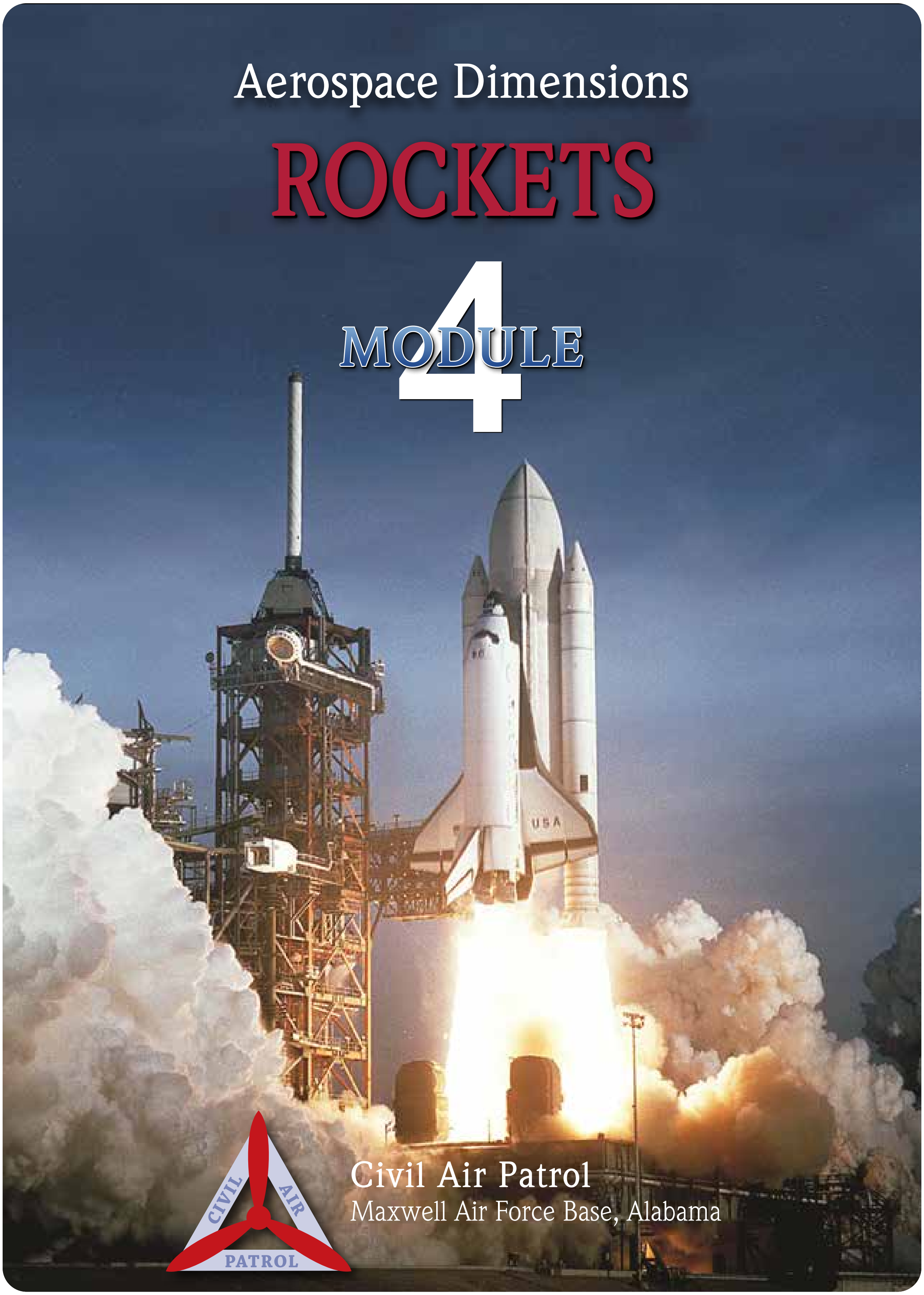
Aerospace Dimensions

ROCKETS

MODULE 4



Civil Air Patrol
Maxwell Air Force Base, Alabama

Aerospace Dimensions
ROCKETS
MODULE 4

WRITTEN BY
DR. JEFF MONTGOMERY
DR. BEN
GARY DAHLKE

DESIGN
BARB PRIBULICK
BLAKE ATKINS

ILLUSTRATIONS
PEGGY GREENLEE

EDITING
BOB BROOKS
SUSAN MALLETT
JUDY STONE
GINNY SMITH

NATIONAL ACADEMIC STANDARD ALIGNMENT
JUDY STONE

PUBLISHED BY
NATIONAL HEADQUARTERS
CIVIL AIR PATROL
AEROSPACE EDUCATION DEPUTY DIRECTORATE
MAXWELL AFB, ALABAMA 36112

FOURTH EDITION
MAY 2021

Introduction

The Aerospace Dimensions module, ***Rockets***, is the fourth of six modules, which combined, make up Phases I and II of Civil Air Patrol's Aerospace Education Program for cadets. Each module is meant to stand entirely on its own, so that each can be taught in any order. This enables new cadets coming into the program to study the same module, at the same time, with the other cadets. This builds a cohesiveness and cooperation among the cadets and encourages active group participation. This module is also appropriate for middle school students and can be used by teachers to supplement STEM-related subjects.

Inquiry-based activities were included to enhance the text and provide concept applicability. The activities were designed as group activities, but can be done individually, if desired. The activities for this module are located at the end of each chapter.

Contents

20th century launch vehicle ... Saturn V

21st century launch vehicle ... Space Launch System

National Academic Standard Alignment

Science Standards	Mathematics Standards	English Language Arts Standards	Social Studies Standards	Technology Standards
Science as Inquiry	3. Geometry Standard: • Specify locations and describe spatial relationships using coordinate geometry and other representational systems	1. Reading Perspective	2. Time, Continuity, and Change	6. Understanding of the role of society in the development and use of technology
Physical Science: • Motions and forces • Properties and changes of properties in matter	4. Measurement Standard: • Apply appropriate techniques, tools, and formulas to determine measurements	2. Understanding the Human Experience	8. Science, Technology, and Society	7. Understanding of the influence of technology on history
Science and Technology: • Abilities of technological design • Understanding about science and technology	5. Data Analysis and Probability Standard: • Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them	3. Evaluation Strategies		8. Understanding of the attributes of design
Unifying Concepts and Processes: • Evidence, models, and explanation • Change, constancy, and measurement	6. Problem Solving Standard: • Solve problems that arise in mathematics and in other contexts	7. Evaluating Data		9. Understanding of engineering design
	10. Representation Standard: • Select, apply, and translate among mathematical representations to solve problems	12. Applying Language Skills		10. Understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving
				11. Ability to apply the design process

1 HISTORY OF ROCKETS

Learning Outcomes

- Identify historical facts about the Greeks, Chinese, and British, and their roles in the development of rockets.
- Describe America's early contributions to the development of rockets.
- List the early artificial and manned rocket launches and their missions.

Important Terms/Persons

Neil Armstrong - first man to walk on moon
Roger Bacon - increased the range of rockets
William Congreve - designed rockets for military use
Jean Froissart - improved the accuracy of rockets by launching them through tubes
Yuri Gagarin - a Russian; the first man in space and the first man to orbit the Earth
John Glenn - first American to orbit the Earth
Robert Goddard - experimented with solid and liquid propellant rockets; is called the "Father of Modern Rocketry"
William Hale - developed the technique of spin stabilization
Hero - ancient inventor who developed a device that would demonstrate rocket propulsion
Sergei Korolev - the leading Soviet rocket scientist; known as the "Father of the Soviet Space Program"
Sir Isaac Newton - laid scientific foundation for modern rocketry with his laws of motion
Hermann Oberth - space pioneer; wrote a book about rocket travel into outer space
Alan Shepard - first American in space
Skylab - first US space station
Space Shuttle - a reusable space transportation system developed for traveling to space and back to Earth
Spin Stabilization - a technique developed by Englishman, William Hale, wherein escaping gases in a rocket hit small vanes that made the rocket spin, and stablize, much like a bullet in flight
***Sputnik* I** - first artificial satellite; Russian
Konstantin Tsiolkovsky - proposed the use of rockets for space exploration and became known as the "Father of Modern Astronautics"
Wernher von Braun - director of the V-2 rocket project and architect of the Saturn family of rockets

Today's rockets are remarkable examples of scientific research and experimentation over thousands of years. Let's take a moment and recall some of the fascinating rocket developments of the past.

Hero Engine

HISTORY

Fireworks and rockets share a common heritage

The history of rocketry can be traced as far back as around 400 BC when a Greek named Archytas Hero Engine built a flying wooden pigeon. It was suspended on a wire and propelled by escaping steam. About 300 years later, another Greek named **Hero** developed what could be characterized as the first rocket engine. It was also propelled by steam. Hero placed a sphere on top of a pot of water. The water was heated and turned into steam. The steam traveled through pipes into the sphere. Two L-shaped tubes on opposite sides of the sphere allowed the gas to escape. This created a thrust that caused the sphere to rotate. This device is known as a Hero Engine. (See associated Activity One at the end of the chapter.)

Early Chinese Rocket

In the first century AD, the Chinese developed a form of gunpowder and used it as fireworks for religious and festive celebrations. The Chinese began experimenting with the gunpowder-filled tubes. They attached bamboo tubes to arrows and launched them with bows, creating early rockets.

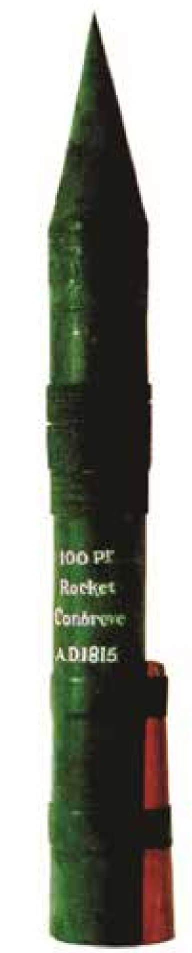
In 1232, with the Chinese and Mongols at war with each other, these early rockets were used as arrows of flying fire. This was a simple form of a solid-propellant rocket. A tube, capped at one end, contained gunpowder. The other end was left open and the tube was attached to a long stick. When the powder 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 guidance system that kept the rocket headed in one general direction as it flew through the air. Records indicate that from this point, the use of rockets spread, as well as the use of fins to add greater guidance and stability.

Rocket experiments continued throughout the 13th to 15th centuries. In England, **Roger Bacon** improved forms of gunpowder, which increased the range of the rocket. In France, **Jean Froissart** achieved more accuracy by launching rockets through tubes. This idea was the forerunner of the bazooka. (See associated Activity Two at the end of the chapter.)

During the latter part of the 17th century, **Sir Isaac Newton** laid the scientific foundations for modern rocketry when he developed his laws of motion. These laws explain how rockets work and are discussed in detail in Chapter 2 of this volume.

Newton's laws of motion influenced the design of rockets. Rocket experimenters in Germany and Russia began working with very powerful rockets. Some of these rockets were so powerful that their escaping exhaust flames bored deep holes in the ground even before liftoff.

At the end of the 18th century, **Colonel William Congreve**, an artillery expert with the British military, set out to design rockets for military use. His designs increased the rocket's range from 200 to 3,000 yards and were very successful in battle, not because of accuracy, but because of the sheer numbers that could be fired. During a typical siege, thousands of rockets could be fired. These became known as the Congreve rockets, and were the rockets that lit the sky during the battle at Fort McHenry in 1812, while Francis Scott Key wrote his famous poem, which later became our national anthem, “The Star Spangled Banner.”



Congreve Rocket

Even with Congreve's work, the accuracy of rockets still had not improved much. So, rocket researchers all over the world were experimenting 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. Many rockets still use variations of this principle today.

MODERN ROCKETRY

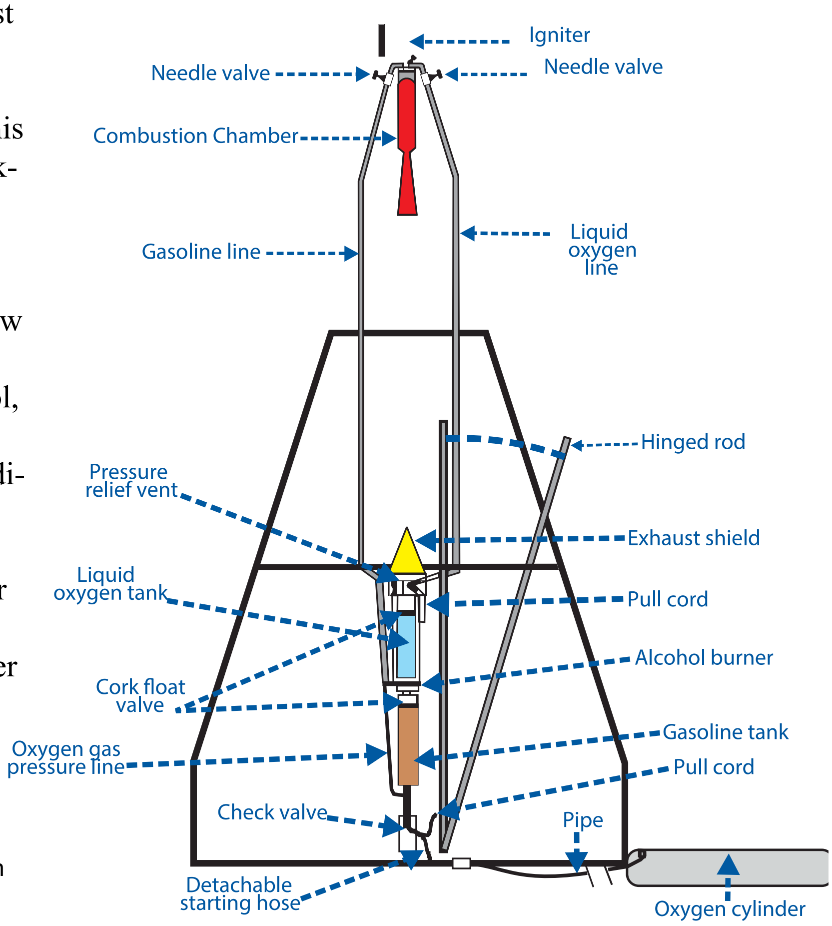
In 1898, a Russian schoolteacher, **Konstantin Tsiolkovsky**, proposed the idea of space exploration by a rocket. He published a report in 1903 suggesting the use of liquid propellants for rockets in order to achieve greater range. Tsiolkovsky stated that only the exhaust velocity of escaping gases limited the speed and range of a rocket*. For his ideas, research, and vision, Tsiolkovsky has been called the "Father of Modern Astronautics."

Dr. Robert H. Goddard

Early in the 20th century, an American physics professor, **Dr. Robert H. Goddard**, conducted many practical experiments with rockets. His research led to major breakthroughs in the development of rockets. His earliest experiments were with solid-propellant rockets. Then he became convinced that liquid propulsion would be better suited for rocketry. In 1926, Goddard achieved the first successful flight with a liquid-propellant rocket (utilizing liquid oxygen and gasoline). This was a forerunner of today's rockets.

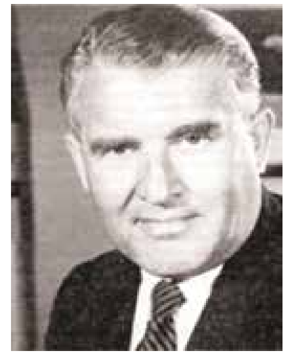
As he continued with his experiments, his liquid-propellant rockets grew bigger and flew higher. He also developed a gyroscope system for flight control, a payload compartment, and a parachute recovery system. Additionally, he believed that multistage rockets were the answer for achieving high altitudes. For his many accomplishments, Dr. Goddard is known as the "Father of Modern Rocketry."

*This theory has later been proved to apply only to atmospheric flight. In a vacuum, speeds much greater than an engine's exhaust are easily attainable.



Goddard Rocket Illustration

In 1923, **Hermann Oberth** of Germany, published a book about rocket travel into outer space. Because of his writings, small rocket societies were started around the world. In Germany, one such group, the Society for Space Travel, had numerous members who would, during World War II, be drafted into the German military to assist in the development of the V-2 missile.

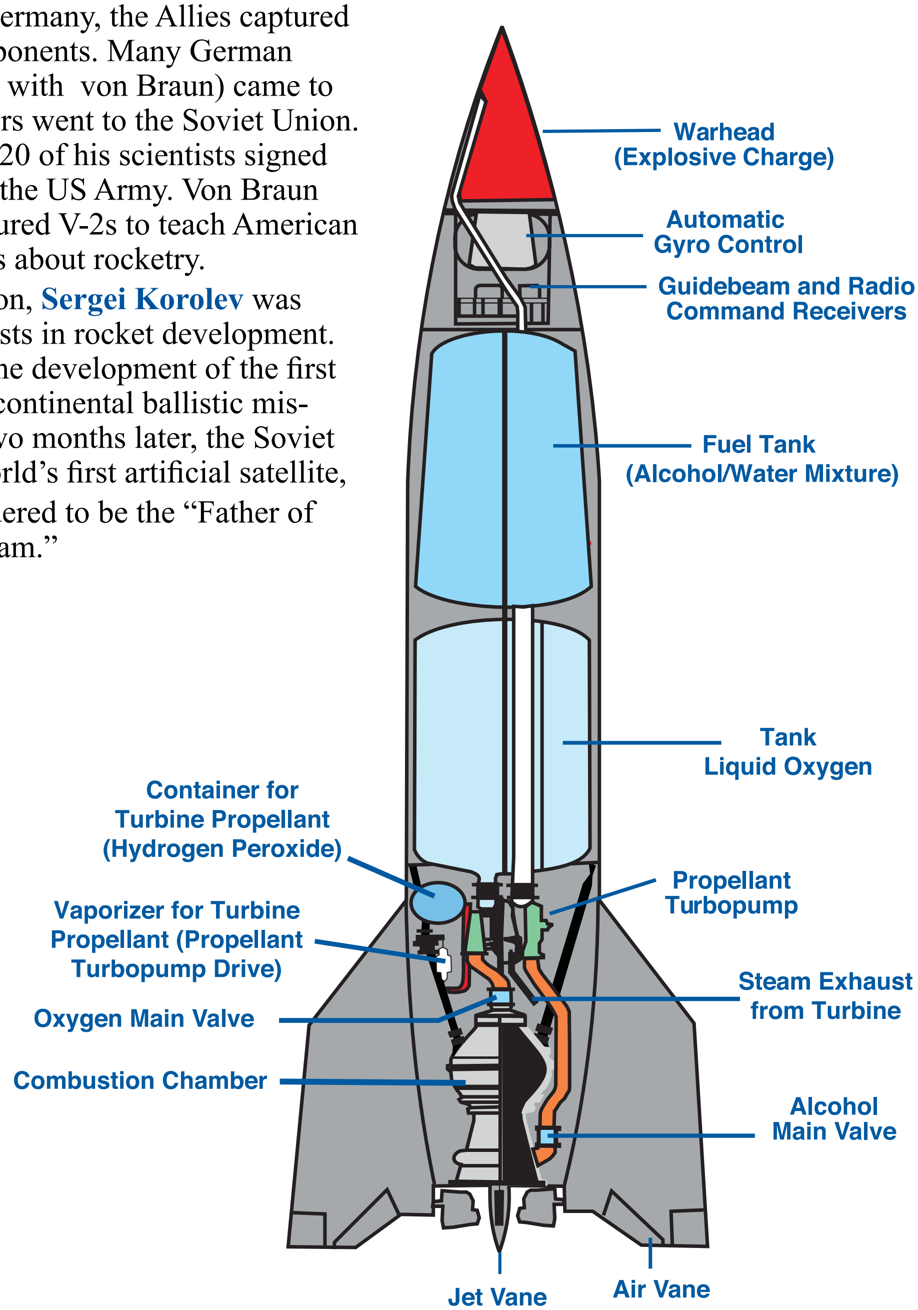


Wernher von Braun

The V-2 rocket, with its explosive warhead, was a formidable weapon which could devastate whole city blocks. Germany used this weapon against London during World War II, but fortunately this occurred too late in the war to change the outcome. The V-2 was built under the directorship of **Wernher von Braun**, a German,who after the war headed up several U.S. rocket programs..

With the fall of Germany, the Allies captured many unused V-2 components. Many German rocket scientists (along with von Braun) came to the United States. Others went to the Soviet Union. Von Braun and about 120 of his scientists signed contracts to work with the US Army. Von Braun and his team used captured V-2s to teach American scientists and engineers about rocketry.

In the Soviet Union, **Sergei Korolev** was leading Russian scientists in rocket development. He organized and led the development of the first successful Soviet intercontinental ballistic missile in August 1957. Two months later, the Soviet Union launched the world's first artificial satellite, ***Sputnik* I**. He is considered to be the "Father of the Soviet Space Program."



V-2 Missile

Space Race

Both the United States and the Soviet Union recognized the potential of rocketry as a military weapon and began a variety of experimental programs. The United States also began a program of high-altitude atmospheric sounding rockets. Then the US developed a variety of short, medium, and long range ballistic missiles. Many of these would be converted into launch vehicles for the US space program.

A launch vehicle is the rocket system that lifts a spacecraft. It gives the spacecraft (payload) enough force to reach orbit. Then, and only then, does a payload become a satellite. These launch vehicles propelled people and cargo into space. The image to the right shows an example of a rocket launch vehicle that was first designed as a missile, and was later used by the US space program.

As stated previously, on October 4, 1957, the Soviet Union launched into space *Sputnik* I - which would become the world's first artificial satellite. The space race between the two world superpowers, the US and the USSR, had begun, and Russia had won the first round.

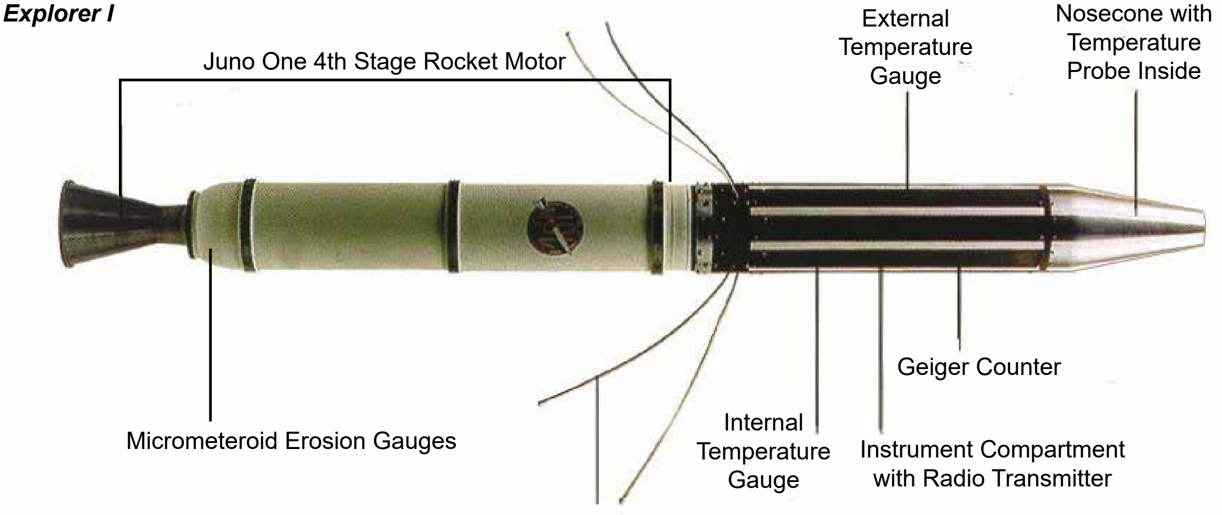
On January 31, 1958, the US launched *Explorer* I (illustration on next page) which would become America's first Earth-orbiting satellite.

Launch of a Titan IIIE with Voyager 2

Full-scale replica of *Sputnik* I on display at a Moscow museum.

William Pickering, James Van Allen, and Wernher von Braun displaying a full - scale model of the *Explorer* I satellite, weighing only 30.80 lbs, at a crowded press conference held in the Great Hall of the National Academy of Sciences at 1:30 A.M. February 1, 1958, when it was confirmed that the satellite was in orbit around the Earth.

Explorer I



Explorer I's most noteworthy discovery was the existence of the radiation belts that surround the planet and are held in place by Earth's magnetic field. The belts are named after the scientist that developed the instrument carried on board *Explorer* that led to the discovery, Dr. James Van Allen. Later in the same year that *Explorer* I was launched, the US formally organized its space program by creating the National Aeronautics and Space Administration (NASA). NASA became the civilian agency with the goal of peaceful exploration of space for the benefit of all humankind. The Department of Defense (DoD) became responsible for research and development in the area of military aerospace activities. Thus, the US began to conduct space exploration in earnest.

Both the US and the Soviet Union began sending many people and machines into space. In April of 1961, a Russian, named **Yuri Gagarin**, became the first human to orbit Earth. Then, less than a month later, **Alan Shepard**, aboard his Mercury capsule, *Freedom* 7, became the first American in space. The Redstone rocket that propelled Shepard was not powerful enough to place the Mercury capsule into orbit. So, the flight lasted only 15 minutes and reached an altitude of 187 kilometers (or 116 miles). Twenty days later, May 25, 1961, even though the Soviet Union was ahead of the US in the space race, President John F. Kennedy announced the objective of putting a man on the Moon by the end of the decade.

In February 1962, **John Glenn** became the first American to orbit the Earth aboard the Mercury capsule, *Friendship* 7. Glenn was launched by the more powerful Atlas rocket and remained in orbit for 4 hours and 55 minutes.

Alan Shepard's Mercury capsule atop a Redstone rocket

John Glenn's Mercury capsule atop an Atlas launch vehicle

The US also began an extensive unmanned space program aimed at supporting the manned lunar landing objective. Programs such as Ranger, Surveyor, and Lunar Orbiter were launched using modified Atlas versions known as Agena and Centaur. (See associated Activity Three at the end of the chapter.)

Next came the Gemini missions in 1965-1966, which were designed to carry two crew members. These missions were launched by a more powerful launch vehicle, the Titan II. Gemini missions were aimed at expanding our experience in space and preparing the U.S. for a manned lunar landing on the Moon. Gemini paved the way for the Apollo missions by demonstrating rendezvous and docking procedures, flying extended duration missions (up to 14 days), and conducting extravehicular activities (space walks).

Neil Armstrong's photo of Buzz Aldren and the American Flag on the Moon

After the Gemini missions, the third manned space program, Apollo, began launching astronauts in 1968 with *Apollo* 17 in 1972 and ended in 1975. Launching men to the Moon required much larger launch vehicles than those available. So, the US developed the Saturn launch vehicles; Saturn I, IB, and V. The Saturn I and IB were large two-stage liquid-propellant launch vehicles assembled from the components of other rockets, and were used mainly for unmanned test flights in Earth orbit.

In October 1968, a Saturn IB launched the first three-person mission, *Apollo* 7. All remaining Apollo flights (8-17) used the much more powerful Saturn V. On July 20, 1969, *Apollo* 11 landed on the Moon and **Neil Armstrong** became the first man to walk on its surface, thus fulfilling the goal set by President Kennedy in 1961.

Skylab in orbit over the Amazon River in Brazil

The next space project of the United States was ***Skylab*** - first US space station. The Saturn V was used to launch *Skylab* into space. The Saturn IB launch vehicles were used to launch crews to the space station. *Skylab* was launched in May 1973 and had three separate missions between 1973 and 1974. The last mission was the longest. It lasted 84 days.

One final mission was flown in 1975 that utilized hardware developed for the Apollo Program. It was known as the *Apollo-Soyuz* Test Project (ASTP). It was a joint mission flown by separate spacecraft from the United States (Apollo) and the Soviet Union (Soyuz). Each spacecraft was launched from the respective nation's homeland, and once in orbit, linked up and remained joined for nearly two days. The project served a diplomatic purpose as much as anything else, demonstrating cooperation between two nations that were still officially engaged in a "cold" war.

After the *Skylab* and ASTP, the US concentrated on a reusable launch system, the Space Transportation System (STS). The STS used solid rocket boosters and three main engines to

A space shuttle launch

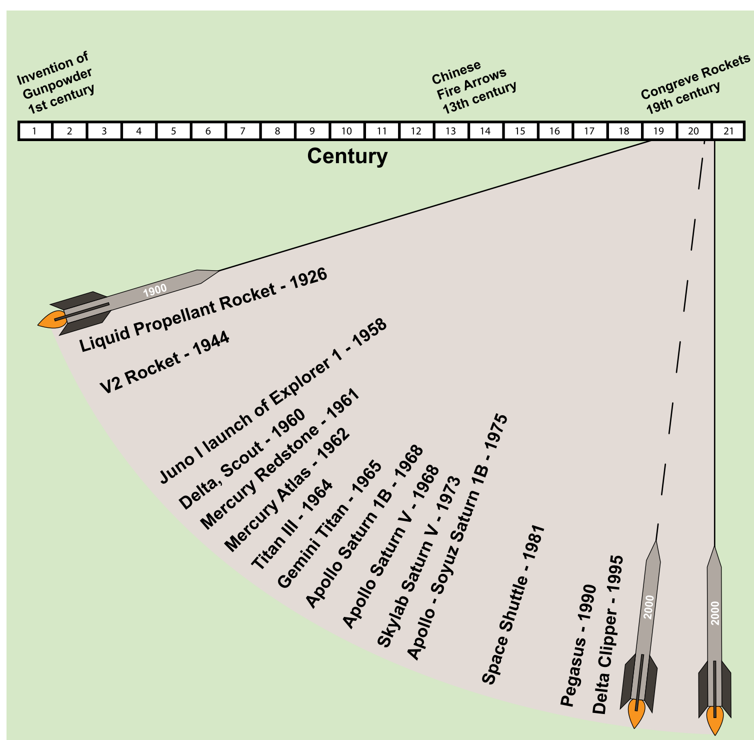
A space shuttle orbiter lands at Kennedy Space Center

launch the shuttle orbiter. The reusable boosters fell off about two minutes into the flight. Parachutes de-ployed to decelerate the solid rocket boosters for a safe splashdown in the Atlantic Ocean, where ships recovered them. The STS, commonly referred to as the **Space Shuttle**, was used for transportation to space and back to Earth.

This chapter gave a brief account of how rocket launch vehicles were used in the space race. A more detailed account of the US manned space program is contained in module six of Aerospace Dimensions.

It should be noted that the vast majority of America's early programs of space exploration were launched by vehicles that were modified military weapons. Redstone, Jupiter, Thor, Atlas, and Titan missiles were all modified to serve space exploration purposes. Additionally, all versions of the Saturn I rocket utilized modified hardware from Redstone and Jupiter missiles for the first stage. This practice represents an important contribution that America's military made to the exploration of space and helped win the "space race" of the 1950s and 1960s.

Rockets evolved from simple gunpowder devices into giant vehicles capable of traveling into outer space, taking astronauts to the Moon and launching satellites to explore our universe. Without a doubt, rockets have opened the universe to our exploration, and the possibilities continue to be endless. They have been, and continue to remain, the indispensable tools of space exploration.



Rocket Timeline

ACTIVITY 1 SECTION

Activity One - The Hero Engine

Purpose: The purpose of this activity is to demonstrate Newton's Third Law of Motion, which was discussed in this chapter as related to the Hero Engine.

Materials: empty soda can, medium-size nail, string, bucket or tub of water, and a hammer

Procedures:

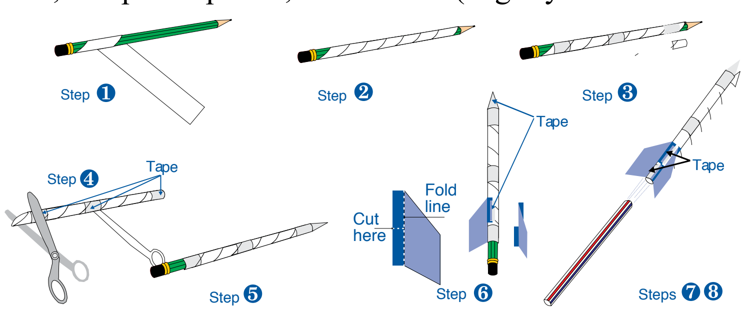
1. Lay the can on its side and carefully punch four equally-spaced holes in the can. Before removing the nail, push the nail to the right so that the hole is slanted in that direction. The holes should be just above the bottom rim. (Adult supervision suggested.)
2. Bend the opener at the top of the soda can straight up and tie a short piece of string to it.
3. Immerse the can in the water until the can is full.
4. Pull the can out of the water by the string. Water will stream out of the openings causing the can to spin.

Summary: This replicates the very first rocket engine, the Hero Engine. Although the Hero Engine was propelled by steam, this activity demonstrates thrust and Newton's Third Law of Motion. Newton's Third Law of Motion states that for every action there is an equal and opposite reaction. The force of falling water at slanted intervals around the can (action) causes the soda can to spin in the opposite direction (reaction).

Activity Two - Making a Paper Rocket

Purpose: The purpose of this activity is to create a paper rocket and experiment with the flight of the paper rocket as pushed through a tube, as discussed in this chapter about early rockets. The use of fins will aid with stabilization of the rocket, as also discussed in the chapter.

Materials: paper, cellophane tape, scissors, sharpened pencil, and a straw (slightly thinner than the pencil)



Procedures:

1. Cut a piece of paper 1.5 inches wide by 1 inch shorter than the straw to be used.
2. Wrap the paper around the pencil.
3. Tape tube in three places as shown.
4. Remove pencil and cut off ends of tube.
5. Reinsert pencil into tube and tape around sharpened point of the pencil.
6. Cut out fins in any shape you like and tape to base of rocket.
7. Remove the pencil from tube. Insert the straw into the open end of the paper rocket.
8. Launch the rocket by blowing on the end of the straw.

Summary: Paper rockets demonstrate how rockets fly through the air and the importance of having fins for control. When experimenting with the flight of the rocket, the more the force of air applied to the paper rocket, the farther it soars. Also, launching the rocket at different angles results in different heights and distances that the rocket achieves. Consider experimenting with the placement of fins and number of fins. Having no fins at all results in an unstable rocket!

Activity Three - Rocket Staging

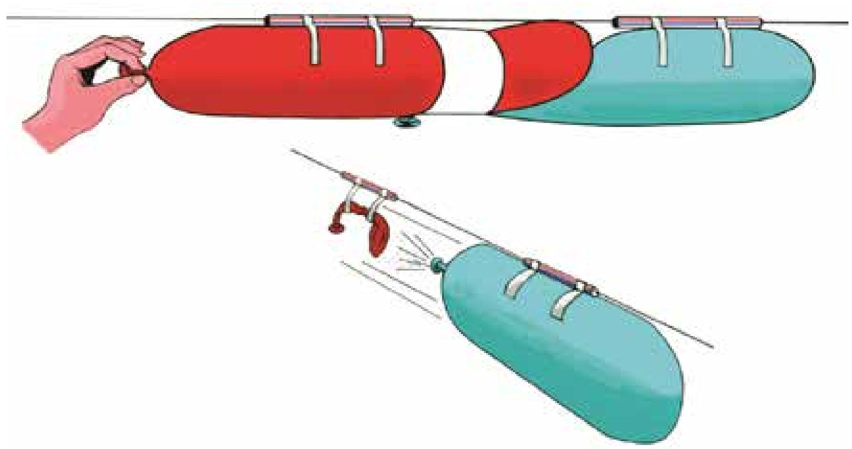
Purpose: In this activity, the concept of how rocket stages work is visually demonstrated using balloons.

Materials: two long party balloons, nylon monofilament fishing line (any weight), two plastic straws (milkshake size), styrofoam coffee cup, masking tape, scissors, and two spring clothespins

Procedures:

1. Thread the fishing line through the two straws. Stretch the fishing line snugly across a room and secure its ends to stable areas, such as a cabinet or wall. 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. Stretch 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. Twist the nozzle and hold it shut with a spring clothespin. Inflate the second balloon. While doing so, make sure the front end of the second balloon extends 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 clip's job of holding it shut. It may take a bit of practice to achieve this. Clip the nozzle of the second balloon shut also with the clothes pin or your fingers.
4. Take the straws to one end of the fishing line and tape each balloon to a straw with masking tape. The balloons should point parallel to the fishing line.
5. Remove the clip from the first balloon and untwist the nozzle. Remove the nozzle from the second balloon as well, but continue holding it shut with your fingers.
6. If you wish, do a rocket countdown as you release the balloon you are holding. 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 along the line.
7. Have students experiment with other ways to make multi-stage rockets work. Add 2, 3, or 4 stages, as is possible.

Summary: This activity demonstrates how a multi-stage rocket works. After a stage exhausts its load of propellants, the entire stage drops away, making the upper stages more efficient in reaching higher altitudes.



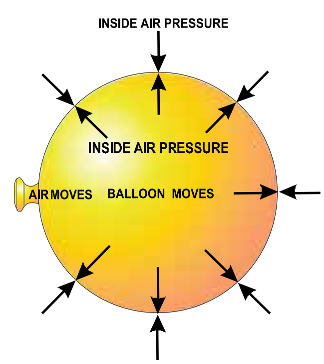
2 ROCKET PRINCIPLES, SYSTEMS & PROPULSIONS

Learning Outcomes

- Define acceleration.
- Define inertia.
- Define thrust.
- Describe Newton's First Law of Motion.
- Describe Newton's Second Law of Motion.
- Describe Newton's Third Law of Motion.
- Identify the four major systems of a rocket.
- Describe the purpose of each of the four major systems of a rocket.
- Define payload.
- Describe how the world land speed record applies to rockets.
- Describe innovations in new rocket technology, to include some of the new launch vehicles that are being developed.

Important Terms/Persons

acceleration - the rate of change in velocity with respect to time
airframe - provides the shape of the rocket, within which all of the other systems are contained
control system - steers the rocket and keeps it stable
Falcon - a new "family" of rockets being developed by Space Exploration Technologies, Inc. (SpaxeX)
guidance system - determines the path the rocket should take; the brain of the rocket
inertia - the tendency of an object at rest to stay at rest and an object in motion to stay in motion
Newton's First Law of Motion - a body at rest remains at rest and a body in motion tends to stay in motion at a constant velocity unless acted on by an outside force; inertia
New Glenn - new rocket in development by Blue Origin
Newton's Second Law of Motion - the rate of change in the momentum of a body is proportional to the force acting upon the body and is in the direction of the force (also expressed as force equals mass times acceleration, or $F = ma$)
Newton's Third Law of Motion - for every action there is an equal and opposite reaction
payload - what the rocket is carrying
propulsion - everything associated with producing the force needed to get the payload to its destination
thrust - to force or push; the amount of push used to get a rocket traveling upwards
Vulcan - new rocket in development by United Launch Alliance



In this chapter, we will take a brief look at some of the concepts and principles that explain how rockets work, with a particular emphasis on Newton's Laws of Motion. These laws lay the scientific foundation for rockets and aid tremendously in explaining how rockets work. We will also look at some of the very newest rockets being developed and the propulsion systems that power them.

PRINCIPLES

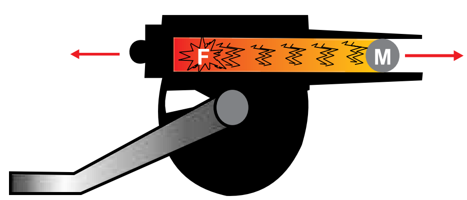
In its simplest form, rocket propulsion consists of a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and thus provides a thrust that propels the rocket in the opposite direction. A good example is a balloon. Balloons and rockets actually have a strong similarity. The only significant difference is the way the pressurized gas is produced. With rockets, the solid or liquid burning propellants produce the gas.

NEWTON'S LAWS OF MOTION

Even though rockets have been around for over 2,000 years, it has only been in the last 300 years that rocket designers have had a scientific basis for understanding how they work. This scientific basis came from Sir Isaac Newton. Newton stated three important scientific principles that govern the motion of all objects, whether on Earth or in space. Understanding these principles has enabled engineers to design the giant rockets we use today. These principles are known as **Newton's Laws of Motion**.

Newton's First Law of Motion: **a body at rest remains at rest and a body in motion remains in motion at a constant velocity unless acted on by an outside, or unbalanced, force.**

Rest and motion are the opposite of each other. If a ball is sitting on the ground, it is at rest. If it is rolling, it is in motion. If you hold a ball in your hand and keep it still, the ball is at rest. All the time the ball is being held there, it is 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. **Thrust** is defined as the amount of push developed by a rocket's propulsion system.

Consider a grocery cart full of groceries that you are pushing down an aisle. Let's pretend there is no friction from the wheels or from the floor. The cart weighs 75 pounds and you have pushed it to a speed of 100 ft/min. What force must you exert on the cart to keep it moving in a straight line at this constant speed? The answer is none. You exerted a force to start it from rest, and you will need to exert a force to stop it, but no force is needed to keep it moving at constant velocity if there is no friction. **Inertia** is the tendency of an object at rest to stay at rest and an object in motion to stay in motion. (See associated Activity Four at the end of the chapter.)

Newton's Second Law of Motion: **the rate of change in the momentum of a body is proportional to the force acting upon the body and is in the direction of the force.**

This law is really not as complicated as it might sound. It is essentially a mathematical equation. There are three parts: mass (m), acceleration (a), and force (f) so that f is the product of m times a, or simply f = ma. The amount of force required to accelerate a body depends on the mass of the body. The more mass, the more force is required to accelerate it.

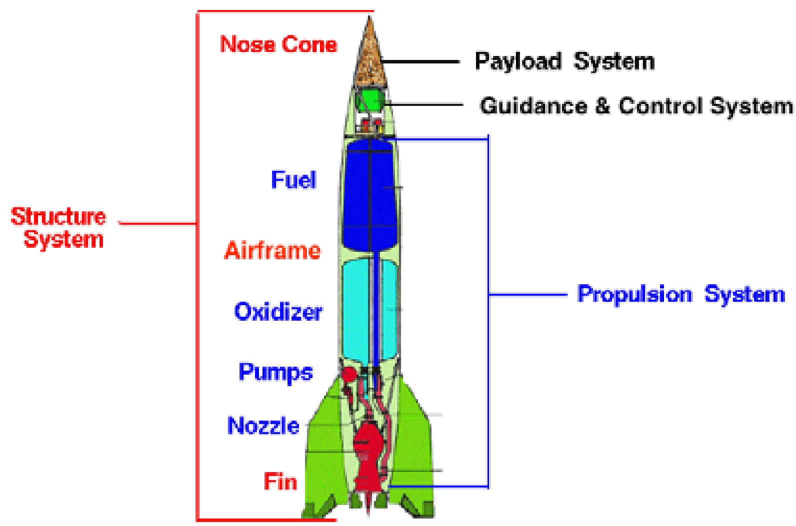
An easy way to visualize this concept is to imagine two individuals (one child and one adult) sitting in identical carts. The child weighs 75 lbs and the adult weighs 150 lbs. You are to push each individual hard enough to get them going 15 mph. Which push will require more effort? It is obvious that it will take more effort to get the adult going 15 mph than it will the child. To see how the equation balances out, keep the weights the same, but get the first cart going 5 mph and the second cart going 15 mph. Now which task will require more effort? The answer should be obvious!

Newton's Third Law of Motion: **for every action, there is an equal and opposite reaction.**

A rocket can lift off from a launch pad only when it produces thrust in a downward direction (the thrust is produced by the combustion of the propellant and being expelled through the nozzle). The rocket's own mass is creating a downward force, and the thrust is creating the upward force (which must be the greater of the two forces if the rocket is to lift off). The example of a skateboard and rider can also illustrate this point. Imagine the skateboard and rider at rest. The rider jumps off the skateboard. The jumping is called the action. The skateboard responds to that action by traveling some distance in the opposite direction. The skateboard's opposite motion is called the reaction. (See associated Activity Five, Six, and Seven at the end of the chapter.)

ROCKET SYSTEMS

Modern rockets consist of four major systems: airframe, guidance, control, and propulsion. These four systems work together to deliver the **payload**. The payload is defined as whatever the rocket is carrying. For instance, the payload of a military rocket might be explosives, while the payload of a civilian rocket might be a space probe.

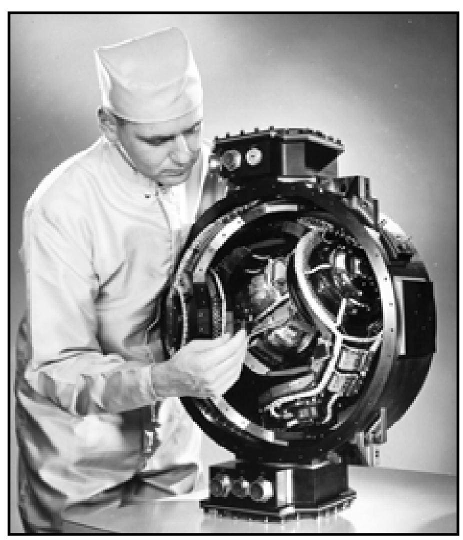


Note: fins are rarely used on larger launch vehicles, but are still used on smaller sounding rockets.

Major Systems of a Rocket

The **airframe** provides the shape of the rocket and all of the other systems are contained within it. The airframe must be light-weight, yet structurally strong. It must withstand heat, stress, and a lot of vibration. The primary objective in the design and construction of an airframe is to build a structure that will withstand all anticipated stresses while using the least possible weight. For example, the airframe of the Atlas ICBM was is thinner than a dime. When the Atlas hpropellant tanks were empty, they had to be pressurized to keep them from collapsing. The airframe is the skin of the rocket and serves as the wall of the propellant tanks. This eliminates the need for separate internal tanks and saves in weight, too.

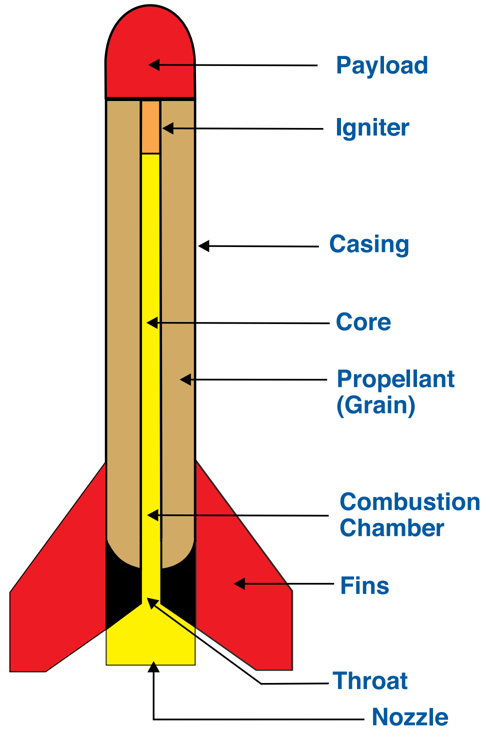
The guidance & control (G&C, sometimes referred to as GNC for guidance, navigation, and control) system is the "brain" of a rocket. It is responsible for getting the rocket



Guidance System

and its payload to its destination. In a military missile, the G&C system delivers the warhead to its target. In a launch vehicle, the system is responsible for delivering the spacecraft to its proper orbit or destination.

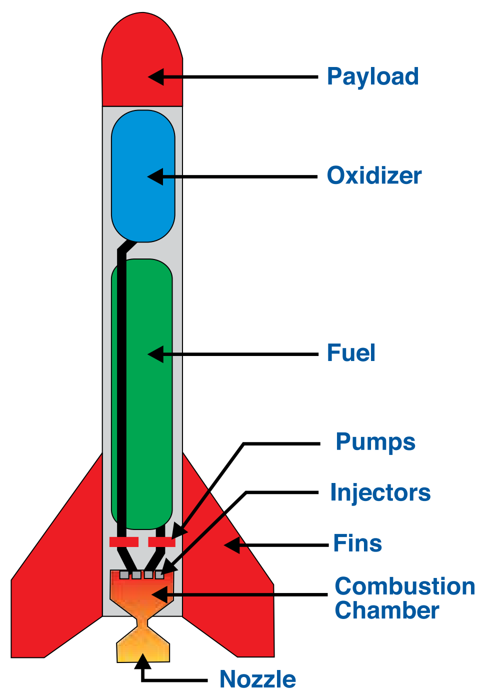
The G&C system is small compared to the rest of the rocket. The accompanying photo gives you an idea of its actual size. It is a self-contained electronic unit with a computer. The computer is programmed to guide the rocket on a desired trajectory.



Solid Propulsion System

The **control** part of the G&C takes the information from the guidance part and steers the rocket to its destination. The control part also keeps the rocket stable. It is actually several controls that work to stabilize and steer the rocket. These controls allow for changes to be made during the rocket's flight.

Vanes, movable fins, gimbaled (movable) nozzles, and attitude control rockets are a few examples of controls that can help steer or stabilize a rocket. Vanes are like small fins that are placed inside the exhaust of the rocket engine. Tilting the vanes deflects the exhaust and changes the direction the rocket is going. A gimbaled nozzle is one that sways while the exhaust passes through it. This also changes a rocket's direction. A rocket's movable fins can be tilted to change the rocket's direction, as well.



Liquid Propulsion System

The **propulsion** system consists of everything directly associated with propelling the rocket. This includes the propellant used, the containers for the propellant, and the engine. The propellant doesn't mean just the fuel, but includes both the fuel and the oxidizer. The fuel is the chemical the rocket burns and the oxidizer (oxygen or some other suitable compound) must be present in order for combustion to take place. Rockets must carry the oxidizer with them because there is none in space.

There are two general types of rocket propellants, liquid and solid. Solid rocket propellants were used for 700 years before liquid propulsion was developed. Solid propellant is carried in the combustion chamber pre-mixed and in solid form. The fuel is usually a mixture of hydrogen compounds and carbon, and the oxidizer is made up of oxygen compounds.

Liquid propellant is much more complicated. Liquid propellants are carried in compartments separate from the combustion chamber, one for the fuel and one for the oxidizer. The liquid propellant is usually kerosene or liquid hydrogen; the oxidizer is usually liquid oxygen. Solid and liquid propellants are often used together on the same rocket—some examples being the Space Shuttle, the Delta IV and the Atlas V. (See associated Activity Eight at the end of the chapter.)

PROPULSION: YOU CAN'T LEAVE HOME WITHOUT IT

The title is a play on words from a well-know television commercial from a few years back. But when we speak of Earth as our "home" then propulsion is absolutely the key to leaving it. This section will describe several new launch vehicles that are in development or have recently been put to use, as well as some of the new rocket engines that will power them.

A NEW GENERATION OF LAUNCH VEHICLES

Throughout the years of the era of "modern" rocket technology, that is, from the 1940s to the present, there have been incremental improvements from one rocket design to the next. For example, the current Atlas V which is being produced by a joint venture between Boeing and Lockheed-Martin (known as United Launch Alliance—ULA), has evolved from the previous Atlas III (there was no Atlas IV), which evolved from the previous Atlas I and II, which evolved from the previous Atlas Centaur, which evolved from the previous Atlas Agena, which evolved from the original Atlas ICBM. That's a long history—going back to the beginnings of the "modern" era! The current Atlas V bears no resemblance whatsoever to the original Atlas ICBM, yet each new model brought incremental improvements. And now another incremental improvement is being made with the development of the new Vulcan Centaur rocket—which evolved from the Atlas V.

Vulcan Centaur will be an incremental improvement over the Atlas V; however, it will also incorporate improved elements of another ULA rocket, the Delta IV. Some interesting innovations for the Vulcan Centaur will be the use of methane propulsion. It will be among the first large rockets use methane as a fuel. Initially, Vulcan Centaur will be a single-use rocket; however, ULA plans to have the booster engines, thrust structure, and avionics recoverable at some future date. ULA states that this process will save some 65% of the cost of the booster. Vulcan Centaur will come in various power configurations depending on how many thrust-augmenting solid rocket motors are strapped onto the booster (either zero, 2, 4, or 6) which will vary the lift-off thrust between 1.1 million pounds to a whopping 4.07 million pounds. Once flights become operational, Vulcan will be the most powerful rocket ever launched from the Cape. To clarify, Vulcan is not as powerful as the Saturn V rocket that took Apollo astronauts to the Moon—but Saturn V launched from nearby Kennedy Space Center, not Cape Canaveral!

Artist's CGI of Vulcan Centaur launch (four of six solid rocket boosters are visible)

Space Exploration Technologies, Inc. (better known as SpaceX) is adding to its current family of Falcon rockets. The diagram represents the Falcon "family" (with a Saturn V included to show scale as well as other rockets that will also be described). The rocket on the far right is being developed right now. The Starship has been made the top SpaceX development priority—and it all started with that little itty bitty rocket shown on the far left—Falcon 1. Falcon 1 was the brainchild of Elon Musk who invested a consider-able amount of his personal wealth to develop it. Falcon 1 was plagued with problems during its development. The first three test flights were failures, with each flight representing a new type of failure that the engineers had to deal with. Musk had decided that he would give the program one more shot, and if that failed, he would pack up and go. The fourth flight succeeded, and as a result, SpaceX is now a major aerospace company. Currently, the most well-known rocket of the family is Falcon 9. For some additional background, the 9 in Falcon 9 comes from the 9 Merlin engines in the first stage. Falcon 1 had 1 Merlin engine, Falcon 9 has 9. Falcon 1 was retired after 5 flights mainly because there was not enough demand for such a small launch vehicle. Falcon 9 on the other hand, is a different story. To date, there have been 92 Falcon 9 launches (by the time this edition is published, there will have been over 100). Falcon 9 is also famous for its recoverable boosters. As soon as the booster separates from its upper stage, it turns around and heads back to the Cape, whereupon it executes a perfect four-point landing (nearly every time—a handful of landing attempts have been unsuccessful). On some launches, the booster does not have enough propellant to make it back to the Cape, so it lands on an autonomous drone ship in the Atlantic Ocean, after which it is brought back to the Cape to be refurbished and used again. For power comparison, Falcon 1 developed 102,000 pounds of thrust at liftoff, Falcon 9 develops 1,710,000, Falcon Heavy develops 5,100,000 pounds. Now, hold on to your seats, Starship will develop sixteen million pounds of thrust at launch—more than twice the power of the Saturn V.

Family of Rockets (L to R): Falcon 1, Falcon 9 (with Crew Dragon), Falcon 9 (cargo), Falcon Heavy, New Glenn (2-Stage), New Glenn (3-Stage), Saturn V (included for size comparison), Space Launch System (Block 2 Cargo), Starship

Twin Falcon boosters return and land at Cape Canaveral

If you've never heard of Blue Origin before reading this module, you most certainly have heard of Amazon.com. And if there had never been an Amazon.com there never would have been a Blue Origin, because the fortune that was and is being made at Amazon is what's giving Blue Origin the money to get it going. The company is transforming the landscape at Kennedy

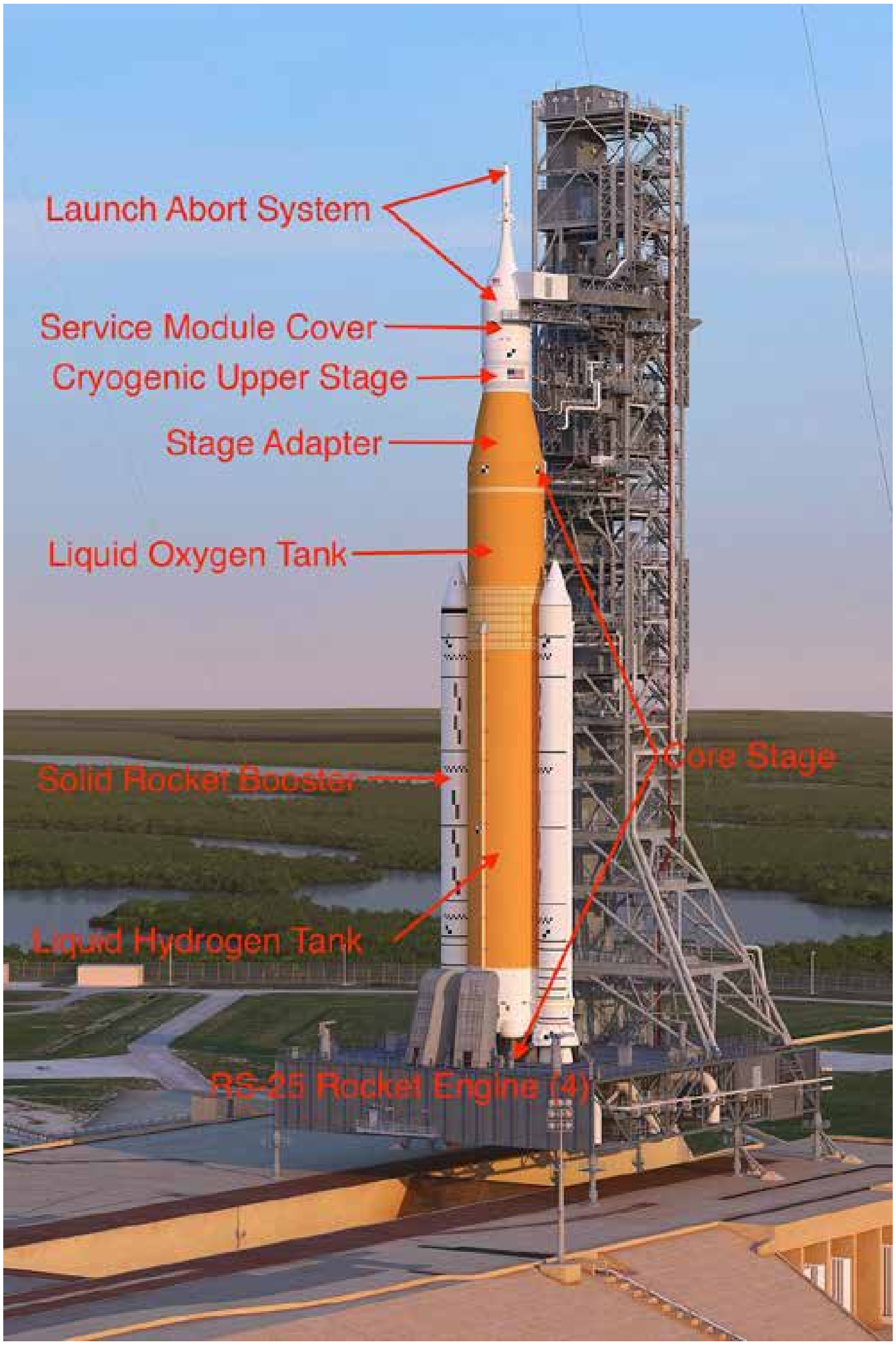
Space Center and Cape Canaveral. The New Glenn rocket (named in honor of John Glenn) is a brand new design that will be manufactured at a brand new sprawling complex nearing completion on KSC. Like the Falcon 9, the first stage of the rocket is intended to be recoverable. It will come in a 2-stage version as well as a 3-stage version (see illustration). New Glenn will launch off Complex 36 on Cape Canaveral and will create quite a thunder when it does, developing 3.85 million pounds of thrust on liftoff. The complex previously operated to support Atlas spaceflight launches for NASA, the Air Force, and commercial customers from 1962 to 2005. It remained deactivated for ten years until Blue Origin chose to use it for their new rocket. Blue Origin also has a much smaller rocket that it is developing for space tourism named New Sheppard (named in honor of Alan Sheppard) which is described in Module 6.

Northrop Grumman is developing a new launch vehicle that will rely heavily on solid (instead of the more common liquid) propulsion for payloads destined for Earth orbit. The Omega launch vehicle will utilize solid rocket motors in its first and second stages, as well as its strap-on boosters (which can vary from 2 to 6). Its third stage will utilize liquid propulsion (hydrogen/oxygen). The rocket will come in two configurations: Medium and Heavy. The performance details have not been released yet but the first stage of the heavy configuration is based on the Space Shuttle Solid Rocket Booster which produced 2.8 million pounds of thrust. That, combined with the maximum strap-on boosters would give it a lift-off thrust of over 5.5 million pounds.

Omega Rocket: Size comparison of the two versions of the rocket; the more powerful version will use a central core based on a full-size Space Shuttle Solid Rocket Booster

The final launch vehicle that will be described is one that will utilize decades of already proven technology, but one that is sure to blaze new trails in human exploration—NASA's Space Launch System (SLS). At first glance, it looks like it is using NOTHING BUT old technology: Space Shuttle main engines, Solid Rocket Boosters, and External Tank, and an upper stage engine that was first tested in 1959 and is still in use to this day—the RL-10. But all those old designs are being refined and updated and employed in the rocket that will be taking the next group of astronauts back to the Moon. The SLS will be assembled in the same building where Apollo Saturn Vs were prepared for their lunar missions. The core stage of SLS is based on the Space Shuttle External Tank, only it has been lengthened to accommodate more propellant (reference the accompanying labeled image). The liquid hydrogen and oxygen from the core stage tanks will be fed to four modified RS-25 engines used on Shuttle (each Shuttle flight used three of these engines). Strapped to each side of the core stage will be lengthened Solid

Rocket Boosters that will be more powerful than the ones used on Shuttle. The rocket will develop nearly 9 million pounds of thrust on lift-off and will be taking up to four crewmembers at a time from the Earth—to the Moon.



Space Launch System, Block 1 (early version) with major components identified—note that the RS-25 engines are mounted below the core stage and are not clearly visible (this represents the configuration that will perform a lunar fly-by with astronauts on board, but will not land)

A NEW GENERATION OF ROCKET ENGINES

Along with this new family of rockets comes a new family of rocket engines. Three new rocket engines are described below, and all of them are designed to be reusable. Most all of the rockets described above will come with rocket engines of new design.

Not quite as new as the other engines, but newly developed for the Falcon 1, 9 and Heavy rockets, is the Merlin 1 engine. The Merlin 1 has been gradually improved since it first flew in 2006 and each new version gets a new letter designation (the Merlin 1D is the current version). Each Merlin 1D produces 190,000 pounds of thrust and each Falcon 9 has nine engines in the booster which gives the 1.71 million pounds described above. Falcon heavy basically has three Falcon 9s strapped together in parallel which means that are 27 Merlin engines firing at liftoff, producing 5.1 million pounds of thrust. These engines are designed to be reused multiple times and burn refined kerosene (referred to as RP1) for fuel and liquid oxygen (LOX) for oxidizer.

If the Starship relied on the Merlin 1 engine for propulsion it would take 84 of them to power the first stage! Naturally, a more powerful engine will be used for Starship. SpaceX is developing the Raptor engine for this purpose. Raptor will be blazing some new trails in engine design. It will be the largest rocket engine developed to date that will utilize liquid methane for fuel. The oxidizer will be the often-used liquid oxygen. Each Raptor engine will develop approximately 516,000 pounds of thrust, which means Starship will have 31 engines in its first stage.

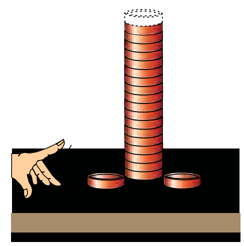
Blue Origin is also developing a new reusable rocket engine, the BE-4, which will power both the New Glenn rocket as well as the Vulcan Centaur. The BE-4 will use liquified natural gas (LNG) for fuel, which is mostly methane and is chilled to -260°F to change its state from gas to liquid. Oxidizer will be standard LOX. Seven BE-4 engines will power the first stage of the New Glenn rocket and 2 BE-4s will power the second stage. The Vulcan Centaur will have just two BE-4 engines powering its first stage, but it will have the option of adding up to six solid rocket motors to augment its thrust.

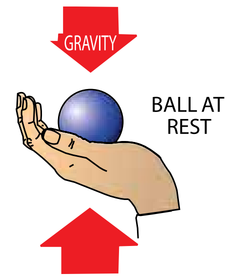
ACTIVITY SECTION 2

Activity Four - Law of Inertia (Newton's First Law)

Purpose: The purpose of this activity is to demonstrate Newton's First Law of Motion, the law of inertia.

Materials: stack of checkers, ball

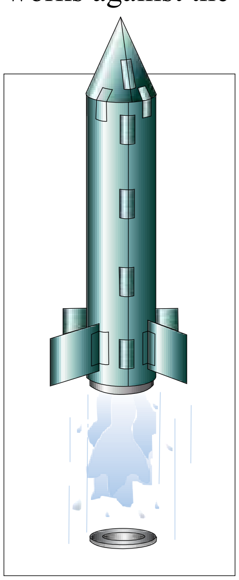




Procedures:

1. Stack the checkers, leaving one out for step #2.
2. Shoot the extra checker so it hits the bottom checker. When you shoot the checker, you are introducing an outside force to the stack of checkers. When it hits the bottom checker, its inertia is transferred and the bottom checker moves with almost the same speed and inertia.
3. Next, you can take a ball and cup it in your hand, like the picture to the right. It is in a state of rest. Gravity is pushing down on the ball, while your hand is pushing up. If you remove your hand, the ball drops and is in a state of motion. It stayed at rest until an unbalanced force, gravity, makes it move downward.

Summary: Newton's First Law of Motion explains that an object at rest remains at rest and a body in motion tends to stay in motion at a constant velocity unless acted on by an outside force. Energy is transferred from the moving checker (the outside force) to the checker at the bottom of the stack (object at rest), resulting in the bottom checker being moved. Depending on the surface of the table or floor being used, 100% of the energy will not be transferred to the other checker due to friction. Friction is the force of two objects in contact that results in the slowing or stopping of an object. A smooth surface results in less friction. A rougher surface, such as carpet, creates more friction. A rocket cannot launch until a force acts upon it resulting in its launch. As the rocket travels through the atmosphere, atmospheric drag (fluid friction) works against the upward motion of the rocket.



Activity Five - 3-2-1 POP

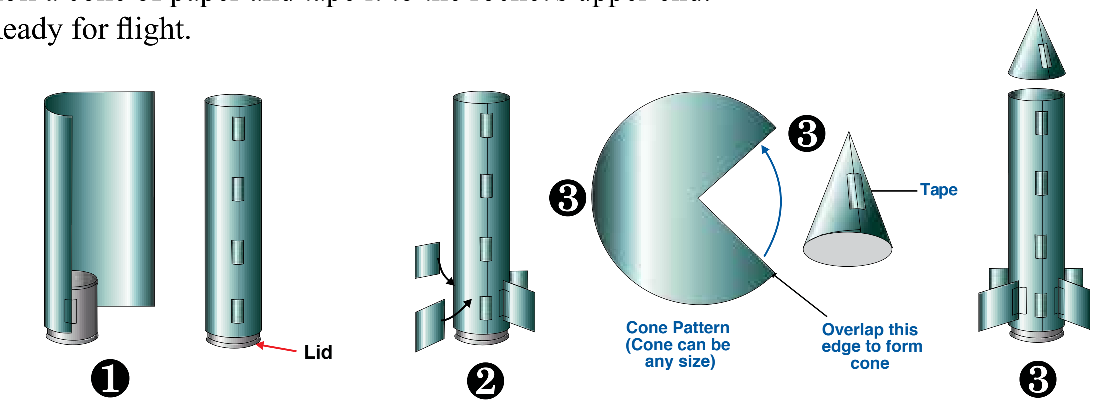
Purpose: This activity helps explain how thrust is generated in a rocket. It also demonstrates Newton's Third Law of Motion.

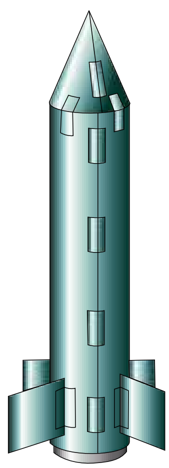
Materials: heavy paper (60-110 index stock or construction paper), plastic 35 mm canister with lid on inside of canister (or equivalent), student sheets, cellophane tape, scissors, effervescing antacid tablet, paper towels, water, and eye protection (Note: In the past, Fuji film canisters were free and easy to locate. Due to digital photography this is no longer the case. A good source to locate film canisters is Educational Innovations @ www.teacher-source.com Item # CAN-300 12@$7.95.)

Procedures:

1. Wrap and tape a tube of paper around the film canister. The lid end of the canister goes down.

2. Tape fins to your rocket.
3. Roll a cone of paper and tape it to the rocket's upper end.
4. Ready for flight.





4

Countdown:

5. Turn the rocket upside down and fill the canister one-third full of water.

Work quickly on these next steps!

6. Drop in 1/2 of the antacid tablet.
7. Snap lid on tight.
8. Turn rocket right-side up and set on ground.
9. Stand back.

10. LIFT OFF!

Summary: Once the fizzy tablet reacts with the water in the film canister, gas bubbles are produced. Much pressure is produced by the gas building up inside the canister. Unlike a balloon, the canister cannot expand as the amount of gas being produced increases. Eventually, so much gas pressure is produced that it forces the canister to pop open. The gas rushing downward out of the canister causes the rocket to move upward, demonstrating Newton’s third law of motion. Real rockets work in a similar way; however, they use real rocket fuel.

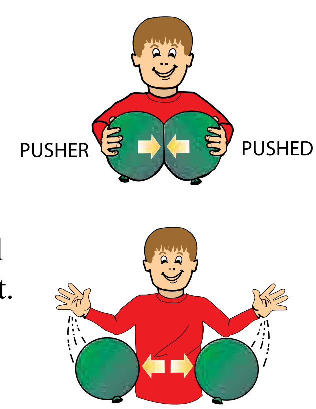
Activity Six - Two Balloons (Newton’s Third Law)

Purpose: This activity demonstrates Newton’s Third Law of Motion.

Materials: two balloons, inflated and tied

Procedures:

1. Squeeze the two balloons together, pushing with only one of them. The pusher is compressed by the force of the push. The pushed is also compressed from pushing back with equal force.
2. To prove further that they are pushing on each other equally, let go all at once. The balloons spring back into shape and push each other apart.

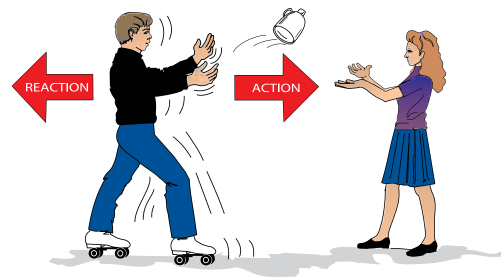


Summary: In this demonstration, only one balloon is doing the pushing, but the other balloon is pushing back at an equal and opposite force. When the balloons are released, they push apart equal distances.

Activity Seven - Roller Skates and Jug (Newton's Third Law)

Purpose: This activity demonstrates Newton's Third Law of Motion.

Materials: roller skates and plastic jug of water

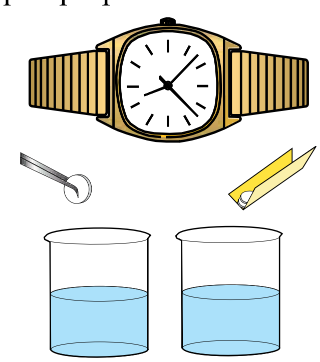


Procedures:
Wearing roller skates, with feet parallel, throw a plastic jug of water to a friend 10 feet away (as you push forward, you roll backward). OR, use a skateboard to demonstrate the same thing. Stand on a skateboard with the board not moving. Then jump off the board. Your jumping off is the action, and the board moving in the opposite direction is the reaction.

Summary: Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction. Throwing the jug forward (action) results in the person with the skates or skateboard to move in the opposite direction (reaction). This action parallels the hot gases from the burning fuel that rush out of the rocket (action) results in the rocket moving in the opposite direction (reaction).

Activity Eight - Antacid Tablet Race - Experiment 1

Purpose: Use scientific investigation skills to compare the reaction rates of effervescent antacid tablets under different conditions, in alignment with the discussion of liquid propellants in the chapter.

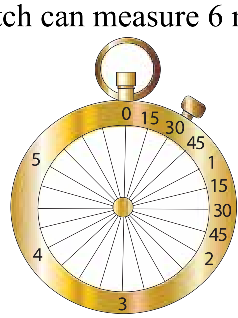


Materials: effervescent antacid tablets (4 per group), two Beakers (or glass or plastic jars), tweezers or forceps, scrap paper, watch or clock with second hand, thermometer, eye protection, and water (warm and cold)

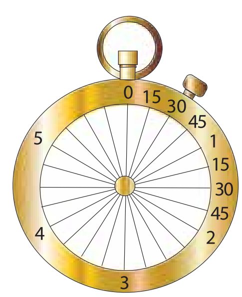
Procedures:
1. Fill both jars half full with water that is the same temperature.
2. Put on your eye protection.
3. Predict how long it will take for the tablet to dissolve in the water. Drop a tablet in the first jar.

Shade in the stop watch face for the actual number of minutes and seconds it took to complete the reaction. The stopwatch can measure 6 minutes.

Jar 1 Results
Temperature: _____
Your prediction: _____ seconds

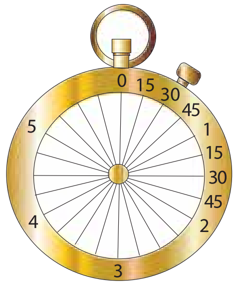


Jar 2 Results
Temperature: _____
Your prediction: _____ seconds

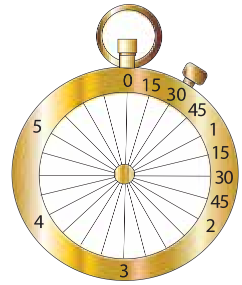


Procedure: Experiment 2
1. Empty the jars from the first experiment. Put warm water in one jar and cold in the other.
2. Measure the temperature of the first jar. Predict how long it will take for a tablet to dissolve.
Drop a tablet in the jar. Shade in the clock face for the actual number of minutes and seconds it
took to complete the reaction.
3. Measure the temperature of the second jar. Predict how long it will take for a tablet to dissolve

Jar 1 Results
Temperature: _____
Your prediction: _____ seconds



Jar 2 Results
Temperature: _____
Your prediction: _____ seconds



in the water. Drop a tablet in the jar. Shade in the clock face for the actual number of minutes and seconds it took to complete the reaction.

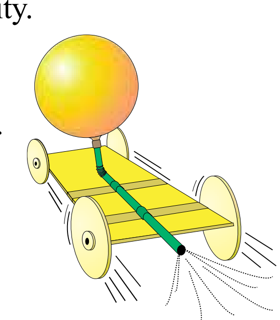
Describe what happened in the experiment and why. How can you apply the results from these experiments to improve rocket performance?

Summary: The amount of surface area of the tablet and the temperature of the water will affect the reaction of the tablets. This activity relates to increasing the power of rocket fuels by manipulating surface area and temperature. When rocket propellants burn faster, the mass of exhaust gases expelled increases, as well as the speed at which those gases accelerate out of the rocket nozzle. Based on Newton's Second Law of Motion, increasing the efficiency of rocket fuels increases the performance of the rocket. Expanding the burning surface increases its burning rate. This increases the amount of gas (mass) and acceleration of the gas as it leaves the rocket engine.

Activity Nine - Rocket Racer

Purpose: Experiment with force and Newton's Laws of Motion in this activity.

Materials: four straight pins, styrofoam meat tray, masking tape, flexible straw, scissors, drawing compass, marker pen, small round party balloon, ruler, and student sheets (one set per group); 10- meter tape measure or other measuring markers for track (one for whole class)

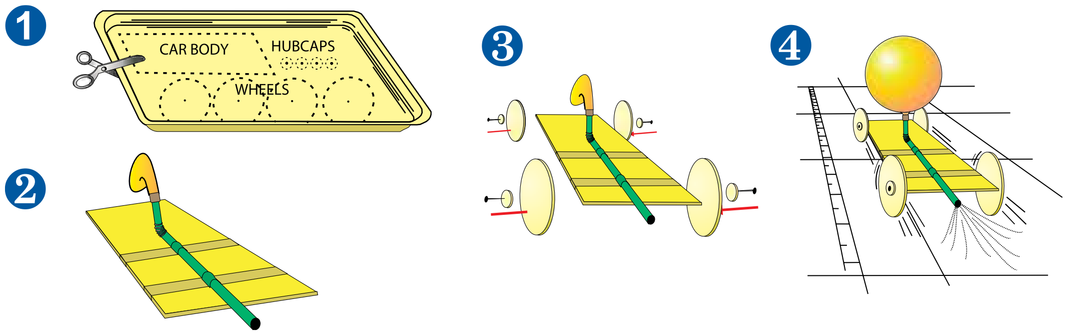


Procedures:

1. Distribute the materials and construction tools to each group. If you are going to construct a second racer, save the styrofoam tray scraps for later. Hold back the additional materials for the second racer until you need them.
2. Build racer, as per directions below. (Note) You should plan the arrangement of parts on the tray before cutting them out. If you do not wish to use scissors, you can trace the pattern pieces with the sharp point of a pencil or a pen. The pieces will snap out of the styrofoam if the lines are pressed quickly.
3. Lay out a track on the floor approximately 10 meters long, (or about 33 feet). Several metric tape measures joined together can be placed on the floor for determining how far the racers travel. Distances should be measured in 10 centimeter intervals.
4. Distance data sheets and a drawing of constructed racer should be prepared to record test runs and actual runs of races.
5. Test racers as they are completed. Fill in the data sheets and create a report cover with a drawing of the racer they constructed.
6. If a second racer will be constructed, distribute design pages before starting construction.

Build Racer:

1.Design a pattern to fit on the styroform tray. You need one car body, four wheels, and four hub caps. Use a compass to draw the wheels. Lay out your pattern on the tray and then cut them out.
2. Blow up the balloon and let the air out. Tape the balloon to the short end of a flexible straw and then tape the straw to the rectangle.
3. Push pins through the hubcaps into the wheels and then into the edges of the rectangle.
4. Blow up the balloon through the straw. Squeeze the end of the straw. Place the racer on the floor and let it go.

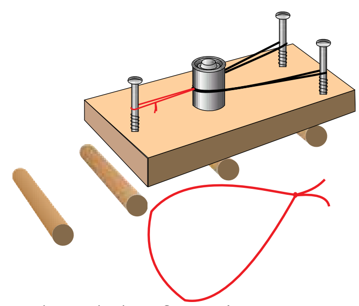


Summary: This activity demonstrates Newton's Laws of Motion. The rocket racer stays at rest unless the force of air released from the balloon causes it to move forward. It will continue moving forward until the air is exhausted from the balloon. (1st law) The more air that is placed in the balloon, the farther the rocket racer travels. (2nd law) Air rushing out of the end of the racers causes the racer to move forward. (3rd law)

Activity Ten - Newton Car

Purpose: Experiment with a slingshot-like device that throws a film canister filled with various objects, and demonstrate Newton's Laws of Motion.

Materials: wooden block about 10x20x2.5 cm (about 4x8x1 inch), 3 3-inch #10 wood screws (round head), 12 round pencils or short lengths of similar dowels, plastic film canister or equivalent, assorted materials for filling canister (washers, nuts, etc.), 3 rubber bands, cotton string, matches or lighter, **eye protection for each student**, metric beam balance (primer balance), vice, screwdriver, and a meter or measuring stick or device



Procedures:

1. Tie six string loops the size shown here.
2. Fill up your film canister and weigh it in grams. Record the mass in the Newton Car Report Chart.
3. Set up your Newton Car as shown in the picture. Slip the rubber band through the string loop. Stretch the rubber band over the two screws and pull the string back over the third screw. Place the rods 6 centimeters (about 2.5 inches) apart. Use only one rubber band the first time.
4. **Put on your eye protection!**
5. Light the string and stand back. Record the distance the car traveled on the chart.
6. Reset the car and rods. Make sure the rods are the same distance apart. Use two rubber bands. Record the distance the car travels.
7. Reset the car with three rubber bands. Record the distance it travels.
8. Refill the canister and record its new mass.
9. Test the car with the new canister mass and with one, two and three rubber bands. Record the distances the car moves each time.
10. Plot your results on the graph. Use one line for the first set of measurements and a different line for the second set.

Summary: Besides demonstrating Newton's First and Third Laws of Motion, this activity is an excellent tool for investigating Newton's Second Law of Motion, which states that force equals mass times acceleration. Manipulating different variables, such as the size of the string loop and the placement of the mass on the car, influences the results. By experimenting with a number of variables on a rocket, scientists can design a rocket that flies according to the purpose for which it was designed.

Newton Car Report:
Team Members:

______________________ ______________________
______________________ ______________________
______________________ ______________________

RUBBER BANDS	DISTANCE TRAVELED
1	
2	
3	

Describe what happened when you tested the car with one, two, and three rubber bands.

____
____
____

RUBBER BANDS	DISTANCE TRAVELED
1	
2	
3	

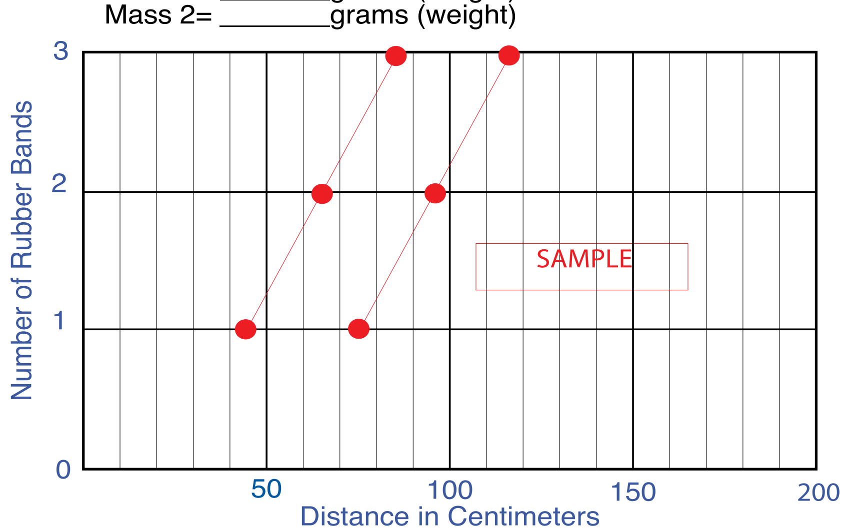
Describe what happened when you tested the car with one, two, and three rubber bands.

____
____
____

Write a short statement explaining the relationship between the amount of mass in the canister, the number of rubber bands, and the distance the car traveled.

____
____
____

Mass 1= ________grams (weight)
Mass 2= ________grams (weight)



3 ROCKETS & PRIVATE SPACE TRAVEL

Learning Outcomes

- Describe the requirements for achieving the X-Prize.
- Describe *SpaceShipOne's* achievements.
- Describe the future flight sequence of *SpaceShipTwo*.

Important Terms/Persons

SpaceShipOne – aircraft with suborbital capability

SpaceShipTwo – *SpaceShipOne*'s successor with the goal of offering the experience of space travel to the general public

ROCKETS IN THE SECOND MILLENIUM

In 1995, Dr. Peter H. Diamandis conceived an award, which he called the "Ansari X-Prize" that would encourage PRIVATE space flight. The requirements were that a non-government-supported aerospace craft would have to fly to an altitude of 100 km or 62 miles above the surface of the Earth and return safely. Then, within a period of 2 weeks, the same flight would have to be repeated. On both occasions, the vehicle was required to carry the weight of three adult humans. For this accomplishment, a prize of $10,000,000 would be awarded.

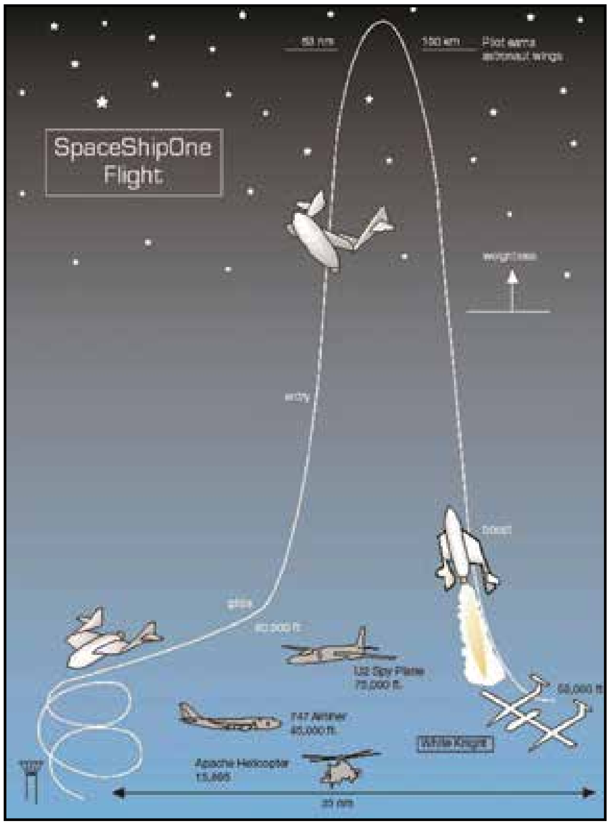
The organizers of the Ansari X-Prize, together with the scientific community, set the altitude of 62 miles, or 100 kilometers, as the line that defines the beginning of space. Twenty-six teams from 7 countries competed for the prize and many attempts to win it were made over a period of 8 years.

On June 21, 2004, Mike Melvill, test pilot for Scaled Composites of Mojave Aerospace Ventures, flew their entry for the competition, *SpaceShipOne*, on a record-breaking flight. Melvill reached an altitude of 328,491 feet, making him the first private pilot to earn the highly-coveted astronaut wings.

Test flight crew of *SpaceShipOne*. From left to right, top to bottom, Brian Binnie, Pete Siebold, Michael Melvill, Douglas Shane. Photography by Bill Deaver. Image courtesy of Aerospace Ventures LLC

Three months later, on September 29, Melvill flew *SpaceShipOne* again on the first official mission to meet the requirements set forth in the rules of competition for the X-Prize. He accomplished all competition requirements on that flight. Then, on October 4, another test pilot for Scaled Composites, Brian Binnie, flew the vehicle to an altitude of 347,442 feet, or 69.2 miles to win the prize. That flight marked the 47th anniversary of the Soviet Union's launch of *Sputnik*.

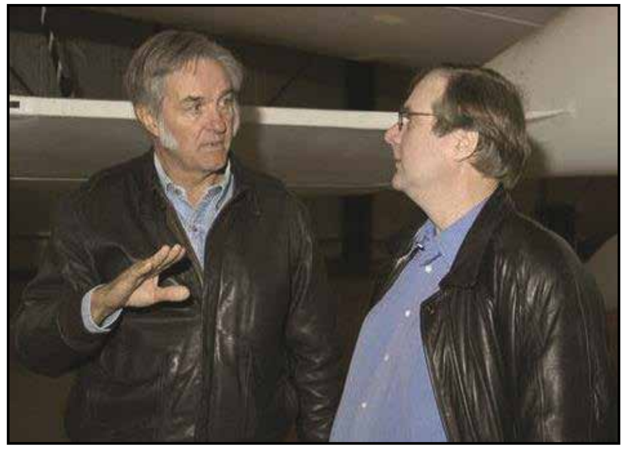
On November 6, 2004, Scaled Composites was awarded the $10M prize. Since that time, more than $1.3B has been invested world-wide in a new industry … private space travel.



The flight profile of *SpaceShipOne* from release to landing. Image courtesy of Mojave Aerospace Ventures, LLC

A NEW FRONTIER – PRIVATE SPACE TRAVEL

Commercial Airline-Type Space Travel - Virgin Galactic The first thing that comes to mind with the word "commercial" is, "how much does it cost to go to space if you're just a passenger and not an astronaut?"

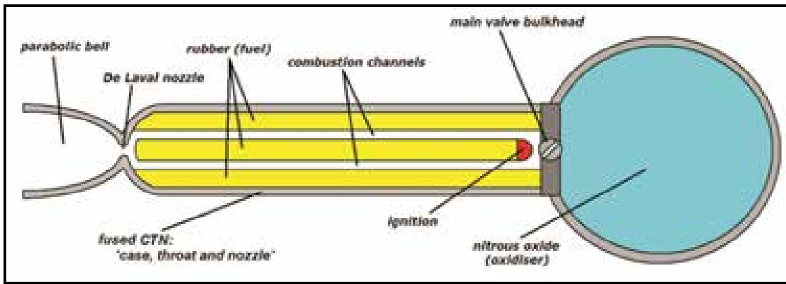


Aeronautical engineer, Burt Rutan, is shown discussing the *SpaceShipOne* project with Microsoft's co-founder Paul G. Allen. Permission was given to Civil Air Patrol by Aerospace Ventures, LLC.

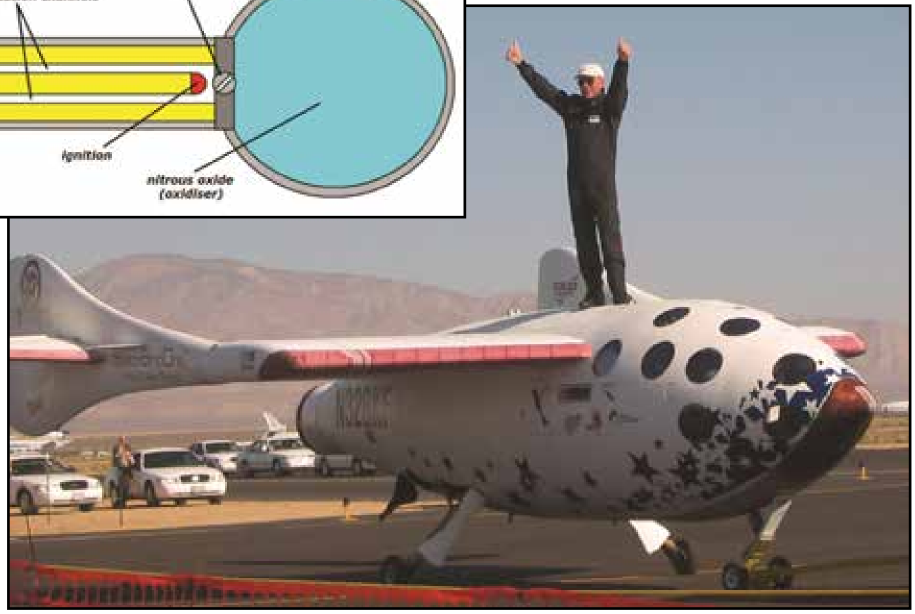
The aerospace "mother ship," known as "White Knight" is shown here carrying *SpaceShipOne* on a test flight. Image courtesy of Mojave Aerospace Ventures, LLC

As of 2020, the price for a seat on such a flight is $250,000. Virgin Galactic, a company that is a subsidiary of English-based Virgin Group and owned by British billionaire Sir Richard Branson, is mounting a serious effort to sell the ultimate thrill ride to the general public (although the ticket price may exclude a few million people).

The success of *SpaceShipOne* prompted the businessman to explore the possibility of offering the general public space transportation in a specially-built spacecraft known as *SpaceShipTwo*. Initially, the venture will take paying passengers on a sub-orbital flight to an altitude



SpaceShipOne Schematic



SpaceShipOne after its successful flight with Mike Melvill as the pilot. Image Courtesy of Mojave Aerospace Ventures, LLC

of 110 kilometers, or 68 miles, just penetrating into the thermosphere. *SpaceShipTwo* will reach 4,000 km/h (2,485 mph) using a single hybrid rocket motor, which goes by the name *RocketMotorTwo*. During the flight, passengers will experience up to six minutes of weightlessness. The complete flight will take about 2½ hours, and as of 2020 the company was on the verge of beginning commercial flights.

From " space bases" located near Upham, New Mexico, and Mojave, California, two crew members and six passengers will be taken aloft by the technologically-advanced "mother ship" known as *White Knight Two*. The journey to get to this point has not been without its setbacks. Throughout the development of the propulsion system, the vehicle prime contractor, Scaled Composites, has made major modifications to the design, resulting in years of delays. Additionally, two mishaps resulting in fatalities, one on the ground, one in flight, have caused further delays. The in-flight mishap resulted in the death of one of the pilots and the destruction of the first vehicle "Enterprise." The company appears to have resolved those problems and is back on track to offering its first flights.

In New Mexico, there will be a 10,000 foot runway and a completely outfitted terminal facility for the pioneering space passengers. The State of New Mexico has invested close to $200 million dollars in the project.

Prospective passengers will have to pass a modified flight physical, as well as undergo centrifuge training where they must be able to withstand up to 6 Gs. They will also take a "training flight" in the *White Night Two*, which has its interior outfitted to look exactly like *SpaceShipTwo*. A type of ground school will also be part of the training, For these trips, it will not be a matter of "just buying a ticket and hopping on a plane."

On the actual flight passengers will board the spacecraft and then be taken to an altitude of 50,000 feet. *SpaceShipTwo* will then separate from the *White Knight Two* and be rocketed into space. When the 110 km, or 68 mile, altitude is reached, passengers will experience approximately 6 minutes of weightlessness. The passengers will be allowed to release themselves from their seats and float around the cabin. The reason for this extended period of weightlessness is the altitude reached is at the boundary of space. By going to 110 km, and a speed in excess of Mach 3, additional time in space can be achieved.

Sir Richard Branson and Burt Rutan showcase a model of the WhiteKnight II and *SpaceShipTwo* for a press conference.

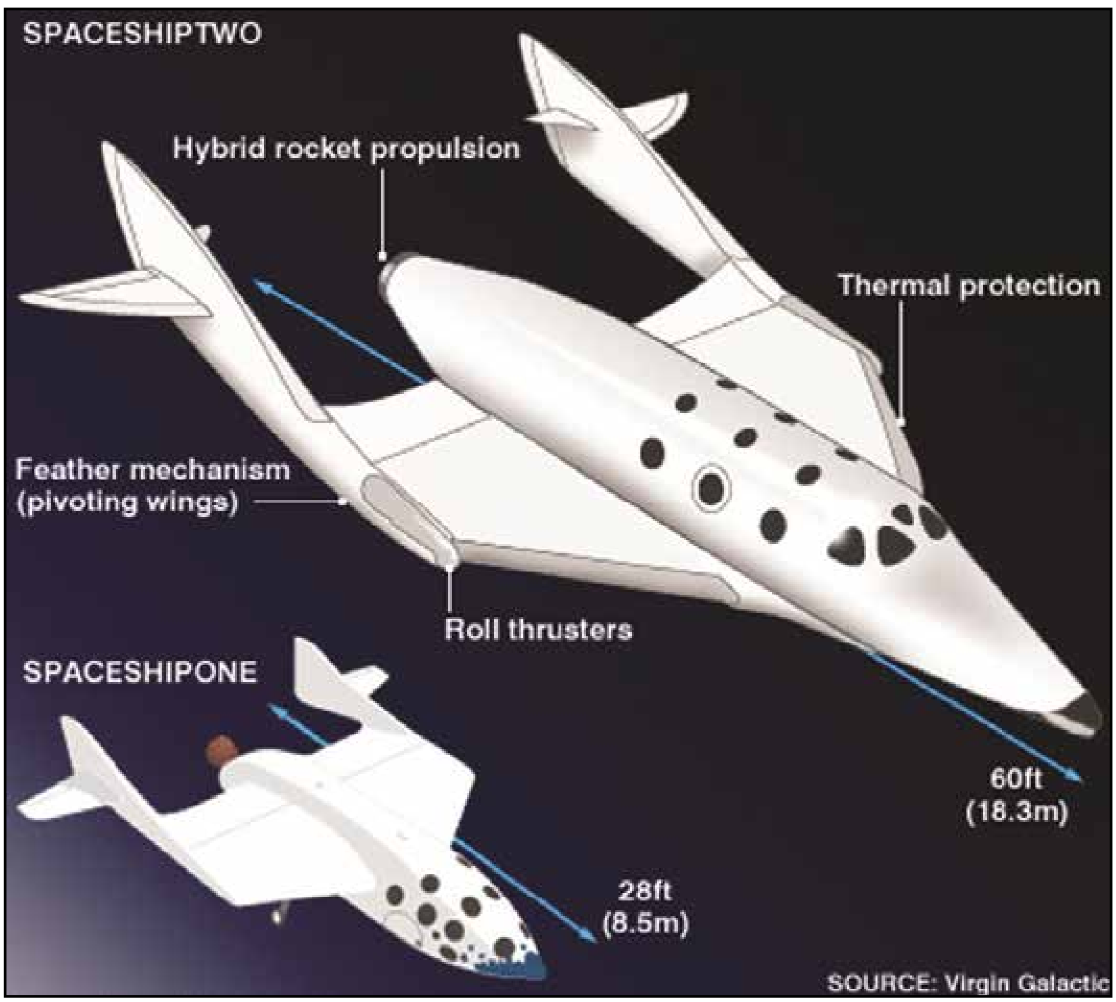
During re-entry into the Earth's atmosphere, *SpaceShipTwo* will fold it's wings upward and be gently slowed to prepare for a glide to landing at the space port.

Sir Richard Branson unveiled the project on December 7, 2009, at the Mojave Spaceport, the home base for Burt Rutan's Scaled Composite's operation. Branson's company, Virgin Galactic, is part of an international conglomerate known as the Virgin Group. All of the initial testing and marketing takes place in the United States; however, there are plans for other space facilities in England, Scotland, Sweden, and Dubai. Initial orders are for two *White Knight Two* carrier aircraft and a fleet of five *SpaceShipTwos*.

WhiteKnight II and *SpaceShipTwo* in flight in preparation for launch – Image courtesy of Virgin Galactic

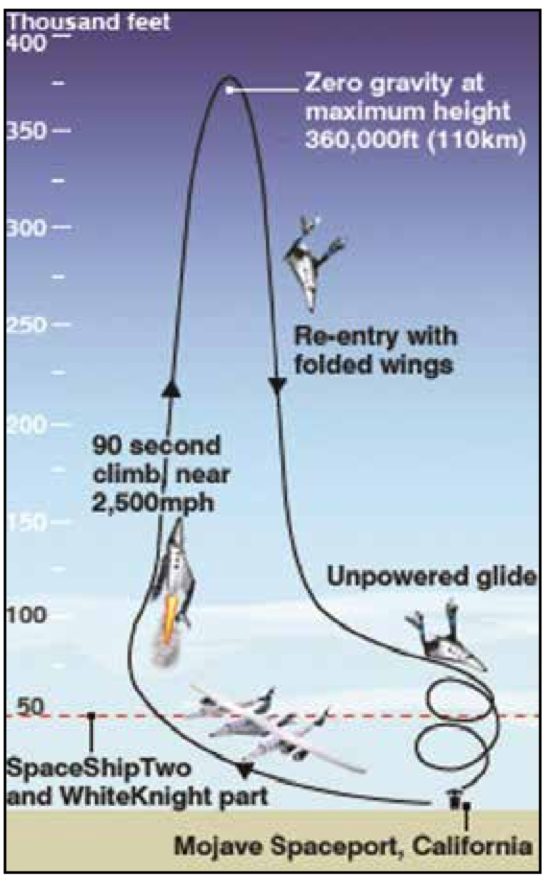
The first space base will be located in the State of New Mexico.

A test firing of the *SpaceShipTwo* rocket at the Mojave facility – Image courtesy of Virgin Galactic



This illustration shows the difference between *SpaceShipOne* and *SpaceShipTwo* in dimensions. Courtesy of Virgin Galactic

After a thrilling venture into space, Virgin Galactic's *SpaceShipTwo* prepares for re-entry and a slower speed for landing. Image courtesy of Virgin Galactic



Flight profile of *SpaceShipTwo* from release to landing

The future also includes collaboration with NASA for the possibility of launching smaller payloads into low Earth orbit. This can be done at a greater savings of money than using conventional orbital rockets. The future of rocketry for continued space travel and exploration is only beginning. The possibilities are limitless and all because of a simple propulsion principle used in the exciting area of rocketry! (See associated Activities Eleven, Twelve, and Thirteen at the end of the chapter.)

ACTIVITY SECTION 3

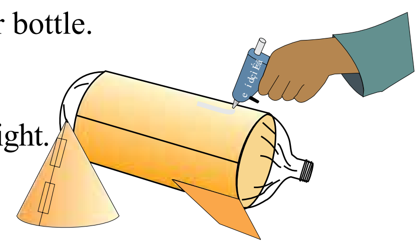
Activity Eleven - Bottle Rocket and Bottle Rocket Launcher

Purpose: This activity demonstrates how a rocket works and Newton's Laws of Motion. It also provides detailed, in-depth instructions to follow, much like the stringent rules governing the Arsari XPrize!

Materials for Building Bottle Rocket: 2-liter plastic soft drink bottles, low-temperature glue guns, poster board, tape, modeling clay, scissors, safety glasses, decals, stickers, marker pens, launch pad for the bottle rocket launcher. Begin saving 2-liter bottles several days or weeks in advance so that you will have enough each participant. You also need a bottle rocket launcher to complete this activity. Instructions for building the launcher are below.

Procedures:

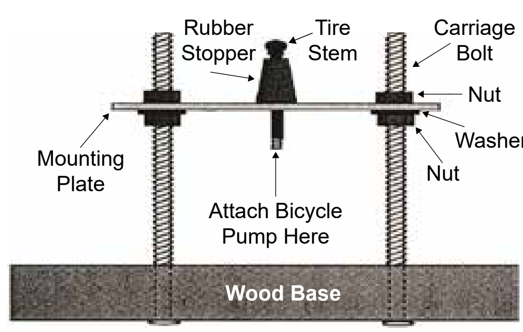
1. Wrap and glue or tape a tube of poster board around the 2 liter bottle.
2. Cut out several fins of any shape and glue them to the tube.
3. Form a nose cone and hold it together with tape or glue.
4. Press a ball of modeling clay into the top of the nose cone for weight.
5. Glue or tape nose cone to upper end of bottle.
6. Decorate your rocket.



Materials for Bottle Rocket Launcher: four 5" corner irons with 12 3/4" wood screws, one 5" mounting gate, two 6" spikes, two 10" spikes or metal tent stakes, two 5"x1/4" carriage bolts with 6 1/4" nuts, one 3" eyebolt with two nuts and washers, four 3/4" diameter washers to fit bolts, one #3 rubber stopper with a single hole, one snap-in tubeless tire valve, wood board 12"x18"x3/4", a 2-liter plastic bottle, electric drill and bits including a 3/8" bit, screw driver, pliers or open-end wrench to fit nuts, vice, 12' of 1/4" cord, a pencil, and a bicycle pump with psi measurement

Procedure:

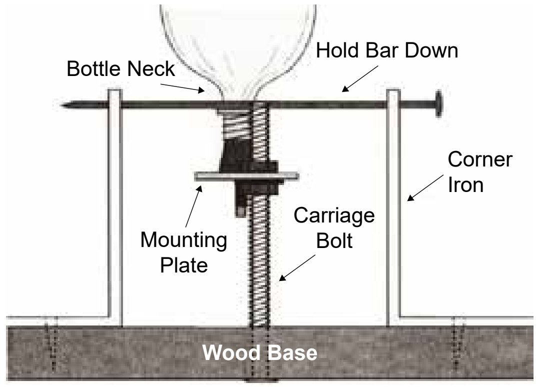
1. Prepare the rubber stopper by enlarging the hole with a drill. Grip the stopper lightly with a vice and gently enlarge the hole with a 3/8" bit and electric drill. The rubber will stretch during cutting, making the finished hole somewhat less than 3/8".
2. Remove the stopper from the vice and push the needle valve end of the tire stem through the stopper from the narrow end to the wide end.
3. Prepare the mounting plate by drilling a 3/8" hole through the center of the plate. Hold the plate with a vice during drilling and put on eye protection. Enlarge the holes at the opposite ends of the plates, using a drill bit slightly larger than the holes to do this. The holes must be large enough to pass the carriage bolts through them. (See diagram)



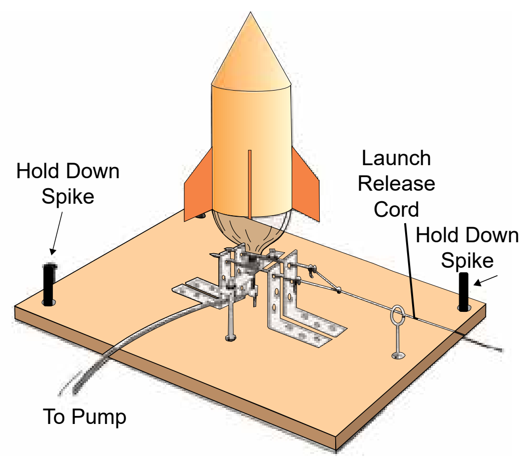
Attachment of Mounting Plate and Stopper

4. Lay the mounting plate in the center of the wood base and mark the centers of the two out side holes that you enlarged. Drill holes through the wood big enough to pass the carriage bolts through.

5. Push and twist the tire stem into the hole you drilled in the center of the mounting plate. The fat end of the stopper should rest on the plate.
6. Insert the carriage bolts through the wood base from the bottom up. Place a hex nut over each bolt and tighten the nut so that the bolt head pulls into the wood.
7. Screw a second nut over each bolt and spin it about half-way down the bolt. Place a washer over each nut and then slip the mounting plate over the two bolts.
8. Press the neck of a 2-liter plastic bottle over the stopper. You will be using the bottle's wide neck lip for measuring in the next step.
9. Set up two corner irons so they look like bookends. Insert a spike through the top hole of each iron. Slide the irons near the bottle neck so that the spike rests immediately above the wide neck lip. The spike will hold the bottle in place while you pump up the rocket. If the bottle is too low, adjust the nuts beneath the mounting plate on both sides to raise it.
10. Set up the other two corner irons as you did in the previous step. Place them on the opposite side of the bottle. When you have the irons aligned so that the spikes rest above and hold the bottle lip, mark the centers of the holes on the wood base. For more precise screwing, drill small pilot holes for each screw and then screw the corner irons tightly to the base on the opposite side of the bottle. When you have the irons aligned so that the spikes rest above and hold the bottle lip, mark the centers of the holes on the wood base. For more precise screwing, drill small pi lot holes for each screw and then screw the corner irons tightly to the base.
11. Install an eye bolt to the edge of the opposite holes for the hold-down spikes. Drill a hole and hold the bolt in place with washers and nuts on top and bottom.
12. Attach the launch "pull cord" to the head end of each spike. Run the cord through the eye bolt.
13. Make final adjustments to the launcher by attaching the pump to the tire stem and pumping up the bottle. Refer to the launching instructions for safety notes. If the air seeps out around the stopper, the stopper is too loose. Use a pair of pliers or a wrench to raise each side of the mounting plate, in turn, to press the stopper with slightly more force to the bottle neck. When satisfied with the position, thread the remaining hex nuts over the mounting plate and tighten them to hold the plate in position.
14. Drill two holes through the wood base along one side. The holes should be large enough to fit large metal tent stakes. When the launch pad is setup on a grassy field, the stakes will hold the launcher in place when you yank the pull cord. The launcher is now complete.



Positioning corner irons



Completed launcher ready for firing

Launch Safety Instructions: 1. Select a grassy field that measures approximately 30 meters, or 98 feet, across. Place the launcher in the center of the field and anchor it in place with the spikes or tent stakes. If it is a windy day, place the launcher closer to the side of the field from where the wind is coming so that the rocket will drift onto the field as it comes down.

2. Have each student or student group setup their rocket on the launch pad. Other students should stand back several meters. It will be easier to keep observers away by roping off the launch site.
3. After the rocket is attached to the launcher, the student pumping the rocket should put on eye protection. The rocket should be pumped no higher than about 50 pounds of pressure per square inch.
4. When pressurization is complete, all students should stand in back of the rope for the countdown.
5. Before conducting the countdown, be sure the place where the rocket is expected to come down is clear of people. Launch the rocket when the recovery range is clear by having one student pull the pull cord.
6. Only permit the students launching the rocket to retrieve it.

Summary: Energy is given to the stationary rocket when the stored air pressure inside the bottle is released, causing the rocket to go from a state of rest to a state of motion. (1st law) The force of the pressure escaping equals the mass of the rocket times its acceleration. Because the mass of the rocket is changing due to the escaping air pressure, force and acceleration will also be changing during flight. (2nd law) The air being forced out of the nozzle of the bottle results in the bottle being thrust upward. (3rd law)

Activity Eleven - Bottle Rocket and Bottle Rocket Launcher

Purpose: Use math skills to determine how high the rocket traveled.

Materials for Building Bottle Rocket: altitude tracker pattern, altitude calculator pattern, thread or lightweight string, scrap cardboard or poster board, glue, cellophane tape, small washer, brass paper fastener, scissors, razor blade knife and cutting surface, meter or measuring stick, rocket, and launcher

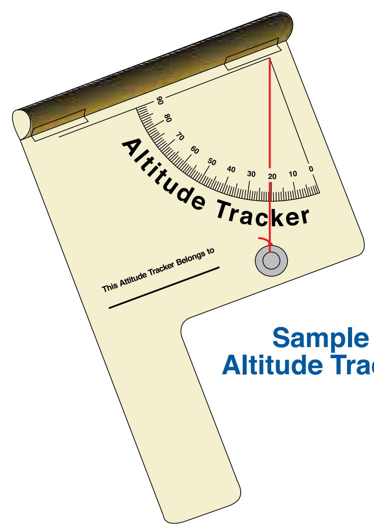
Procedures:

Constructing the Altitude Tracker Scope

1. Glue the altitude tracker pattern onto a piece of cardboard. Do not glue the dotted portion of the tracker above the dashed line.

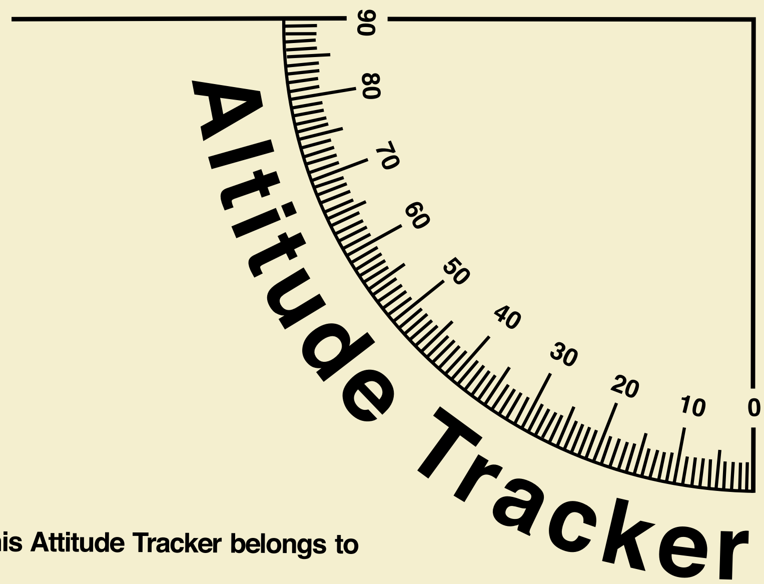
Launch rockets and measure altitude with Altitude Tracker

2. Cut out the pattern and cardboard along the outside edges.
3. Roll the part of the pattern not glued to the cardboard into a tube and tape it as shown in the illustration.
4. Punch a tiny hole in the apex of the protractor quadrant.
5. Slip a thread or lightweight string through the hole. Knot the thread or string on the backside.
6. Complete the tracker by hanging a small washer from the other end of the thread as shown in the diagram to the right.



Sample Altitude Tracker

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



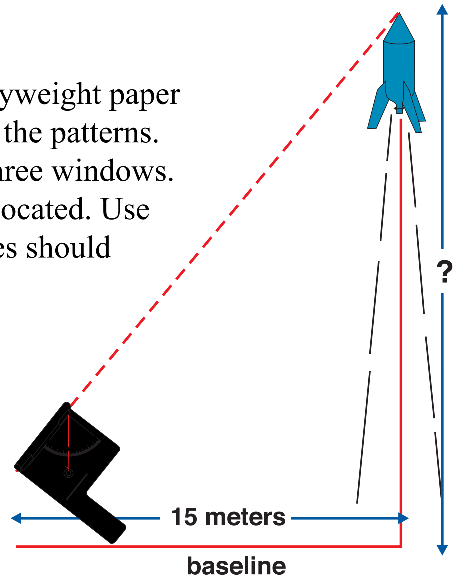
This Attitude Tracker belongs to

________________________.

Altitude Tra cker Pattern

Procedure:
Constructing the Altitude Calculator

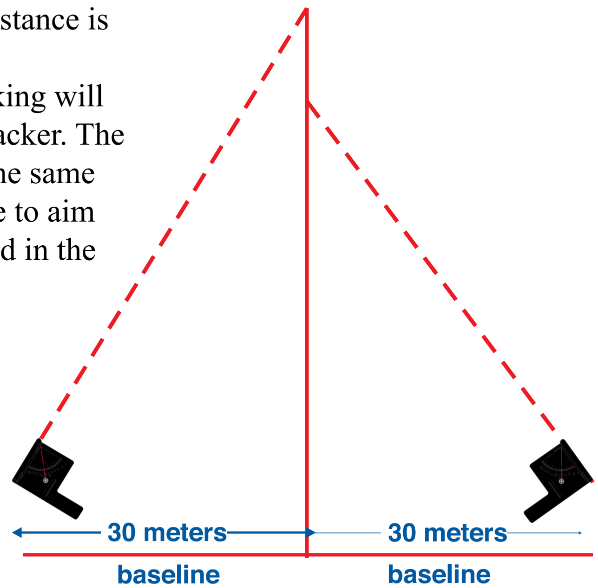
1. Copy the two patterns for the altitude calculator onto heavyweight paper or glue the patterns on to lightweight poster board. Cut out the patterns.
2. Place the top pattern on a cutting surface and cut out the three windows.
3. Join the two patterns together where the center marks are located. Use a brass paper fastener to hold the pieces together. The pieces should rotate smoothly. (See next page for pattern.)



Using the Altitude Tracker

Procedure:
Using the Altitude Tracker

1. Setup a tracking station location a short distance away from the rocket launch site. Depending upon the expected altitude of the rocket, the tracking station should be 5 meters (16.5 ft), 15 meters (49 ft,) or 30 meters (98 ft) away. Generally, a 5-meter distance is sufficient for paper rockets and antacid-powered rockets. A 15-meter distance is sufficient for bottle rockets, and a 30-meter distance is sufficient for model rockets.
2. As a rocket launches, the person doing the tracking will follow the flight with the sighting tube on the tracker. The tracker should be held like a pistol and kept at the same level as the rocket when it is launched. Continue to aim the tracker at the highest point the rocket reached in the sky. Have a second student read the angle that the thread or string makes with quadrant pro tractor. Record the angle.

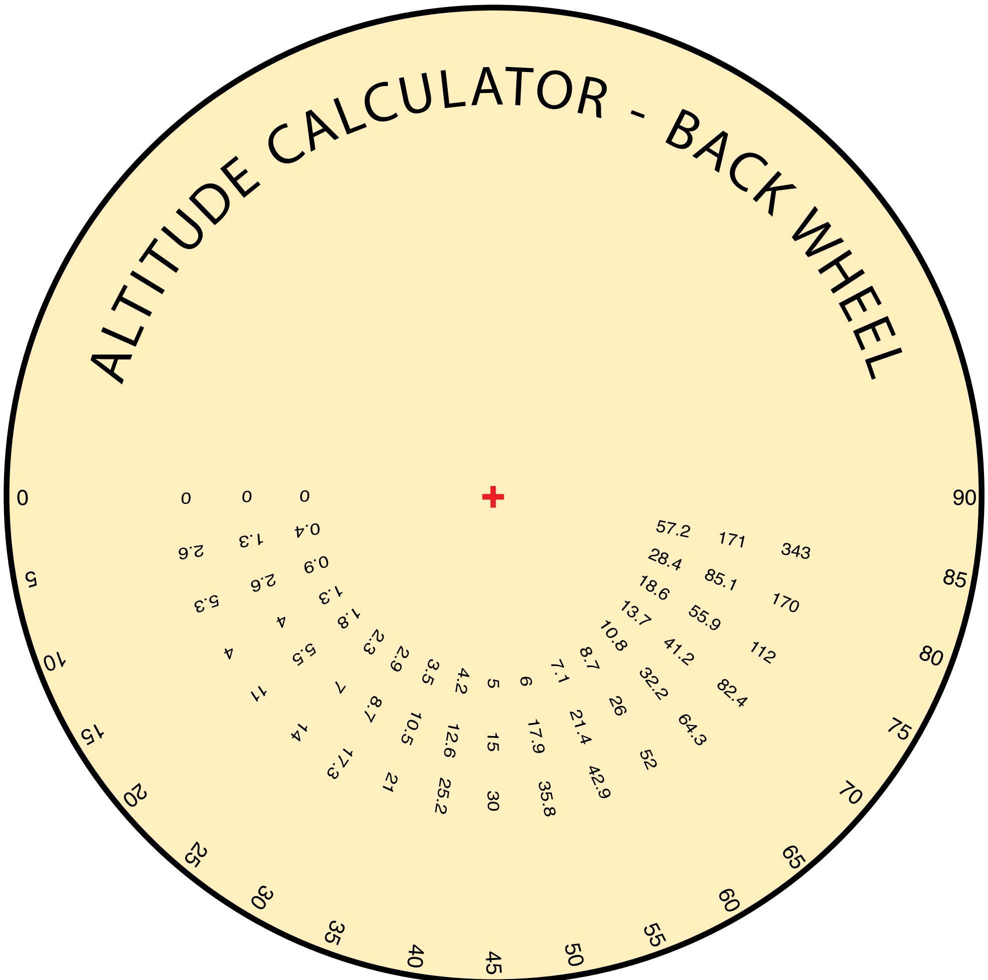


Two station tracking uses the average of the two stations

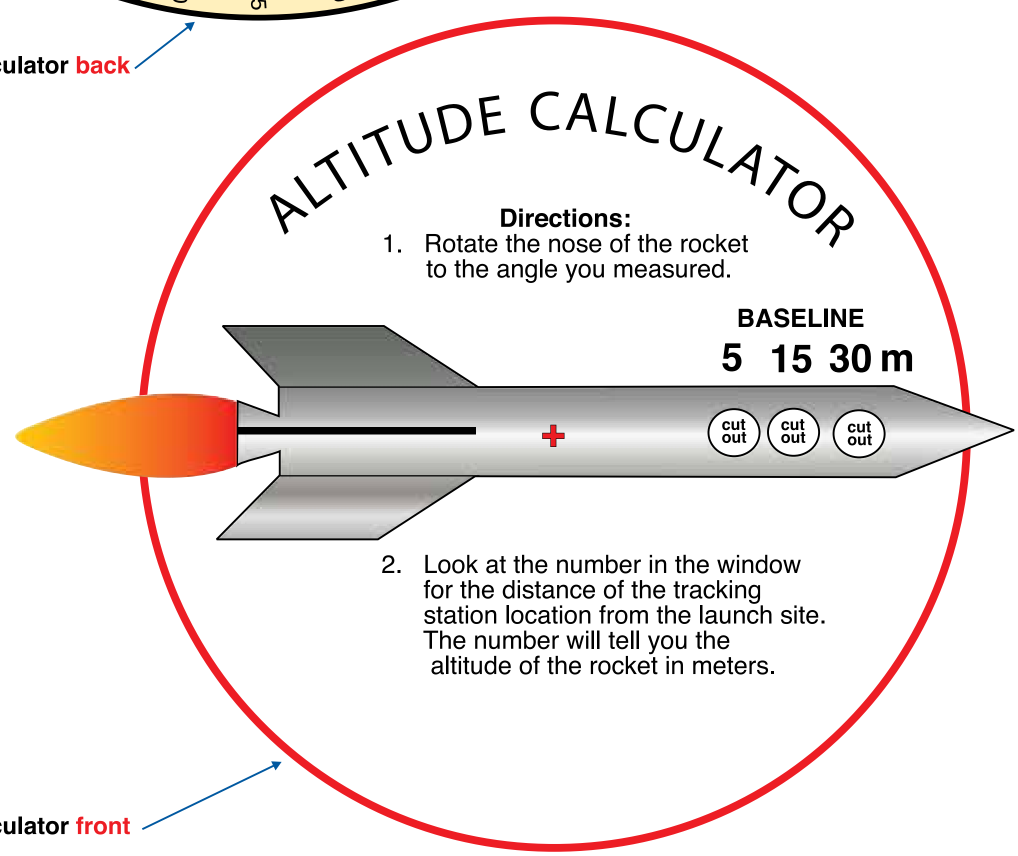
Procedure:
Determining the Altitude

1. Use the Altitude Calculator to determine the height the rocket reached. To do so, rotate the inner wheel of the calculator so that the nose of the rocket pointer is aimed at the angle measured in Step 2 of the previous procedure.
2. Read the altitude of the rocket by looking in the window. If you use a 5-meter (16.5 ft) baseline, the altitude the rocket reached will be in the window beneath the 5. To achieve a more accurate measure, add the height of the person holding the tracker to calculate altitude. If the angle falls between twodegree marks, average the altitude numbers above and below the marks.

Summary: This activity makes use of simple trigonometry to determine the altitude a rocket reaches in flight. Accuracy can be increased by having two people use an altitude tracker at different locations and averaging the results.



Altitude Calculator back



Altitude Calculator front

Activity Thirteen - Goddard Rocket

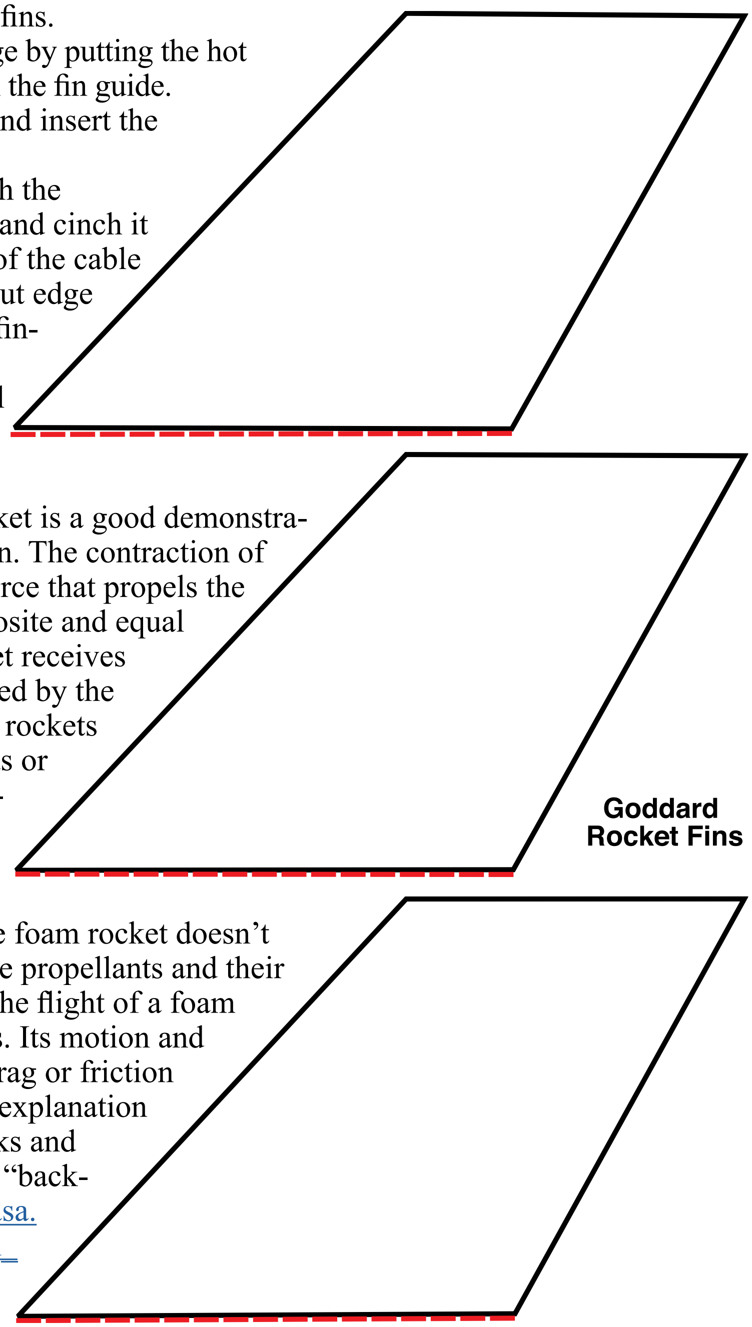
Purpose: Demonstrate Newton's Laws of Motion by creating and experimenting with flight with a flight-worthy foam rocket that is named after the first man to develop a liquid-fueled rocket in 1926, Robert Goddard. (This particular rocket resembles Goddard's 1931 rocket.)

Materials: 14 " length of 1 -3/4" outside diameter foam pipe insulation, a foam meat tray for fin templates, a # 64 rubber band for propulsion, a nylon cable tie to tie the rubber band in the fuselage of the rocket, a metal washer, and a hot glue gun to bond the foam parts together

Procedure:

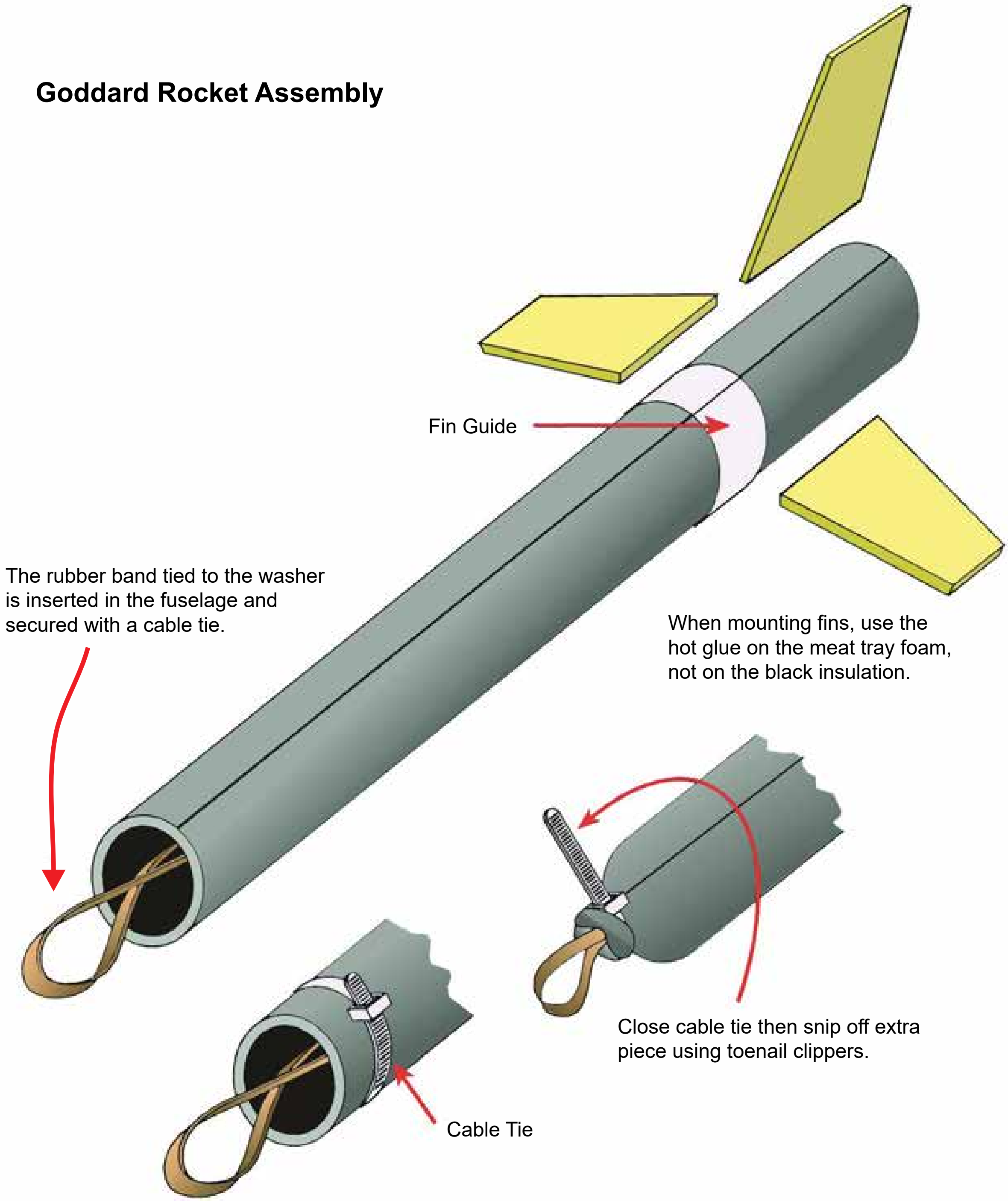
1. Copy the fin template to the right on a copy machine.
2. Place the fin template on the foam meat tray and cut out fins.
3. Place the "fin guide" on page 40 around the foam fuselage to show where to equally — place the fins.
4. Hot glue the foam fins to the fuselage by putting the hot glue on the fin only and placing it on the fin guide.
5. Tie the rubber band to the washer and insert the washer into the fuselage.
6. Pull a cable tie around the nose with the end of the rubber band hanging out and cinch it down tight. Clip the remaining tail of the cable tie. Drop a bit of hot glue over the cut edge of the cut cable tie to avoid cutting fingers.
7. To launch, put one thumb in the tail pipe of the rocket and stretch the rubber band with the other.

Summary: The launch of a foam rocket is a good demonstration of Newton's Third Law of Motion. The contraction of the rubber band produces an action force that propels the rocket forward while exerting an opposite and equal force on the launcher. The foam rocket receives its entire thrust from the force produced by the elastic rubber band. The thrust of real rockets typically continues for several seconds or minutes, causing continuous acceleration, until propellants are exhausted. The foam rocket gets a quick pull and thrusting is over. Once in flight, it coasts. Furthermore, the mass of the foam rocket doesn't change in flight. Real rockets consume propellants and their total mass diminishes. Nevertheless, the flight of a foam rocket is similar to that of real rockets. Its motion and course is affected by gravity and by drag or friction with the atmosphere. For an in-depth explanation of how the foam Goddard rocket works and relates to the forces of flight, read the "background" information at http://www.nasa.gov/pdf/295787main_Rockets_Foam_Rocket.pdf.



Goddard Rocket Fins

Goddard Rocket Assembly



Wrap this guide around the 3/4" outside diameter pipe foam tube a little more than 3 " from the rocket's tail pipe. The two ends should meet at the seam of the foam tube. Put a small piece of tape on this guide to hold it in place. Hot glue one rocket fin on to the seam of the foam tube. The arrows show where the other two fins should be mounted.