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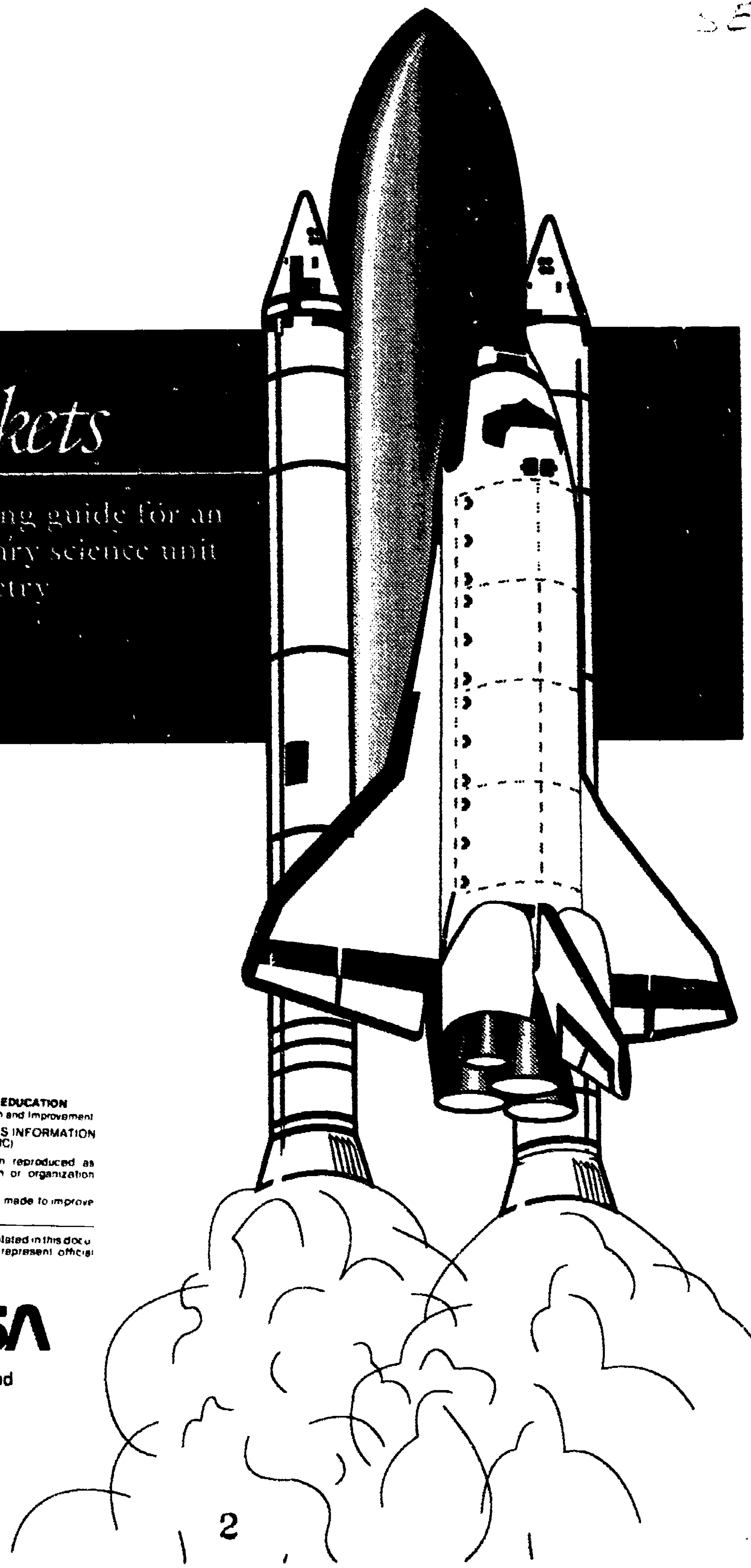
ABSTRACT

Utilizing simple and inexpensive equipment, elementary and middle school science teachers can conduct interesting, exciting, and productive units on rockets, the oldest form of self-contained vehicles in existence. This teaching guide contains the following: (1) a brief history of experimentation and research on rockets and rocket propulsion from ancient Chinese warfare to modern space exploration; (2) the mechanical principles of rockets in terms of Newton's Laws of Motion; (3) a discussion of the science of practical rocketry in terms of rocket engine design, types of propellants, engine thrust control, flight path stability and control, and weight versus payload considerations; (4) 10 hands-on classroom activities which include required materials and tools, procedures, and typical classroom discussion topics relating to each activity; and (5) a list of commercial suppliers for model rocketry resources. The activities are effective for teaching the science of rocketry, utilizing readily available materials such as soda cans, pencils, balloons, and straws. Further, these activities are suggested as an introduction to a follow-up activity of building and launching commercially-supplied model rockets. (PR)

Rockets

A teaching guide for an elementary science unit on rocketry



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By Gregory L. Vogt

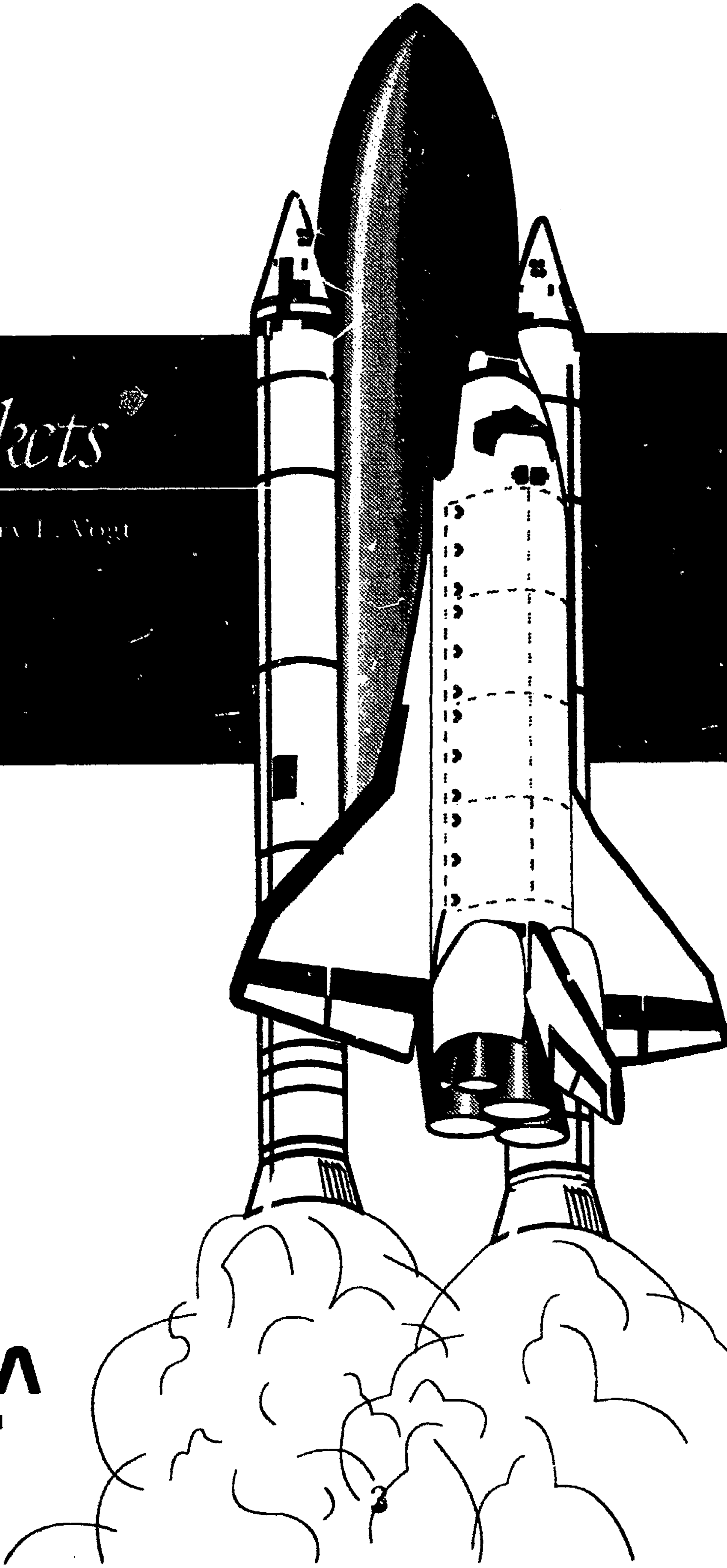

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Table of Contents

Introduction

Rockets are the oldest form of self-contained vehicles in existence. Forerunners to the rocket were in use more than two thousand years ago. Over a long and exciting history, rockets have evolved into mighty vehicles capable of launching a spacecraft that can travel out into the galaxy beyond our solar system. Few experiences can compare with the excitement and thrill of watching a rocket-powered vehicle such as the Space Shuttle thunder into space.

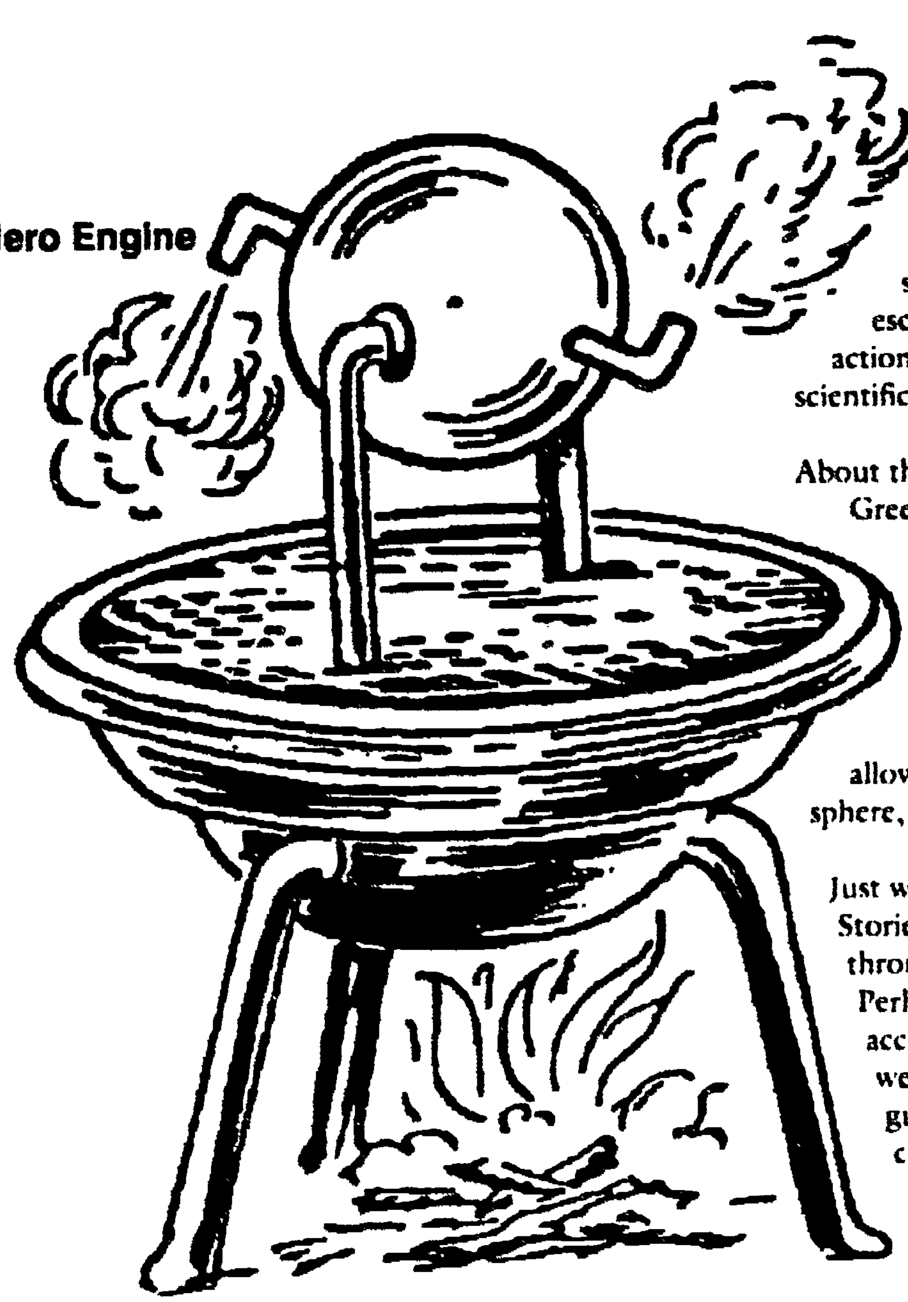
Children are interested in rockets. Rockets are exciting. They thunder, roar, and shoot flames. They carry machines and humans off the Earth and out into space (the only kind of transportation now able to accomplish that). It is only natural that dreams of rocket flight to distant worlds fire the imagination of children.

With some simple and inexpensive materials, you can conduct an exciting and productive science unit about rockets for children even if you don't know much about rockets yourself. The many activities contained in this teaching guide emphasize hands-on involvement. Background information about the history of rockets and basic science explaining why rockets work will make you an "expert."

The science unit that follows is based on Isaac Newton's laws of motion. These laws explain why rockets work and how to make them more efficient. The unit also includes basic concepts of rocket control and descriptions of different kinds of rockets.

Brief History of Rockets

Today's rockets are remarkable collections of human ingenuity. NASA's Space Shuttle and the Soviet Union's Buran (shuttle) are among the most complex flying machines ever invented. They stand upright on a launch pad, lift off as rockets, orbit Earth as spacecraft, and return to Earth as gliding airplanes. The Space Shuttle and the Buran are true space ships. In a few years they will be joined by other spaceships. The European Space Agency is building the Hermes and Japan is building the HOPE. Still later will come aerospace planes that will take off from runways as airplanes, fly into space, and return as airplanes. The United States, European Space Agency, United Kingdom, and Japan are all working on vehicles for the early twenty-first century. All these new and future spaceships 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.

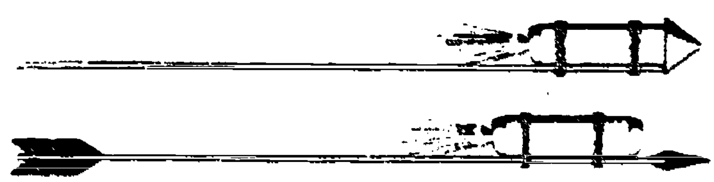

Hero Engine

One of the first devices to employ the principles essential to rocket flight successfully 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 BC, Archytas mystified and amused the citizens of Tarentum by flying a pigeon made of wood. The bird was suspended on wires and propelled along by escaping steam. The pigeon operated on the action-reaction principle that was not to be stated as a scientific law until the seventeenth century.

About three hundred years after the pigeon, another Greek, Hero of Alexandria, invented a similar rocketlike 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 so doing thrust the sphere, rotating it.

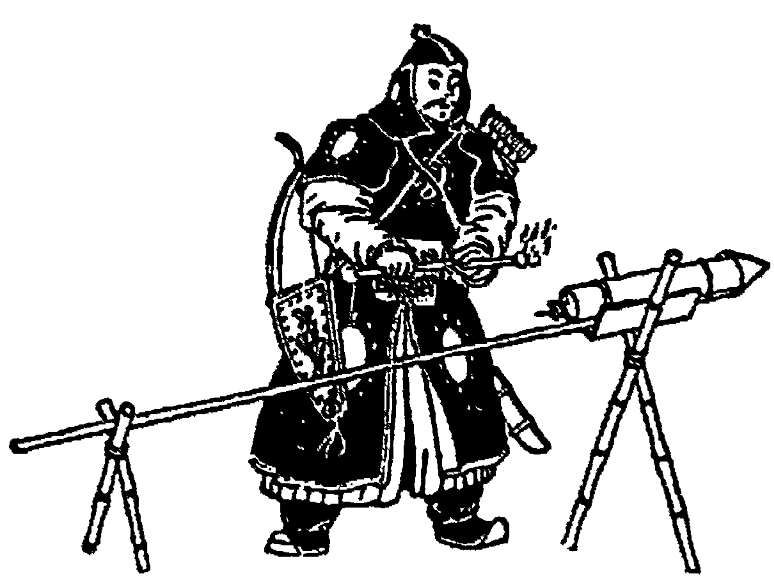
Just when the first true rockets appeared is unclear. Stories of early rocket-like devices appear sporadically through the historical records of various cultures. Perhaps the first true rockets were created by accident. In the first century A.D., the Chinese were reported to have had a simple form of 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 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.

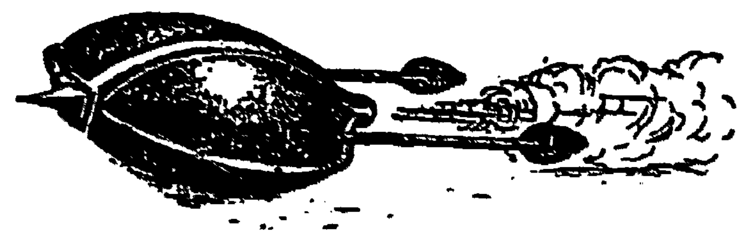


Chinese Fire-Arrows

True rockets were probably launched beginning in 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 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.

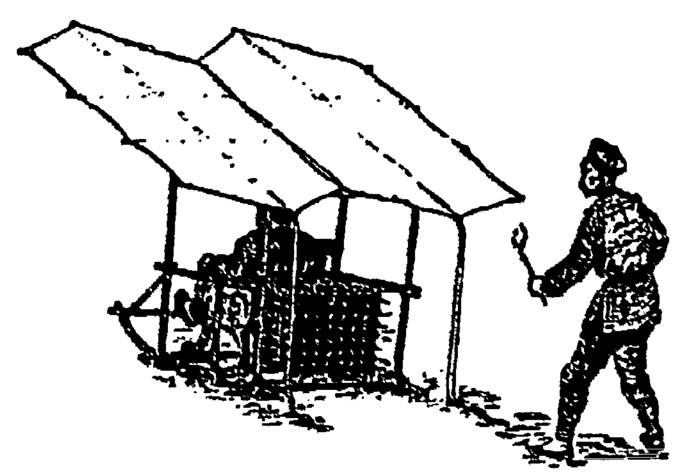


Following the battle of Kai-Keng, the Mongols produced their own rockets and may have been responsible for the spread of rockets to Europe. All through the thirteenth to the fifteenth centuries there were reports of many rocket experiments. In England, a monk named Roger Bacon improved gunpowder to increase the range of rockets. In France, Jean Froissart found that flights could be more accurate 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.



Surface-Running Torpedo

By the sixteenth century rockets were no longer used as weapons of war, though they were still used for fireworks displays. A German fireworks maker, Johann Schmidlap, invented the "step rocket," a multi-staged vehicle for lifting fireworks to higher altitudes. A large sky rocket carried a smaller sky rocket as a payload. 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.



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 low-ranking 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 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. 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.

Rocketry Becomes a Science

During the latter part of the seventeenth 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 weight of more than 45 kg. 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 eighteenth century and early into the nineteenth, 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 designed 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," in his poem that later became *The Star-Spangled Banner.*

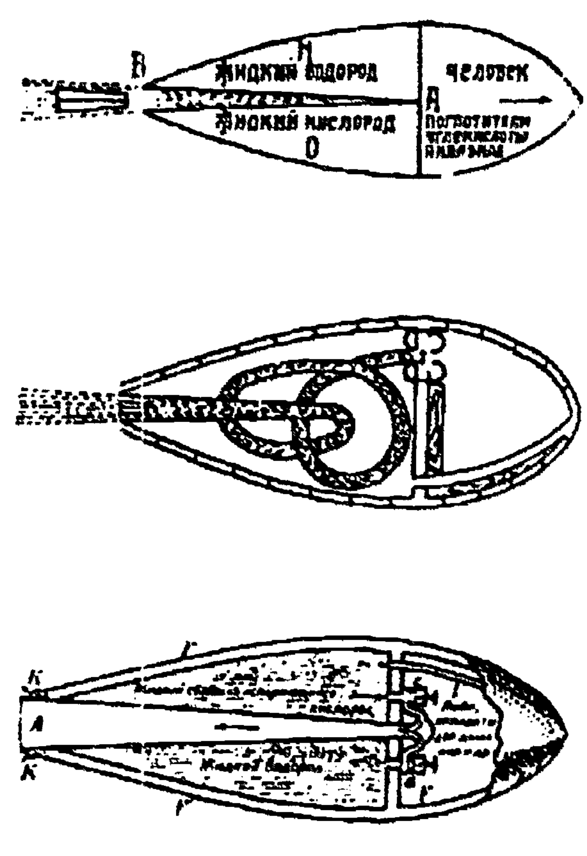
Even with Congreve's work, the accuracy of rockets had not improved significantly from the early days. The devastating nature of war rockets was not their accuracy or power, but their numbers. During a typical siege, thousands of them might be fired at the enemy. All over the world, rocket researchers 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 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.

Early in the twentieth 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 was possible for lighter-than-air balloons. He published a pamphlet in 1919

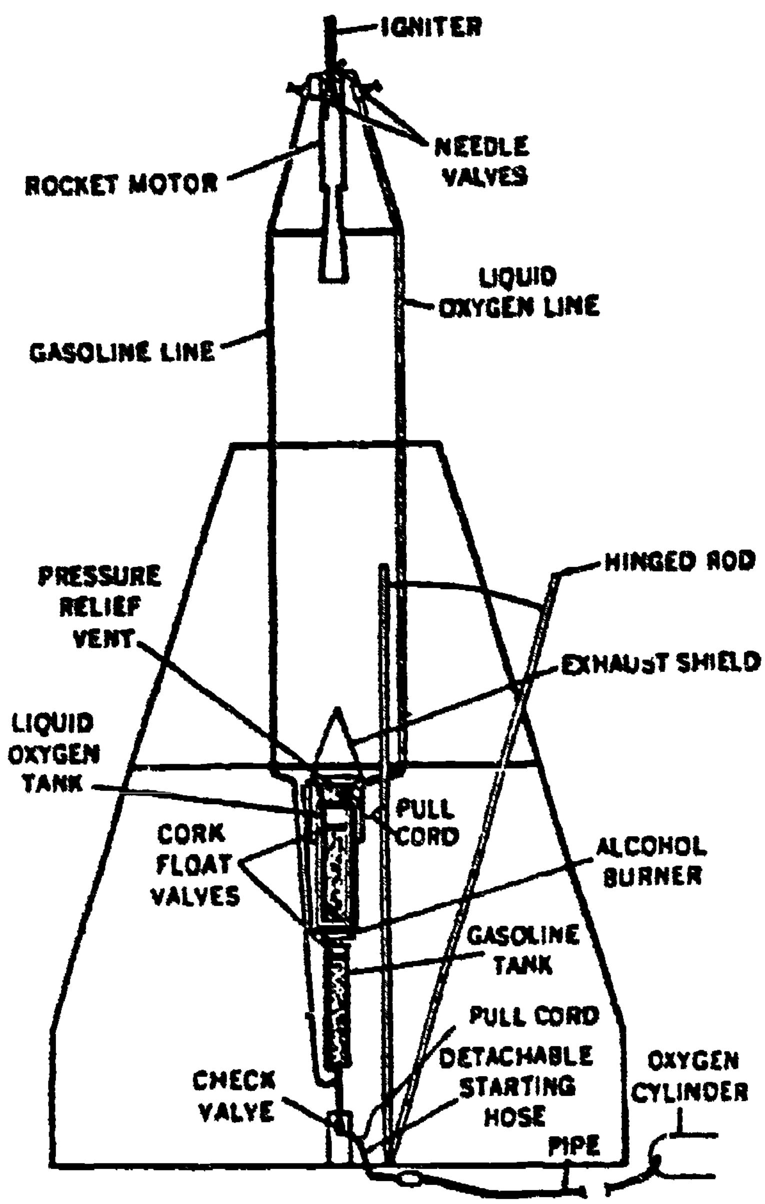


Tsiolkovsky Rocket Designs

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 the 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 1925 Rocket

While working on solid-propellant rockets, Goddard became convinced that a rocket could be propelled more efficiently 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 m, and landed 56.1 m 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 new era in rocket flight. Goddard, for his achievements, has been called the father of modern rocketry.

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.

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, thousands of 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. The range of one of these multistage vehicles with a winged upper stage would have been 6440 to 8050 km. It could have carried a warhead of only about about 20 kg, would have glided at low altitude and subsonic speed, and would have had an inacurracy of at least 32.2 or 48.3 km.

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 ideas from many years before. 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 Earth orbit.

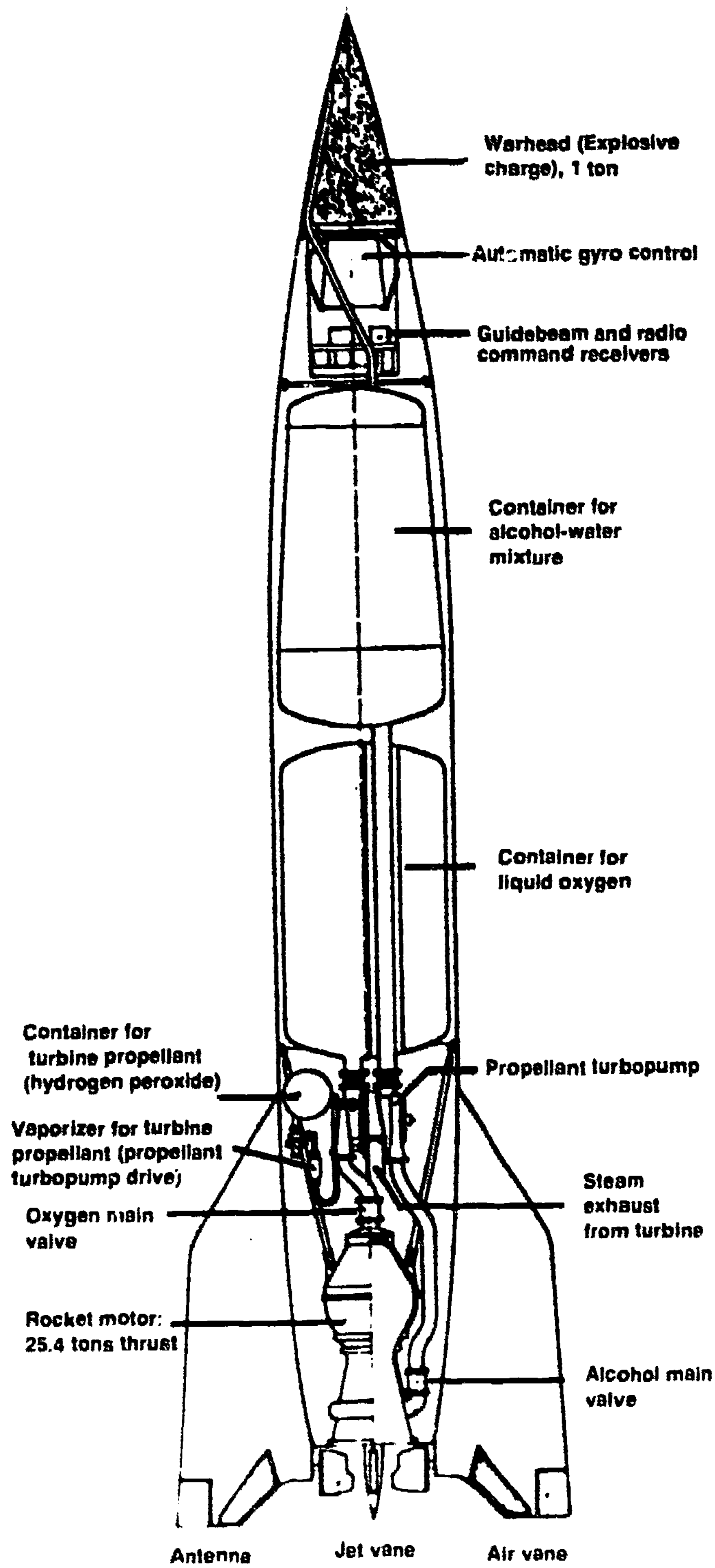
On October 4, 1957, the world was stunned by the news of an Earth-orbiting artificial satellite launched by the Soviet Union. Called *Sputnik I*, the satellite was the first successful entry in a race for space between the two superpower nations. Less than a month later, the Soviets followed with the 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 the 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, newer and bigger rockets had to be built.

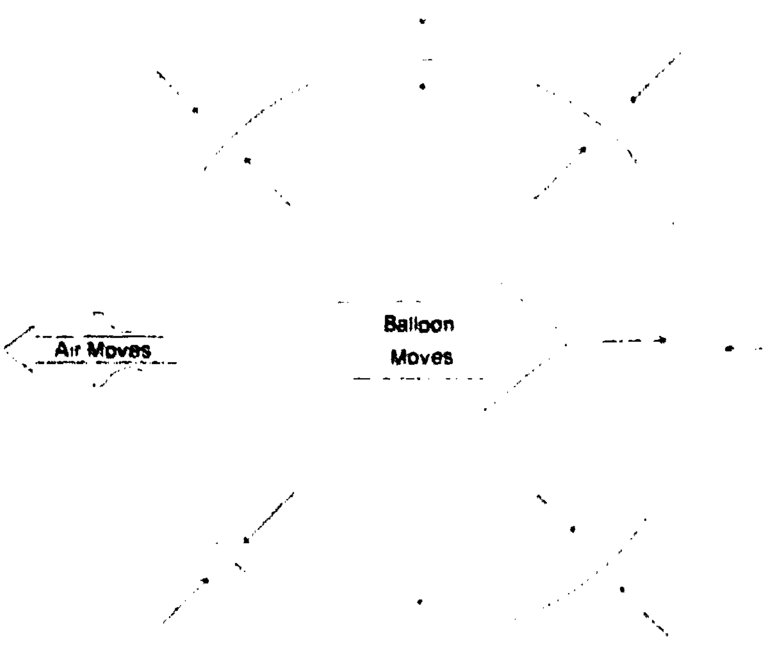
At present, 18 nations working alone and in consortia have rockets capable of orbiting satellites around Earth. Two nations, the United States and the Soviet Union, have manned orbital launch capability and Japan, China, and the 13 member nations of the European Space Agency expect to orbit astronauts before the year 2005.

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 so doing 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 and propels the balloon in a rocket flight. The balloon's flight is highly erratic because there are no structures to stabilize it.

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 past three hundred years that rocket experimenters have had a scientific basis for understanding how they work.

The science of rocketry was first recorded 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 today 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

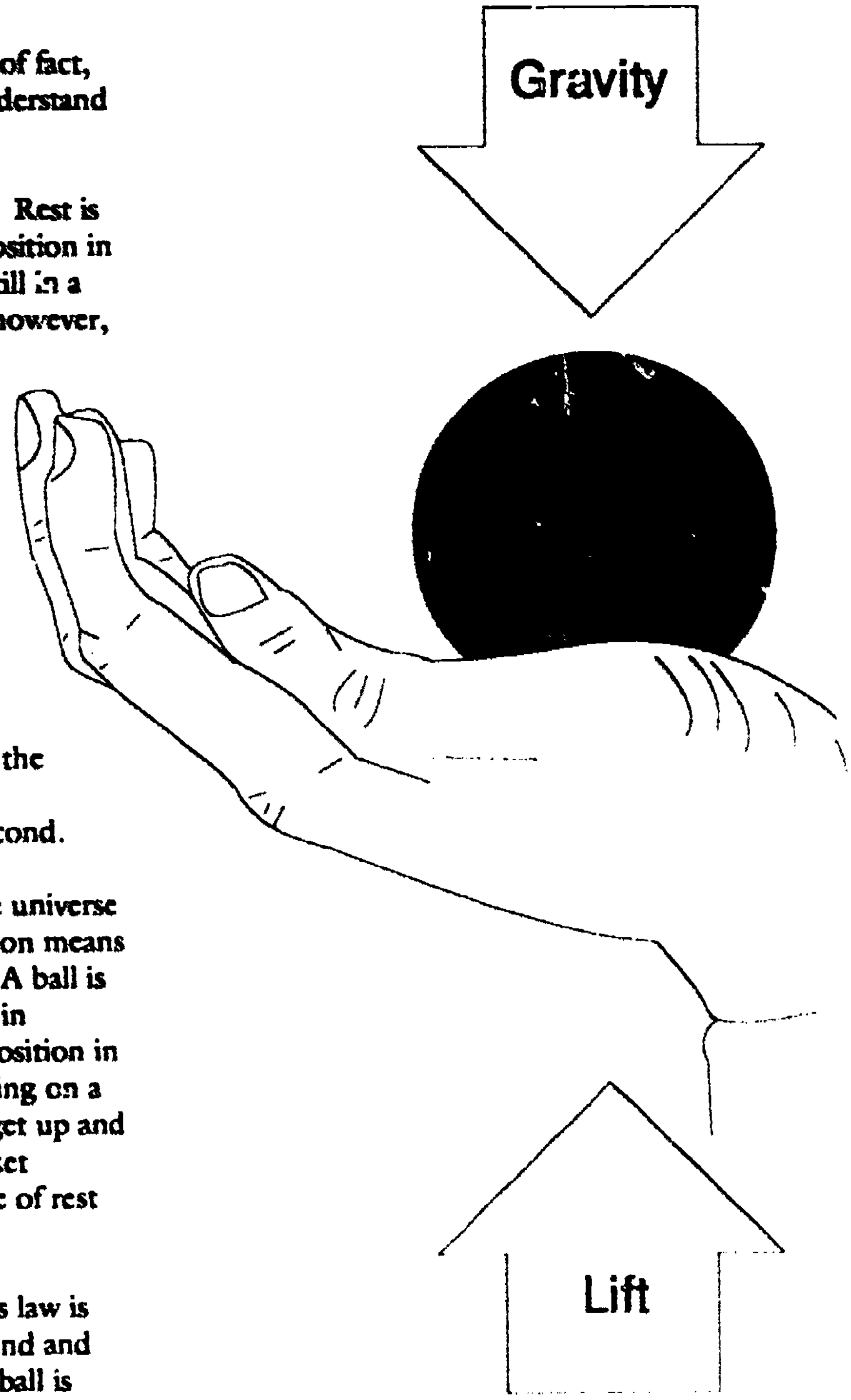
This law of motion is just an obvious statement of fact, but to know what it means, it is necessary to understand the terms *rest*, *motion*, and *unbalanced force*.

Rest and motion can be thought of as opposite. 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, and 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 miles per second.

Motion is also a relative term. All matter in the universe is moving all the time, but in the first law, motion 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. Then it is changing 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 pulling the ball downward, while 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 the Earth.



Ball at Rest

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 the 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 spacecraft is sent by a rocket on a path that is parallel to the Earth's surface. If the rocket shoots the spacecraft fast enough, the spacecraft will orbit the Earth. As long as an unbalanced force, (friction or the firing of a rocket engine in the opposite direction from its movement) does not stop the spacecraft, it will orbit the 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 or to change its direction or 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 steps off the skateboard. In the third law, the stepping off is called an *action*. The skateboard responds to that action by traveling some distance in the opposite direction. The skateboard's 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 weighs less than the rider.

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 weight 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 to oppose their movement. 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

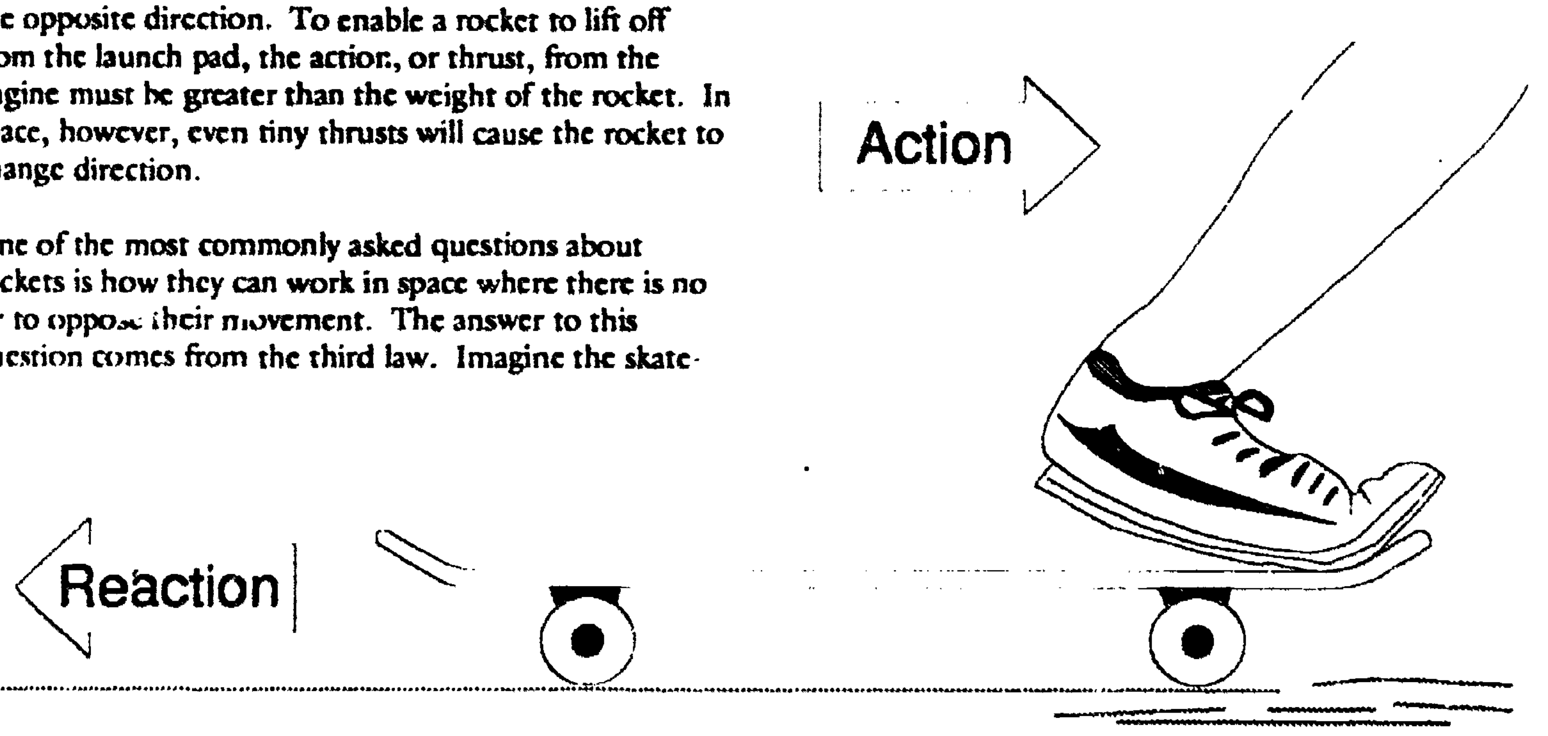
This law of motion is essentially a statement of a mathematical equation. The three parts of the equation are mass (m), acceleration (a), and force (f). Using letters to symbolize each part, the equation can be written as follows:

$$f = ma$$

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.

Force in the equation can be thought of as the thrust of the rocket. Mass in the equation is the amount of rocket fuel being burned and converted into gas that expands and then escapes from the rocket. Acceleration is the rate at which the gas escapes. Inside the rocket, the gas does not really move, but as it leaves the engine it picks up speed.

The second law of motion is especially useful when designing efficient rockets. To enable a rocket to climb into low Earth orbit or escape the Earth's gravitational pull, it is necessary to achieve velocities, or speeds, in excess of 28,000 km per hour. The speed necessary to escape Earth's gravity, 40,250 km per hour, is called "escape velocity." Attaining escape velocity requires the rocket engine to achieve the greatest action force possible in the shortest time. In other words, the engine must burn a large amount 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 an opposite direction from 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 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 the Earth. Modern rockets are also more efficient because we have a firm understanding of the scientific principles behind rocketry. This has led us to develop a wide variety of advanced rocket hardware and to devise new propellants that can be used for longer trips and more efficient 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 the rocket burns, but for burning to take place, an oxidizer (oxygen) must be present. Rockets do not have the luxury that jet planes have. Jet engines draw oxygen into their engines from the surrounding air. Rocket engines, which operate mostly in space where there is no air, must carry their oxygen with them.

Solid rocket propellants, which are dry to the touch, contain both the fuel and oxidizer in the chemical itself. Usually the fuel is a mixture of hydrogen compounds and carbon. 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, a 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 the 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 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 contacts to the combustion point.

Many igniters are more advanced than the hot-wire device. Some are encased in a chemical that ignites first, which then ignites the propellants. 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.

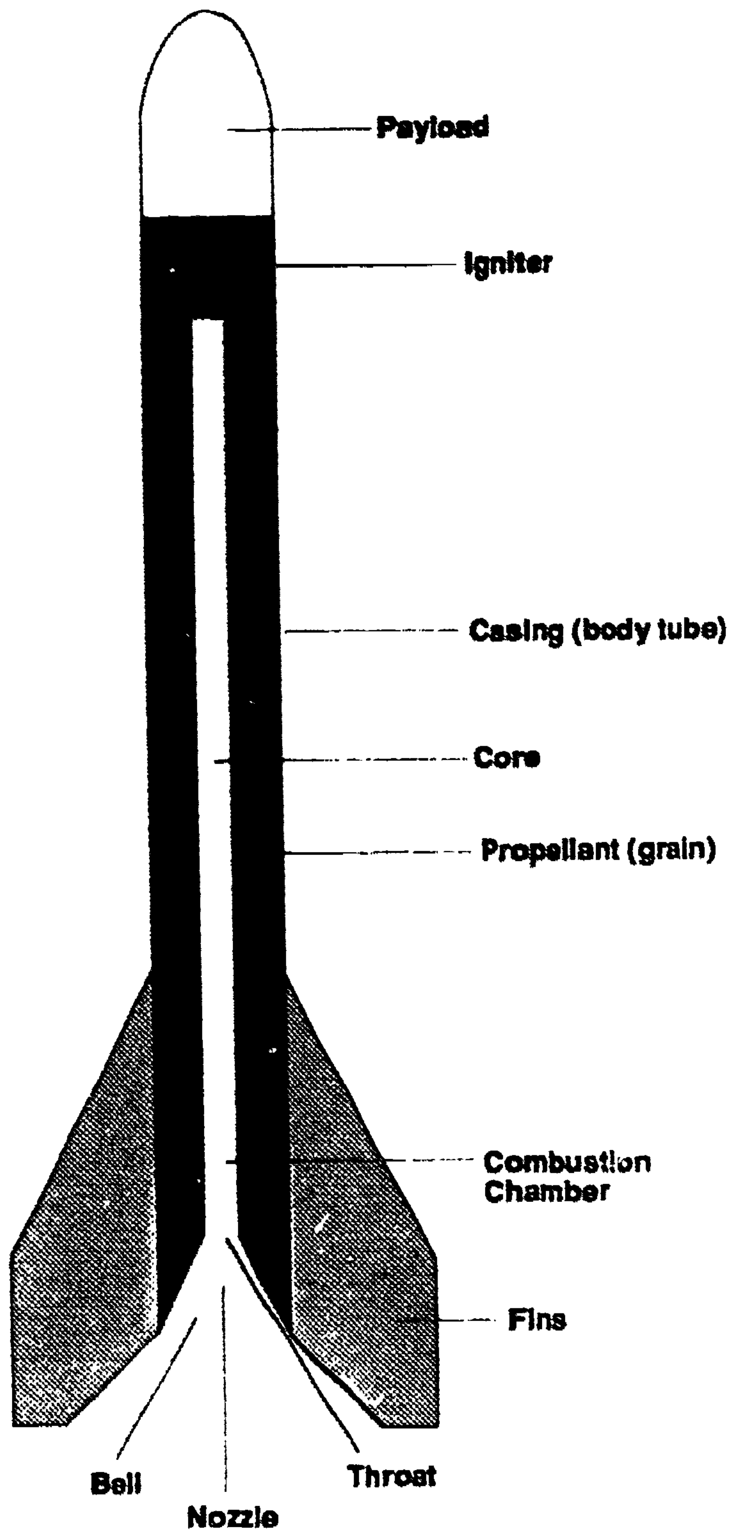
The nozzle in a solid-propellant engine is an opening at the back of the rocket that permits the hot expanding gases to escape. The narrow part of the nozzle is the throat. Just beyond the throat is the exit cone.

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 it. 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.

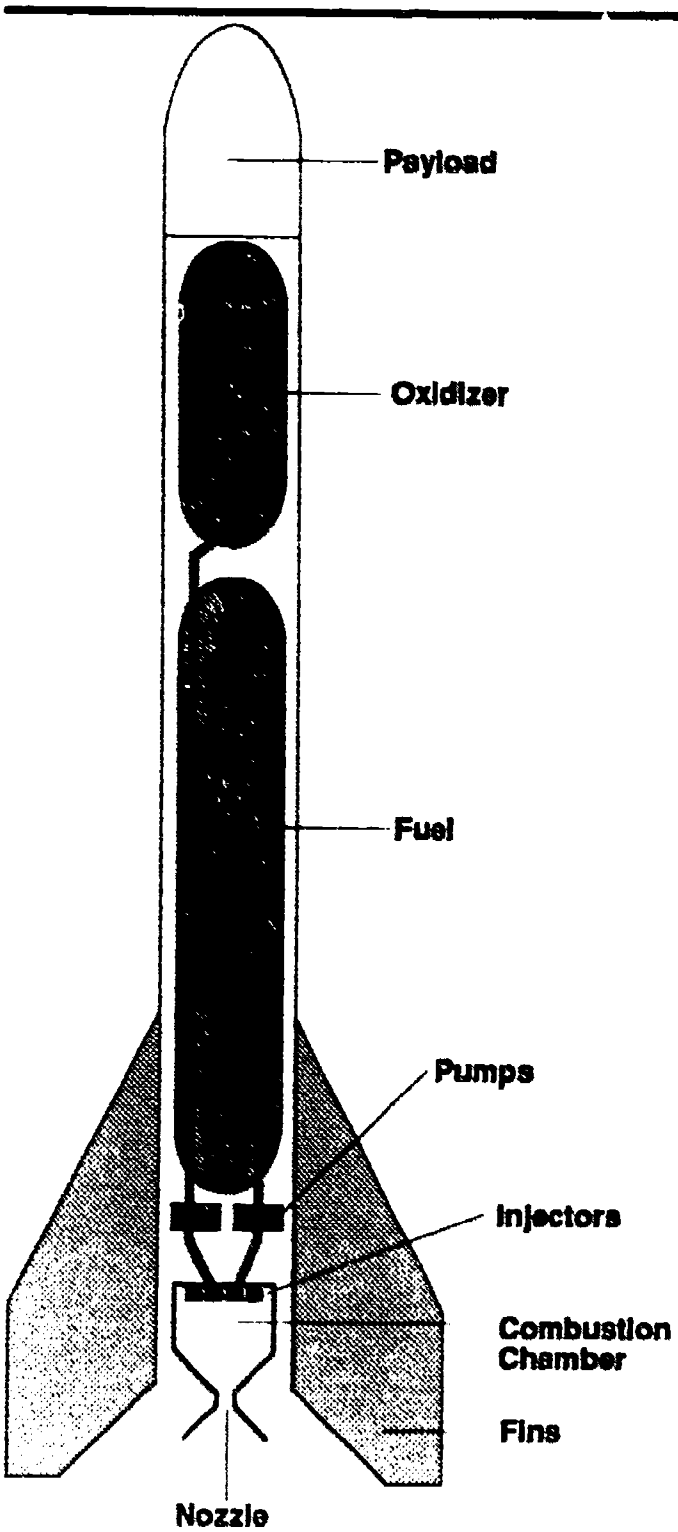
The other main kind of rocket engine is one that uses liquid propellants. This is a much more complicated engine, as is evidenced by the fact that solid rocket engines were used for at least seven hundred years before the first successful liquid engine was tested.



Solid Propellant Rocket

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.

The fuel of a liquid engine 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 to high temperatures and pressures, and the expanding gas escapes through the nozzle at the lower end. To get the



Liquid Propellant Rocket

most power from the propellants, they must be mixed as completely as possible. Small nozzle injectors on the roof of the chamber spray and mix the propellants at the same time. Because the chamber operates under high pressures, the propellants need to be forced inside the chamber. Powerful, lightweight turbine pumps between the propellant tanks and combustion chambers do 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 minus 423°F (-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 the 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.

CAUTION: 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 that is 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.

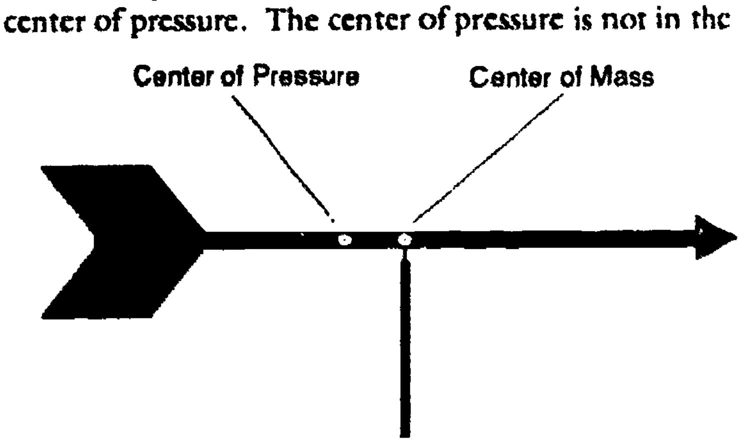
All matter, regardless of size, mass, or shape, has a point inside called the *center of mass* (CM). The center of mass is the exact spot where all of the mass of that object is perfectly balanced. You can easily find the center of mass of an object such as a ruler by balancing the object on your finger. 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 within the object. 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 arrowlike stick that is mounted on a rooftop and is 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 oncoming 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 following air imparts a greater force to the tail than the head, and therefore the tail is pushed away. There is a point in the arrow where there is exactly the same surface area on one side of the point as on 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 keep a rocket stable in flight and steer it. Small rockets usually require only a stabilizing control system, but large rockets, such as the ones that launch satellites into orbit, require a system that not only stabilizes the rocket but also enables 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.

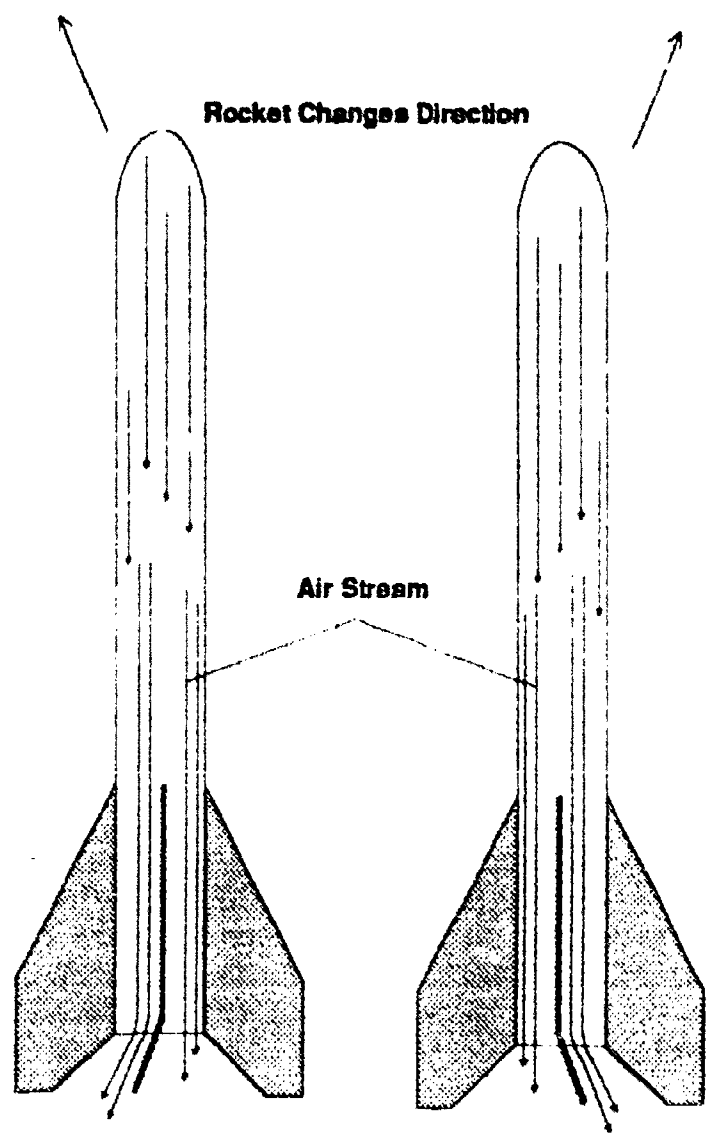
The simplest of all passive controls is a stick. The Chinese fire-arrows were simple rockets mounted on the ends of sticks. The stick kept the center of pressure behind the center of mass. In spite of this, fire-arrows were notoriously inaccurate. Before the center of pressure could take effect, air 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 twentieth 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, tilting 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



Movable Fins

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.

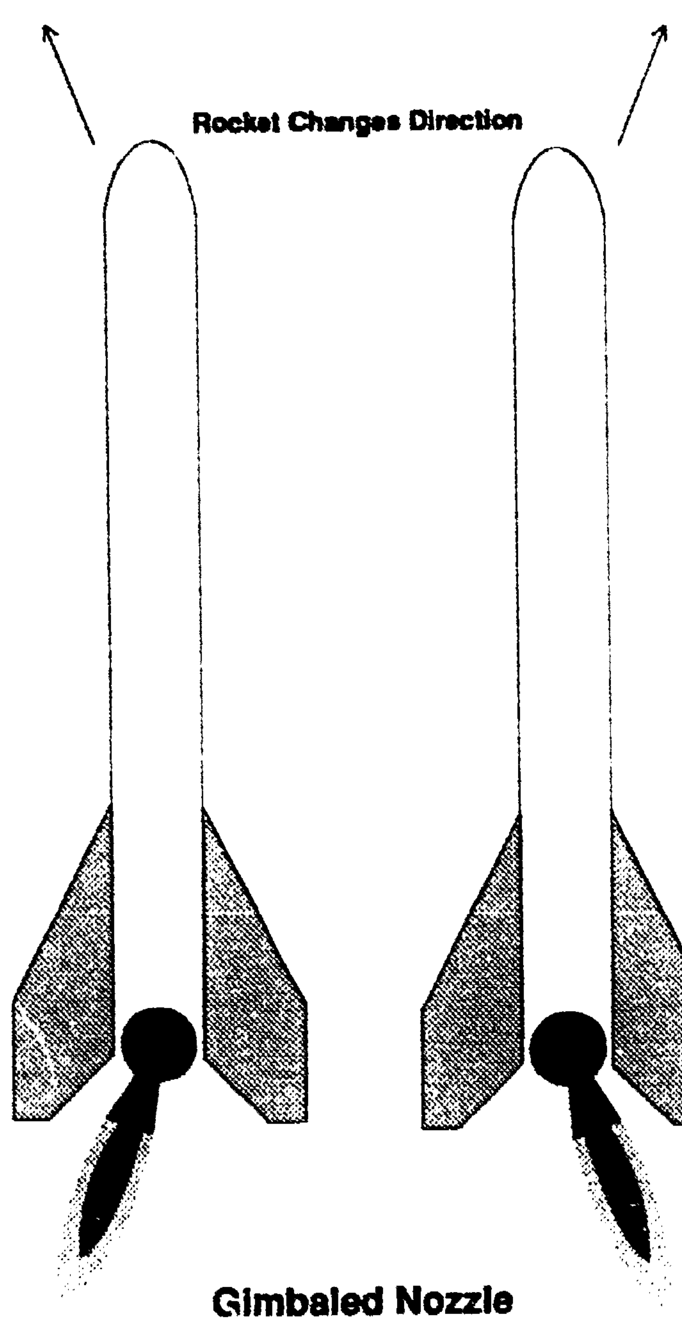
Other active control systems can eliminate fins and canards altogether. By tilting the angle at which the exhaust gas leaves the rocket engine, course changes can be made in flight. Several techniques can be used for changing exhaust direction.

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.



Gimbaled Nozzle

Weight

There is another important factor affecting the performance of a rocket. The weight 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 weight of the vehicle. It is obvious that a rocket with a lot of unnecessary weight will not be as efficient as one that is trimmed to just the bare essentials.

For an ideal rocket, the total weight 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 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:

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

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.

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, and 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 sixteenth-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 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.

Activities

The following activities are useful for teaching about the science of rocketry. They make use of simple and inexpensive materials. It is suggested that these activities be used as an introduction to a follow-up activity of building and launching commercial model rockets.

Classroom Activities

Soda Pop Can Hero Engine

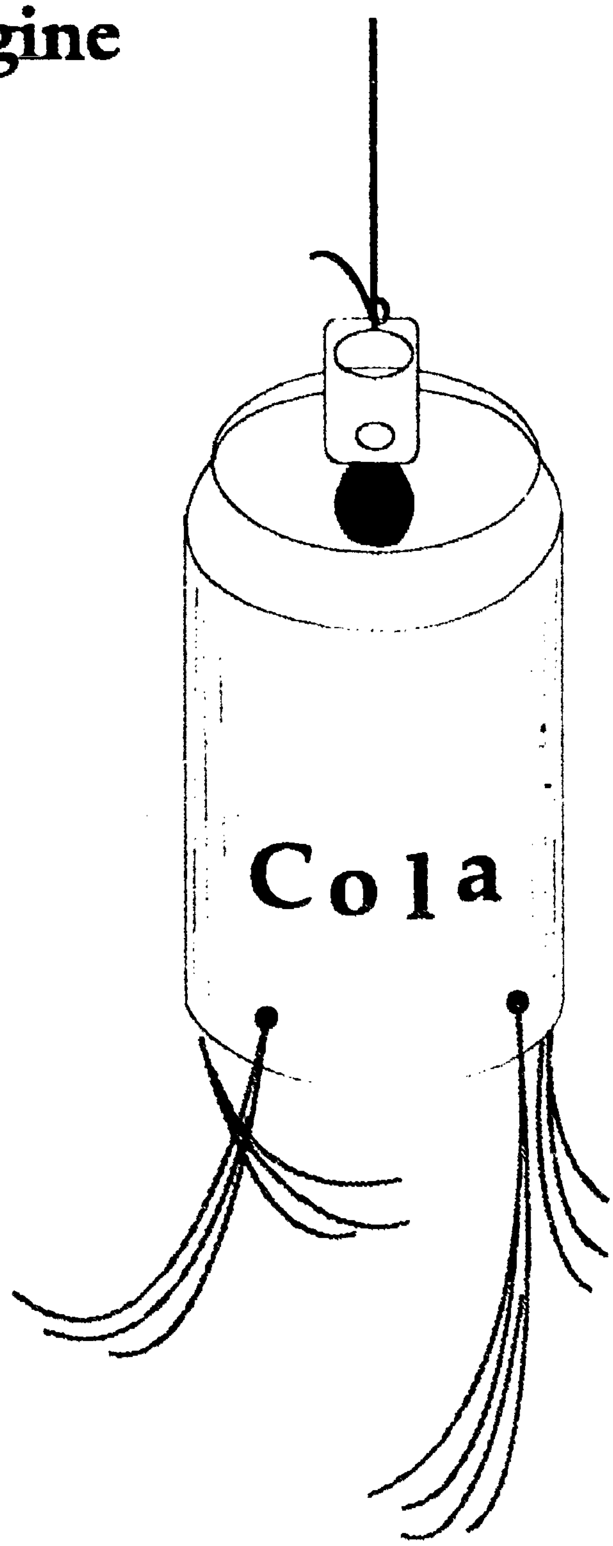
Subject: Rocketry
Topic: Newton's Laws of Motion
Description: Water streaming through holes in the bottom of a suspended soda pop can causes the can to rotate.
Contributed by: Tom Clausen, Kennedy Space Center Explorations Station

Materials and Tools:

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

Method:

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 hole is slanted in that 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. Water streams will start the can spinning.



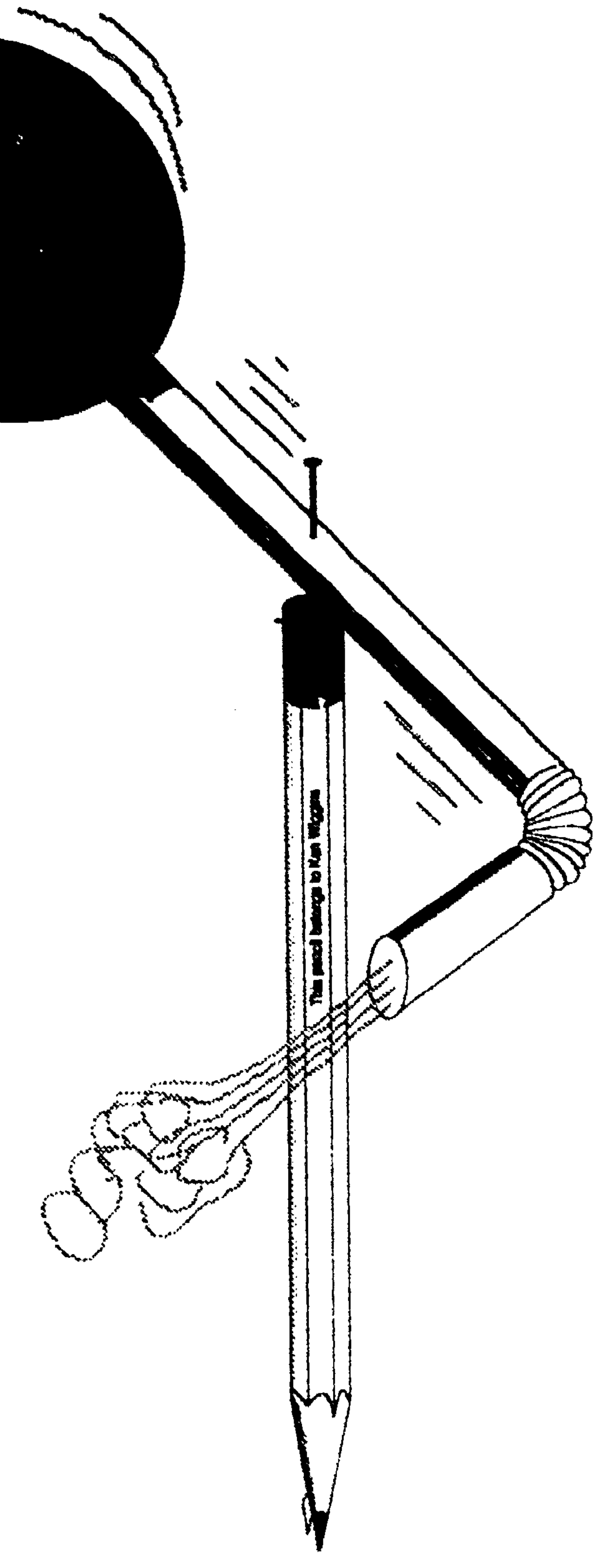
Discussion:

The soda pop can Hero engine is an excellent demonstration of Newton's laws of motion. The can rotates because a force is exerted by the flowing water (first law). The rate of rotation will vary with different numbers of holes and different diameters of holes in the can (second law). Try two holes and try a can with large holes versus a can with small holes. The can rotates in the opposite direction from the direction of the water streams (third law).

For more information about Hero engines, refer to the "Hero Engine" activity.

Classroom Activities

Rocket Pinwheel



Subject: Rocketry
Topic: Action-Reaction Principle
Discription: Construct a balloon-powered pinwheel.
Contributed by: John Hartsfield, Lewis Research Center

Materials:

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

Method:

1. Inflate the balloon to stretch it out a bit.
2. Slip the nozzle end of the balloon over the end of the straw farthest away from the 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 so that it balances. Push the pin through the straw at the balance point and then continue pushing the pin into the eraser of the pencil and finally into the wood itself.
5. Spin the straw a few times to loosen up the hole the pin has 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. Stated simply, the law says every action is accompanied by an opposite and equal reaction. In this case, the balloon produces an action by squeezing on the air inside causing it to rush out the straw. 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.

Classroom Activities

Rocket Car

Subject: Rocketry
Topic: Newton's Third Law of Motion
Description: A small car is propelled by the action-reaction force generated by a balloon.
Contributed by: Gregory Vogt, Oklahoma State University

Materials and Tools:

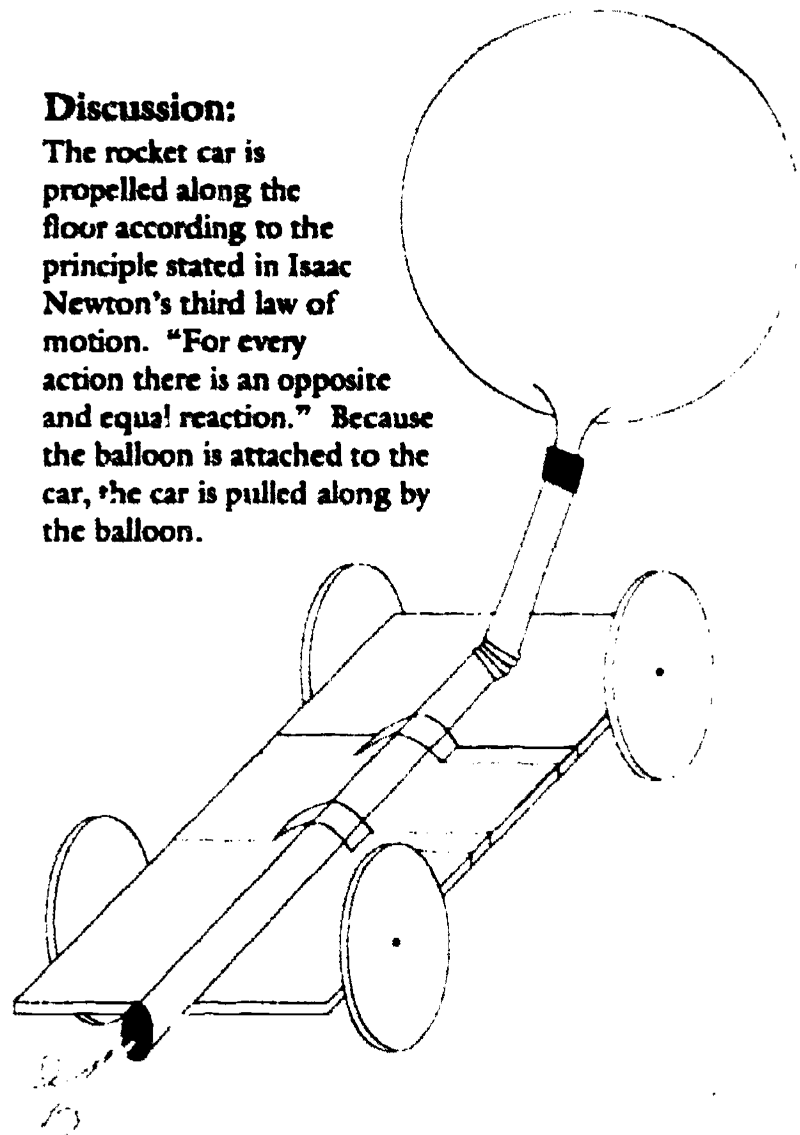
4 Pins
Styrofoam meat tray
Cellophane tape
Flexi-straw
Scissors
Drawing compass
Marker pen
Small party balloon
Ruler

Procedure:

1. Using the ruler, marker, and drawing compass, draw a rectangle about 7.5 by 18 cm and four circles 7.5 cm in diameter on the flat surface of the meat tray. Cut out each piece.
2. 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 alright if the wheels wobble.
3. Inflate the balloon a few times to stretch it out a bit. 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.
4. Tape the straw to the car as shown in the picture.
5. Inflate the balloon and pinch the straw to hold in the air. Set the car on a smooth surface and release the straw.

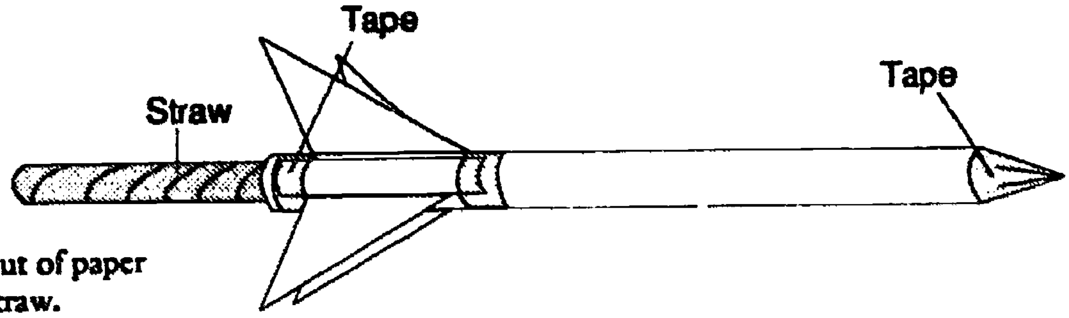
Discussion:

The rocket car is propelled along the floor according to the principle stated in Isaac Newton's third law of motion. "For every action there is an opposite and equal reaction." Because the balloon is attached to the car, the car is pulled along by the balloon.



Classroom Activities

Paper Rockets



Subject: Rocketry
Topic: Stability
Description: Small flying rockets made out of paper and propelled with air blown through a straw.

Materials:

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

Procedure:

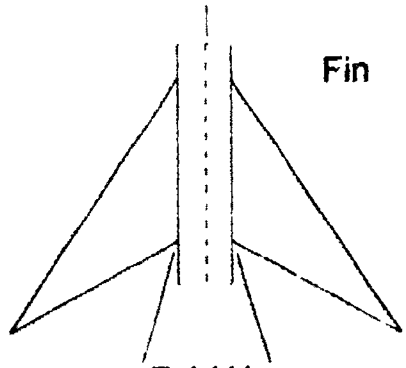
1. Cut a narrow rectangular strip of paper about 13 cm long and roll it tightly around the fat pencil. Tape the cylinder and remove it from the pencil.
2. Cut points into one end of the cylinder to make a cone and slip it back onto the pencil.
3. Slide the cone end onto the pencil tip and squeeze and 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 the diagram. 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, sharply blow through the straw. The rocket will shoot away. **Be careful not to aim the rocket toward anyone because the rocket could poke an eye.**

Discussion:

Paper rockets demonstrate how rockets fly through the atmosphere and the importance of having fins for control. For experimental purposes, try building a rocket with no fins and one with the fins in the front to see how they will fly. Practice flying the rockets on a ballistic trajectory towards a target. Also try making a rocket with wings so that it will glide.



Fin Shape

Classroom Activities

Water Rockets

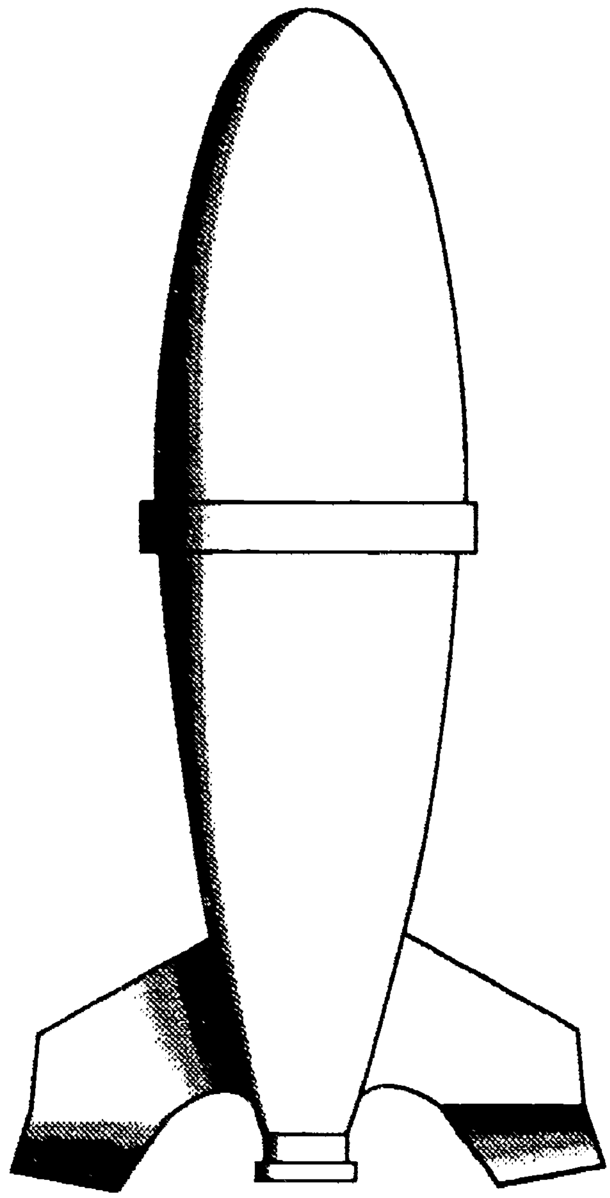
Subject: Rockets
Topic: Newton's second law of motion
Description: Varying the amount of water and pressure in water rockets affects the distance they travel.
Contributed by: Gregory Vogt, Oklahoma State University

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

Procedure:

1. Take the water rockets, pumps, water supply, and markers to an outside location such as a clear, grassy playing field.
2. Attach both rockets to their pumps as shown on the package they came in. 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 30.48 meter line. 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 a student. If the student stands to the side for the release, the water spray should miss the student.)



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 differently. Be sure to change only one variable at a time (i.e. vary only the water or only the pumping).

Discussion:

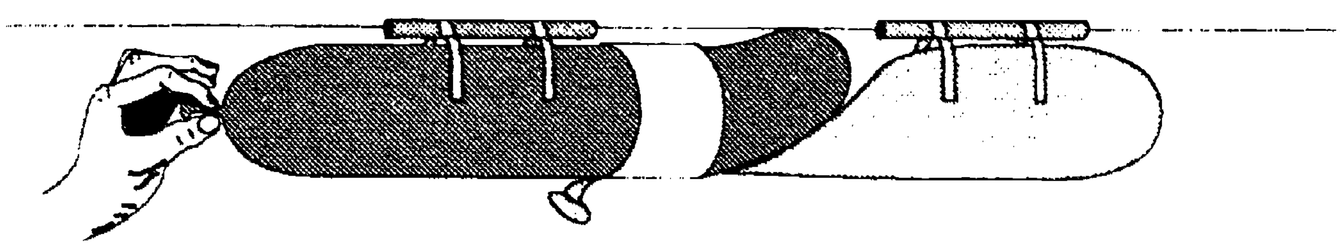
Isaac Newton's second law of motion states that *force is equal to mass times acceleration.* In rocket terms, it means that the thrust of a rocket is equal to the amount of mass (fire, smoke or steam, and gas) expelled by the rocket engine times how fast it is expelled. Designers of powerful rockets try to maximize both mass and acceleration to get the greatest thrust possible because thrust is a product of the two. In the 1960s, designers of the Saturn V rocket built first-stage engines that burned kerosene and liquid oxygen. The two propellants were injected into each of the five engines of the first stage by high-speed turbines. Kerosene was chosen as the fuel because it is a very dense liquid when compared to other rocket fuels. During operation, the five engines consumed 15 tons of propellants per second. The combination of dense fuel and high-speed combustion produced a liftoff thrust of 7.5 million pounds.

Water rockets can demonstrate Newton's second law 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 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. 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, stud- ts can see that the thrust of the rocket is dependent c he mass being expelled and how fast it is being expe -d. Thrust is greatest when mass and acceleration are greatest.

Classroom Activities

Balloon Staging

Subject: Rocketry
Topic: Rocket staging
Description: Two inflated balloons simulate a multi-stage rocket launch as they slide along a fishing line on the thrust produced by escaping air.



Materials and Tools:

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

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 preinflating 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.

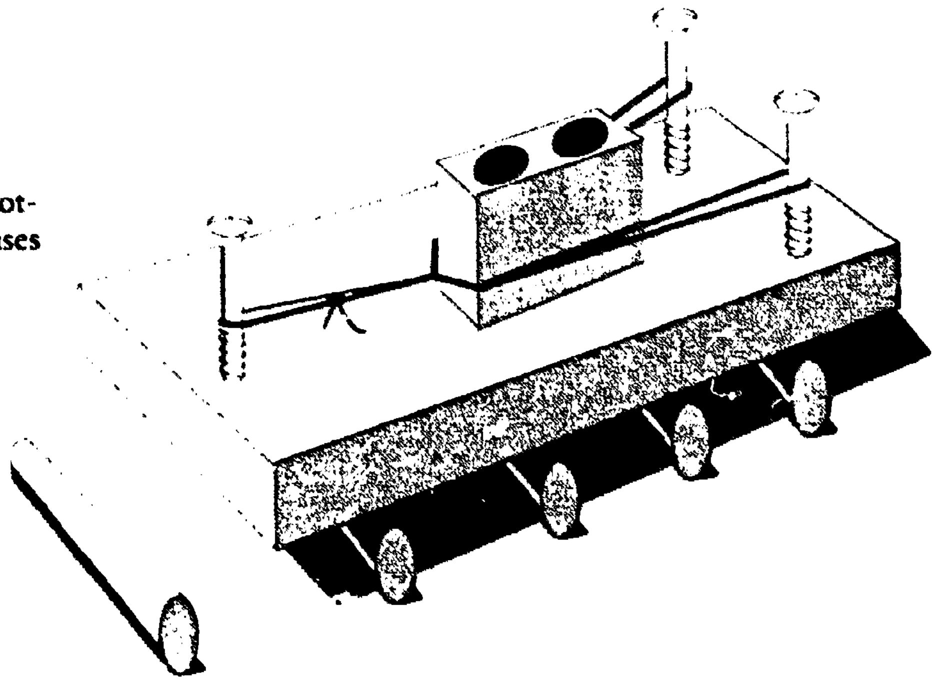
Discussion:

Traveling into outer space takes enormous amounts of energy. Much of that energy is used to lift rocket propellants that will be used for later phases of the rocket's flight. To eliminate the technological problems and cost of building giant one-piece rockets to reach outer space, NASA, as well as all other space-faring nations of the world have chosen to use a rocket technique that was invented by sixteenth-century fireworks maker Johann Schmidlap. To reach higher altitudes with his aerial displays, Schmidlap attached smaller rockets to the top of larger ones. When the larger rockets were exhausted, the smaller rockets climbed to even higher altitudes. Schmidlap called his invention a "step rocket."

Today's space rockets make use of Schmidlap's invention through "multistaging." A large first-stage rocket carries the smaller upper stages for the first minute or two of flight. When the first stage is exhausted, it is released to return to the Earth. In doing so, the upper stages are much more efficient and are able to reach much higher altitudes than they would have been able to do simply because they do not have to carry the expired engines and empty propellant tanks that make up the first stage. Space rockets are often designed with three or four stages that each fire in turn to send a payload into orbit.

Classroom Activities

Newton Cart



Subject: Rocketry
Topic: Newton's laws of motion
Description: A wooden block is thrown by a slingshot-like device from a cart and produces a thrust that causes the cart to move in the opposite direction.

Materials and Tools:

1 Wooden block about 10x20x2.5 cm
1 Wooden block about 7.5x5x2.5 cm
3 - 7.62 cm No. 10 wood screws (round head)
12 Round pencils or short lengths of similar dowel rods
3 Rubber bands
Cotton string (several feet)
Matches
6 Lead fishing sinkers (about 14 gm each)
Drill and bit
Vice
Screwdriver

Procedure:

1. Screw the three screws in the large wood block as shown in the figure.
2. Hold the short piece of wood with a vice and drill two holes large enough to drop two sinkers in each.
3. Tie several small loops of string (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 wooden block. Pull the rubber band back like a slingshot and slip the string over the third screw to hold the rubber band stretched.
5. Arrange the pencils or dowel rods in a row like railroad ties on a level table top. Set the large block on one end of the row so that the single screw points to the middle of the row. 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 cart and the cart will roll in the other direction. Note how far the cart travels along the table top.
7. Reset the equipment and add a second rubber band. Again, light the string and note how far the cart travels.
8. Reset the equipment and try again with 3 rubber bands. Try again with one rubber band and two sinkers, 4 sinkers, etc.

Discussion:

The Newton cart provides an excellent demonstration of Isaac Newton's three laws of motion. The laws are stated in general terms below.

First Law:	An object at rest will remain at rest or an object in motion will remain in motion in a straight line unless acted upon by an unbalanced force.
Second Law:	Force equals mass times acceleration.
Third Law:	For every action there is an opposite and equal reaction.

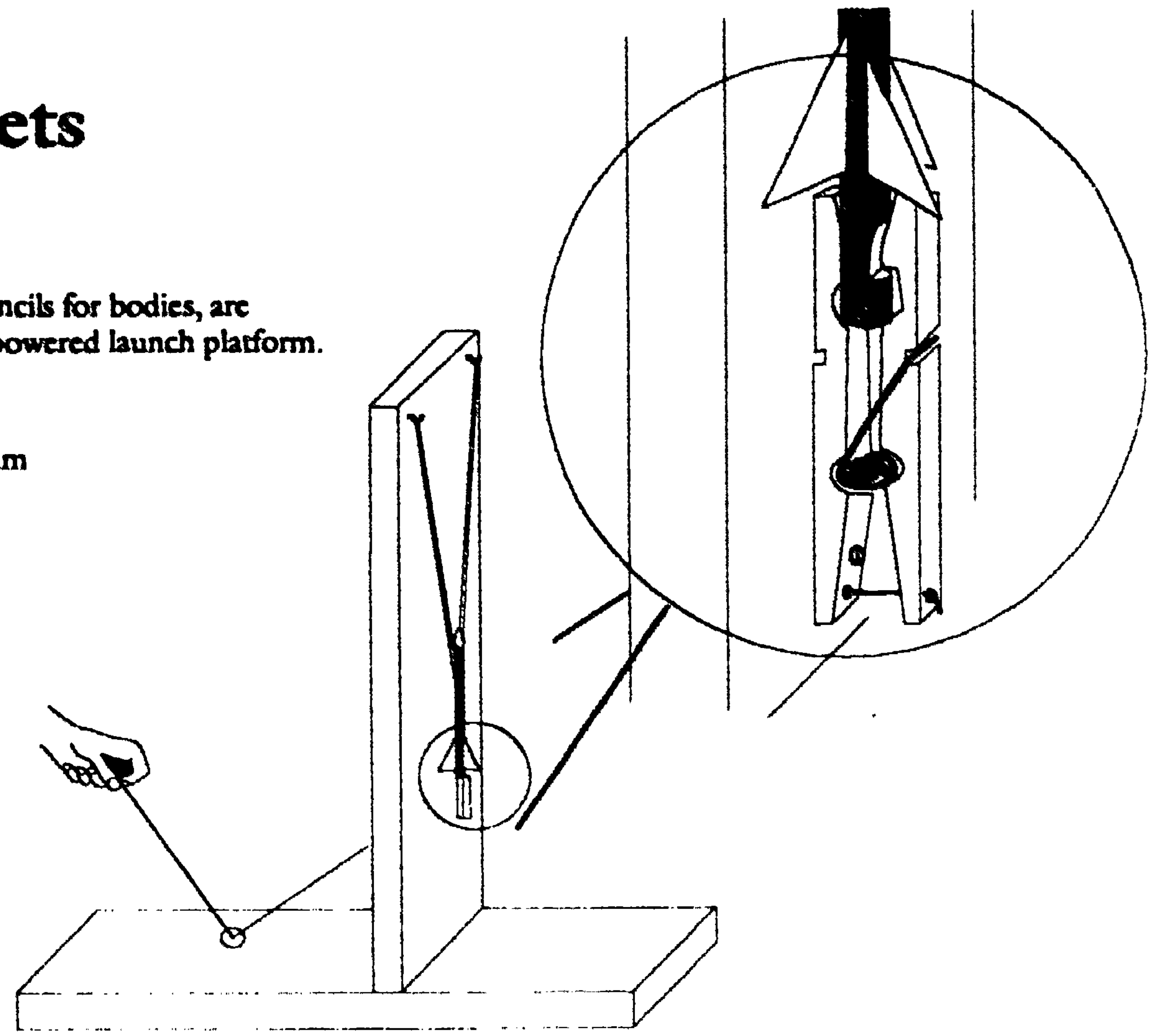
The Newton cart remains at rest on the tabletop until an unbalanced force (from the expelled block) causes it to move. A rocket remains on the launch pad until the thrust from the engines propels it upward.

The amount of thrust on the cart is determined by the mass of the block and how fast it is thrown off. This can easily be seen in how far the cart traveled. The cart with a single rubber band and no sinkers did not travel very far. With two and three rubber bands, the block was thrown off much faster (acceleration). With sinkers added to the block, the block had more mass and this caused the cart to travel farther than when the block had no sinkers at all. In rockets, the propellants provide the mass and the rocket engine burns the propellants and directs the gases produced in the proper direction. Rockets can increase their thrust by burning propellants faster (mass) and by expelling the gases produced out of the engine faster (acceleration).

Throwing the block from the cart is an "action" and the cart's movement is a "reaction." The action and reaction are in opposite directions. Rockets produce action, or thrust, by the escape of gases out of their engines. The rocket's movement in the opposite direction is its reaction.

Classroom Activities

Pencil Rockets



Subject: Space Flight
Topic: Rockets
Description: Rockets, with pencils for bodies, are launched with a rubber-band-powered launch platform.

Materials and Tools:

2 Pieces of wood 7.5x10x2.5 cm
2 Cup hooks
1 Wooden spring clothespin
1 Small wood screw
1 Screw eye
2 Metal angle irons and screws
4 Feet of heavy string
Iron baling wire
Several rubber bands
Several wooden pencils
Several pencil cap erasers
Cellophane or masking tape
Heavy paper
Saw
Wood file
Drill 0.5 cm diameter
Pliers

Figure 1

Procedure: Launch Platform

1. Join the two pieces of wood as shown in the diagram to form the launch platform. Use a metal angle iron on each side to strengthen the structure.
2. Screw in the cup hooks and screw eye into the wood in the places 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.
4. Drill a hole through the upright piece of the launch platform as shown and screw th lothespin to the upright piece so that the lower holes in the pin line up with the hole in the upright. Reassemble the clothespin.
5. Tie a big knot in one end of the string and feed it through the clothespin as shown in 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 won't 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.

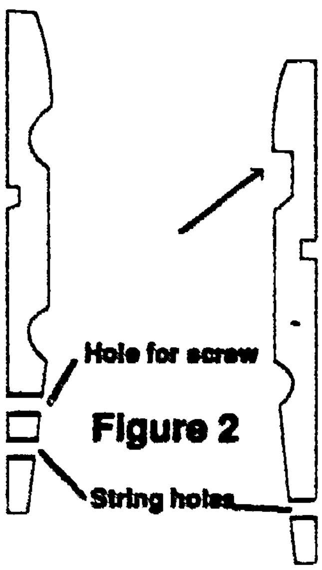


Figure 2

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.
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.

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. 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 22.79 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 its nose area rather than its 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.

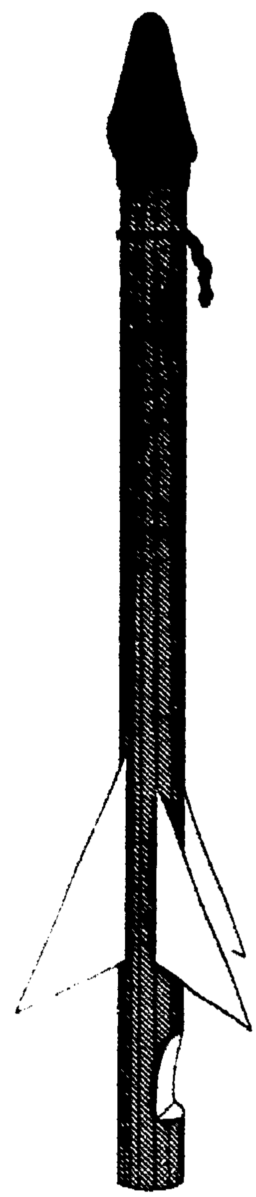
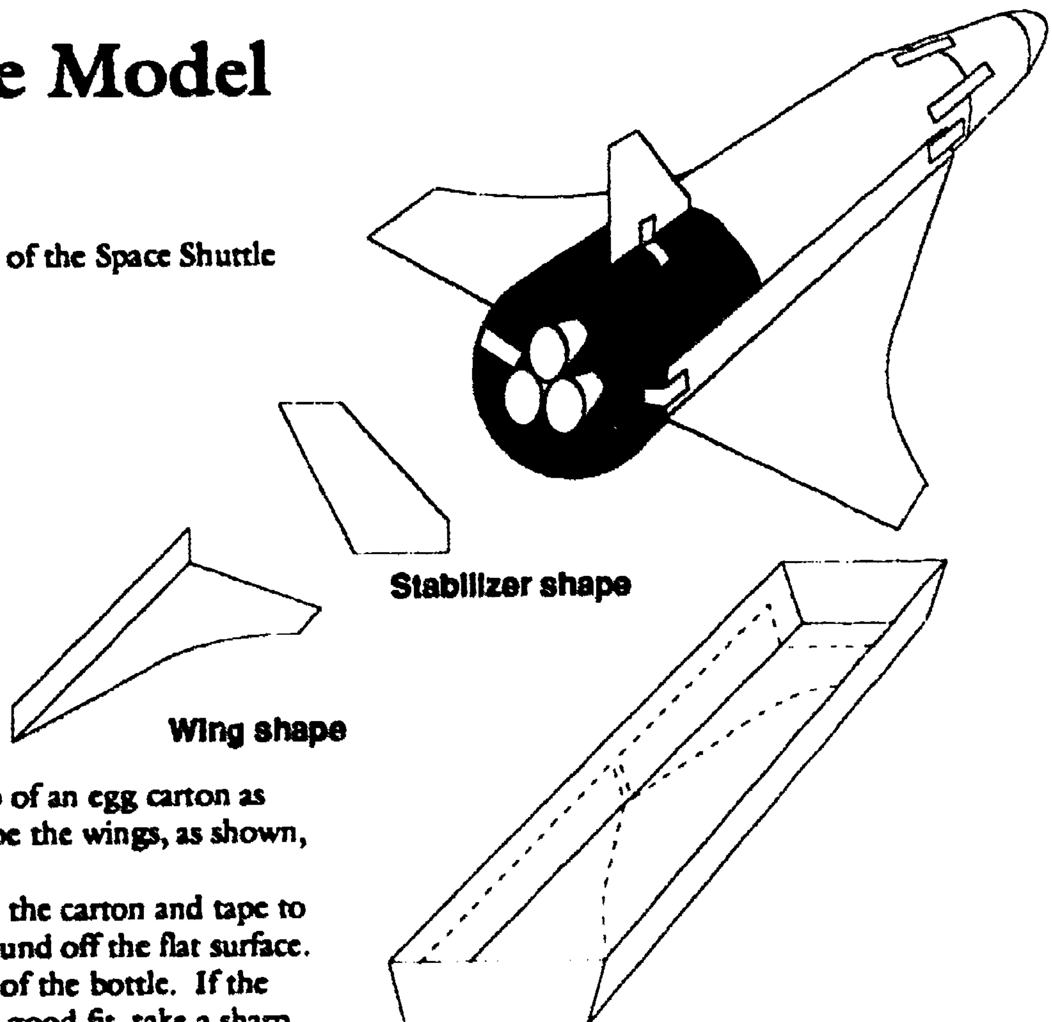


Figure 3

Classroom Activities

Space Shuttle Model



Subject: Manned Space Flight
Topic: Model Building
Description: Construct a model of the Space Shuttle orbiter from scrap materials.

Materials and Tools:

2-Liter plastic soda pop bottle
2 Egg cartons
6-oz Paper cup
Masking tape
Newspaper
Glue for papier-maché
White glue
Scissors

Procedures:

1. Cut two wings from the top of an egg carton as shown in the diagrams. Tape the wings, as shown, to the bottle.
2. Cut out an "egg well" from the carton and tape to the bottom of the cup to round off the flat surface. Tape the cup over the neck of the bottle. If the neck is too long to permit a good fit, take a sharp knife and trim it off a bit.
3. Cut out a vertical tail for the model from the egg carton and tape it onto the bottle.
4. Cover the model with papier-maché. Narrow strips of newspaper are easiest to work with. Let the papier-maché dry and add additional layers for strength.
5. Cut three egg wells to make engines for the orbiter. Cover each well with papier-maché and let it dry.
6. When the body of the orbiter and the engines are dry, glue the engines to the tail end of the model as shown.
7. Paint the model and add decals, stars, and other decorations when dry.

Classroom Activities

Hero Engine

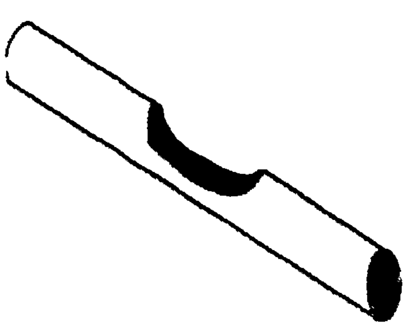
Subject: Aeronautics, Rocketry
Topic: Weightlessness
Desciption: Plans for constructing a working model of a Hero engine.
Contributed by: Gregory Vogt, Oklahoma State University

Materials and Tools:

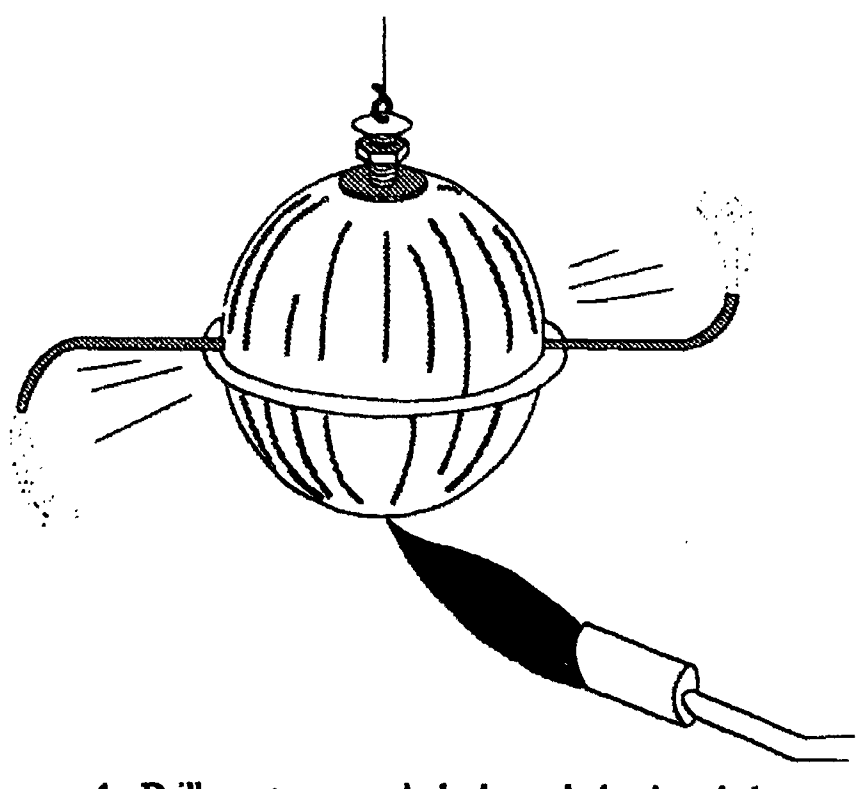
Copper toilet tank float
Thumb screw, 0.635 cm
Brass tube, 30.48 cm, .476 in diameter (from hobby shops)
Solder
Fishing line and swivel
Ice pick or drill
Metal file
Propane Torch

Procedure

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 to makr filling with water easier. (Water can enter the compl͏eted engine through the tubes.)
5. Using the torch again, heat the protruding tubes about 2.54 cm from each end. With pliers, carefully bend the tube tips in opposite directions. Bend slowly so that the tubes 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.

Procedure: Using the Hero Engine

1. Place a few tablespoons of water into the float. The precise amount is not important. The float can be filled through the top if you drill 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 it at 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 balanced and may wobble violently. If it begins to wobble, remove the heat.

Caution: This demonstration should be done by adults only. Eye protection is advised. 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.

Discussion:

The Hero engine was invented by Hero (also called Heron) of Alexandria sometime in the first century BC. His engine was a sphere with two L-shaped tubes connected to a water-filled kettle heated from below. Steam produced by boiling water caused the sphere to spin. Remarkably, the Hero engine was considered a novelty and, reportedly, no attempt to harness its power was made at that time.

The principle behind the engine is simple. Steam from the boiling water inside the float pressurizes the float. The steam rapidly escapes through the tubes producing an action-reaction force causing the float to spin. The action-reaction principle of the Hero engine is the same that is used to propel airplanes and rockets.

For an interesting follow-up demonstration, make a second engine using a larger diameter brass tube. Compare the rotation of the two engines. The escaping steam from the larger-tube engine will have a lower acceleration and will not spin as fast (Newton's second law of motion).

Resources

1990 Model Rocketry Manufacturers Directory

(Provided by the National Association of Rocketry, 1311 Edgewood Drive, Dept. JB, Altoona, WI 54720)

Estes Industries
1295 H Street
Penrose, CO 81240
Estes Industries is a leader in the model rocket industry. Estes carries a complete line of model rocket kits, motors, launchers, computer programs, and educational materials.

Apogee Components
11111 Greenbrier Road
Minnetonka, MN 55343
Apogee Components is your source for high technology competition parts. Apogee's components include phenolic body tubes, injection molded nose cones, and "waferglass" fin stock.

Spectrum Video Productions
Box 3698
Ontario, CA 91761
Spectrum Video Productions offers a complete line of NASA films in the VHS format. Film topics include Mercury, Gemini, and Apollo missions, as well as coverage of many of the Space Shuttle missions.

U.S. Rockets
Box 1242
Claremont, CA 91711
U.S. Rockets offers kits and parts for the high-power rocket enthusiast.

Model Aviation Fuels
R.D. 6, Box 172
Clarke Summit, PA 18411
Model Aviation Fuels offers interesting kits to the model-making enthusiast. They offer body tubes, nose cones, and fin materials for the D-E-F-G powered models.

MARS
2240 9th Street
National City, CA 92050
MARS offers specialized tubes for the modeler. Their tubes are bright silver for easy tracking.

Space Frontiers
Box 6488
Newport News, VA 23606
Space Frontiers magazine offers modelers interesting facts on space and rocketry.

Belleville Wholesale Hobby
1827 North Charles Street
Belleville, IL 62211
Belleville Wholesale Hobby offers the modeler wholesale prices on the complete line of Estes products.

Flight Systems, Inc.
9300 East 68th Street
Raytown, MO 64133
Flight Systems, Inc., offers a complete line of kits and motors in D-G powered model rockets.

ACME Rockets
Box 28283 Dept. AS27
Tempe, AZ 85285
If you are interested in building the kits of yesterday, then ACME Rockets is your resource for finding out-of-production model rocket kits.

East Coast Rockets
408 Lark Drive
Mount Laurel, NJ 08054
East Coast Rockets offers a line of kits for the A-D class model rocket flyer, as well as a line of parts and accessories.