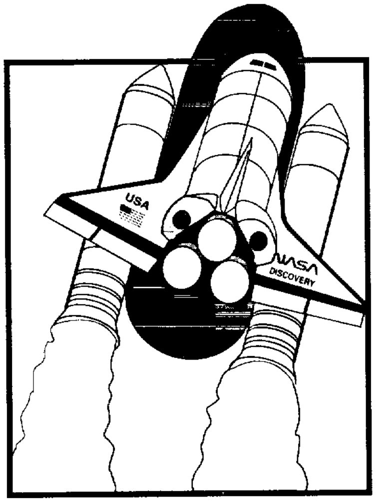
- Encourage students to design their own cars. Cars can be made long or short, wide or narrow, or even trapezoidal. Wheels can be large or small. If styrofoam coffee cups are available (retrieved from the waste basket and washed is preferable), the bottoms can be cut off and used as wheels.
- Hold car distance trials on the floor. Have students measure and chart the distance each car travels.



Average multiple runs for individual cars to identify the best cars. What makes one car design perform better than another? Are large wheels better than small wheels?

Materials and Tools:

4 pins
Styrofoam meat tray
Cellophane tape
Flexi-straw
Scissors
Drawing compass
Marker pen
Small party balloon
Ruler



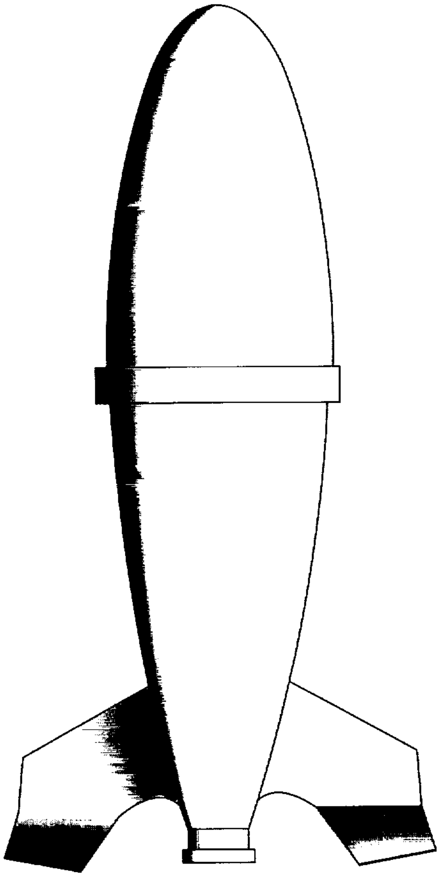
Water Rocket

Objective: To demonstrate how rocket performance is improved through application of Newton's Second Law of Motion

Description: In this activity, students test fire a commercial water rocket using varying amounts of air pressure and water to learn how optimum performance can be achieved.

Procedure:

1. Take the water rockets, water supply, measuring tape, and markers to an outside location such as a clear, grassy playing field.
2. Attach both rockets to their pumps according to the manufacturer's instructions. Pump one rocket 10 times. Pump the second rocket 20 times. Have two students point the rockets across the field in a direction in which no one is standing. The rockets should be held next to each other at exactly the same height above the ground and aimed upward at about a 45 degree angle. Count backwards from 3 and have the students release the rockets. Mark the distance each rocket flew.
3. Pour water into one rocket so that it fills up to the recommended level in the instructions. Do not pour water into the other rocket. Attach both rockets to their pumps. Pump both rockets 20 times. Again aim the rockets across the field as before and release them simultaneously. Mark the distance each rocket flew. **Caution: The rocket with the water will expel the water from its chamber and may spray the students. If the students stand to the side for the release, the water spray should miss them.**
4. Try other combinations for simultaneous firings of the rockets, such as a small amount of water in one and a larger amount of water in the other, or equal amounts of water but one pumped a different number of times. Be sure to change only one variable at a time (i.e., vary only the water or only the pumping).



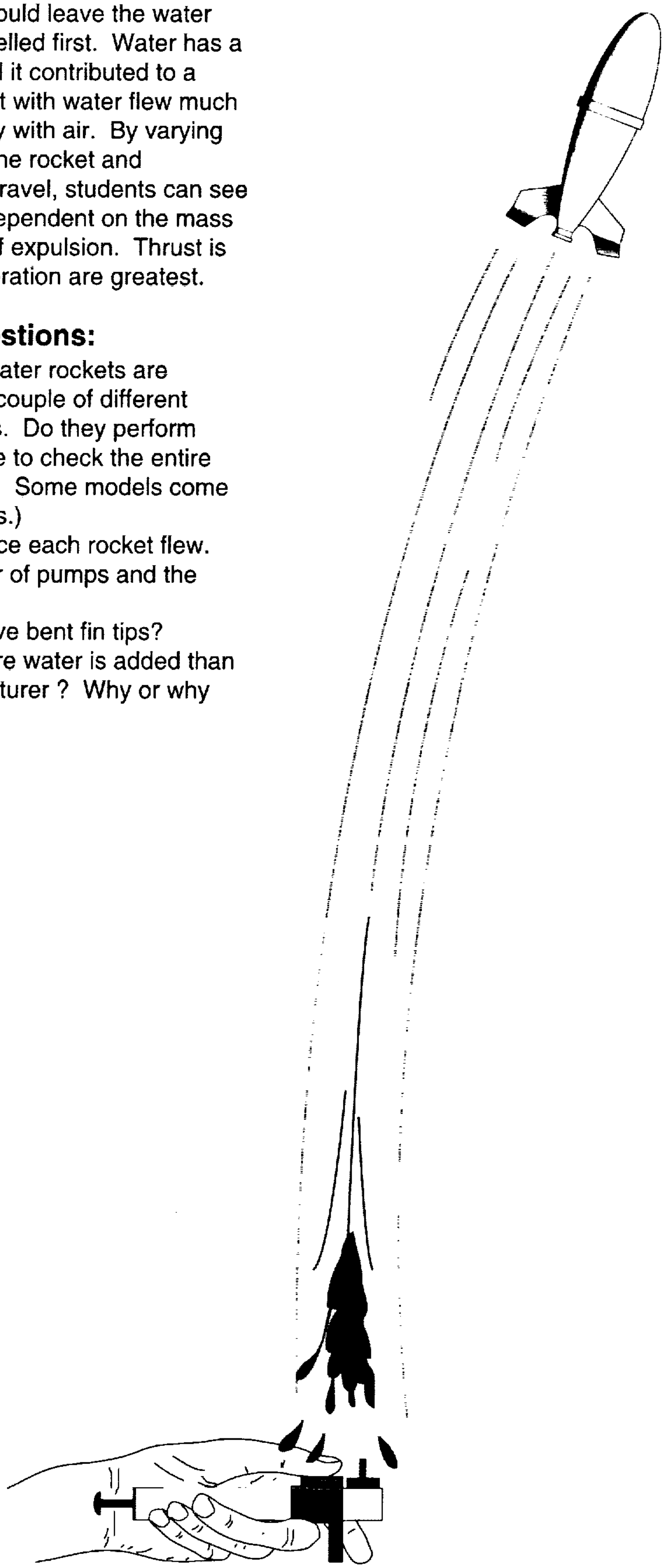
Discussion:

Water rockets can demonstrate Newton's Second Law of Motion where one varies the pressure inside the rocket and the amount of water present. In the first test, neither rocket went very far because the air inside did not have much mass. The rocket that was pumped more did travel farther because the air in that rocket was under greater pressure and it escaped the rocket

Materials and Tools:

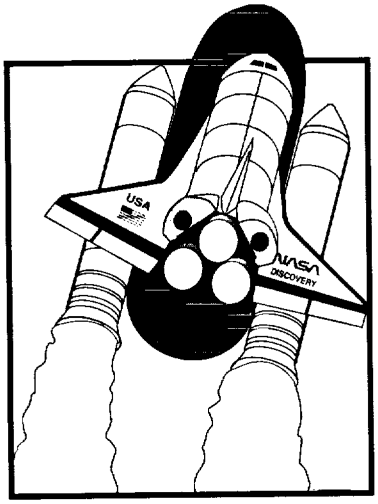
2 Water rockets and pumps (available for a few dollars each from toy stores)
Water
Small wooden stakes, small flags, or other materials to serve as markers
Tape measure

at a higher speed (acceleration). When water was added to one of the rockets, the effect of mass was demonstrated. Before the air could leave the water rocket, the water had to be expelled first. Water has a much greater mass than air and it contributed to a much greater thrust. The rocket with water flew much farther than the rocket filled only with air. By varying the amount of water and air in the rocket and measuring how far the rockets travel, students can see that the thrust of the rocket is dependent on the mass being expelled and the speed of expulsion. Thrust is greatest when mass and acceleration are greatest.



Teaching Notes and Questions:

- Several different versions of water rockets are available. If you can obtain a couple of different models, run comparison flights. Do they perform equally? If not, why? (Be sure to check the entire rocket to answer this question. Some models come with bigger nozzles than others.)
- Measure and graph the distance each rocket flew. Be sure to indicate the number of pumps and the quantity of water used.
- Why does the water rocket have bent fin tips?
- Will the rocket go farther if more water is added than recommended by the manufacturer ? Why or why not?



Bottle Rocket

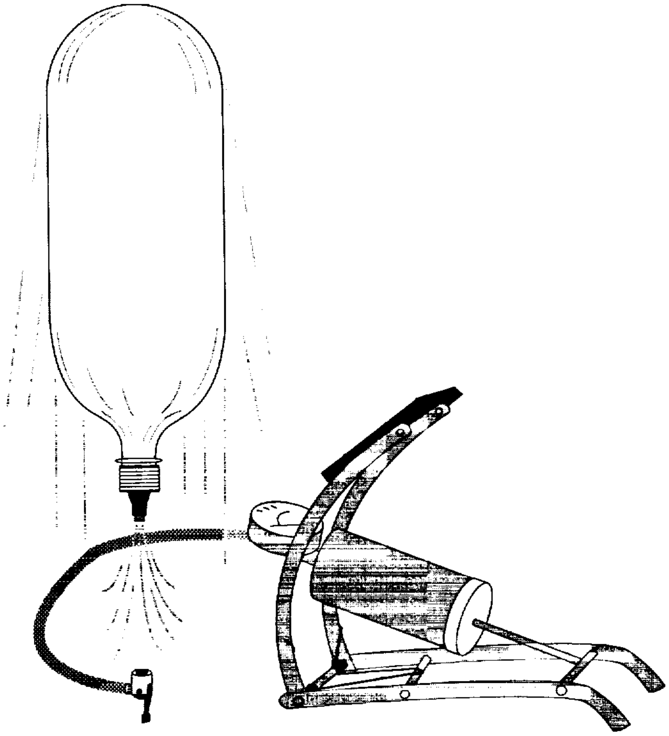
Objective: Rocket performance is improved through application of Newton's Second Law of Motion.

Description: In this activity, students construct a high-performance bottle rocket from a plastic soft drink bottle and a hand or foot operated air pump to test the effect of varying air pressure.

Procedure: (steps 1-5 should be done by the teacher)

Tubeless Tire Valve

1. Using a small knife blade or a valve stem tool, remove the needle valve from within the tire valve. To do so, place the blade point inside the valve (cap end) and gently turn the valve. The needle valve will begin to unscrew. Remove it and discard.
2. Enlarge the hole inside the tire valve with the drill 5/32" bit. Hold the valve with a vise while drilling. Press the drill gently to avoid jamming the bit.
3. Using the 9/16 bit, drill a hole through the center of the plastic cap of the soft drink bottle. Carefully clean off any plastic burrs with the knife.
4. Press the tire valve from the inside through the hole in the plastic cap until it locks into place.
5. Screw the plastic cap on the soft drink bottle. The bottle is ready for launch.
6. Attach the pump valve to the rocket. Push the lever to lock the valve on the rocket. While wearing safety goggles, pump the rocket to a pressure of 30 pounds. Hold the rocket upward by the pump hose and valve. Aim the rocket in a clear direction and quickly open the lever on the pump valve. The rocket will take off. Pump the rocket up again but this time to a pressure of 60 pounds. **Caution: For a safety margin, pump the rocket no higher than 90 pounds. This is approximately 50% of the industry specifications for this kind of container.**



Discussion:

Like a balloon full of air, the bottle rocket is pressurized. When the pump valve is opened, air escapes the bottle, providing an action force that is accompanied by an equal and opposite reaction force (Newton's Third Law of Motion). Increasing the pressure inside the bottle rocket produces greater

Materials and Tools:

- Plastic soft drink bottle with plastic cap (large or small)
- Tubeless tire valve - 1 1/4" long, TR No. 413 (available from auto supply stores)
- Drill
- Drill bits - 5/32", and 9/16" (or spade bit)
- Small vise
- Air pump, foot or hand style (not bicycle frame pump) with pressure gauge and lever-type valve attachment
- Small knife blade or valve stem tool
- Safety goggles

thrust. This is because a greater mass of air inside the bottle escapes with a higher acceleration (Newton's Second Law of Motion). Try adding a small amount of water to the bottle. The escaping mass increases, and thereby increases the action force produced.

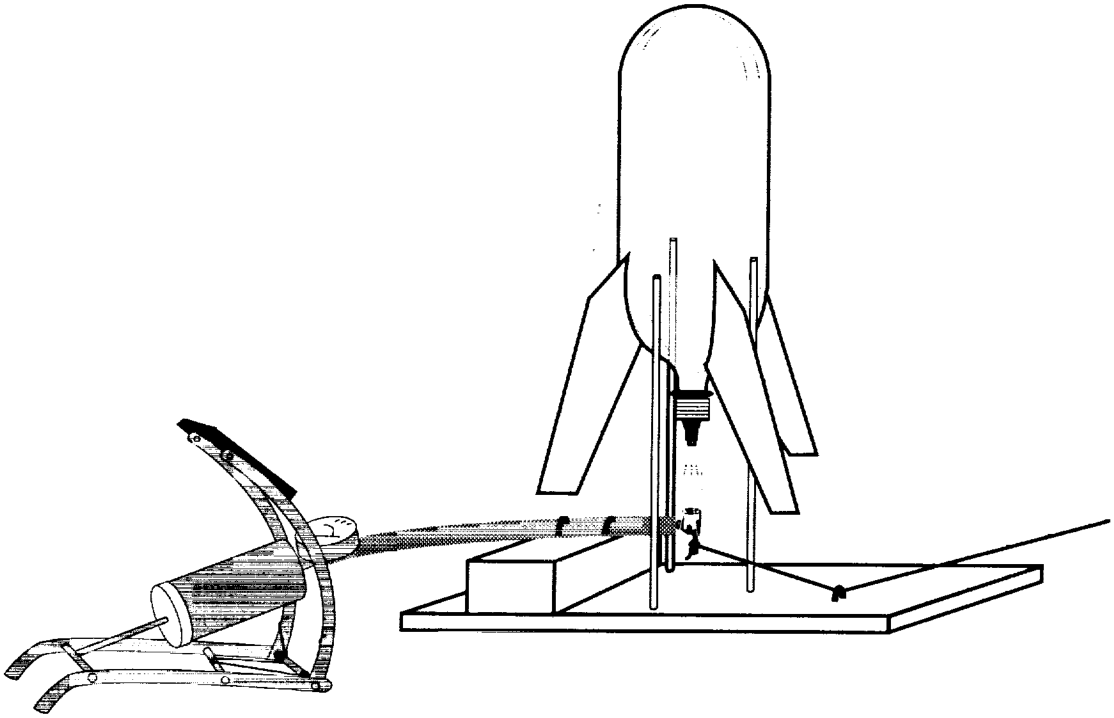
Teaching Notes and Questions:

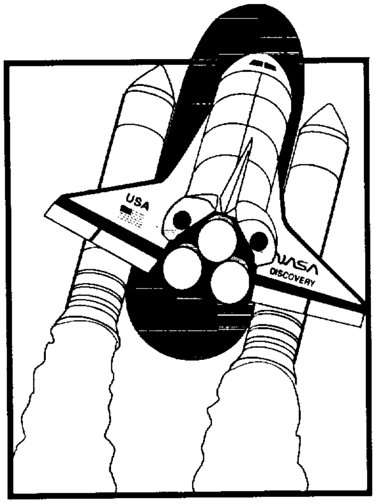
- Have each student bring plastic soft drink bottles to school to decorate and fly. The tire valve/cap can be shared among the different bottles. Is there any difference between the flight of large and small bottles? Is there any difference in the amount of effort required to raise bottles of different size to equal pressures? Compare the volume of the bottles with the number of pump strokes required.
- Because the bottle rocket does not have any passive or active stability controls, the bottle tumbles through the air. Experiment with attaching fins to the bottle rocket to stabilize its flight.
- Will the addition of a small amount of water to the bottle rocket improve its performance? (See Water Rocket activity.) What will happen to the rocket's performance if more water is added? Is there a limit to how much water should be added?
- A launch pad can be constructed from boards, dowel rods, and string. The launch pad shown here uses dowel rods to hold the rocket upright for launch. The pump valve is opened and the rocket released by pulling on the string.
- If your community has a plastic recycling program, be sure to recycle damaged bottle rockets and plastic scraps.
- Look up the following references for plans for constructing a different kind of bottle rocket launcher and for additional teaching strategies:

Hawthorne, M. & Saunders, G. (1993), "Its Launchtime!," <u>Science and Children</u>, v30n5, p17-19, 39.

Rogis, J. (1991), "Soaring with Aviation Activities," <u>Science Scope</u>, v15n2, pp14-17.

Winemiller, J., Pedersen, J., & Bonnstetter, R. (1991), "The Rocket Project," <u>Science Scope</u>, v15n2, pp18-22.





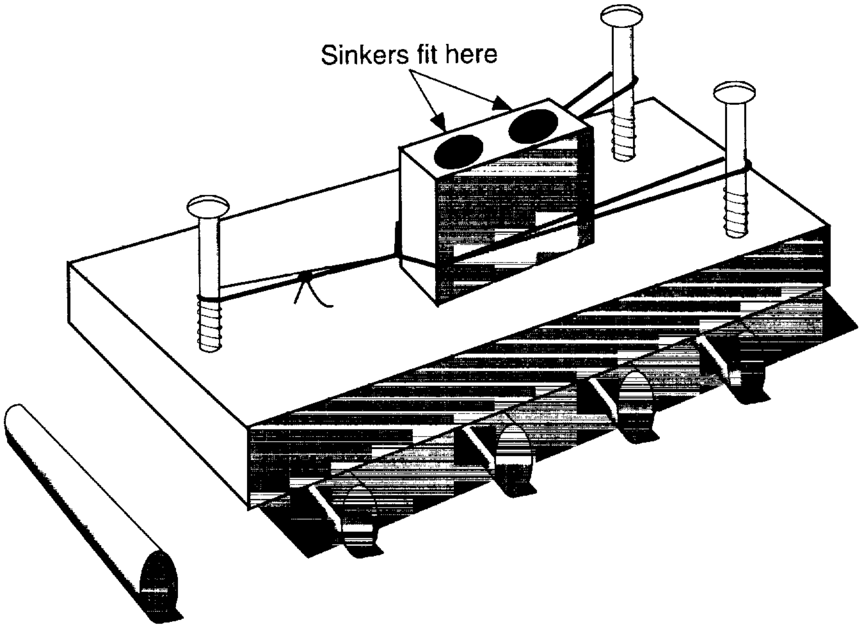
Newton Car

Objective: To demonstrate Newton's Second Law of Motion by showing the reaction of a rolling car by increasing its mass and acceleration.

Description: In this activity, students test a slingshot-like device that throws a wooden block that causes the car to move in the opposite direction.

Procedure:

1. Screw the three screws in the large wood block as shown in the diagram.
2. Hold the short piece of wood with a vice and drill two holes large enough to drop two sinkers in each.
3. Tie the string into several small loops of the same size.
4. Place one string loop over a rubber band and then place the ends of the rubber band over the two screws on one end of the large wood block. Pull the rubber band back like a slingshot and slip the string over the third screw to hold the rubber band stretched.
5. On a level table top arrange the pencils or dowel rods in a row like railroad ties. Be sure to mark the position of each dowel rod to make the experiment exactly the same way each time it is tried. Place the large block on one end of the row so that the tips of each single screw points toward the other dowel rods. Slip the small block (without sinkers) into the rubber bands.
6. Light a match and ignite the ends of the string hanging down from the loop. When the string burns through, the rubber band will throw the block off the car and the car will roll in the other direction. Measure how far the car travels along the table top.
7. Reset the equipment and add a second rubber band. Again, light the string, then measure and record how far the car travels.
8. Reset the equipment and try again with 3 rubber bands. Then try again with one rubber band and two sinkers, 4 sinkers, etc.
9. Plot the data from each of the experiments on a graph similar to the sample on the next page.



Materials and Tools:

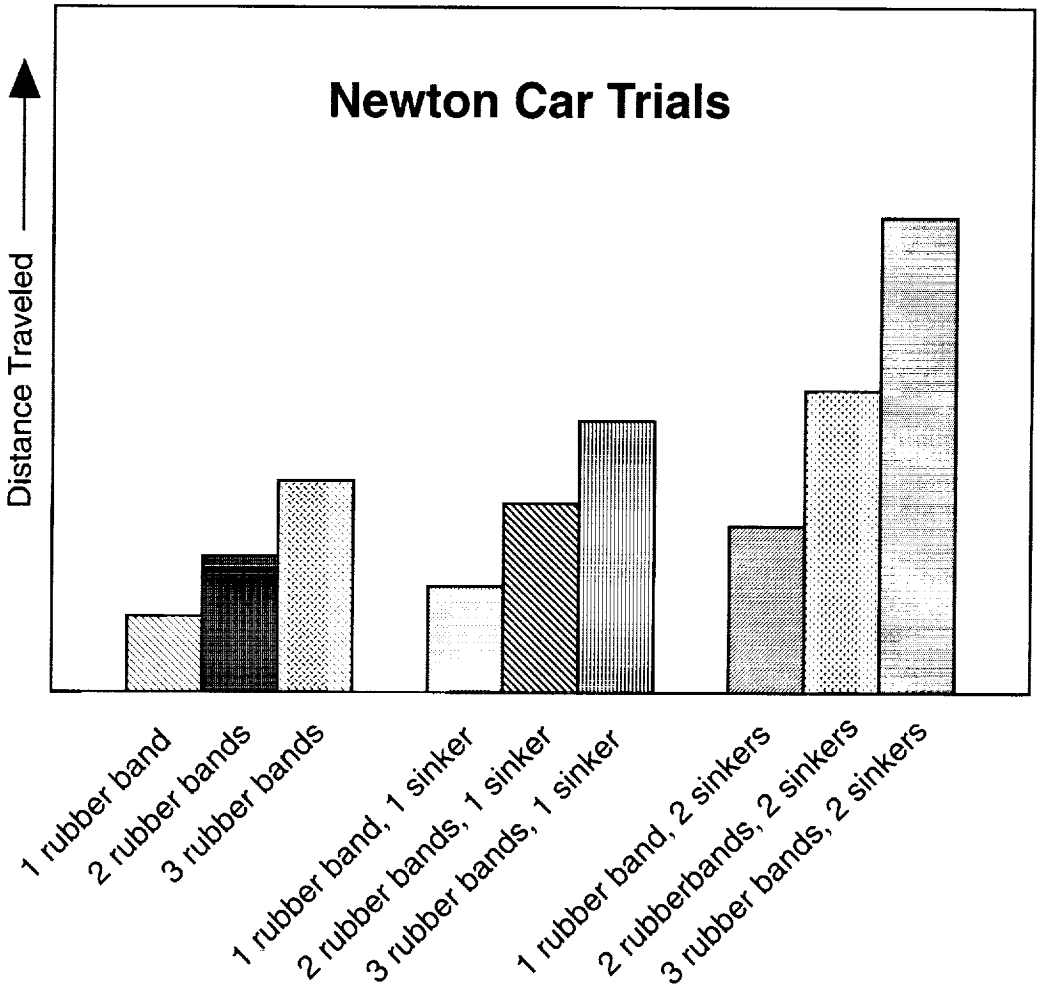
1 Wooden block about 10x20x2.5 cm
1 Wooden block about 7.5x5x2.5 cm
3 3-inch No. 10 wood screws (round head)
12 Round pencils or short lengths of similar dowel rods
3 Rubber bands
Cotton string
Matches
6 Lead fishing sinkers (about 1/2 ounce each)
Drill and bit (bit size determined by the diameter of the fishing sinkers)
Vice
Screwdriver
Meter stick

Discussion:

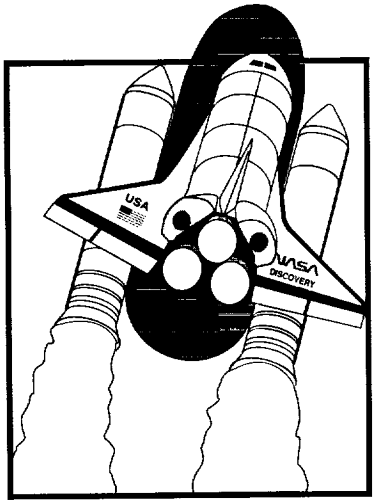
The Newton car provides an excellent demonstration of Isaac Newton's Second Law of Motion. By repeated trials of the experiment, it will become clear that the distance the car travels depends on the number of rubber bands used and the mass of the block being expelled. By adding sinkers to the block, the mass of the block is increased. By adding rubber bands, the acceleration of the block increases. (Refer to the chapter on rocket principles for a more detailed explanation of this law. The cannon and cannon ball example in the chapter is very similar to the Newton Car.)

Teaching Notes and Questions:

- This activity offers a number of opportunities to combine science and mathematics. Mathematic skills that can be employed include measurement, recording data, plotting data on a graph, and interpreting graphical data.
- Because this activity involves the use of matches, be sure to exercise proper safety procedures. **Caution: Provide adequate ventilation and a place to dispose of used matches.** Scissors can be substituted for the matches. Using scissors requires some practice because the scissors must be quickly withdrawn after cutting the string so as to not interfere with the reaction motion of the car.
- Permit students to test this principle for themselves by first stepping and then jumping off a stationary skateboard. Observe how far the skateboard travels. **Caution: Be sure to have a student spotter nearby so the student will not get hurt jumping from the skateboard.**
- Compare this activity with the water rocket activity.



(Sample graph. Actual student graphs will vary with skill and care in experiment setup and measurement.)



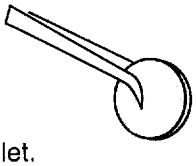
Antacid Tablet Race

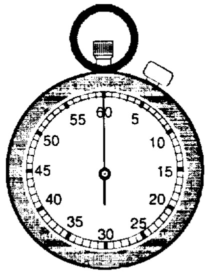
Objective: To demonstrate how increasing the surface area of a chemical increases its reaction rate.

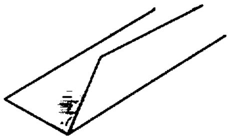
Description: A whole antacid tablet and a crushed tablet are added to separate beakers of water so that their relative reaction rates can be compared.

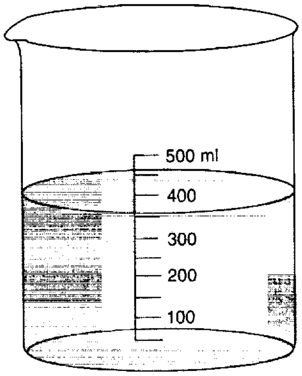
Procedure:

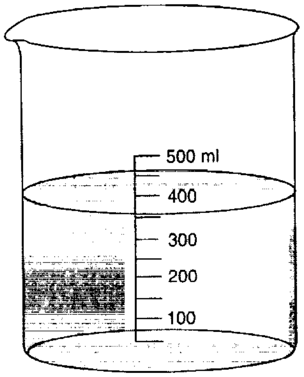
1. Fill both beakers about half full with water of the same temperature.
2. Wrap paper around one antacid tablet. Place the packet on a hard surface and crush the tablet by pressing on it with the wood block.
3. Open the paper packet with the crushed tablet and hold it over one of the beakers. Pour the power in the water and time how long it takes for the powder to dissolve.
4. Pick up a whole tablet and drop it into the second beaker of water. Time how long it takes to dissolve completely.











Discussion:

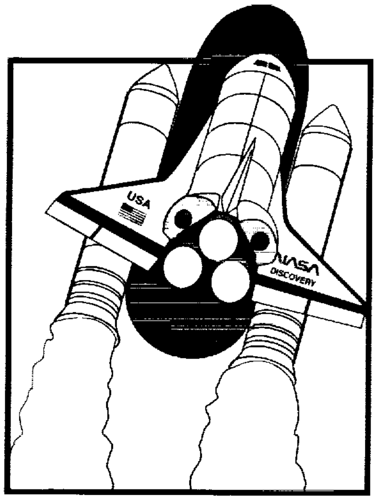
This activity demonstrates how increasing the surface area of an antacid tablet by crushing it into a powder increases the rate in which it dissolves in water. This is a similar situation to the way the thrust of a rocket is increased by increasing the burning surface of its propellants. Increasing the burning surface increases its burning rate. In solid rockets, a hollow core extending the length of the propellant will permit more propellant to burn at a time. This increases the acceleration of the gases produced as they leave the rocket engine. Liquid propellants are sprayed into the combustion chamber of a liquid propellant rocket to increase their surface area. Smaller droplets react more quickly than do large ones, increasing the acceleration of the escaping gases.

Teaching Notes and Questions:

- This activity is an ideal way for safely showing how the burning rate of rocket propellants is increased without having the students use fire.
- A similar activity can be tried with small pieces of hard candy. Take two pieces of candy and crush one. Then, give the whole candy piece to one student and the crushed candy to another student to dissolve in their mouths. Which candy will dissolve first?
- Demonstrate the same effect by trying to ignite a thick piece of wood with a match. Next, cut the wood with a sharp knife to make shavings. Then, try to ignite the shavings. **Caution: Be sure to exercise proper safety precautions with fire.**

Materials:

Antacid tablets (two per test)
Two beakers (or glass or plastic jars)
Tweezers or forceps
Scrap paper
Watch or clock with second hand
Small block of wood

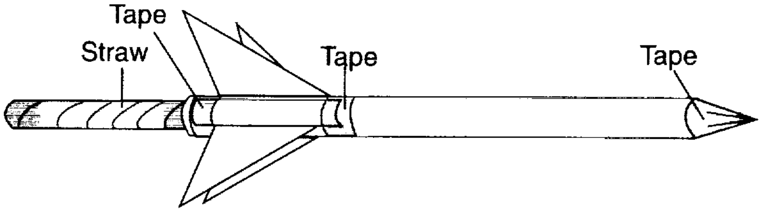


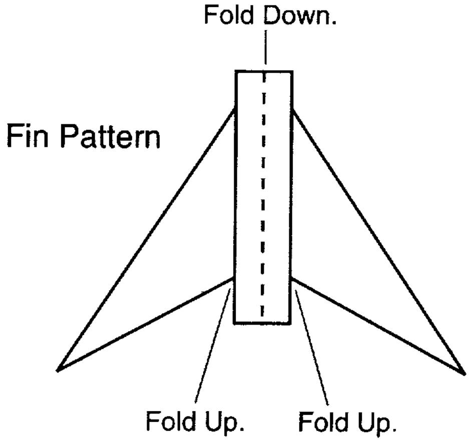
Paper Rockets

Objective: To demonstrate the importance of using control systems, such as fins, to stabilize rockets in flight.
Description: In this activity, students construct small flying rockets out of paper and propel them by blowing air through a straw.

Procedure:

1. Cut a narrow rectangular strip of paper about 13 cm long and roll it tightly around the fat pencil. Tape the cylinder and remove it from the pencil.
2. Cut points into one end of the cylinder to make a cone and slip it back onto the pencil.
3. Slide the cone end onto the pencil tip. Squeeze and tape it together to seal the end and form a nose cone (the pencil point provides support for taping). An alternative is just to fold over one end of the tube and seal it with tape.
4. Remove the cylinder from the pencil and gently blow into the open end to check for leaks. If air easily escapes, use more tape to seal the leaks.
5. Cut out two sets of fins using the pattern on this page and fold according to instructions. Tape the fins near the open end of the cylinder. The tabs make taping easy.





Flying the Paper Rocket:

Slip the straw into the rocket's opening. Point the rocket in a safe direction and blow sharply through the straw. The rocket will shoot away. **Caution: Be careful not to aim the rocket toward anyone because the rocket could poke an eye.**

Discussion:

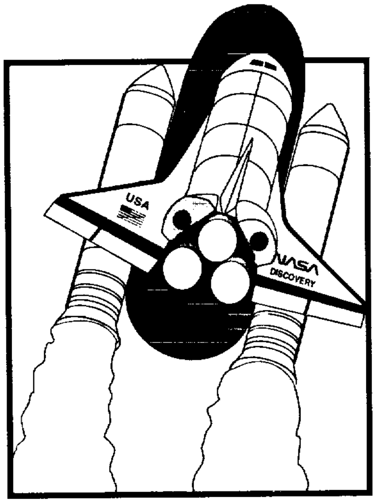
The paper rocket activity demonstrates how rockets fly through the atmosphere. A rocket with no fins is much more difficult to control than a rocket with fins. The placement and size of the fins is critical to achieve adequate stability while not adding too much weight.

Teaching Notes and Questions:

- Try flying a paper rocket with the fins placed on the front end of the cylinder. Also try attaching delta-shaped wings to achieve a gliding flight.
- How small can the fins be made and still stabilize the rocket? How many fins are required?
- What will happen to the rocket if the lower tips of the fins are bent pinwheel fashion?
- Test fly different paper rockets to see which will travel higher or farther. Investigate the designs of the rockets that travel the farthest and shortest distances. What makes one rocket perform better than another? (Do not forget to examine the weight of each rocket. Rockets made with extra tape and larger fins weigh more.)
- Are rocket fins necessary in outer space?

Materials:

Scrap bond paper
Cellophane tape
Scissors
Sharpened fat pencil
Milkshake straw (slightly thinner than pencil)



Pencil "Rocket"

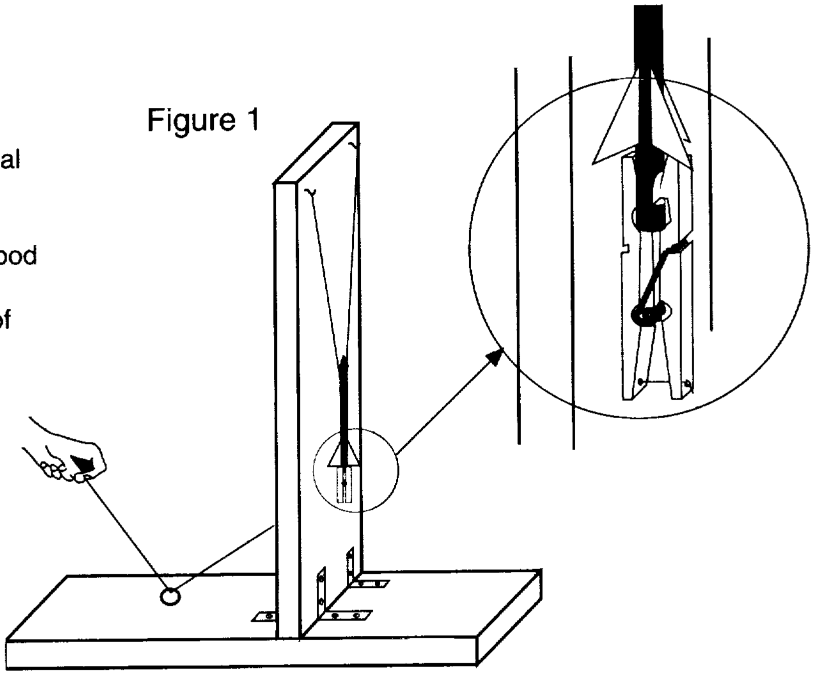
Objective: To demonstrate the effect fins have on rocket flight through the atmosphere.

Description: In this activity, students fly pencil "rockets" using a rubber band powered launch gantry.

Procedure: Launch Platform

1. Join the two pieces of wood as shown in the diagram to form the launch platform. Use metal angle irons on each side to strengthen the structure.
2. Screw the cup hooks and screw eye into the wood as indicated in Figure 1.
3. Disassemble the clothespin, and file the "jaw" of one wood piece square as shown in Figure 2. Drill a hole in this piece and two holes in the other piece as shown in the figure.
4. Drill a hole through the upright piece of the launch platform as shown in Figure 1, and screw the clothespin to the upright piece so that the lower holes in the clothespin line up with the hole in the upright board. Reassemble the clothespin.
5. Tie a big knot in one end of the string and feed it through the clothespin as shown in the magnification of Figure 1, through the upright piece of the platform, and then through the screw eye. When the free end of the string is pulled, the string will not slip out of the hole, and the clothespin will open. The clothespin has become a rocket hold-down and release device.
6. Loop four rubber bands together and loop their ends on the cup hooks. The launch platform is now complete.

Figure 1



Procedure: Rocket

1. Take a short piece of baling wire and wrap it around the eraser end of the pencil about 2.5 cm from the end. Use pliers to twist the wire tightly so that it "bites" into the wood a bit. Next, bend the twisted ends into a hook as shown in Figure 3.
2. Take a sharp knife and cut a notch in the other end of the pencil as shown in Figure 3.

Materials and Tools:

- 2 Pieces of wood about 1 meter by 7.5 centimeters (thickness can vary)
- 2 Cup hooks
- 1 Wooden spring clothespin
- 1 Small wood screw
- 1 Screw eye
- 4 Metal angle irons and screws
- 4 Feet of heavy string
- Iron baling wire
- Several rubber bands
- Several unsharpened wooden pencils
- Several pencil cap erasers
- Cellophane or masking tape
- Heavy paper
- Saw
- Wood file
- Drill about 3/16 inch in diameter
- Pliers

3. Cut out small paper rocket fins and tape them to the pencil just above the notch.
4. Place an eraser cap over the upper end of the rocket. This blunts the nose to make the rocket safer if it hits something. The rocket is now complete.

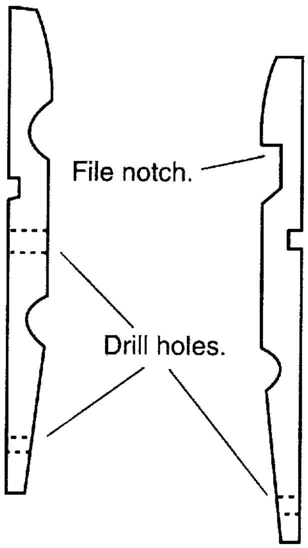


Figure 2

Launching Pencil Rockets

1. Choose a wide-open area to launch the rockets.
2. Spread open the jaw of the clothespin and place the notched end of the rocket in the jaws. Close the jaws and gently pull the pencil upward to insure the rocket is secure. If the rocket does not fit, change the shape of the notch slightly.
3. Pull the rubber bands down and loop them over the wire hook. **Caution: Be sure not to look down over the rocket as you do this, in case the rocket is prematurely released.**
4. Stand at the other end of the launcher and step on the wood to provide additional support.
5. Make sure no one except yourself is standing next to the launch pad. Count down from 10 and pull the string. Step out of the way from the rocket as it flies about 20 meters up in the air, gracefully turns upside down, and returns to Earth.
6. The rocket's terminal altitude can be adjusted by increasing or decreasing the tension on the rubber bands.

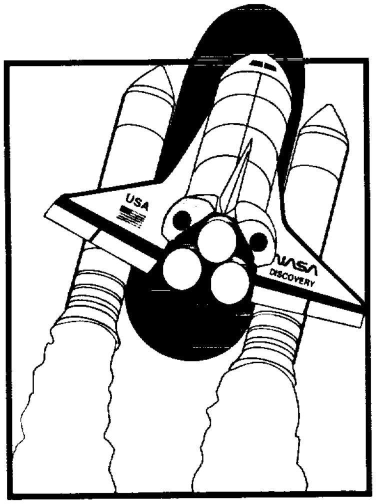
Discussion

Like Robert Goddard's first liquid-fuel rocket in 1926, the pencil rocket gets its upward thrust from the nose area rather than the tail. Regardless, the rocket's fins still provide stability, guiding the rocket upward for a smooth flight. If a steady wind is blowing during flight, the fins will steer the rocket toward the wind in a process called "weather cocking." Active controls steer NASA rockets during flight to prevent weather cocking and to aim them on the right trajectory. Active controls include tilting nozzles and various forms of fins and vanes.

Figure 3

Teaching Notes and Questions:

- Permit each student to make his or her own pencil rocket. If the children are too young to safely make their own notches, have an adult or older student notch enough pencils and clothespins for the entire class.
- What would happen if the rocket had only one fin? Two? What would happen if the fins are placed in the middle of the pencil rocket? At the upper end?
- Is the pencil rocket a genuine rocket? Why?

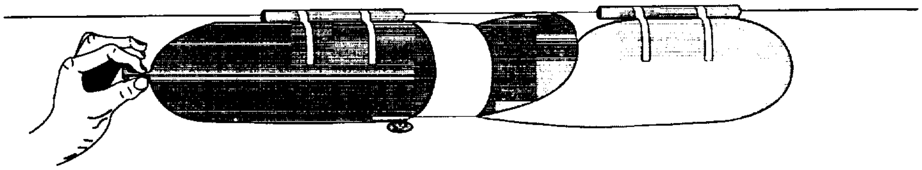


Balloon Staging

Objective: To demonstrate the principle of rocket staging.
Description: In this activity, students simulate a multistage rock launch using two inflated balloons that slide along a fishing line by the thrust produced from escaping air.

Procedure:

1. Thread the fishing line through the two straws. Stretch the fishing line snugly across a room and secure its ends. Make sure the line is just high enough for people to pass safely underneath.
2. Cut the coffee cup in half so that the lip of the cup forms a continuous ring.
3. Loosen the balloons by pre-inflating them. Inflate the first balloon about three-fourths full of air and squeeze its nozzle tight. Pull the nozzle through the ring. While someone assists you, inflate the second balloon. The front end of the second balloon should extend through the ring a short distance. As the second balloon inflates, it will press against the nozzle of the first balloon and take over the job of holding it shut. It may take a bit of practice to achieve this.
4. Take the balloons to one end of the fishing line and tape each balloon to a straw. The balloons should be pointed along the length of the fishing line.
5. If you wish, do a rocket countdown and release the second balloon you inflated. The escaping gas will propel both balloons along the fishing line. When the first balloon released runs out of air, it will release the other balloon to continue the trip.



Discussion:

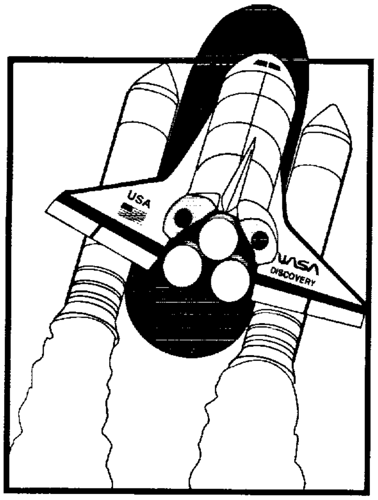
Traveling into outer space takes enormous amounts of energy. This activity is a simple demonstration of rocket staging that was first proposed by Johann Schmidlap in the 16th century. When a lower stage has exhausted its load of propellants, the entire stage is dropped, making the upper stages more efficient in reaching higher altitudes. In the typical rocket, the stages are mounted one on top of the other. The lowest stage is the largest and heaviest. In the Space Shuttle, the stages are attached side by side. The solid rocket boosters are attached to the side of the external tank. Also attached to the external tank is the Shuttle orbiter. When exhausted the solid rocket boosters are dropped. Later, the external tank is dropped as well.

Teaching Notes and Questions:

- Several launchings may be necessary to get the second "upper stage" balloon to travel completely across the classroom.
- Encourage the students to try other launch arrangements such as side-by-side balloons and three stages.
- Can a two stage balloon be flown without the fishing line as a guide? How might the balloons be modified to make this possible?

Materials and Tools:

2 Long party balloons ("airship")
Nylon monofilament fishing line (any weight)
2 Plastic straws (milkshake size)
Styrofoam coffee cup
Masking tape
Scissors



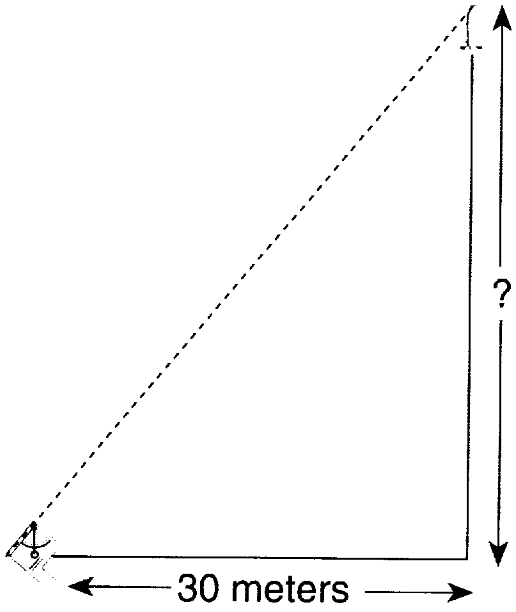
Altitude Tracking

Objective: To use geometry to estimate the altitude a water or bottle rocket achieves during flight.

Description: In this activity, students construct simple altitude tracking devices that are used to measure the angle a rocket reaches above ground, as seen from a remote tracking site. The angle is drawn on a graph and the altitude is read from a scale.

Procedure: Constructing the Altitude Tracker

1. Copy the Altitude Tracker pattern on white or colored paper. Cut out the outline and glue the pattern to a piece of scrap file folder or poster board. Do not glue the hatched area to the folder or posterboard.
2. Cut off the excess file folder or posterboard.
3. Roll the hatched area at the top of the pattern into a tube and tape the upper edge along the dashed line at the lower edge. Shape the paper into a sighting tube.
4. Punch a tiny hole in the apex of the protractor quadrant.
5. Cut out the Altitude Calculator and punch a hole at the apex of its protractor quadrant. Glue the Altitude Calculator to the back of the tracker so that the two holes line up.
6. Slip a thread or lightweight string through the holes. Knot the thread or string on the calculator side.
5. Hang a small washer from the other end of the thread as shown in the diagram of the completed tracker.



Procedure: Using the Altitude Tracker

1. Select a clear spot for launching water or bottle rockets.
2. Measure a tracking station location exactly 30 meters away from the launch site.
3. As a rocket is launched, the person doing the tracking will follow the flight with the sighting tube on the tracker. The tracker should be held like a pistol. Continue to aim the tracker at the highest point the rocket reached in the sky. Have a second student read the angle the thread or string makes with the quadrant protractor.

Materials and Tools:

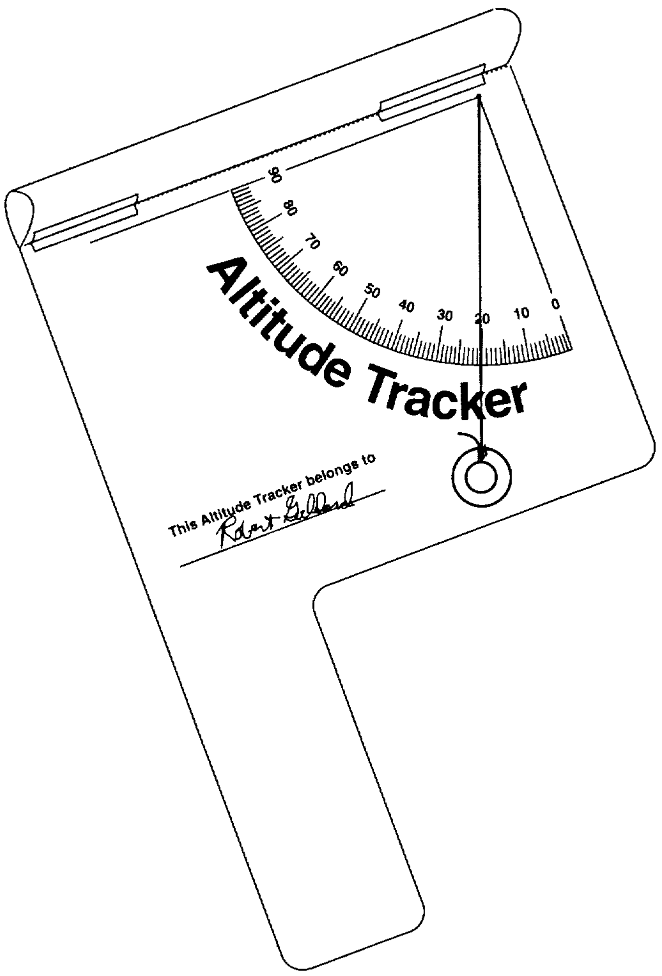
Altitude Tracker patterns
Thread or lightweight string
Scrap file folders or posterboard
Glue
Cellophane tape
Small washer
Scissors
Meter stick or steel tape measure (metric)

Procedure: Determining the Altitude

1. Use the Altitude Calculator to determine the height the rocket reached. To do so, pull the thread or string through the hole in the tracker to the Altitude

Calculator side until the washer stops it. Lay the string across the protractor quadrant and stretch it so that it crosses the vertical scale. (See sample calculation.)

2. Read the altitude of the rocket. The altitude is the intersection point of the string and the vertical scale to that number. Add the height of the person holding the tracker to determine the altitude the rocket reached.

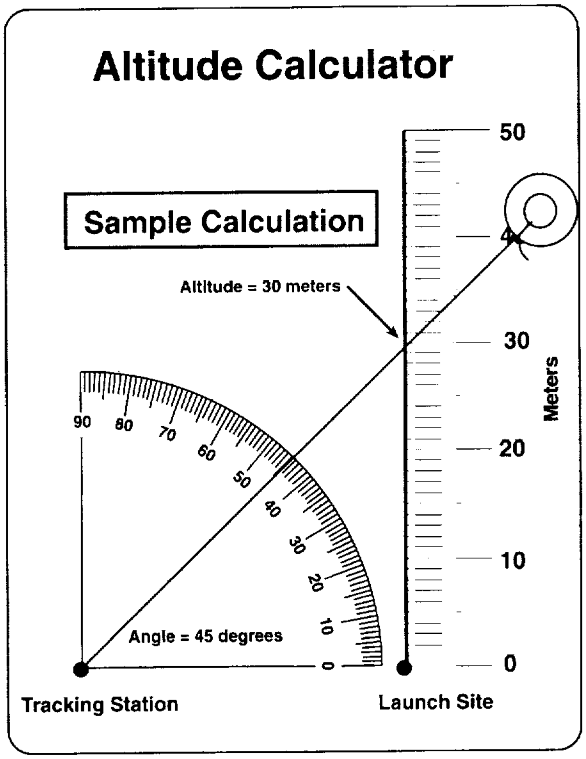


Discussion:

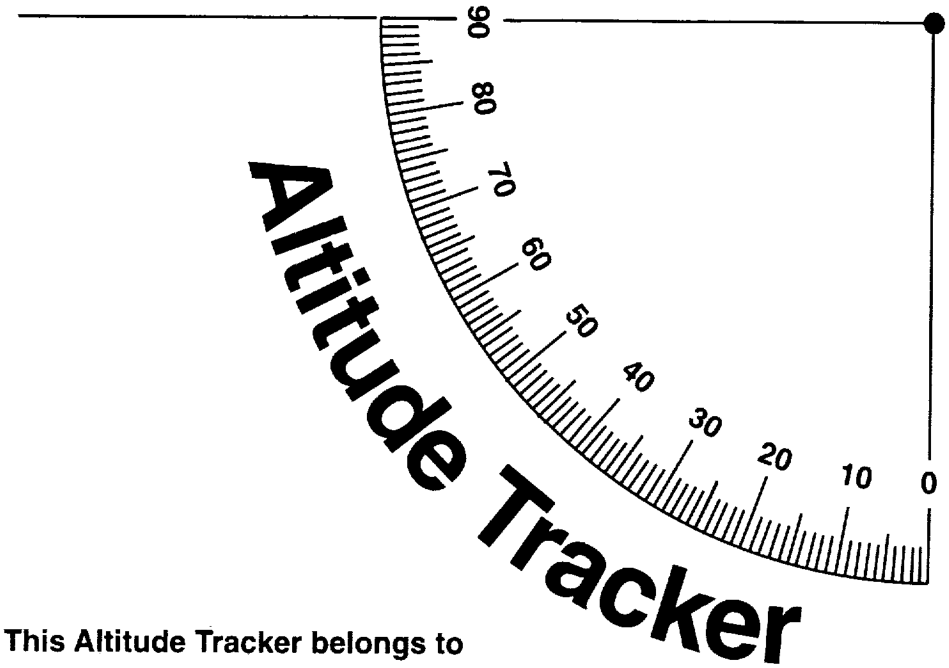
This activity makes use of simple trigonometry to determine the altitude a rocket reaches in flight. The basic assumption of the activity is that the rocket travels straight up from the launch site. If the rocket flies away at an angle other than 90 degrees, the accuracy of the procedure is diminished. For example, if the rocket flies toward a tracking station as it climbs upward, the altitude calculation will yield an answer higher than the actual altitude reached. On the other hand, if the rocket flies away from the station, the altitude measurement will be lower than the actual value. Tracking accuracy can be increased, however, by using more than one tracking station to measure the rocket's altitude. Position a second or third station in different directions from the first station. Average the altitude measurements.

Teaching Notes and Questions:

- This activity is simple enough so each student can construct his or her own Altitude Tracker. Permit each student to try taking measurements while other students launch the rockets. To assure accuracy in taking measurements, practice measuring the height of known objects such as a building or a flagpole. It may also be necessary for a few practice launches to familiarize each student with using the tracker in actual flight conditions.
- Why should the height of the person holding the tracker be added to the measurement of the rocket's altitude?
- Curriculum guides for model rocketry (available from model rocket supply companies) provide instructions for more sophisticated rocket tracking measurements. These activities involve two station tracking with altitude and compass direction measurement and trigonometric functions.



Roll this section over and tape the upper edge to the dashed line. Shape the section into a sighting tube.



This Altitude Tracker belongs to

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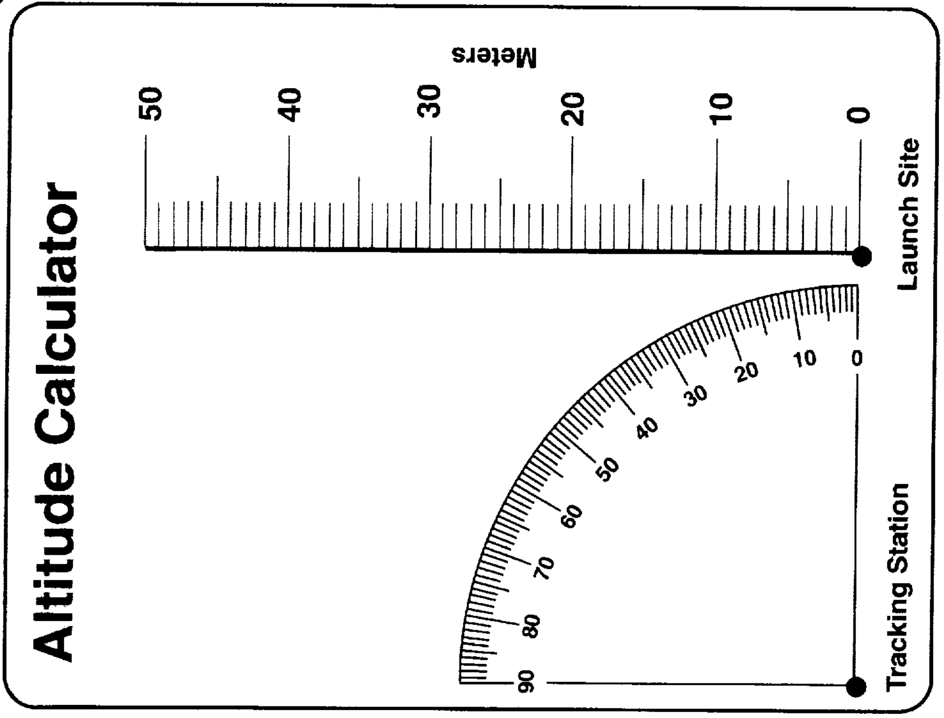
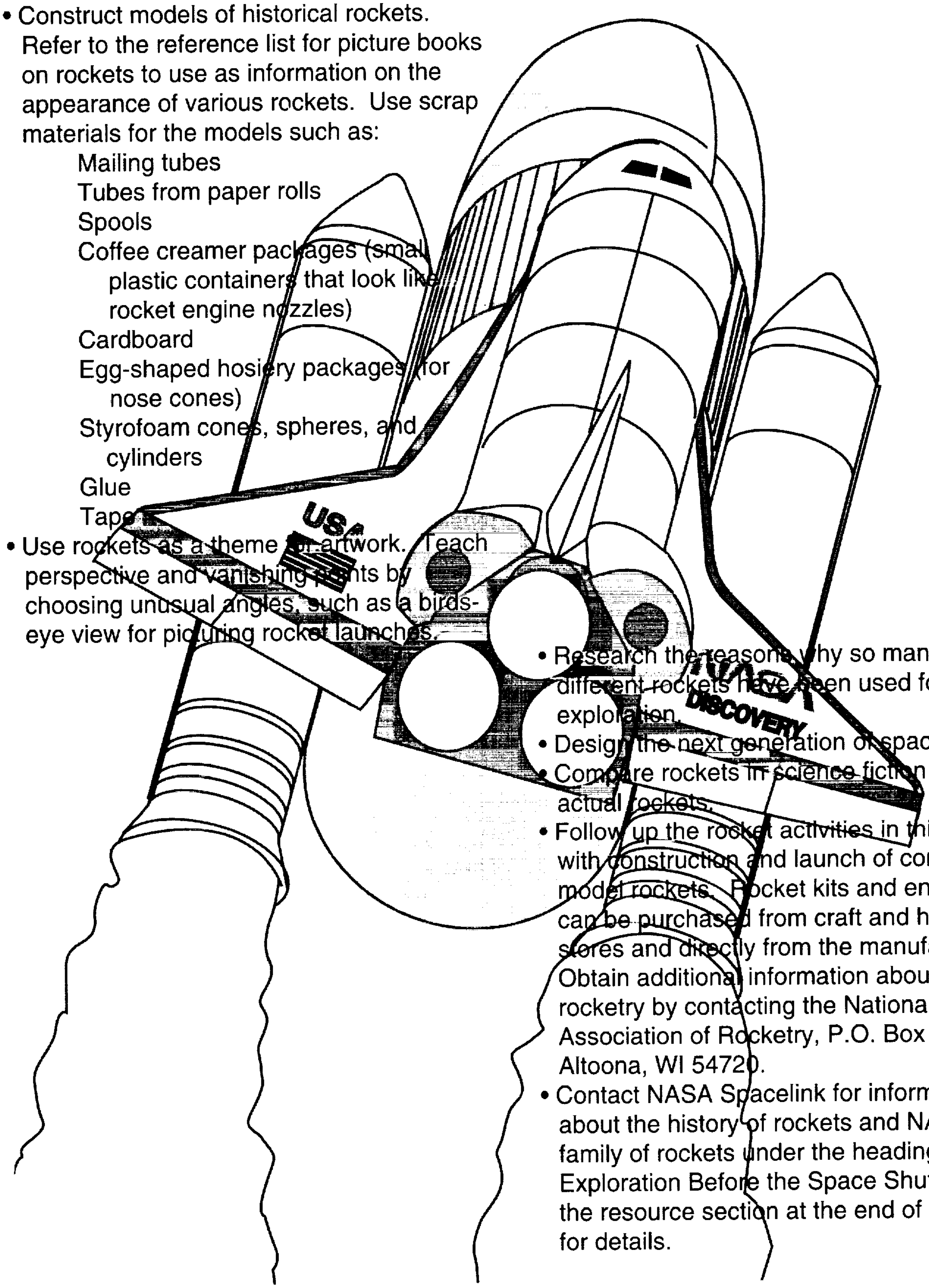


Additional Activities



- Construct models of historical rockets. Refer to the reference list for picture books on rockets to use as information on the appearance of various rockets. Use scrap materials for the models such as:
    - Mailing tubes
    - Tubes from paper rolls
    - Spools
    - Coffee creamer packages (small plastic containers that look like rocket engine nozzles)
    - Cardboard
    - Egg-shaped hosiery packages (for nose cones)
    - Styrofoam cones, spheres, and cylinders
    - Glue
    - Tape
- Use rockets as a theme for artwork. Teach perspective and vanishing points by choosing unusual angles, such as a birds-eye view for picturing rocket launches.
- Research the reasons why so many different rockets have been used for space exploration.
- Design the next generation of spaceships.
- Compare rockets in science fiction with actual rockets.
- Follow up the rocket activities in this guide with construction and launch of commercial model rockets. Rocket kits and engines can be purchased from craft and hobby stores and directly from the manufacturer. Obtain additional information about model rocketry by contacting the National Association of Rocketry, P.O. Box 177, Altoona, WI 54720.
- Contact NASA Spacelink for information about the history of rockets and NASA's family of rockets under the heading, "Space Exploration Before the Space Shuttle." See the resource section at the end of this guide for details.

Glossary

Action - A force (push or pull) acting on an object. See Reaction.
Active Controls - Devices on a rocket that move to control the rocket's direction in flight.
Attitude Control Rockets - Small rockets that are used as active controls to change the attitude (direction) a rocket or spacecraft is facing in outer space.
Canards - Small movable fins located towards the nose cone of a rocket.
Case - The body of a solid propellant rocket that holds the propellant.
Center of Mass (CM) - The point in an object about which the object's mass is centered.
Center of Pressure (CP) - The point in an object about which the object's surface area is centered.
Chamber - A cavity inside a rocket where propellants burn.
Combustion Chamber - See Chamber.
Drag - Friction forces in the atmosphere that "drag" on a rocket to slow its flight.
Escape Velocity - The velocity an object must reach to escape the pull of Earth's gravity.
Fins - Arrow-like wings at the lower end of a rocket that are used to stabilize the rocket in flight.
Fuel - The chemical that combines with an oxidizer to burn and produce thrust.
Gimbaled Nozzles - Tiltable rocket nozzles used for active controls.
Igniter - A device that ignites a rocket's engine(s).
Injectors - Showerhead-like devices that spray fuel and oxidizer into the combustion chamber of a liquid propellant rocket.
Insulation - A coating that protects the case and nozzle of a rocket from intense heat.
Liquid Propellant - Rocket propellants in liquid form.
Mass - The amount of matter contained within an object.
Mass Fraction (MF) - The mass of propellants in a rocket divided by the rocket's total mass.
Motion - Movement of an object in relation to its surroundings.
Movable Fins - Rocket fins that can move to stabilize a rocket's flight.
Nose Cone - The cone-shaped front end of a rocket.
Nozzle - A bell-shaped opening at the lower end of a rocket through which a stream of hot gases is directed.
Oxidizer - A chemical containing oxygen compounds that permits rocket fuel to burn both in the atmosphere and in the vacuum of space.
Passive Controls - Stationary devices, such as fixed rocket fins, that stabilize a rocket in flight.
Payload - The cargo (scientific instruments, satellites, spacecraft, etc.) carried by a rocket.
Propellant - A mixture of fuel and oxidizer that burns to produce rocket thrust.
Pumps - Machinery that moves liquid fuel and oxidizer to the combustion chamber of a rocket.
Reaction - A movement in the opposite direction from the imposition of an action. See Action.
Rest - The absence of movement of an object in relation to its surroundings.
Regenerative Cooling - Using the low temperature of a liquid fuel to cool a rocket nozzle.
Solid Propellant - Rocket fuel and oxidizer in solid form.
Stages - Two or more rockets stacked on top of each other in order to reach higher altitudes or have a greater payload capacity.
Throat - The narrow opening of a rocket nozzle.
Unbalanced Force - A force that is not countered by another force in the opposite direction.
Vernier Rockets - Small rockets that use their thrust to help direct a larger rocket in flight.

NASA Educational Materials

NASA publishes a variety of educational resources suitable for classroom use. The following resources, specifically relating to the topic of rocketry, are available from the NASA Teacher Resource Center Network. Refer to the next pages for details on how to obtain these materials.

Liftoff to Learning Educational Video Series

Space Basics
Length: 20:55
Recommended Level: Middle School
Application: History, Physical Science
Space Basics explains space flight concepts such as how we get into orbit and why we float when orbiting Earth. Includes a video resource guide.

Newton in Space
Length: 12:37
Recommended Level: Middle School
Application: Physical Science
Newton in Space demonstrates the difference between weight and mass and illustrates Isaac Newton's three laws of motion in the microgravity environment of Earth Orbit. Includes a video resource guide.

Other Videos

Videotapes are available about Mercury, Gemini, Apollo, and Space Shuttle projects and missions. Contact the Teacher Resource Center that serves your region for a list of available titles.

Publications

McAleer, N. (1988), Space Shuttle - The Renewed Promise, National Aeronautics and Space Administration, PAM-521, Washington, DC.

NASA (1991), Countdown! NASA Launch Vehicles and Facilities, Information Summaries, National Aeronautics and Space Administration, PMS-018-B, Kennedy Space Center, FL.

NASA (1991), A Decade On Board America's Space Shuttle, National Aeronautics and Space Administration, NP-150, Washington, DC.

NASA (1987), The Early Years: Mercury to Apollo-Soyuz, Information Summaries, National Aeronautics and Space Administration, PMS-001-A, Kennedy Space Center, FL.

NASA (1991), Space Flight, The First 30 Years, National Aeronautics and Space Administration, NP-142, Washington, DC.

NASA (1992), Space Shuttle Mission Summary, The First Decade: 1981-1990, Information Summaries, National Aeronautics and Space Administration, PMS-038, Kennedy Space Center, FL.

Roland, A. (1985), A Spacefaring People: Perspectives on Early Spaceflight, NASA Scientific and Technical Information Branch, NASA SP-4405, Washington, DC.

Lithographs

HqL-311 Black Brant XII Sounding Rocket (color lithograph with text)

HqL-367 Space Shuttle *Columbia* Returns from Space (color lithograph with text)

HqL-368 Space Shuttle *Columbia* Lifts Off Into Space (color lithograph with text)

Suggested Reading

These books can be used by children to learn more about rockets. Older books on the list provide valuable historical information rockets and information about rockets in science fiction. Newer books provide up-to-date information about rockets currently in use or being planned.

Asimov, I. (1988), Rockets, Probes, and Satellites, Gareth Stevens, Milwaukee.

Barrett, N. (1990), The Picture World of Rockets and Satellites, Franklin Watts Inc., New York.

Branley, F. (1987), Rockets and Satellites, Thomas Y. Crowell, New York.

Bolognese, D. (1982), Drawing Spaceships and Other Spacecraft, Franklin Watts, Inc., New York.

Furniss, T. (1988), Space Rocket, Gloucester, New York.

Gatland, K. (1976), Rockets and Space Travel, Silver Burdett, Morristown, New Jersey.

Gatland, K. & Jeffris, D. (1977), Star Travel: Transport and Technology Into The 21st Century, Usborn Publishers, London.

Gurney, G. & Gurney, C. (1975), The Launch of Sputnik, October 4, 1957: The Space Age Begins, Franklin Watts, Inc., New York.

Malone, R. (1977), Rocketship: An Incredible Voyage Through Science Fiction and Science Fact, Harper & Row, New York.

Quackenbush, R. (1978), The Boy Who Dreamed of Rockets: How Robert Goddard Became The Father of the Space Age, Parents Magazine Press, New York.

Vogt, G. (1987), An Album of Modern Spaceships, Franklin Watts, Inc., New York.

Vogt, G. (1989), Space Ships, Franklin Watts, Inc., New York.

NASA Educational Resources

NASA Spacelink: An Electronic Information System

NASA Spacelink is a computer information service that individuals may access to receive news about current NASA programs, activities, and other space-related information; historical data, current news, lesson plans, classroom activities, and even entire publications. Although it is primarily intended as a resource for teachers, anyone with a personal computer and a modem can access the network.

Users need a computer, modem, communications software, and a long-distance telephone line to access Spacelink. The Spacelink computer access number is (205) 895-0028. The data word format is 8 bits, no parity, and 1 stop bit. For more information contact:

Spacelink Administrator
Mail Code CA21
NASA Marshall Space Flight Center
Marshall Space Flight Center, AL 35812
Phone: (205) 544-0038

NASA Spacelink is also available through the Internet, a worldwide computer network connecting a large number of educational institutions and research facilities. Callers with Internet access may reach NASA Spacelink at any of the following addresses:

spacelink.msfc.nasa.gov
xsl.msfc.nasa.gov
192.149.89.61

NASA Educational Satellite Videoconferences

During the school year, NASA delivers a series of educational programs by satellite to teachers across the country. The content of each videoconference varies, but all cover aeronautics or space science topics of interest to the educational community. The broadcasts are interactive; a number is flashed across the bottom of the screen, and viewers may call collect to ask questions or to take part in the discussion. For further information contact:

Videoconference Coordinator
NASA Aerospace Education Services Program
300 North Cordell
Oklahoma State University
Stillwater, OK 74078-0422
Phone: (405) 744-7015

Technology and Evaluation Branch
Education Division
Code FET
NASA Headquarters
Washington, DC 20546

NASA Select Television

NASA Select Television is the Agency's distribution system for live and taped educational programs. The educational and historical programming is aimed at inspiring students to achieve, especially in mathematics, science, and technology.

If your school's cable television system carries NASA Select, or if your school has access to a satellite antenna, the programs may be downlinked and videotaped. NASA Select is transmitted on SatCom F2R, transponder 13, C-band, 72 degrees west longitude, frequency 3954.5 MHz, vertical polarization, audio on 6.8 MHz. A schedule for NASA Select is published daily on NASA Spacelink. For more information contact:

NASA Select
c/o Associate Administrator for Public Affairs
NASA Headquarters, Code P
Washington, DC 20546

Teacher Resource Center Network

To make additional information available to the education community, the NASA Education Division has created the NASA Teacher Resource Center (TRC) network. TRCs contain a wealth of information for educators: publications, reference books, slides, audio cassettes, videocassettes, telelecture programs, computer programs, lesson plans and activities, and lists of publications available from government and nongovernment sources. Because each NASA field center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area. A list of the centers and the geographic regions they serve starts at the bottom of this page.

NASA's Central Operation of Resources for Educators (CORE) was established to facilitate the national and international distribution of NASA-produced educational materials in audiovisual format. Orders are processed for a small fee that includes the cost of the media. Send a written request on your school letterhead for a catalogue and order forms. For more information contact:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294

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National Aeronautics and Space Administration Information for Teachers and Students

IF YOU LIVE IN:		Center Education Program Officer	Teacher Resource Center
Alaska Arizona California Hawaii Idaho Montana	Nevada Oregon Utah Washington Wyoming	Chief, Educational Programs Branch Mail Stop TO-25 **NASA Ames Research Center** Moffett Field, CA 94035 PHONE: (415) 604-5543	NASA Teacher Resource Center Mail Stop TO-25 NASA Ames Research Center Moffett Field, CA 94035 PHONE: (415) 604-3574
Connecticut Delaware District of Columbia Maine Maryland Massachusetts	New Hampshire New Jersey New York Pennsylvania Rhode Island Vermont	Chief, Educational Programs Public Affairs Office (130) **NASA Goddard Space Flight Center** Greenbelt, MD 20771 PHONE: (301) 286-7207	NASA Teacher Resource Laboratory Mail Code 130.3 NASA Goddard Space Flight Center Greenbelt, MD 20771 PHONE: (301) 286-8570

IF YOU LIVE IN:		Center Education Program Officer	Teacher Resource Center
Colorado Kansas Nebraska New Mexico	North Dakota Oklahoma South Dakota Texas	Center Education Program Officer Public Affairs Office (AP-4) **NASA Johnson Space Center** Houston, TX 77058 PHONE: (713) 483-1257	NASA Teacher Resource Room Mail Code AP-4 NASA Johnson Space Center Houston, TX 77058 PHONE: (713) 483-8696
Florida Georgia Puerto Rico Virgin Islands		Chief, Education and Awareness Branch Mail Code PA-EAB **NASA Kennedy Space Center** Kennedy Space Center, FL 32899 PHONE: (407) 867-4444	NASA Educators Resource Laboratory Mail Code ERL NASA Kennedy Space Center Kennedy Space Center, FL 32899 PHONE: (407) 867-4090
Kentucky North Carolina South Carolina Virginia West Virginia		Office of Education Programs Mail Stop 400 **NASA Langley Research Center** Hampton, VA 23681-0001 PHONE: (804) 864-3307	NASA Teacher Resource Center Mail Stop 146 NASA Langley Research Center Hampton, VA 23681-0001 PHONE: (804) 864-3293
Illinois Indiana Michigan	Minnesota Ohio Wisconsin	Chief, Office of Educational Programs Mail Stop 7-4 **NASA Lewis Research Center** 21000 Brookpark Road Cleveland, OH 44135 PHONE: (216) 433-5583	NASA Teacher Resource Center Mail Stop 8-1 NASA Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135 PHONE: (216) 433-2017
Alabama Arkansas Iowa	Louisiana Missouri Tennessee	Chief, Education Services Branch Public Affairs Office (CA 21) **NASA Marshall Space Flight Center** Marshall Space Flight Center, AL 35812 PHONE: (205) 544-7391	NASA Teacher Resource Center Alabama Space and Rocket Center Huntsville, AL 35807 PHONE: (205) 544-5812
Mississippi		Center Education Program Officer Mail Stop AA00 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529 PHONE: (601) 688-2739	NASA Teacher Resource Center Building 1200 NASA John C. Stennis Space Center Stennis Space Center, MS 39529 PHONE: (601) 688-3338
The Jet Propulsion Laboratory (JPL) serves inquiries related to space and planetary exploration and other JPL activities.		Manager, Public Education Office Mail Code 180-205 **Jet Propulsion Laboratory** 4800 Oak Grove Drive Pasadena, CA 91109 PHONE: (818) 354-8592	NASA Teacher Resource Center JPL Educational Outreach Mail Stop CS-530 Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109 PHONE: (818) 354-6916
California (mainly cities near Dryden Flight Research Facility)			NASA Dryden Flight Research Facility Public Affairs Office (Tri. 42) NASA Teacher Resource Center Edwards, CA 93523 PHONE: (805) 258-3456
Virginia and Maryland's Eastern Shores			Wallops Flight Facility Education Complex - Visitor Center Building J-17 Wallops Island, VA 23337 PHONE: (804) 824-1176

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