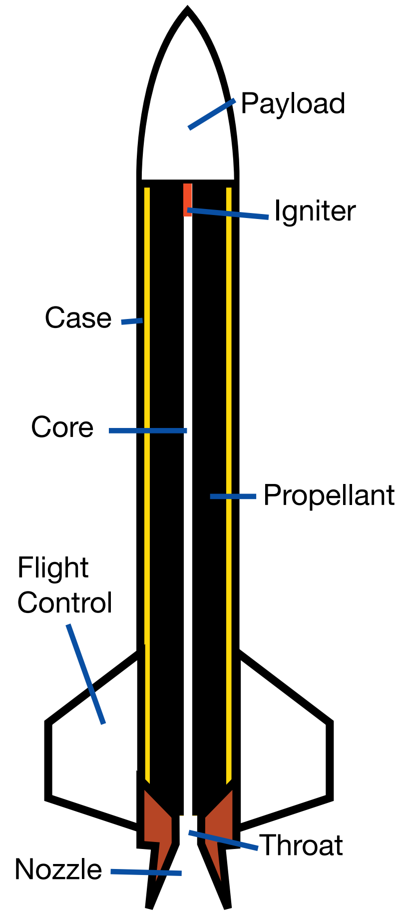
Four-stage, solid propellant Scout rocket.

through the air. This wasn't a very accurate system, but the rocket usually flew in the intended direction.

More than 1,000 years later, solid propellant rockets are not appreciably different from the Chinese fire arrows. The solid rocket boosters (SRBs) for the space shuttle are very large tubes packed with propellants that are closed off at one end and have a hole at the other. The SRBs do have many other sophisticated innovations, but, in principle, they are no different from their primitive ancestors.

Solid propellant rockets have a simple design. They consist of a case or tube in which the propellants are packed. Early rockets used cases made of paper, leather, and iron. Modern rockets use a thin and lightweight metal such as aluminum. Making the case from thin metal reduces the overall weight of the structure and increases flight performance. However, the heat from the burning propellants could easily melt through the metal. To prevent this, the inner walls of the case have to be insulated.

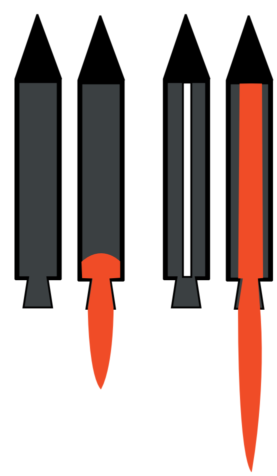
The upper end of the rocket is closed off and capped with a payload section or recovery parachutes. The lower end of the rocket is constricted with a narrow opening called the *throat*, above a larger cone-shaped structure, called the *nozzle*. By constricting the opening, the throat causes the combustion products to accelerate greatly as they race to the outside (second law). The nozzle aims the exhaust straight downward so that the rocket travels straight upward (third law).



Solid propellant rocket.

To appreciate how the throat of the rocket accelerates the combustion products, turn on the water for a garden hose. Open the nozzle to the widest setting. Water slowly flows out. Next, reduce the opening of the nozzle. Water quickly shoots out in a long stream (second law) and the hose pushes back on you (third law).

The propellant in solid rockets is packed inside the insulated case. It can be packed as a solid mass or it may have a hollow core. When packed as a solid mass, the propellant burns from the lower end to the upper end. Depending upon the size of the rocket, this could take a while. With a hollow core, the propellants burn much more rapidly because the entire face of the core is ignited at one time.



End-burning and hollow core rockets.

Rather than burning from one end to the other, the propellant burns from the core outward, towards the case. The advantage of a hollow core is that the propellant mass burns faster, increasing thrust (second law).

To make solid rockets even more powerful, the core doesn't have to be round. It can have other shapes that increase the surface area available for burning. The upper ends of the space shuttle SRBs have star-shaped cores. When ignited, the large surface area of the star points boost liftoff thrust. In about one minute, however, the points burn off, and the thrust diminishes somewhat. This is done on purpose because the space shuttle begins accelerating through the sound barrier. Passing through causes vibrations that are diminished by the temporary thrust reduction of the SRBs (second law).

Solid propellant rockets have two other major systems at work. One is the control system, which will be discussed later. The other is the igniter.

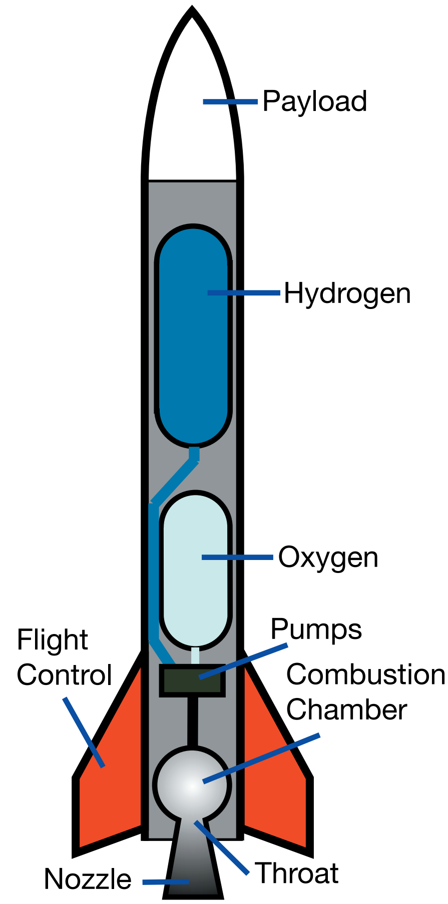
The Chinese fire arrows were ignited with fuses. This was a dangerous practice because the fuse could burn too quickly and not give the rocketeer time to get out of the way. Fuses were used for centuries until they were replaced by electric ignition. With an electric system, a wire with high resistance heats and ignites the propellant.

The space shuttle's SRBs (and soon the *Ares* version of the SRBs) add an extra component to the ignition system. A small rocket motor is mounted inside the upper end of the core. When it ignites, it shoots a long tongue of flame down the core to ignite the entire surface at once. This causes the SRBs to reach full thrust in less than one second.

Liquid Propellant Rockets

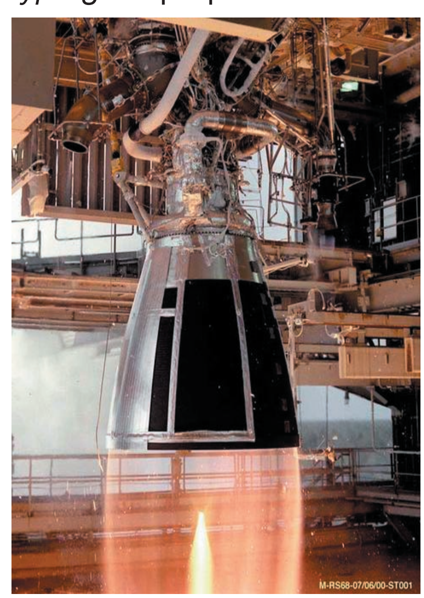
Liquid propellant rockets are an invention of the twentieth century. They are far more complex than solid rockets. Generally, a liquid rocket has two large tanks within its body. One tank contains a fuel, such as kerosene or liquid hydrogen. The other tank contains liquid oxygen.

When the liquid rocket engine is fired, high-speed pumps force the propellants into a cylindrical or spherical combustion chamber. The fuel and oxidizer mix as they are sprayed into the chamber. There they ignite, creating huge quantities of combustion products that shoot through the throat and are focused downward by the nozzle. (Remember how the laws control this!)



Liquid propellant rocket

Liquid propellant engines have a number of advantages over solid propellant engines. A wider array of propellant combinations are available for different applications. Some of these require an ignition system and others simply ignite on contact. Monomylmethylhydrozene (fuel) and nitrogen tetroxide (oxidizer) ignite spontaneously. These are called *hypergolic* propellants. With hypergolic propellants, a rocket engine does not need an ignition system. Hypergolic propellants are great for attitude control rockets like those that will be arrayed around the *Orion* service



RS-68 Liquid propellant engine test firing.

module and the ascent stage of the *Altair* lunar lander.

Another advantage of liquid propellants is that they can be controlled. Adjusting their flow into the combustion chamber adjusts the amount of thrust produced. Furthermore, liquid engines can be stopped and restarted later. It is very difficult to stop a solid propellant rocket once it is started, and thrust control is limited.

Naturally, with any technology, there is a price to pay. The engine of a liquid propellant rocket is very complex and subject to failure. It also has more structural mass than comparable solid propellant rockets. One method for mass reduction is to use thin, lightweight metal for the nozzle. Normally, the nozzle is very thick and heavy, to prevent it from eroding away in the high-temperature streams of exhaust gases. A thin-wall nozzle needs a cooling system. Small tubes lace the walls and carry liquid hydrogen. Hydrogen becomes a liquid at 20.27 K (-252.87°C or -423.17°F). The super cold hydrogen absorbs the heat from the gas stream and protects the walls of the nozzle. The hydrogen, now heated, is then injected into the combustion chamber. With this system, the engine has less mass and produces greater thrust (second law again!).

Liquid propellant Delta rocket carrying the *Dawn* spacecraft.

Controlling Flight

Newton's third law gets a workout in the control systems for rockets. Launch rods for old rockets were ineffective. Military rockets were launched by the thousands so that at least a few would hit their targets. Accuracy improved when small vanes were added to the exhaust stream. The vanes imparted stability by causing the rockets to spiral like bullets.

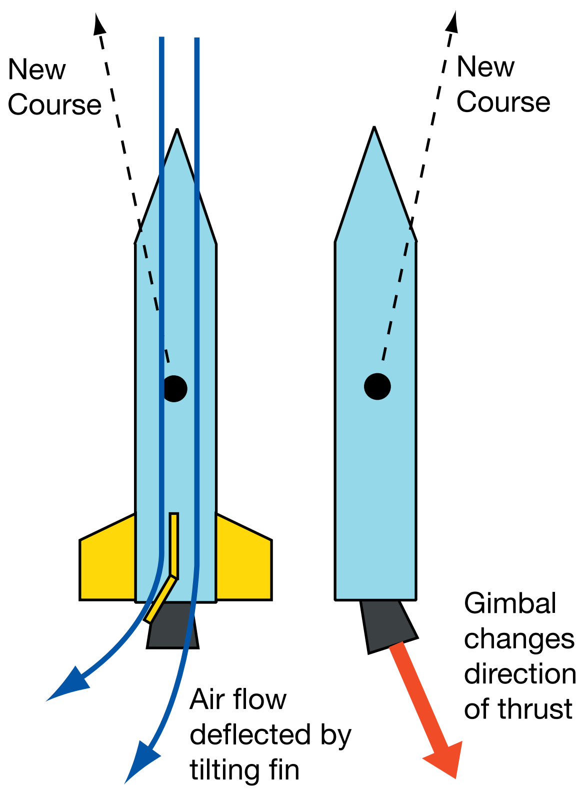
Another technique was to add fins, like the feathers on an arrow, to the lower end of the rocket case. As long as a rocket flies "straight as an arrow," the fins provide little drag or friction with the air. However, if the engine end of the rocket begins "fishtailing," drag increases greatly. The air stream strikes the fin, and the fin directs the stream to the side. The lower end of the rocket moves the opposite way and corrects the fishtailing (Newton's third law). Fins are used extensively with model rockets and small missiles.

Rocket fins on model rockets are a passive system for flight control. They remain fixed and do their job if the rocket starts going astray. Robert Goddard took fins a giant step forward by turning them into an active system. Goddard's fins could be made smaller (and lighter!) because they were not fixed. Even a slight straying from the planned course would cause the fins to react and tilt slightly in the appropriate direction.

The heart of Goddard's control system, later used in the V2 and other advanced rockets, was a gyroscope. Gyroscopes, which are a kind of top, spin at high speeds and become stable due to their inertia (first law). In other words, the axis of the gyroscope points in one direction. If the rocket veers from course, the movement acts on the alignment of the gyroscope, and a linkage or an electrical system connected to the gyroscope transmits the appropriate corrections to the movable rocket fins.

You can get an idea of the effectiveness of movable fins with a simple demonstration. Balance a long stick on the palm of your hand. If the stick starts tilting to the right, you automatically move your hand to the right to straighten up the stick. Movable fins do the same thing. The rocket starts tilting to the right. The leading edge of the fins bend to the right. This causes the air stream to be deflected to the left. The lower end of the rocket moves to the right, and the rocket is back on course.

Naturally, some fins are more complicated than just described. Depending upon the rocket design, the entire fin may not move. Instead, a lower flap might be the controllable part of the fin (kind of like a rudder). Very small movable fins might also be placed towards the nose of the rocket. These are called *canards,* and they permit rapid and extreme control maneuvers for air-to-air military missiles. Small fins, called *vanes*, may be placed within the exhaust stream of the engine. When a vane tilts, it directs part of the exhaust to one side or another. The lower end of the rocket responds by moving the other way. All of these fin styles are examples of Newton's third law in action.



Another way the third law is applied for controlling flight is through gimballed engine nozzles. *Gimballed* means the nozzle can tilt in different directions. Movements of the nozzle can steer the rocket on a new course or make course corrections. The solid rocket boosters used for the *Ares I* and *V* first stages will use gimballing for control.

Controlling Mass

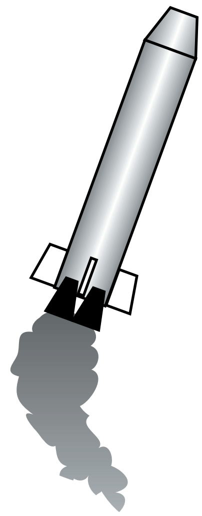
The total mass of a rocket has a major influence on its performance. If the rocket has a greater mass than the engines are capable of lifting, the rocket remains stuck on Earth (first law). The lighter the rocket, the better. However, since the rocket must carry all of its propellants (there aren't any filling stations in space —YET!), a big part of the rocket's mass has to be its propellants. The mass of the propellants burned is a big part of thrust (second law). Mass savings have to come from elsewhere — the rocket structure.

Engineering rocket tanks out of lightweight materials strengthened by ribs is a great way of saving mass. Chilling hydrogen and oxygen propellants until they liquefy reduces their total volume. That means smaller, less massive tanks can be used. Gimbaling engines for control means that heavy fins can be eliminated.

When designing new rockets, rocket scientists (and engineers) concern themselves with mass fraction. Mass fraction is a simple inverse mathematical relationship between the mass of the propellants of the rocket and the total mass of the rocket. Although there is wiggle room in this equation, the most efficient rockets have mass fractions of about 0.91. That means that of the total rocket,

$$MF = \frac{\textit{mass}\text{ (propellant)}}{\textit{mass}\text{ (total rocket)}}$$

propellant accounts for 91% of its mass. The rocket structure and payload comprises the other 9%. Since you need the mass of the propellants, efforts on saving mass are primarily focused on structure and payload.

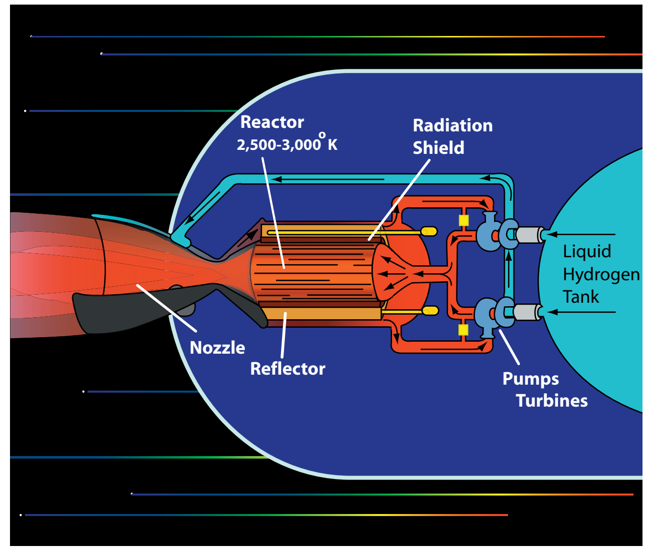


One simple but old trick is staging. Begin with a large rocket, stack a smaller one on top of it, stack a still smaller rocket on top of the second one, and then the payload on top of the third rocket. The large rocket lifts its own mass and the mass of the other two. When the large rocket (first stage) is empty, it drops off. The second rocket (second stage) fires and accelerates itself and the third stage with its payload to higher speeds and altitudes. When it is empty, the second stage is dropped, and the third stage finishes the job of delivering the payload. By staging, the mass of the rocket is reduced in flight, making the upper stages more efficient in doing their jobs.

Future Rockets

Part of the fun of rocket science is that there are always new ideas and new ways of doing things. Solid and liquid rockets are not the only way to go. Other kinds of rockets are "on the drawing board," going through prototype testing, or churning about in the imaginations of dreamers.

Electric rockets have been around since the 1960s. Rather than burning propellants, ions — electrically charged atoms — are driven out of the rocket engine using magnetic forces. In doing so, a very small thrust is imparted to the rocket. (Newton's laws are still at work in this rocket.) Electric rockets, sometimes referred to as "ion drive," are very efficient in converting electrical energy into thrust, but since the mass of ions is very low, the thrust is small, about the force needed to push a walnut across a table. One would think, "Why bother?" The answer



Proposed nuclear thermal rocket engine

is that ion drive can function continuously for months or years on end. It may start off slow, but after months and months of thrusting a vehicle could achieve velocities higher than a chemical rocket that burns all its propellants in a few minutes. Another thing — the electricity for ion drives can come from sunlight captured by solar panels on the spacecraft.

Nuclear power is also under consideration for rocket propulsion. An onboard nuclear reactor would generate lots of heat through nuclear fission (breaking down of radioactive atoms). A supply of hydrogen gas would be heated by the reactor, causing the gas molecules to expand rapidly and stream out of the engine nozzle. No burning would be involved. Think of this kind of rocket as a nuclear-powered balloon.

Still another concept is beaming a powerful laser from Earth towards collectors on a spacecraft. The energy received would be used to heat a supply of gas for propulsion. In this way, the nuclear reactor could be eliminated.

Still further in the future, matter/antimatter drives, such as those proposed in *Star Trek,* might actually be possible.

Where we go and how we will get there all comes down to the rocket scientists of the future, who are sitting in classrooms today.

Rocket Activities

There are few classroom topics that generate as much excitement as rockets. The scientific, technological, engineering, and mathematical (STEM) foundations of rocketry provide exciting classroom opportunities for authentic hands-on, minds-on experimentation. The activities and demonstrations that follow are suitable for students at many grade levels.

For the most part, material and tool requirements are simple, but a few of the bigger projects require launch platforms that need to be constructed or purchased in advance. Although purchasing platforms from school science catalogs and specialty companies is an option, constructing your own is a learning process in which you can involve your students. Minimal proficiency with tools (saw, screw driver) is required. Detailed instructions (with lots of illustrations!) are provided.

As you review the activities you will notice that each supports state and national educational standards for science, technology, and mathematics. A matrix identifying specific national standards and recommended grade levels follow on the next two pages. You may "cherry-pick" activities, but linking several or using all of the activities will provide your students with a memorable and beneficial STEM unit and turn your students into "rocket scientists." *You Are Go For Launch!*

A Note about Measurement

Where possible, all measurements used in the activities are metric. However, English units are often employed when constructing devices because most materials and parts are sized with English measures.

National Curriculum Standards

The rocket activities in this guide support national curriculum standards for science, mathematics, and technology. The standards identified for each activity are based on science standards developed by the National Research Council and the mathematics standards developed by the National Council of Teachers of Mathematics. While not practical to identify individual standards by state, national standards provide a guide for selecting activities that meet local needs.

National Science Education Standards K-12

National Research Council

Rocket Activities	Unifying Concepts and Processes		Science as Inquiry	Physical Science			Science and Technology			
	• Evidence, models and explanation	• Change, constancy, and measurement	• Abilities necessary to do scientific inquiry	• Position and motion of objects	• Motions and forces	• Properties of objects and materials	• Abilities of technologic design	• Understanding about science and technology	• Risks and benefits	• Science and technology in local challenges
Pop Can “Hero Engine”		✓	✓	✓	✓			✓		
3...2...1...PUFF!	✓		✓	✓	✓		✓			
Heavy Lifting			✓	✓	✓		✓			
Newton Car	✓	✓	✓	✓	✓	✓		✓		
Rocket Races		✓	✓	✓	✓		✓			
Pop! Rockets Launcher				✓	✓		✓			
Pop! Rockets	✓	✓	✓	✓	✓	✓	✓			
Foam Rocket	✓	✓	✓	✓	✓	✓	✓			
Launch Altitude Tracker				✓	✓			✓		
High-Power Paper Rocket Launcher				✓	✓		✓			
High-Power Paper Rockets	✓	✓	✓	✓	✓		✓			
Rocket Wind Tunnel	✓	✓	✓	✓	✓		✓			
Advanced High-Power Paper Rockets	✓	✓	✓	✓	✓		✓			
Water Rocket Launcher				✓	✓		✓			
Water Rocket Construction				✓	✓		✓			
Project X-51	✓	✓	✓	✓	✓				✓	✓

Principles and Standards for School Mathematics
Pre K - 12

National Council of Teachers of Mathematics

Rocket Activities

Rocket Activities	Content Standards: Number and Operations	Content Standards: Algebra	Content Standards: Geometry	Content Standards: Measurement	Content Standards: Data Analysis and Probability	Process Standards: Problem Solving	Process Standards: Reasoning and Proof	Process Standards: Communication	Process Standards: Connections	Process Standards: Representations
Pop Can “Hero Engine”	✓			✓	✓		✓	✓	✓	✓
3...2...1...PUFF!	✓		✓	✓	✓				✓	✓
Heavy Lifting	✓				✓	✓	✓	✓	✓	✓
Newton Car	✓			✓	✓	✓	✓	✓	✓	✓
Rocket Races	✓		✓	✓	✓	✓	✓	✓	✓	✓
Pop! Rockets Launcher				✓				✓		
Pop! Rockets	✓		✓	✓	✓	✓	✓	✓	✓	✓
Foam Rocket	✓	✓	✓	✓	✓		✓	✓	✓	✓
Launch Altitude Tracker	✓		✓	✓	✓	✓	✓	✓	✓	✓
High-Power Paper Rocket Launcher				✓				✓		
High-Power Paper Rockets	✓		✓	✓	✓	✓	✓	✓	✓	✓
Rocket Wind Tunnel	✓			✓	✓	✓	✓	✓	✓	✓
Advanced High-Power Paper Rockets	✓		✓	✓	✓	✓	✓	✓	✓	✓
Water Rocket Launcher				✓					✓	
Water Rocket Construction			✓	✓					✓	
Project X-51	✓		✓	✓	✓	✓	✓	✓	✓	✓

Suggested Grade Levels

The matrix below displays suggested grade levels for the activities in this guide. Each activity is appropriate for a wide range of student abilities. Although grade levels are suggested, small modifications will enable activities to be used successfully with other grade levels. One area of potential adjustment are the student pages. The reading level and vocabulary on these pages may be below or above your students' abilities. Many of the activities contain tips, suggestions, and extensions that will assist you in preparing the lesson for the appropriate audience.

Suggested Grade Levels

Rocket Activities	K	1	2	3	4	5	6	7	8	9	10	11	12
Pop Can "Hero Engine"	✓	✓	✓	✓	✓	✓	✓	✓	✓				
3...2...1...PUFF!	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Heavy Lifting	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Newton Car				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rocket Races				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pop! Rockets Launcher	✓	✓	✓	✓	✓	✓	✓						
Pop! Rockets	✓	✓	✓	✓	✓	✓	✓						
Foam Rocket					✓	✓	✓	✓	✓	✓	✓	✓	✓
Launch Altitude Tracker					✓	✓	✓	✓	✓	✓	✓	✓	✓
High-Power Paper Rocket Launcher				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
High-Power Paper Rockets				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rocket Wind Tunnel				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Advanced High-Power Paper Rockets				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Water Rocket Launcher					✓	✓	✓	✓	✓	✓	✓	✓	✓
Water Rocket Construction					✓	✓	✓	✓	✓	✓	✓	✓	✓
Project X-51					✓	✓	✓	✓	✓	✓			

Rocket Activity

Pop Can "Hero Engine"

Objective
To investigate Newton's third law of motion using thrust produced by falling water.

Description
Small student teams will construct water-propelled engines out of soft drink cans and investigate ways to increase the action-reaction thrust produced by water shooting out of holes punched in the can sides.

National Science Content Standards

Unifying Concepts and Processes
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Understanding about science and technology

National Mathematics Content Standards
- Number and Operations
- Measurement
- Data Analysis and Probability

National Mathematics Process Standards
- Reasoning and Proof
- Communication
- Connections
- Representations

Materials
4 empty aluminum soft drink cans per team, with pull tabs intact
Carpenter's nails of different sizes (6,12, 16D, etc.)
String (about 50 cm)
Water tub (large plastic storage tub, small kiddy pool, sink, etc.)
Water
Towels
Rulers
Stickers or bright permanent marker

Management
Divide your students into small groups. Set up one or more water tubs around your classroom and fill the tubs with about 20 cm of water. Have no more than one or two teams test their engines at one time. Discuss the importance of keeping the water in the tubs. When engines are filled, they should not be raised any higher than the rim of the tub. This will keep water coming out of the holes from falling on the surrounding floor. Be sure to recycle the cans at the conclusion of the activity.

Tip Ask students to bring undented and washed soft drink cans from home. You will need at least three cans per student team.

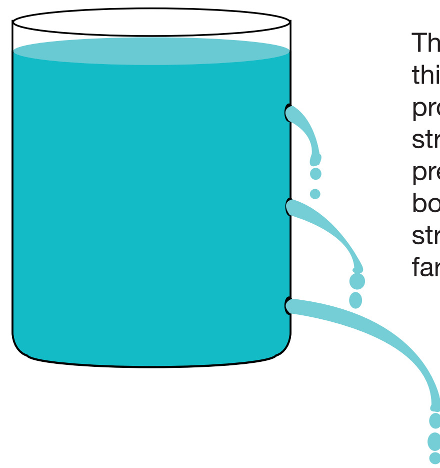
Background

This activity simulates the operation of the classic aleoliphile engine invented by Hero of Alexandria more than 2,000 years ago. (See page 2.) Hero's engine was a spinning copper sphere that was propelled by a thrust produced by a jet of steam. The engine was an early demonstration of the action-reaction principle (third law of motion) stated by Sir Isaac Newton 1,700 years later. (See page 4.) Steam, shooting out through two L-shaped holes, creates an action force that is accompanied by an equal reaction force in the opposite direction.

Hero's invention was not self-contained and therefore, not a true rocket device. Heat to generate the steam had to be applied externally. Rockets are completely self-contained.

In this activity, a Hero engine-like device is created by the students. Holes are punched in the side of a soft drink can. The holes are angled pinwheel fashion. A string, tied to the pull tab, supports the can and permits it to rotate. The can is immersed in water and pulled out. Gravity draws the water through the angled holes, and streams shoot out in either a clockwise or counterclockwise direction. The streams produce an action force that is accompanied by a reaction force. The can spins in the opposite direction.

There are many potential variables with the Pop Can Hero engine. Hole size, hole angle, number of holes, and the placement of the hole above the base of the can all affect the thrust produced. The most significant of these variables is the hole placement. The greatest thrust occurs when the holes are punched just above the bottom of the can. This is a gravity effect. The strength of the water stream (thrust) is based on the pressure. Water pressure in a container is the greatest at the bottom. The pressure at the top of the water in the container is zero (ignoring air pressure in this example). Water dribbles out of a hole near the top of the column. The water stream gets stronger the closer the hole is to the container bottom. Thrust stops when water drains out to the level of the holes. Holes at the bottom of the container produce thrust for a longer time. However, the magnitude of the thrust diminishes as the water column lowers (pressure drops with column height).



The three holes in this container each produce a water stream. Greater pressure at the bottom makes the stream shoot out farther.

The effects of the other variables are many. For example, more holes means more water streams out of the can, but the water drains from the can more quickly. Large holes drain water more quickly than small holes. Holes angled in different directions counteract each other. Holes that are not angled produce water streams that leave the can perpendicular and no rotation occurs. (The object is to have students discover the effects of the different variables themselves.)

Procedure Making the Pop Can "Hero Engine"

1. Divide your students into small teams of two or three members.
2. Demonstrate the procedure for punching holes in the cans. The idea is to punch the hole without crushing the can sides. Place the nail point near the bottom rim of the can. Apply pressure with the nail, turning it, if necessary, to make the hole.
3. When the hole is punched, push the nail head to the right or to the left. This will angle the hole so that water will stream out on a tangent to produce thrust.

tangent to produce thrust.
4. Rotate the can 1/4 turn and punch a second hole. Again angle the hole (in the same direction as before).
5. Repeat the procedures two more times to make four holes in total. (Cans may have different number of holes.)
6. Tie a string to the pop top.
7. Immerse the can in the tub of water.
8. When the can is full of water. Pull it out by the string and observe the rotational motion.

Procedure: Student Team Experiment
1. Provide each team with copies of the “Pop Can Hero Engine” experiment sheet.
2. Review the instructions on the page and discuss the objective (“Design an experiment to find a way to increase the number of rotations the Pop Can Hero Engine makes.”)
3. Make a list of student ideas for variables to test - hole size, number of holes, etc. Discuss the importance of changing only one thing at a time. The first Hero engine they create will serve as the baseline experiment. The second and third engines will vary just one thing. (E.g. Can 1 - medium size holes, Can 2 - smaller holes, Can 3 - larger holes)
5. Discuss ideas for keeping track of the number of rotations the cans make. (Place a large bright mark on one side, etc.)
4. Give teams time to pick their experiment, devise their hypothesis, and to write the procedures they will follow on their experiment page.
5. Distribute the materials to the teams and have them begin their investigation.

Discussion:

• *What provides the force that causes the cans to rotate?*
Actually, there are a combination of factors that contribute to the force that causes the cans to rotate. The most important is the force of gravity. It attracts the water in the can and causes it to stream out the holes. The shape of the holes directs the water streams. The diameter of the holes determines how fast the water streams out, etc.

Tip: Make sure the nails used for punching holes have good points on them. They do not have to be needle sharp, just not blunt.

• *Which of Newton’s laws of motion explains why the can rotates in the opposite direction from the direction of the water streams?*
Newton’s Third Law of Motion
• *Based on the results of the individual team experiments, what could you do to maximize the number of rotations of the Pop Can Hero Engines?*
Individual answers: combine best hole size with the right number of holes, best placement, etc.

Assessment

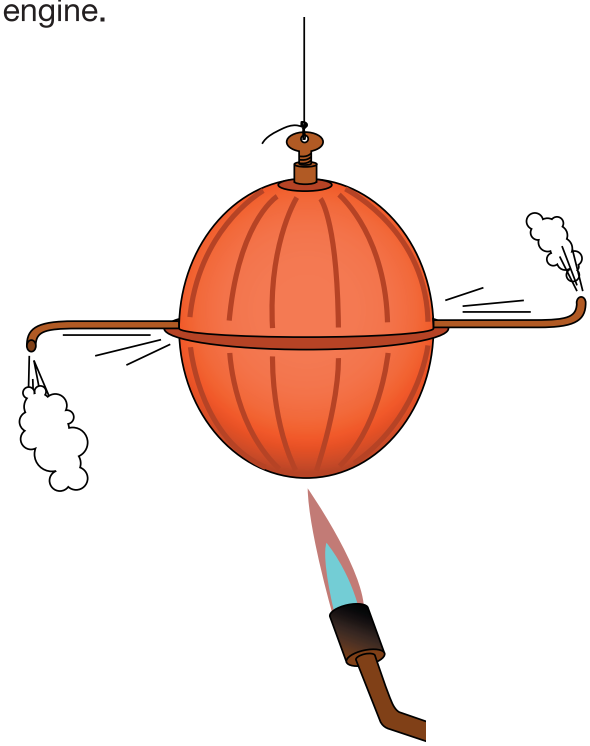
- Ask teams to state their experiment hypotheses, explain their procedures, and present their results. Make a list of the different ways one can increase the number of rotations the Hero engine makes.
- Have teams submit their completed data sheet with their written conclusion based on their results.

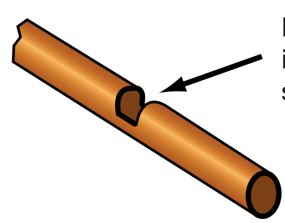
Extensions

- Construct an actual steam-powered hero engine and use it as a demonstration device. Although not difficult to construct, the engine will require some basic construction skills, principally soldering. You will need the following materials:

  - Copper toilet tank float (available from plumbing supply stores and from on-line plumbing supply stores - search “copper toilet tank floats.”
  - 12” copper tube, 3/16” diameter (from hobby shops)
  - Thumbscrew to fit threads for float arm attachment
  - Metal file
  - 3/16” drill
  - solder
  - propane torch
  - pliers
  - string
  - water
  - eye protection

1. File a notch in the center of the tube. Do not file all the way through. In Instruction 3, the tube will be inserted completely through the sphere. This supports the tube while it is being soldered. (See diagram to the right.)
2. Drill 3/16th” holes through opposite sides of the float just above the “equator” joint.
3. Insert the tube through the holes. Lightly heat the place where the tubes contact the sphere. Touch solder to the contact point to seal the tube to the float.
4. Apply heat to soften the opposite ends of the tube until they bend easily. Using pliers to grasp the ends, bend the tube ends into an L shape. Be careful not to overheat or bend too forcefully, or the tube may flatten on the bend.
5. Drill through the center of the threads for the attachment point for the float arm. This will open a water-filling hole into the float.
6. Drill a hole through the flat side of the thumb screw to permit tying of the string.
7. Pour about 30 milliliters of water (about 1 tablespoon) into the float through the filling hole.
8. Thread the thumbscrew into the hole and attach the string.
9. Suspend the engine from above and gently heat the bottom of the engine with a torch. Be sure to wear eye protection. When the water boils, steam will be produced that will jet out of the two nozzles and propel the engine.





Filing produces an opening in the tube through which the steam can pass.

Tip Before using your steam Hero engine, confirm the tubes are not blocked by blowing through them. If air comes out the opposite tube, the engine is safe to use.

Pop Can Hero Engine

Team Member Names:

____

____

____

Design an experiment to find a way to increase the number of rotations the Pop Can Hero Engine makes.

Write your experiment hypothesis below.

____

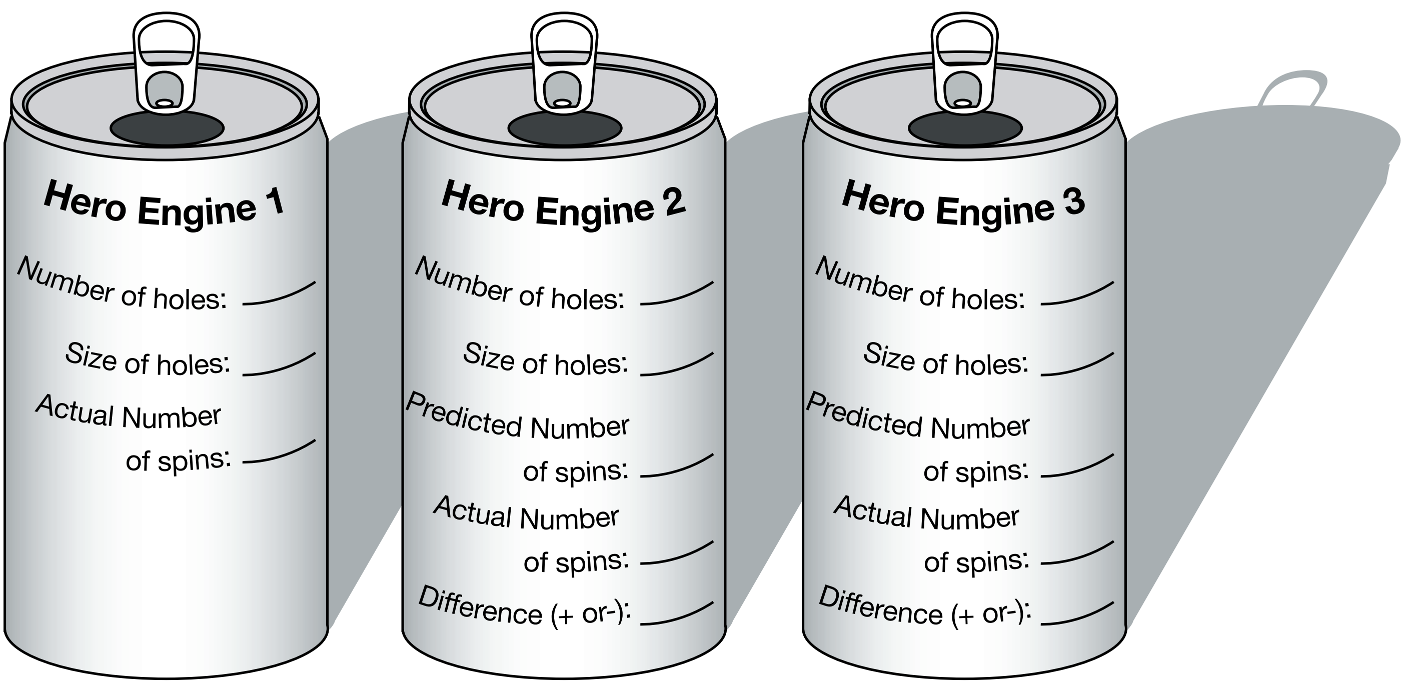
____

Briefly explain your experiment procedures below.

____

____

____



Based on your results, was your hypothesis correct? ____________________

Why?

____

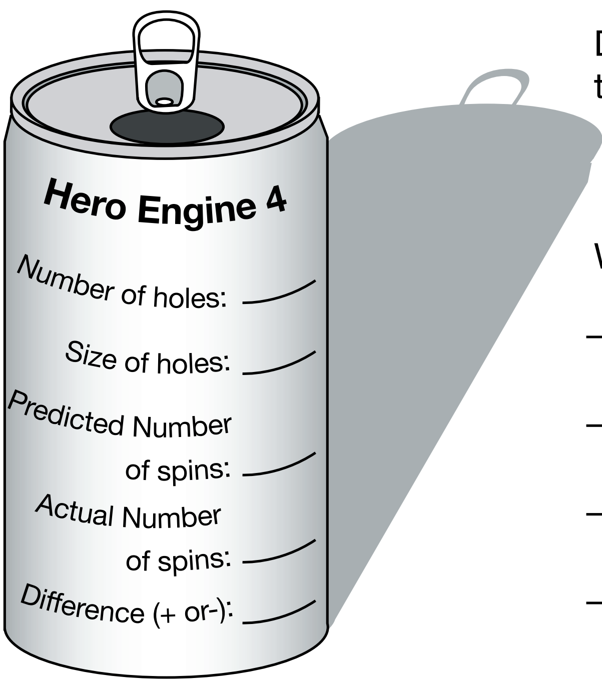
____

Pop Can Hero Engine

Design and build a new Hero Engine that maximizes rotation rate.

What things did you learn from your experiment and the experiments of others for increasing the Hero engine rotation rate?

Briefly describe your new Hero Engine (hole size, number of holes, placement, etc.)



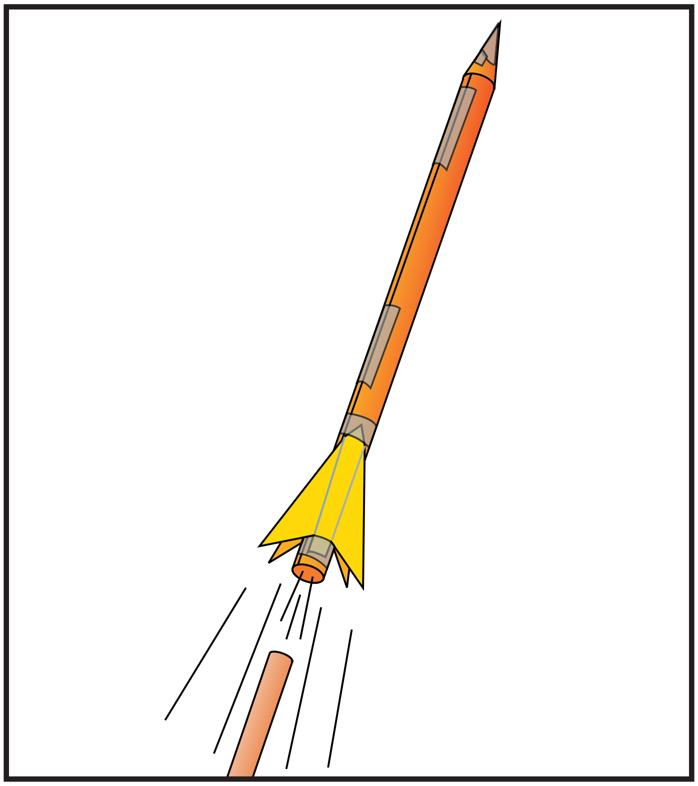
Did your new Hero engine out-perform the original engines you built?

Why or why not?

What did you learn about Newton's laws of motion by building and testing Hero engines?

Rocket Activity

3...2...1...*PUFF!*



National Science Content Standards

Unifying Concepts and Processes

- Evidence, models, and explanation

Science as Inquiry

- Abilities necessary to do scientific inquiry

Physical Science

- Position and motion of objects
- Motions and forces

Science and Technology

- Abilities of technological design

National Mathematics Content Standards

- Number and Operations
- Geometry
- Measurement
- Data Analysis and Probability

National Mathematics Process Standards

- Connections
- Representations

Objective
Students will learn about rocket stability as they construct and fly small paper rockets.

Description
Students will construct small "indoor" paper rockets, determine their flight stability, and launch them by blowing air through a drinking straw.

Materials
Sheet of 8.5 x 11 paper (white or colored)
Cellophane tape
Scissors
Ruler
Meter stick or tape measure
Fat, round pencil or dowel (see tips, p. 43)
Eye protection
Drinking straws
Copy of the *Ares I* paper rocket plans

Management
Hold on to the straws until students have completed their rockets and tested them for stability. Select a clear space for the launches. Depending upon student lung power, rockets may fly 7-10 meters. Be sure students wear eye protection. Although the rockets have little mass, the pointed nose cones could injure eyes. Make sure students understand that the rockets are not to be launched toward anyone.

Background
Rocket stability is an important issue for rocket scientists. The success of a space launch depends upon "pinpoint" accuracy. If a future *Ares I* rocket arrives in space in the wrong orbit, it may not have enough fuel or supplies to make

rendezvousing with the International Space Station possible. The crew would have to return to Earth and "chalk off" a failed mission.

Stability means making sure the rocket follows a smooth path in flight. If it wobbles, the ride will be rough and extra fuel will be burned to get back on course. If it tumbles, it's time to push the destruct button! An unstable rocket is dangerous.

Fortunately, it is relatively easy to ensure stability if two things are kept in mind. These two things are *center of mass* and *center of pressure*.

Center of mass (COM) is easy to demonstrate. It is the balance point of a rocket. Think of it like balancing a meter stick on an outstretched finger. If the stick rests horizontally, the COM is directly over your finger. If the COM is to the right of your finger, the stick will tip to the right. If to the left of your finger, the stick will tip to the left.

An object, tossed into the air, rotates around its COM. Rockets also try to rotate around their COM while in flight. If this rotation is allowed to happen, the rocket becomes unstable. This is where Center of pressure (COP) comes to the rescue.

COP is a balance point too but it has to do with the pressure exerted on the rocket surface by air molecules striking the surface as the rocket flies through the air. Like COM, there is a midpoint for the flight pressure on the rocket body. This is the COP. For a stable rocket, the COP is located to the rear of the rockets and the COM is to the front. To understand why the rocket is stable, let's take a look at a couple of devices that also depend upon the placement of COM and COP.

A weather vane pivots on a vertical axle when the wind blows. One end of the vane is pointed and the other end has a broad surface. When the wind blows, the broad end of the vane catches more air (more air pressure) and is blown down wind. The narrow end of the vane has less pressure exerted on it and points into the wind.

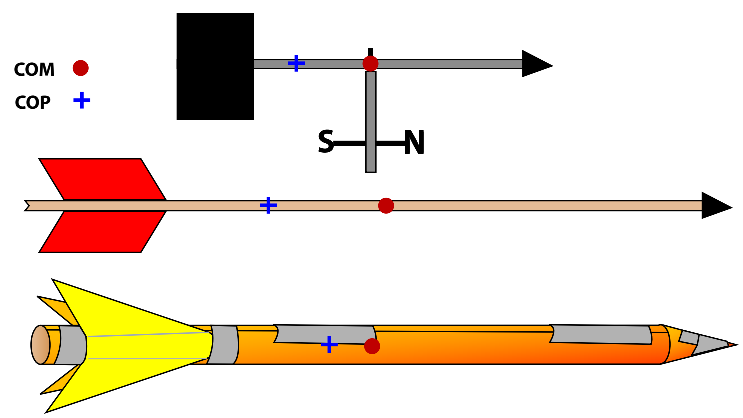
One end of an arrow is long, narrow, and pointed while the other end has large feathers (or modern plastic fins). In flight, greater air pressure is exerted on the feathers than on the narrow end. This keeps the arrow from tumbling around its COM and on course to its target.

In both examples, there was more surface area on one side of the COM than the other. Both devices were stable. Stability of a rocket is the same thing.

In this activity, students will build paper rockets and test them for stability using a drop test. Later activities will further explore the COM/COP concept and employ an advanced string test for rocket stability.

Procedures: First Activity

1. Demonstrate the construction technique for making paper rockets. (Refer to the diagrams on the next page.)
   a. Cut a strip of paper for the rocket body (about 4 cm wide by 28 cm long).



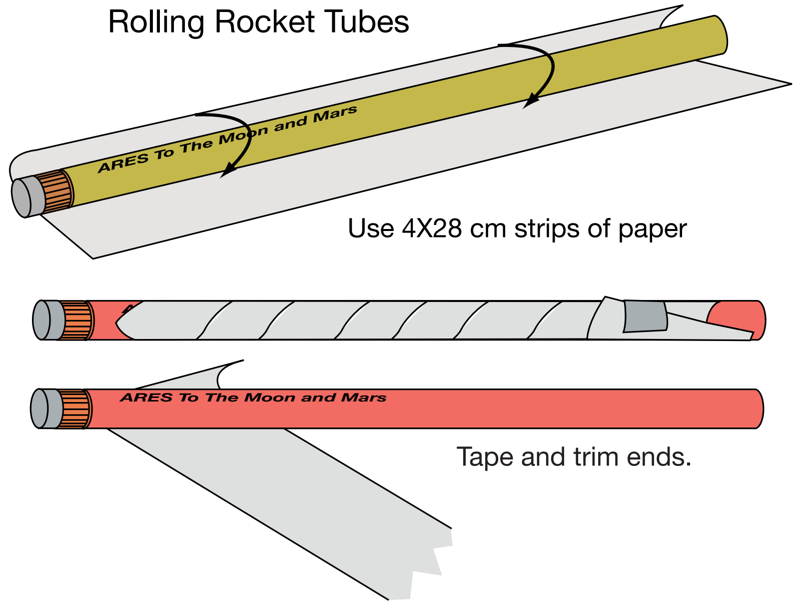
The positions of center of mass (red dot) and center of pressure (blue +) are shown for a weather vane, arrow and a rocket. The center of pressure is to the rear of the center of mass in each device. This enables them to point into the wind.

   b. Use a round pencil as a form and roll the strip around the pencil.
   c. Tape the long seam.
   d. Close off one end to make a nose cone.
   e. Cut out three our four fins.
   f. Tape the fins to the open (lower) end of the rocket. Bend them outward to space them equally.
2. After students have constructed their rockets, show them how to perform drop tests to check for stability. Hold the rocket horizontally at eye level and drop it to the floor. If the nose of the rocket hits the floor first, the rocket is stable and ready for flight.

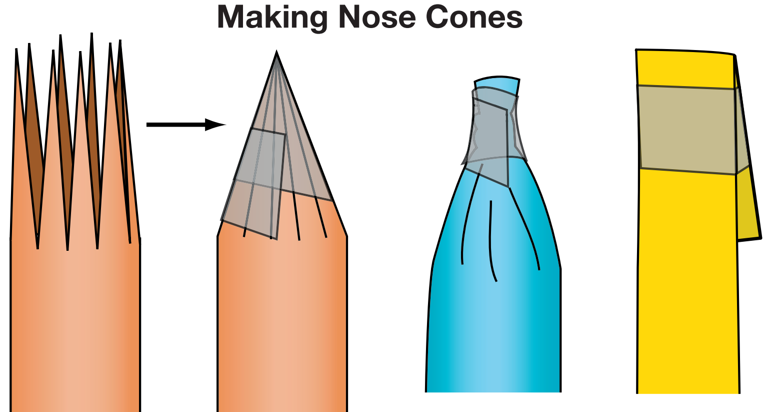
If the rocket falls horizontally or the fin end hits first, the rocket is unstable. Larger fins may be needed to stabilize the rocket. Have students perform their own stability tests and make adjustments to their rockets if needed.

3. Finally, demonstrate the launch procedure for the rocket. Stand at one end of your launch range. Insert a straw into the rocket body. Aim the rocket down range and puff strongly into the straw. Liftoff!
4. Talk over ideas for safety. Discuss wearing safety glasses. Ask students what should be done when they retrieve their rockets for another launch. (Other students should wait until the range is clear before launching.)
5. Have students improve their rocket design by holding distance trials. Students will launch their rocket three times and find the average distance the rocket travels. They will then try to improve their rocket design to get greater distance. The student data sheets outline the procedures and provide space to jot down and analyze data.

Rolling Rocket Tubes

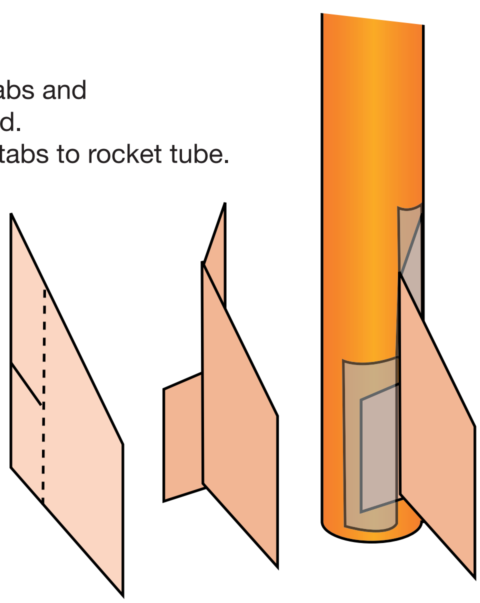


Making Nose Cones

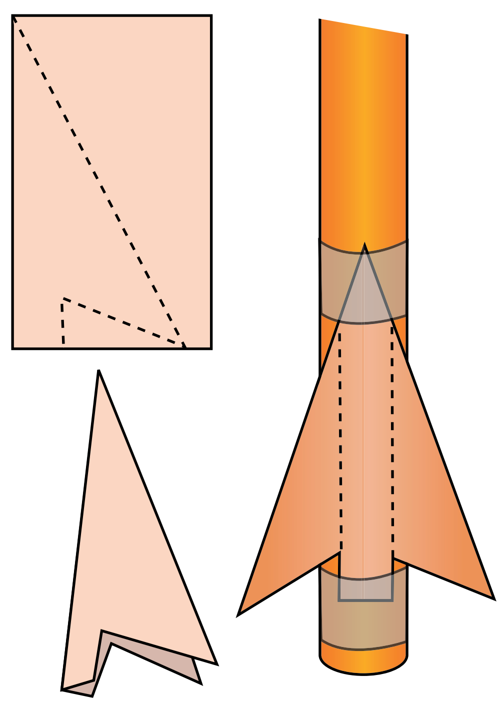


Making and Attaching Fin

Cut tabs and spread.
Tape tabs to rocket tube.



Fold paper square. Cut out fins. Spread fins and tape to rocket tube. Bend fin tips outward.



Procedure Second Activity

1. Give students *Ares I* rockets to assemble. (These rockets do not have any fins. The actual *Ares I* uses steerable rocket engines to keep the rocket stable in flight.) After forming the rocket body, the upper end of the tube is folded four times and taped.
2. Before flying these rockets, have students repeat the stability drop test.

Discussion

- *Why is the* Ares I *rocket stable even though it doesn't have any fins?*
  Folding the paper makes that end of the rocket heavier than the other. Run a balance test with a finger. The balance point (center of mass) is far forward. The center of pressure is to the rear. This combination stabilizes the rocket for flight. The stability control for the paper version of *Ares I* is similar to the control used by the Chinese for their fire arrows (See pictorial history section.) The actual *Ares I* will employ steerable engines to maintain stability.
- *How do paper rockets work?*
  Unlike traditional rockets, paper rockets do not carry their own propellants. Instead, a sharp puff through the straw momentarily fills the rocket tube with "high pressure" air. The tube directs the air back through the opening, producing an action force. The rocket launches because of the equal and opposite reaction force (Newton's third law).

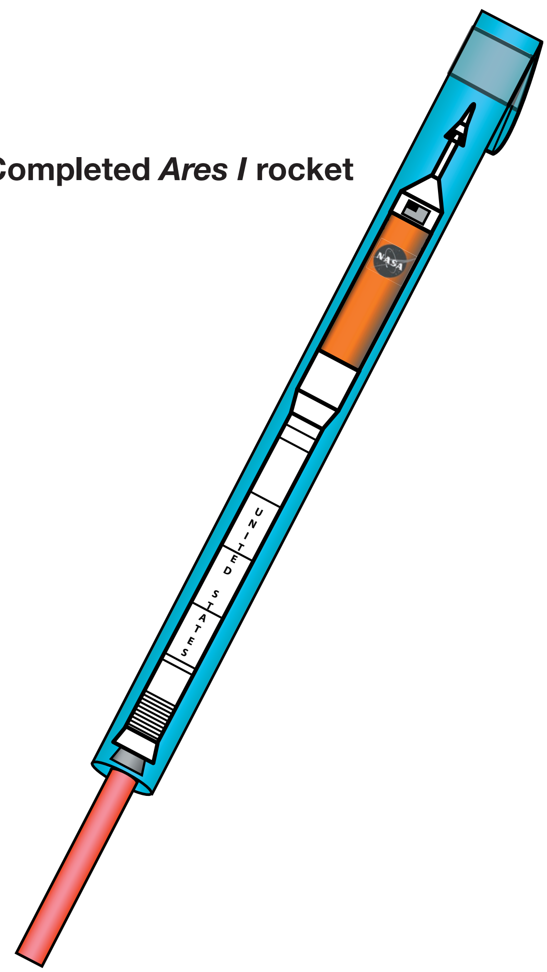
Assessment

- Have students write and illustrate a paragraph that describes their improvements to their rockets and how these improvements affected their experimental results.

Extensions

- Have students investigate fin size and placement for its effect on flight stability. What will happen if the fins are placed at the nose end of the rocket? What will happen if the fin tips are bent pinwheel fashion? (Don't forget to perform drop tests before the actual flights!)
- Hold a rocket flight contest. See whose rocket flies the furthest or whose rocket is the most accurate (make a target).
- In a gym or other room with a high ceiling, launch rockets straight up next to a wall. Have other students estimate the altitudes reached by the rockets. Count the number of concrete blocks the rocket reached and multiply by the height of one block.
- Place a target at the far end of the launch range. An empty box makes a good target and rockets that land within the box are a "bull's eye."

Completed *Ares I* rocket



> **Tip** Segments of a 1/4" or 3/8" dowel can be substituted for fat pencils. Cut the dowels slightly longer than the paper strips. The extra length makes rolling the tubes easier.

Paper Rocket Test Report

Name: ______________________

1. Launch your rocket three times at the same launch angle. Each time, measure how far it flew. Record your measurements in the data sheet below under the space labeled “Rocket 1.” Calculate the average distance for the three flights.

2. *What can you do to improve the distance your rocket travels? Can you think of any improvements for your rocket?* Design and build a new rocket. Predict how far it will fly. Record your answer below in the space labeled “Rocket 2.” Launch your second rocket three times and measure its distance. Record your data below.   What is the difference between your predicted and actual distance? Did Rocket 2 fly farther than Rocket 1? Write your answers below.

3. *Did your changes in the rocket improve its flight?* Design and build a third rocket. Fly it the same way you did for Rockets 1 and 2. Did Rocket 3 fly farther than Rocket 2?

4. On the back of this paper, write a short paragraph describing the improvements you made to your rockets, how well they flew, and what you can conclude from your experiments. Draw pictures to illustrate how each rocket looked.

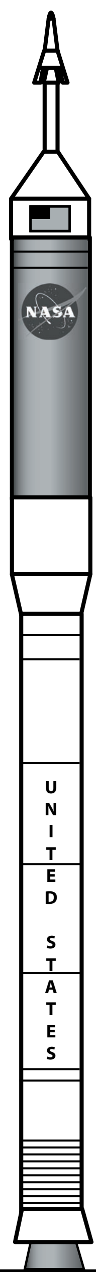
ROCKET 1	Flight Distance (in cm)		
	Flight 1		Make notes about the flights here.
	Flight 2		
	Flight 3		
	Average Distance		

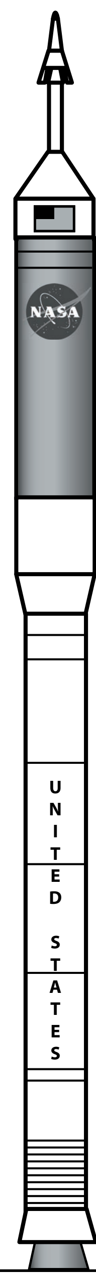
ROCKET 2	Flight Distance (in cm)			
Distance Prediction		Flight 1		Make notes about the flights here.
		Flight 2		
Difference between your prediction and the average flight distance		Flight 3		
		Average Distance		

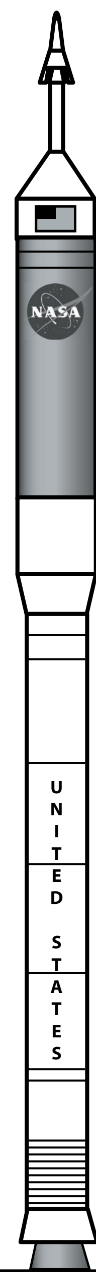
ROCKET 3	Flight Distance (in cm)			
Distance Prediction		Flight 1		Make notes about the flights here.
		Flight 2		
Difference between your prediction and the average flight distance		Flight 3		
		Average Distance		

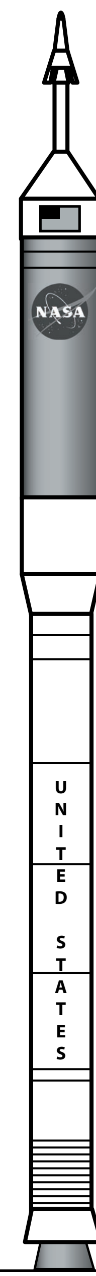
Ares I Paper Rocket Patterns

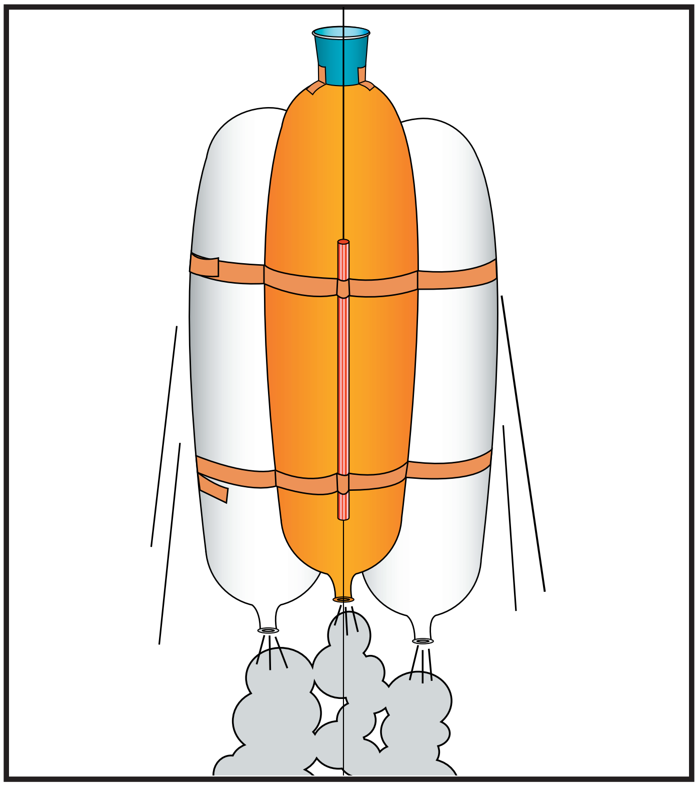
Fold 1	Fold 1	Fold 1	Fold 1
Fold 2	Fold 2	Fold 2	Fold 2
Fold 3	Fold 3	Fold 3	Fold 3
Fold 4	Fold 4	Fold 4	Fold 4











Rocket Activity

Heavy Lifting

Objectives

Students construct balloon-powered rockets to launch the greatest payload possible to the classroom ceiling.

Description

Student teams receive identical parts with which they construct their rockets. Drinking straws guide balloon rockets up strings suspended from the ceiling. Teams compete to launch the greatest number of paper clips to space (ceiling).

National Science Content Standards

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Abilities of technological design

National Mathematics Content Standards
- Number and Operations
- Data Analysis and Probability

National Mathematics Process Standards
- Problem Solving
- Reasoning and Proof
- Communication
- Connections
- Representations

Materials

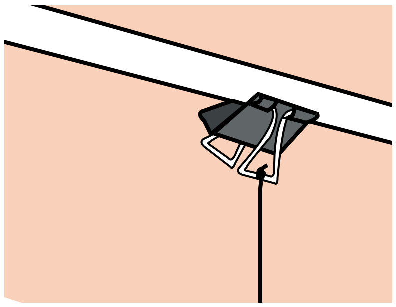
Large binder clips (one per launch pad)
Fishing line or smooth string
Long balloons (see note on next page about sources)
Bathroom size (3 oz) paper cup
2 straight drinking straws
50 small paper clips
Sandwich size plastic bag
Masking tape
Balloon hand pumps (optional)
Wooden spring-type clothespins (optional)

Management

Prepare your classroom by setting up “launch pads” consisting of pieces of fishing line or string suspended from the ceiling (one line per team of students). If your classroom has a suspended ceiling, use binder clips or clothespins to attach to the metal frame supporting the ceiling tiles. Tie the fishing line to the clip or pins. Make sure the line is long enough to reach the floor. Provide open working space around each launch pad.

Explain how the straw is used for guiding the rockets. The fishing line or string is fed through the straw and one or more balloons are attached to it with masking tape. When the balloon is released, the straw will ride up the line. Stress that it is very important for students to hold the lower end of the line to the floor. If there is slack in the line or if the lower end of the line is free, the rocket will waffle about and not reach the ceiling.

If you have balloon pumps, demonstrate how they are used to inflate the balloons.

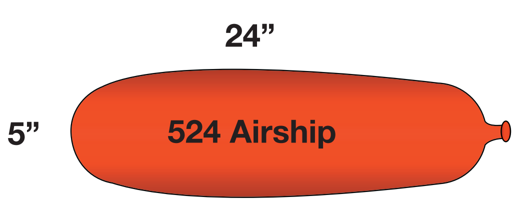


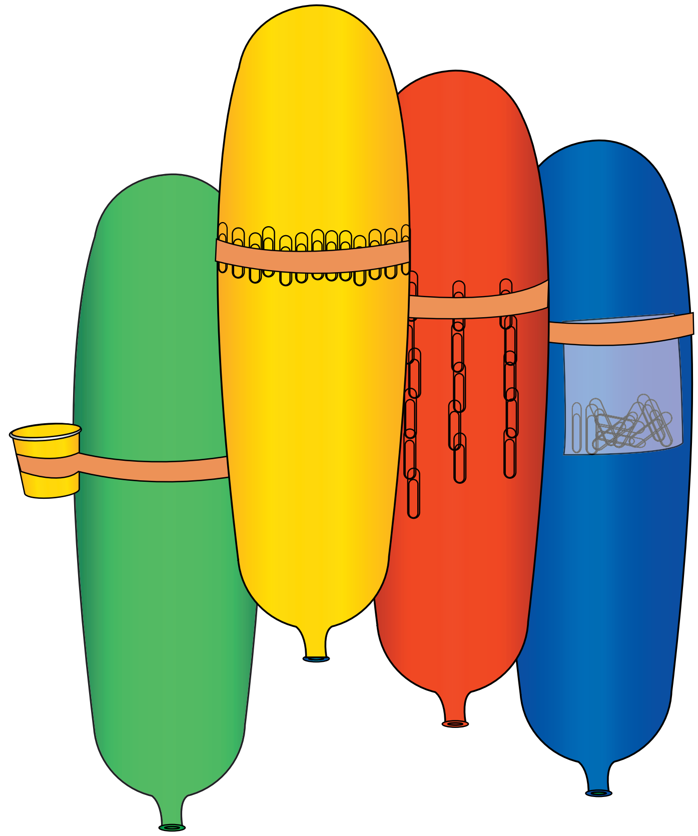
Binder clip attached to ceiling grid.

Avoid providing too much information for the students. This is an exercise in creativity, skill, and problem solving. Simply explain the activity, how to use the straws for stability, and tell them that they can use any or all of the parts in their supply kits to build and fly their rockets. The supply kits contain three balloons. Remind students that they only get three balloons.

Balloon Sources

Many party supply stores carry variety packs that may include long balloons. Ask if they will special order packs of long balloons for you. The balloons become cylinders 5 inches in diameter and 24 inches long when inflated. They are sometimes called 524 (5 by 24 inches) airships. Find manufacturers and distributors by searching "524 balloons" on the Internet.





Some different ways students may devise to carry the paper clips. The plastic bag can be used too. Let teams come up with their own ideas.

Background

NASA's Constellation program for the next generation of space rockets includes a heavy lift launcher called the *Ares V*. (See pages 13-17 for a detailed description of the rocket and pictures). *Ares V* will carry heavy payloads into orbit, such as very large scientific satellites, space station replacement modules and supplies, and Earth departure stages that will propel human spacecraft to the Moon and Mars.

Raising heavy payloads to orbit is challenging. Rockets require powerful engines and massive amounts of propellants. NASA's *Ares V* will be able to accomplish the job. It will be one of the largest and most powerful rockets ever built. However, *Ares V* won't be the only heavy lift vehicle needed. There will be a market for commercial delivery of propellants and modules and robots for constructing tourist hotels, supply delivery, and more. In the future, heavy lift vehicles will become (excuse the expression) a "booming business."

Procedure

1. Divide your students into teams of three. Explain the project to them.

   "NASA is looking for creative ideas for launching heavy payloads into orbit. Payloads include parts and supplies for the International Space Station and spacecraft that will carry humans to the Moon and Mars. NASA is also interested in rockets that can transport large fuel tanks that will be used to power deep space rockets. You are challenged to build the most efficient heavy-lift rocket from the same set of materials. The team that is able to lift the greatest payload into space (the ceiling) is the winner."

2. Provide each team with an identical kit of materials. Tell them that any or all of these materials can be used for their rockets.
3. Review the launching procedure. Explain how the straw guides the rocket up the fishing line or string and that the line must be held snug to the floor for the launch. Remind the teams that they only get three balloons. They can launch as many times as they want to but should try to improve how many paper clips they can successfully lift.
4. Draw a chart on the board for teams to record their results (i.e., the number of paper clips that reach the ceiling).

> **Tip** If you wish to do so, provide one extra balloon to each team as a replacement in case of a mishap (pop!) or as a fourth rocket for their cluster. Make a small coupon for the extra balloon and put it in the parts bag. The coupons will help you keep track of which teams have already requested an extra balloon.

Discussion

- *Why is NASA supportive of commercial space companies?*
  NASA's space efforts are aimed at expanding our horizons in space. Although their space rockets are easily capable of launching communications, weather, and Earth resources satellites, NASA continually looks beyond. NASA explores, and when it pioneers a new technology, it seeks to turn over continued development to U.S. commercial interests. That way, NASA can focus on and advance to the next new horizon. NASA's current new horizons include the first permanent bases on the Moon and the first human expeditions to Mars. These are demanding challenges. When they are met, commercial space companies will follow, permitting NASA to move on to even greater challenges.

- *Why is it important to construct efficient heavy-lift vehicles?*
  Traveling into space is a very difficult and expensive endeavor. Huge rockets and tremendous amounts of propellants are required to accomplish the job. With some rockets, launch costs were approximately $20,000 per kilogram of payload delivered into Earth orbit. If that cost were to continue, imagine staying at a space hotel where it would cost about $10,000 for a half liter bottle of drinking water! Improving heavy-lift rockets (lighter rocket structures, more propellant efficient engines, etc.) will enable us to accomplish much more in space at far more reasonable costs!

> **Tip** Occasionally, a balloon will have a tiny pinhole that will prevent it from being inflated or from holding air very long. Keep a small supply of replacement balloons.

Assessment

- Have each team describe their design to the class.

  How many balloons did they use?
  How many paperclips did their rocket carry to the ceiling?
  How did they attach the paperclips to the balloon?
  What problems did they encounter? How did they solve those problems?

- Write a summary of your launch vehicle using correct science and technology terms (e.g., lift, payload, mass, thrust).

Extensions

- Challenge students to design a two-stage rocket. The lower balloon "fires" before the upper balloon. The upper balloon carries the payload to the ceiling.

Heavy Lift Rocket Mission Report

Team Member Names: ____________________
____
____

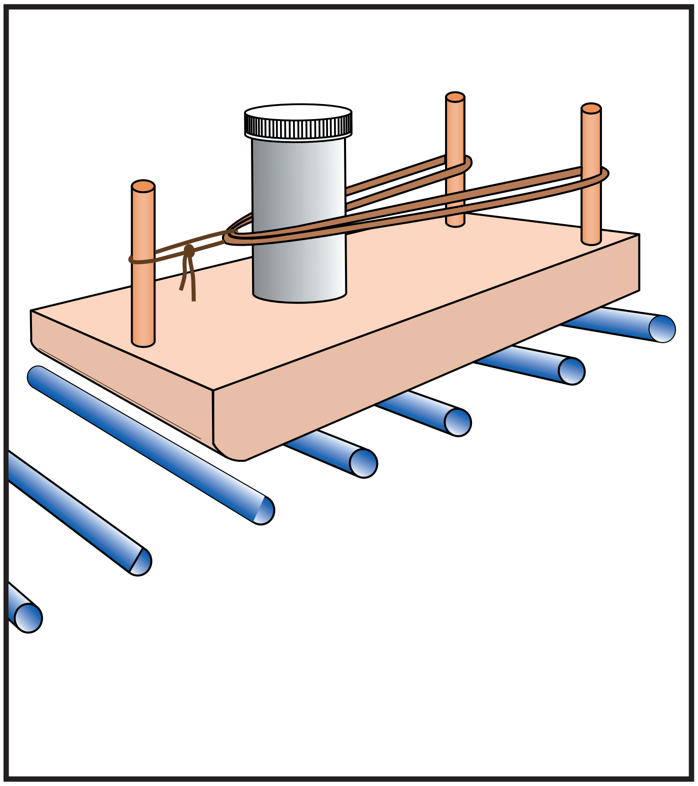
Make a sketch of your best rocket

Flight Test	Predict How Much Mass Your Rocket Will Lift 1 paper clip = 2gm	Actual Mass Lifted
1.		
2.		
3.		
4.		
5.		

Describe your first rocket.

How did you change your rocket to make it carry more mass?

What other ways could you change your rocket to improve it?



Rocket Activity

Newton Car

Objective

To investigate the relationship between mass, acceleration, and force as described in Newton's second law of motion.

Description

Small student teams use a wooden car and rubber bands to toss a small mass off the car. The car, resting on rollers, will be propelled in the opposite direction. During a set of experiments, students will vary the mass being tossed from the car and change the number of rubber bands used to toss the mass. Students will measure how far the car rolls in response to the action force generated.

National Science Content Standards:

Unifying Concepts and Processes
- Evidence, models, and explanation
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces
- Properties of objects and materials

Science and Technology
- Understanding about science and technology

National Mathematics Content Standards:
- Number and Operations
- Measurement
- Data Analysis and Probability

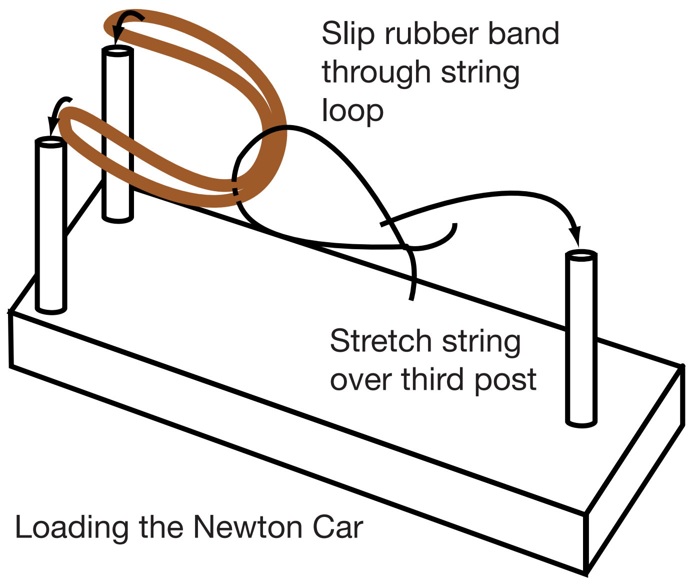
National Mathematics Process Standards:
- Problem Solving
- Reasoning and Proof
- Communication
- Connections
- Representations

Materials

Newton Cars (see separate instructions)
Cotton string
Two rubber bands (size 19)
Medicine bottles (see Tip)
25 straight drinking straws (not flexi)
Meter stick or ruler
Metric beam balance or scale
Scissors or lighters (see Management below)
Popcorn seeds, washers, pennies, marbles, paper clips, etc. (for filling the bottles)
Safety goggles

Management

This activity requires a smooth floor or long tables for a rolling surface. Be sure teams understand how to set up the car and are consistent in their placement of straws. Demonstrate the "loading" of the car. After attaching the rubber band and string to the car, press the bottle into the "V" of the rubber bands. This process must be done the same way each time. Also demonstrate the string cutting process. The string must be cut and the



Loading the Newton Car

scissors moved out of the way in one smooth and quick movement. Lighters can also be used for burning through the string. Have students light the ends of the string dangling down from the knot. The flame will climb up the strings and burn through the knot. Students must wear eye protection with either string cutting technique.

Background

Although the purpose of the Newton Car is to investigate Newton's second law of motion, it provides an excellent demonstration of all three laws. The car is a slingshot-like device. Rubber bands are stretched between two posts and held with a string loop ringing a third post. A bottle, holding various materials that can be changed to vary its mass, is placed between the stretched rubber bands. When the string is cut, the bottle is tossed off the car and the car travels the other way on straw rollers.

Newton's first law is demonstrated by the act of exerting a force. The car remains at rest until the mass is expelled, producing a force. The car then moves. The action force exerted on the car produces an equal and opposite reaction force. The car moves the other way from the tossed bottle. This demonstrates Newton's third law.

How far the car moves demonstrates the second law. The magnitude of the force is determined by how much mass is tossed and how fast it is accelerated off the car.

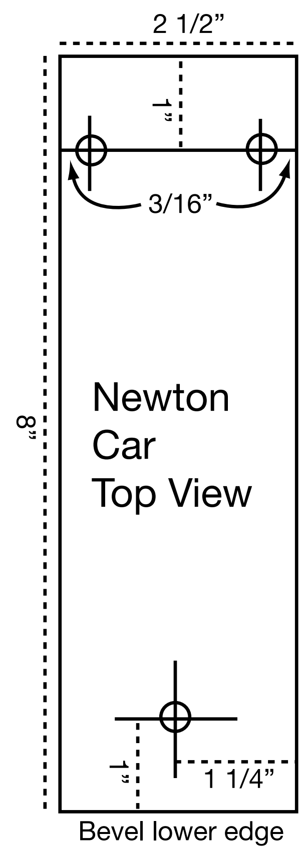
By varying the mass and the number of rubber bands, students are able to see a visual demonstration of the relationship of mass and acceleration on force. The greater the mass of the bottle and its contents and the greater the acceleration (more rubber bands), the greater the force. The effect is that the car will travel further in the opposite direction. (Refer to pages 19-23 for a more detailed explanation of Newton's laws of motion.)

Procedure Making Newton Cars

Materials

1 1 X 3 X 8 inch board*
3 1/4" diameter by 2 1/2" long dowels (or wood screws)
Wood glue

1. Cut the board into 12 8" lengths. (Optional: Bevel one edge as shown on the previous page.)
2. Drill three 1/4" holes 3/8" deep for the dowels. If using screws for posts instead of dowels, skip Step 3.
3. Glue the dowels into the holes. If desired, bevel the upper end of the dowels with sand paper.



* Note: Dimensions of lumber are based on rough cuts. When planed, thickness and width are smaller. A 1X3" board is actually 0.75 by 2.5 inches.

Procedure The Experiment

1. Provide student teams with the instruction sheet on how to set up the Newton Car and the data sheet.
2. Clear areas for each team to set up their experiment.
3. Provide a station where teams can fill their bottles with different materials to change their total mass. Place the popcorn seeds, washers, etc., in different bowls for easy access. The bottles do not have to be filled to the top. However, the rubber bands should be positioned around the approximate center of mass of the bottle to get a uniform toss.
4. Check each team to ensure they are being consistent in their procedures. For instance, placing straws differently for each test would introduce a new variable into the experiment that could affect the results.

> **Tip:** Provide masking tape so that students can use small tape pieces to mark the positions of the straws for consistency.

Discussion

- *How does adding additional rubber bands change the acceleration?*

Like all matter, the bottle has inertia, which is the property of resistance to change in motion. Newton's first law of motion is often referred to as the law of inertia. A force is needed to change the motion of the bottle. In this experiment the inertia of the bottle retards the contraction of the rubber band. Two rubber bands, working together, are able to contract more rapidly and consequently are able to impart a greater acceleration to the bottle.

> **Tip:** Ask a pharmacist for a donation of new, 8-dram-size medicine bottles.

Assessment

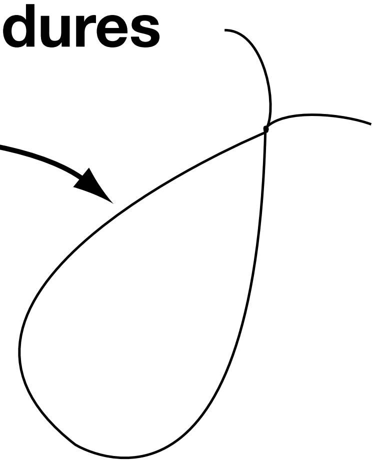
- Review the experiment report for completeness and check team statements, explaining the relationship between mass, acceleration, and the distances the Newton Cars traveled.
- Ask students for other examples of Newton's laws of motion at work.

Extensions

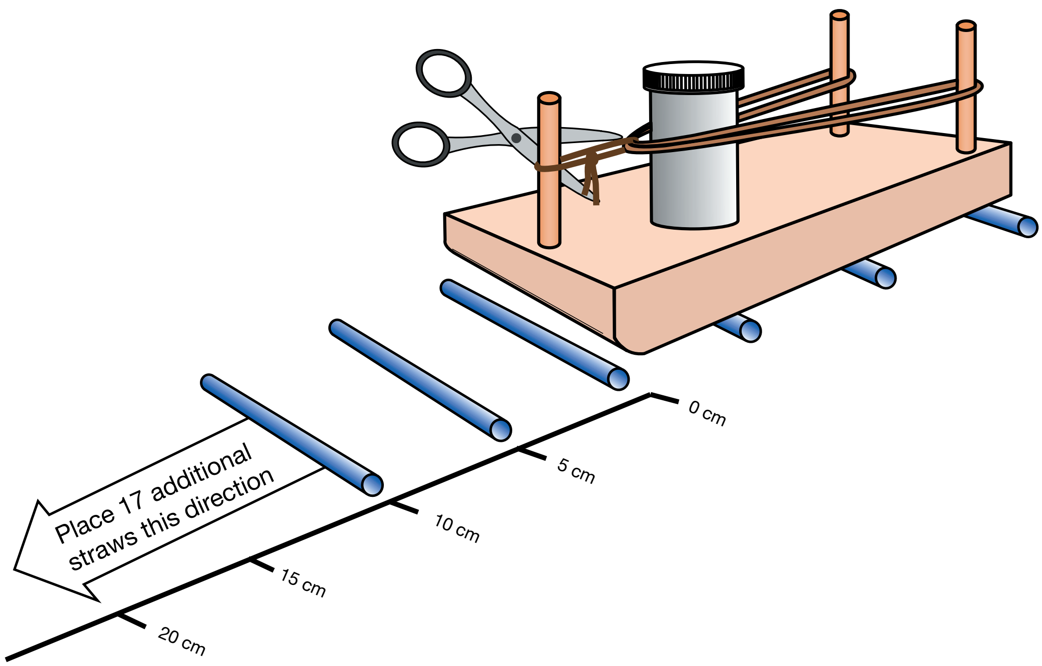
- Newton's second law of motion can also be demonstrated using a water rocket. Vary the pressure in the water rocket by using different numbers of pumps. Vary the amount of water inside the bottle. Changes in mass and acceleration will affect the performance of the rocket in flight.

Newton Car Experiment Procedures

1. Tie six string loops approximately this size.



2. Fill the plastic bottle with small weights provided by your teacher. Measure the mass of the filled bottle and record the amount on your data sheet for test 1.
3. Set up your Newton Car as shown in the picture. Slide the rubber band through the first string loop. Slip the ends of the rubber band over the two posts. Pull the string back to stretch the rubber bands, and slip the loop over the third post to hold the loop.



4. Lay the straws on a smooth floor or tabletop. Place them like railroad ties 5 centimeters apart. Put the Newton Car on top of the straws at one end of the line.
5. Using the scissors, cut the string. Quickly move the scissors out of the way! The rubber band will toss the bottle off the Newton Car while the car rolls the other way on the straws.
6. Measure how far the Newton Car moved and record the distance on the data sheet.
7. Repeat the experiment using two rubber bands. Be sure to set up the straws and place the Newton Car on them exactly as before. Record your data.
8. Put different weights in the bottle and measure its mass. Record the mass and repeat the experiment with one and two rubber bands. Record your data.
9. Once more, put different weights in the bottle and measure its mass. Record the mass and repeat the experiment with one and two rubber bands. Record your data.
10. Answer the questions on the data sheet and write a general statement about the relationship between the mass and number of rubber bands used and the distance the Newton Car travels.

Newton Car Experiment Report

Team Members: ____________________

____

____

	Mass of Bottle	Number of Rubber Bands	Distance Car Traveled
Test 1		1	
		2	
Test 2		1	
		2	
Test 3		1	
		2	

Did the number of rubber bands affect how far the Newton Car moved? Describe what happened.

____

____

____

____

____

Did the mass of the bottle affect how far the Newton Car moved? Describe what happened.

____

____

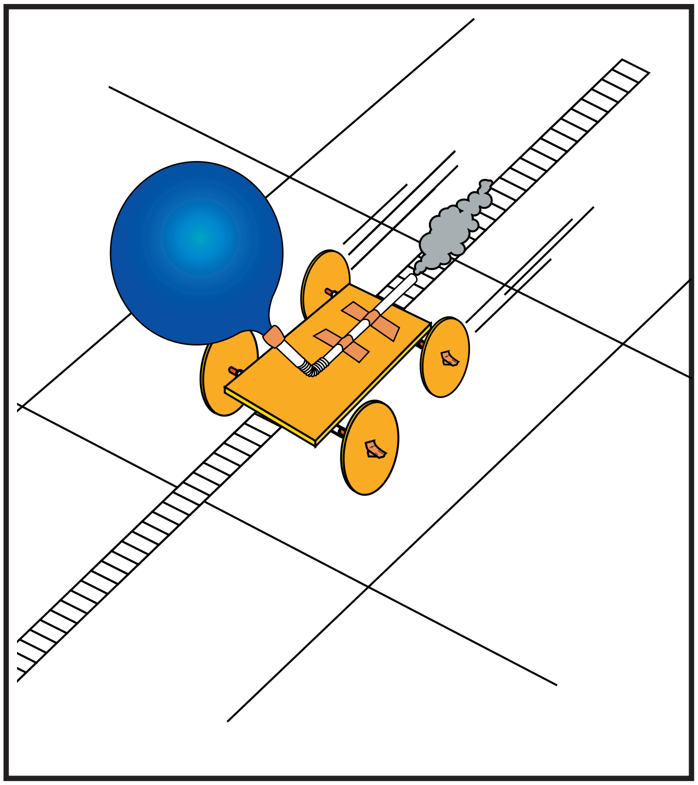
Construct a bar graph showing how far the Newton Car moved for each test.

Test 1 (1)																				
(2)																				
Test 2 (1)																				
(2)																				
Test 3 (1)																				
(2)																				

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

Centimeters Traveled

On the back of this page write a short statement explaining the relationship between the amount of mass in the bottle, the number of rubber bands used, and the distance the Newton Car traveled.



Rocket Activity

Rocket Races

Objective
Students investigate Newton's third law of motion by designing and constructing rocket-powered racing cars.

Description
Individual students construct racing cars from Styrofoam food trays and power them with the thrust of an inflated balloon. In three racing trials, the racers shoot along a straight course, and the distance the racers travel is measured. Between trials, students redesign their racers to improve their performance and solve any "mechanical" problems that crop up. At the conclusion of the activity, students submit a detailed report on their racer design and how it performed in the trials.

Materials
Styrofoam food trays (ask for donations from local supermarkets)
Small plastic stirrer straws (round cross section) - 2 per racer
Flexi-straws - 3 per racer
4- or 5-inch round balloon
Masking tape
Sharp pencil
Scissors (optional)
Ruler
Meter stick or metric measuring tape for laying out race course
Sandpaper (optional)

Management
Each student will need a Styrofoam food tray. Request donations from your local supermarket. Ask for thicker trays (about 3/16" thick). Yellow trays used for poultry work well. Waffle-bottom trays are acceptable. Although the trays can be cut using scissors, save the scissors

National Science Content Standards
Unifying Concepts and Processes
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Abilities of technological design

National Mathematics Content Standards
- Number and Operations
- Geometry
- Measurement
- Data Analysis and Probability

National Mathematics Process Standards
- Problem Solving
- Reasoning and Proof
- Communication
- Connections
- Representations

for trimming. It is much easier to score the Styrofoam with a sharp pencil and then break away the pieces. Score lines can be continuous or the tip of the pencil can be punched into the Styrofoam to make a dotted line. Demonstrate the scoring process to your students. After the pieces are broken out, the edges are smoothed. Wheels can be smoothed by rolling them on a hard surface while applying pressure. Sandpaper can also be used for smoothing.

Lay out a race course in a large open space or hallway. The space can be carpeted, but textured carpets interfere with the movements of the racers. Stretch out a 10 meter-long line of masking tape and mark 10-centimeter intervals. If you have a 10 meter tape measure, just tape it to the floor.

Double check the taping of the balloon to the straw. The balloon should be completely sealed, or it will be difficult to inflate, and some of its thrust will be lost through the leaks. Pre-inflating the balloon will loosen it and make it easier to inflate through the straw.

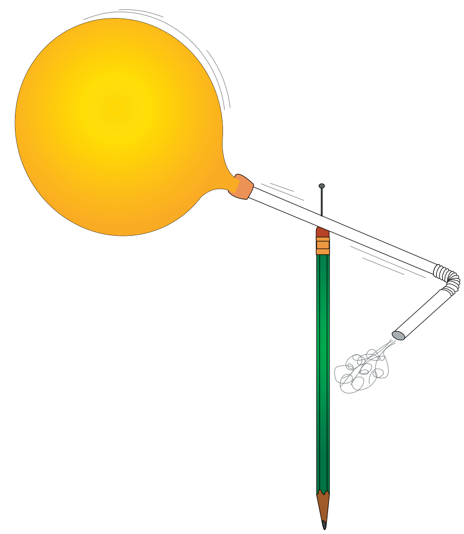
Guide students through the redesign process to improve their racers. If their racers are not running well, ask them what they think the problem is. Then, ask them what they can do about it. Typical problems include having wheels too tight to the sides of the cars (friction), wheels or axles mounted crooked (racer curves off course), and axles not mounted in center of wheel or wheels not round (like "clown car" wheels).

Background

The rocket racer is an excellent demonstration of Newton's third law of motion. Air is compressed inside a balloon that is expanded. When the nossle is released, the balloon returns to its original uninflated size by propelling the air out its nozzle. The straw mounted to the balloon extends the nozzle beyond the rear end of the car. The action force of the expelling air produces a reaction force that pushes the racer in the opposite direction. The racer's wheels reduce friction with the floor, and the racer takes off down the race course.

Although the rocket racer seems simple, there are many challenging complexities in its operation. In principle (Newton's second law of motion), the less mass the car has, the greater its acceleration will be. Generally, heavy rocket racers do less well than lighter racers. However, very small racers are limited by other factors. Vehicles with short wheel bases tend to circle or partially lift off the floor. Balance becomes a problem. The mass of the balloon may cause the car to tilt nose down to the floor, causing a poor start.

The engineering design of the racer is very important. Many designs are possible, including wide, narrow, and I-beam shaped bodies and three, four, or even six wheels.



Demonstrate the action-reaction principle by inserting a pin through the straw and into a pencil eraser. Inflate the balloon, and it will pinwheel around the pencil as air rushes out. Compare this to the straight thrust produced by the balloon in the rocket cars.

Students will have to review the trade-offs of their design. For example, an extra-long body may provide a straighter path, but the car might travel a shorter distance as a result.

Procedure

1. Explain the activity to the students. Provide them with the How To Build A Rocket Racer Sheet. Go over the construction steps and demonstrate how to snap out parts, mount the wheels, and attach the straw to the balloon.

2. Stress that the racer shown in the instructions is a basic racer. Many designs are possible. Have them think up their own designs.
3. Review the Rocket Racer Data Sheet and make sure students know how to fill out the graphs and what data they should collect.
4. Distribute materials and lay out the racer course.
5. When student racers are ready, have one or two students at a time inflate their balloons and pinch off the end of the straw to keep the air inside. Have them place their racers just behind the starting line and release the straws. Regardless of how much curving a racer does, the measured distance is how far along the straight line of the race course the car reached.
6. Post distance records to motivate students to modify their racers to set new records.
7. After each racer runs three times, have students complete their data sheets and sketch their final design on the design sheets.

Discussion

- *Would it be a good idea for automobiles to be powered by rocket engines?*
  If there was only one rocket powered automobile on the road, it would work fine. However, imagine rush hour traffic loaded with rocket cars. Each would blow exhaust gas at the vehicles to the rear.
- *How are the wheels on a rocket racer similar to and different from wheels on a regular automobile?*
  Rocket racer wheels reduce friction with the ground. They turn when the air coming from the balloon exerts a thrust. Wheels for an automobile also permit the car to roll across the ground, but the thrust of an automobile depends upon friction. The engine turns the wheels, and friction with the rubber and the pavement transmits the action force so that the car rolls forward.

Assessment

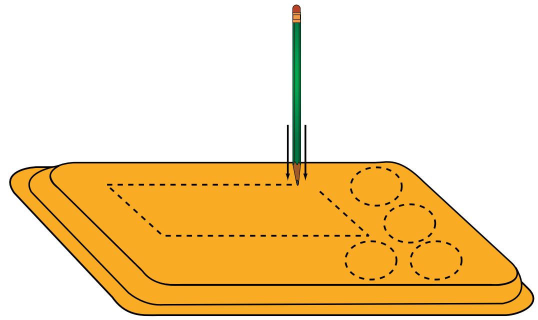
- Review student Rocket Racer Data Sheets and Design Sheets.
- Have students write an explanation of Newton's third law of motion using their rocket racers as examples.

Extensions

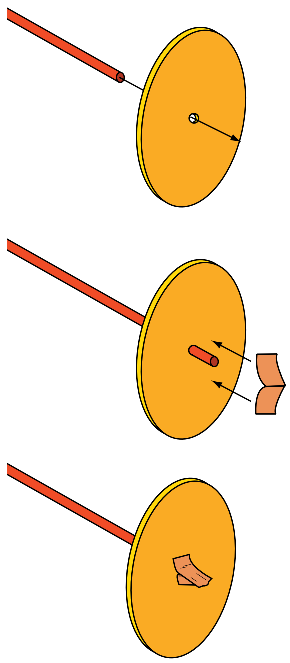
- Hold Rocket Racer drag races. Lay out a 3-meter-long course. The fastest car is the one that crosses the finish line first. Calculate racer average speed by timing start to finish with a stopwatch (e.g., four seconds to go three meters = 0.75 m/second or 2.7 km/h).
- Have students try multiple balloons for additional thrust. How will students design cars that are balanced with the extra load?
- Have students control the thrust of their balloons by inflating them to the same diameter each time. How can students ensure that the balloon is always the same?
- Using the same materials, what other devices can be created that demonstrate the action-reaction principle of Newton's third law of motion?

How to Build a Rocket Racer

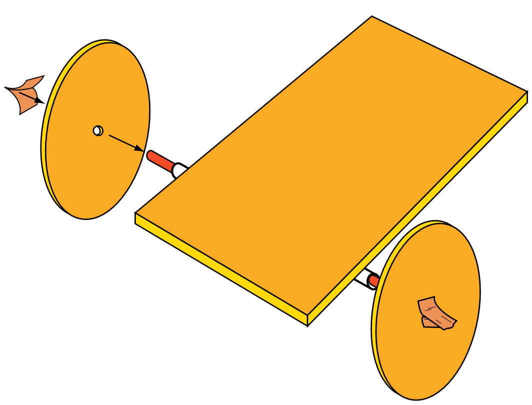
1. Lay out your pattern on the Styrofoam tray. You will need a racer body and wheels. Use a pencil point to score the Styrofoam. Snap out your pieces and smooth them. Make sure your wheels are round! Use sandpaper to round the wheels OR press them on a hard surface and roll them.



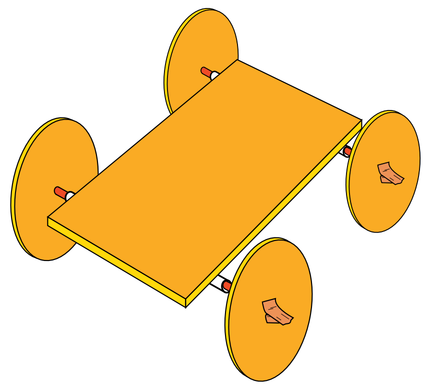
2. Punch a small hole in the center of each wheel with the pencil. Push the axle (stirrer) straw through the hole of one wheel so that it extends 1 cm on the other side. Pinch a piece of masking tape around the end of the straw and smooth it on to the wheel. Do the same for the second axle. Do not add wheels to the other ends yet!



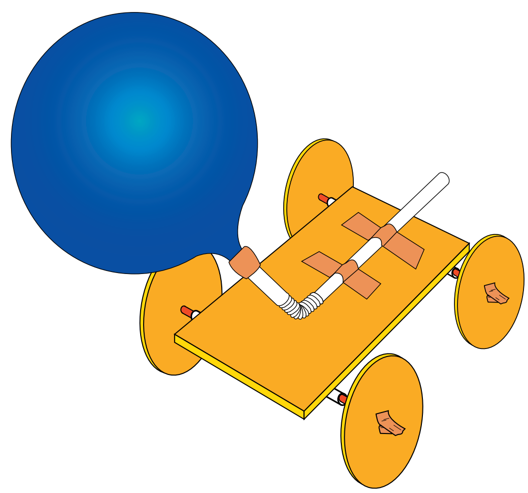
3. Cut two large straws to the size you want. Tape them parallel to each other on the bottom of the racer body at opposite ends. Slide a wheel and axel through one of the straws and mount a second wheel on the other end of the axle.



4. Slide the second wheel and axle through the remaining straw and mount the remaining wheel at its opposite end.



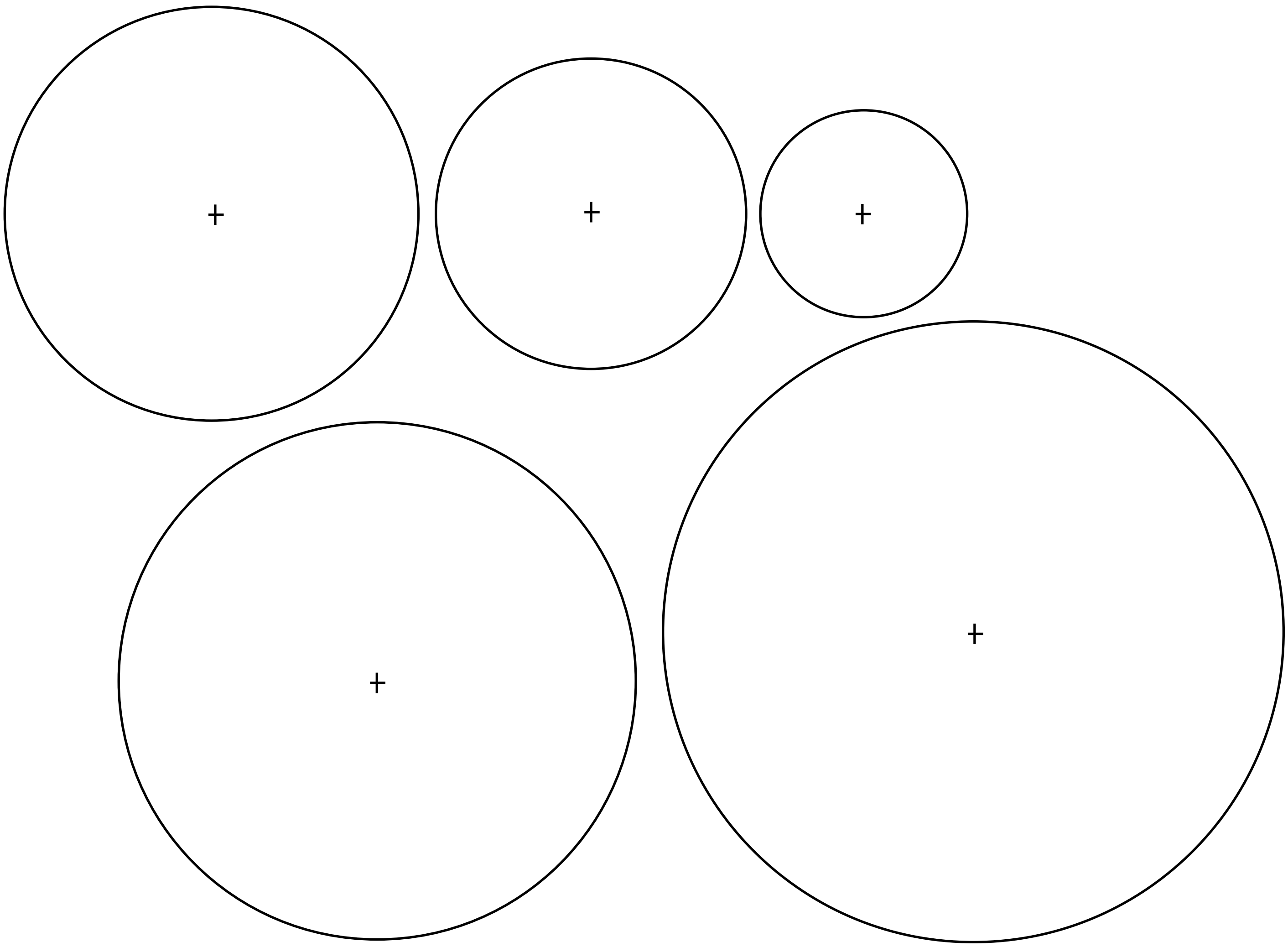
5. Blow up the balloon and then let the air out. Next, slip the straw into the balloon as shown. Use masking tape to seal the balloon nozzle to the straw. Squeeze the tape tightly to seal all holes. Test the seal by blowing up the balloon again through the straw.



6. Mount the balloon and straw to the racer with masking tape as shown. Be sure the end of the straw (rocket nozzle) extends off the end of the racer body.

Wheel Patterns

Cut out the desired wheel size. Trace the wheel outline on the Styrofoam. Punch the pencil point through the cross to mark the center.



Name: ____________________

Rocket Racer Design Sheet

Draw a diagram showing your best design for a rocket racer.

Show your racer as seen from the front, top, and side.

Each square on the graphs = 1cm.

TOP VIEW

FRONT VIEW

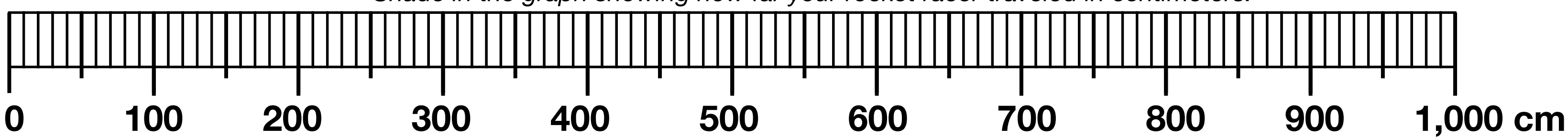
SIDE VIEW

Rocket Racer Data Sheet

Name: ____________________________

Shade in the graph showing how far your rocket racer traveled in centimeters.

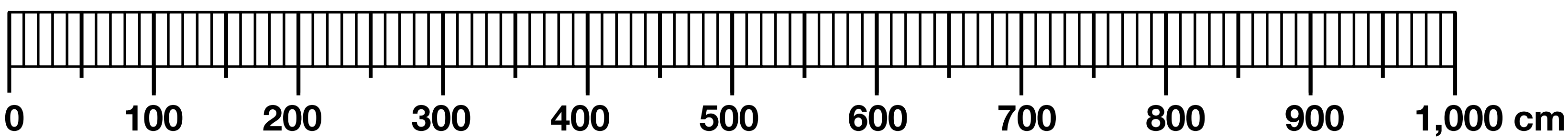
Rocket Racer Trial #1



Describe how your rocket racer ran (straight, curved, circles, stuck, etc.).

Did your racer perform as well as you hoped? Explain why or why not.

Rocket Racer Trial #2



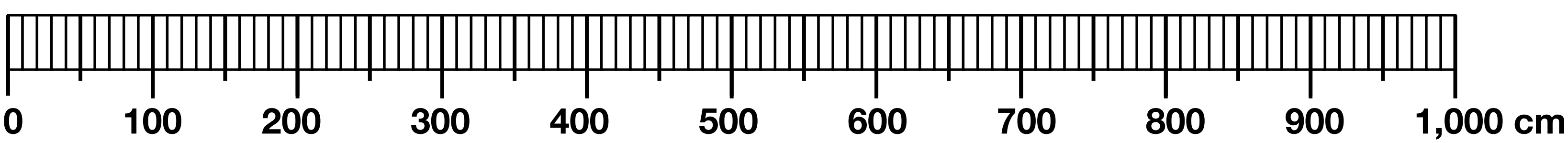
How did you improve your rocket racer?

Predict how far your racer will run. ___________ cm

Describe how your rocket racer ran.

Did your improvements work? Explain why or why not.

Rocket Racer Trial #3

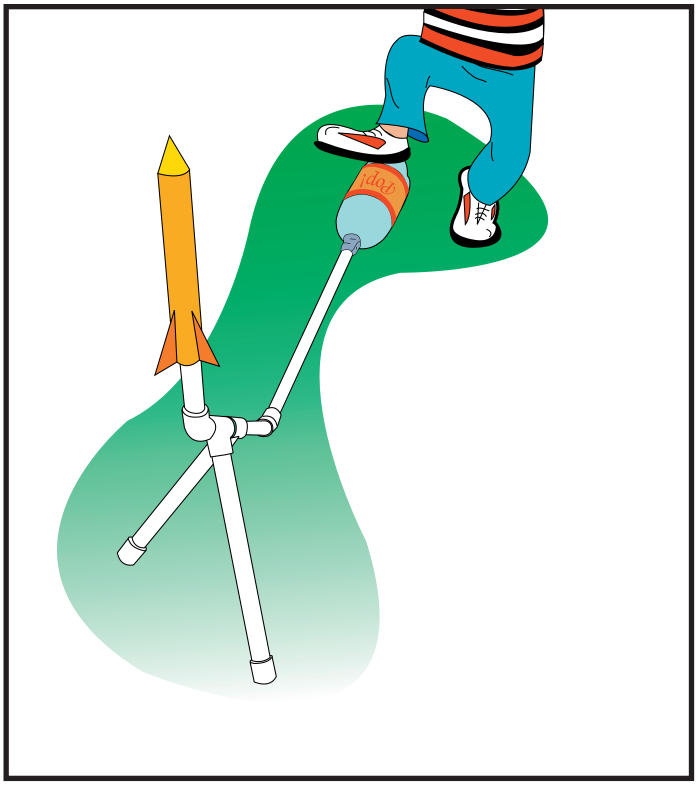


How did you improve your rocket racer?

Predict how far your racer will run. ___________ cm

Describe how your rocket racer ran.

Did your improvements work? Explain why or why not.



Rocket Activity

Pop! Rocket Launcher

Objective
To construct a simple air pressure launcher for paper rockets.

Description
Students stomp or jump on an empty 2-liter soft drink ("pop") bottle and force the air inside through connected plastic pipes to propel a paper rocket.

National Science Content Standards
Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Abilities of technological design

National Mathematics Content Standards
- Measurement

National Mathematics Process Standards
- Connections

Materials
Empty (and rinsed) 2-liter plastic soft drink bottle
2 1/2" PVC tee connectors
2 1/2" PVC 45 degree elbows
2 1/2" PVC caps
1- 5' length of 1/2" PVC pipe
Duct tape
Ruler
Balloon or basketball hand pump
Rubber stopper or cork (#1 size, 1 hole)
Eye protection for anyone near launcher

Management
The Pop! Rocket Launcher, although fun for all students, is an ideal launcher for younger students because they love to stomp on the bottle to launch the rocket. The launcher can be used for any kind of large paper rocket, including the high-power paper rockets described on page 91. However, the Pop! Rockets described in the activity starting on page 66 are well-suited for this group of students because of their relatively easy construction.

Take the shopping list on the next page to the hardware store to obtain the PVC parts. The PVC pipe will be cut into smaller pieces. Use a fine-tooth saw or a PVC cutter (available from the hardware store). The PVC parts do not have to be cemented together. Friction will hold the parts with occasional adjustment. Leave the label on the bottle. This gives students a target to aim for when stomping. If the ends of the bottle are accidentally squashed, the bottle becomes difficult to reinflate and has to be replaced. If you prefer to remove the label, use a marker and draw a bull's-eye on the side of the bottle.

The PVC legs are of different lengths. The leg nearest the bottle is the shortest. Angling the legs to the sides results in a tripod arrangement that supports the launch tube (the part the paper rocket slips over for launch (part #11). The launch tube can be aimed at different angles by tilting to one side or another. Rotating the entire launcher horizontally changes its direction.

When using the launcher, place it in an open space. It can be used inside a gymnasium or cafeteria. If using inside, aim the launch tube at a low angle towards a far wall. Select a target to aim for. If using outside (choose a calm day), the launcher should be aimed at a clear area. For fun, place a basketball in the landing zone. Tell students to imagine the ball is the planet Mars (it's the right color!) and have them launch their rocket to Mars.

Make sure the student doing the launching and any other students near the launcher are wearing eye protection. Do not permit any students to stand in front of the launcher or in the landing zone while "launch operations" are taking place.

Procedure

1. Cut the PVC pipe into the following lengths:

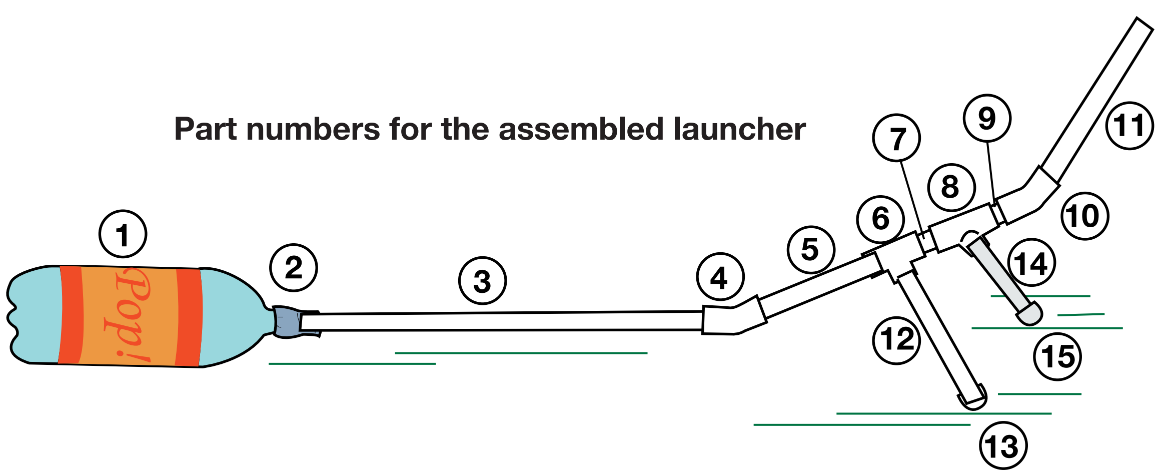
   #3 - 50 cm
   #5 -18 cm
   #7 - 4 cm
   #9 - 4 cm
   #11 - 25 cm
   #12 - 20 cm
   #14 - 25 cm

   The part numbers indicate where each piece is placed in the assembled launcher diagram below.
2. Insert the end of pipe #3 into the neck of the bottle and tape it securely with duct tape.
3. Follow the construction diagram below for assembly of the launcher. Match the pipe lengths with the parts numbers.
4. Swing the two legs outward or inward until each touches the ground to form the tripod. The launcher is ready for use.
5. Insert the inflator tube of the balloon pump/ basketball hand pump into the hole of the stopper.

Using the Pop! Rocket Launcher

1. Place the launcher in an open space and tilt

Part numbers for the assembled launcher

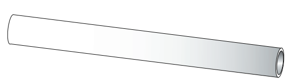
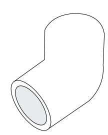
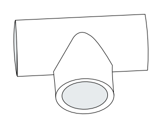
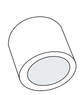
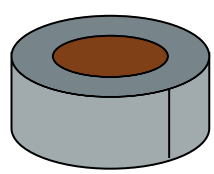
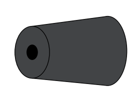


the launch tube in the desired direction. If shooting at targets, have each student aim the launcher for his or her flight.

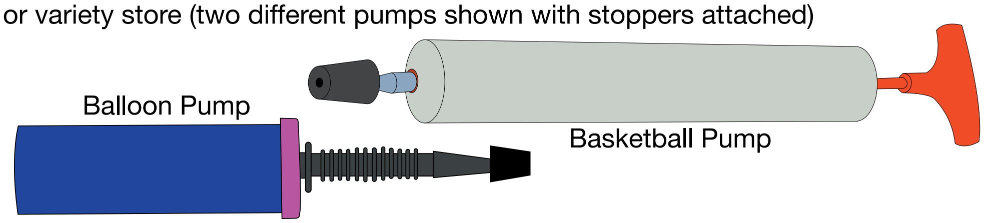
2. Make sure the flight zone is clear of anyone who might be hit by the rocket.
3. Have the student put on eye protection and do a countdown to zero.
4. The student should stomp or jump on the label of the bottle. This will force most of the air inside the bottle through the tubes and launch the rocket.
5. While the student is retrieving the rocket, have the next student reinflate the bottle by pushing the rubber stopper attached to the hand pump into the end of the launch tube. Pumping will pop the bottle back into shape.
6. When the flight zone is clear, have the next student put on the goggles, slide the rocket on to the launcher, aim the launcher, do the countdown, and stomp on the bottle.

> **Tip** Have a couple of spare bottles and the duct tape ready for a quick change-out in case the launcher bottle becomes damaged and no longer usable.

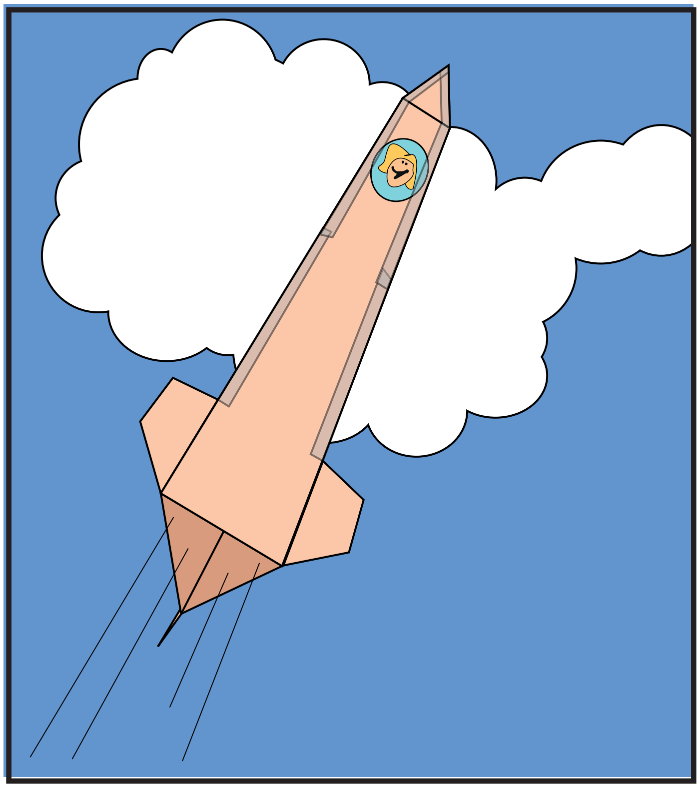
Shopping List

1 - 1/2" (PVC) 5 feet long (to be cut into smaller pieces) Hardware store or plumbing supply 	**2 - 1/2" 45º Elbow** (PVC) Slip* Hardware store or plumbing supply 	**2 - 1/2" Tee** (PVC) Slip* Hardware store or plumbing supply 
2 - 1/2" Caps (PVC) Slip* Hardware store or plumbing supply 	**Duct Tape** Hardware store 	**1 #1, 1-hole Rubber Stopper** May be available from hardware store or from school science supply 

Balloon or Basketball Pump
Toy or variety store (two different pumps shown with stoppers attached)



* Slip means a joint connected with cement rather than threads.



Rocket Activity

Pop! Rockets

Objective

Students design, construct, and launch paper rockets.

Description

A rocket with a triangular cross section is made from three rocket-shaped strips of card-stock paper and launched with the Pop! Rocket Launcher. Students can customize their rocket fin shapes and decorate the rockets using a computer with an illustration program. An alternative single-piece Pop! Rocket is also explained.

Materials

Card-stock paper
Glue stick
Cellophane tape
Scissors
Optional - Computer with an illustration program and printer
Crayons or colored markers
Ruler
Pop! Rocket Launcher (see page 63)
Penny
30 cm-long pieces of 1/2” PVC pipes

National Science Content Standards

Unifying Concepts and Processes
- Evidence, models, and explanation
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Abilities of technological design

National Mathematics Content Standards
- Number and Operations
- Geometry
- Measurement
- Data Analysis and Probability

National Mathematics Process Standards
- Problem Solving
- Reasoning and Proof
- Communication
- Connections
- Representations

Management

Pop! Rockets are made by cutting out three rocket-shaped pieces of paper and joining them together. The basic pattern is a long rectangle with a triangle on one end. When the three rocket sides are taped together, the triangles are bent inward and taped to form a three-sided pyramid that serves as the rocket’s nose cone. At the opposite end are geometric shapes such as triangles or parallelograms, that extend from the sides of the rectangles to form the fins. The fins are glued or taped together face-to-face to make them stiff.

The basic pattern is found on page 70. If you have a computer with an illustration program available, the pattern can be laid out on the computer and the fins custom-designed by your students. The only dimension that must be preserved is the width of the rectangle. The three rectangles, when taped side-to-side, form a triangular prism shape that slides over the launch tube of the Pop! Rocket Launcher.

Print the blank rocket pattern or student's custom-designed rockets on card stock paper. If designing by computer, make three copies of the pattern on the page. To make all patterns fit, use the rotation control to rotate the middle pattern upside down.

If using the rocket with young students, enlist the aid of older students for the rocket assembly (peer teaching) or have the patterns cut out and fold lines scored in advance. Before taping, have students draw pictures of themselves or friends or family peering out from "port holes" near the nose cone end of the rockets. The rockets can be decorated along their entire length. If using a computer illustration program, the decoration can be added to the pattern before printing.

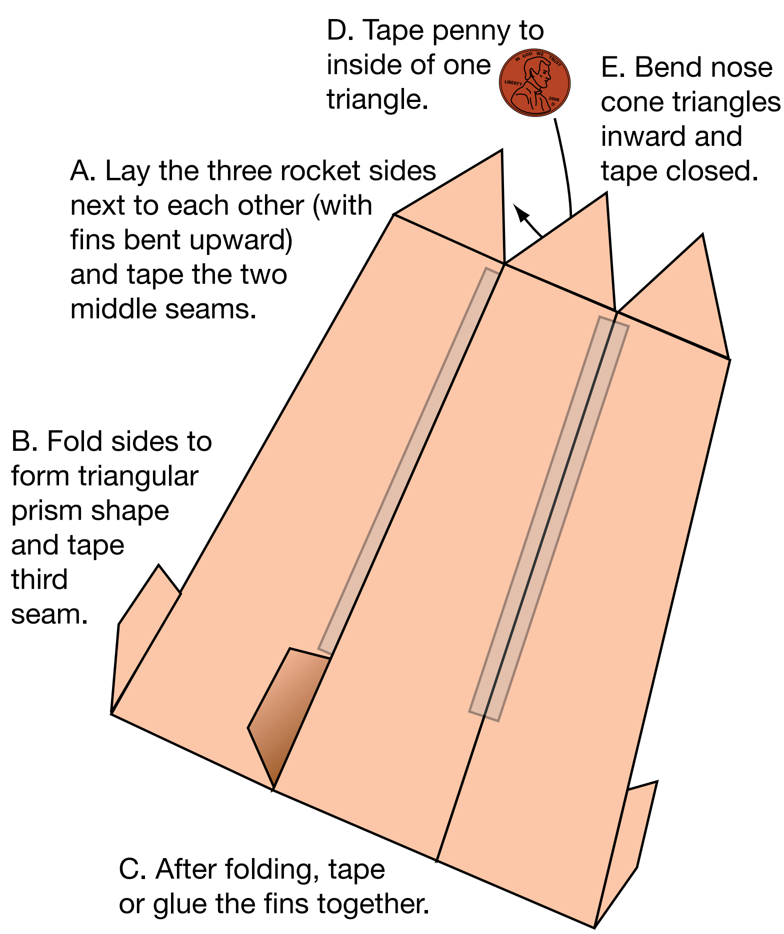
Have students tape a penny to the inside of one of the three nose cone triangles before taping the nose cone together. The penny adds additional mass to the nose and increases its flight stability.

To provide support for the nose cone during taping, insert a PVC pipe segment into the rocket.

Ask students why fins are important to the rocket shape. After collecting their ideas, demonstrate how fins work by tossing two rockets (without the pennies) like javelins into the air. One should have fins and the other should not. The rocket with fins will sail straight across the room, while the one without will flop or tumble in the air. Have your students describe and explain what happened.

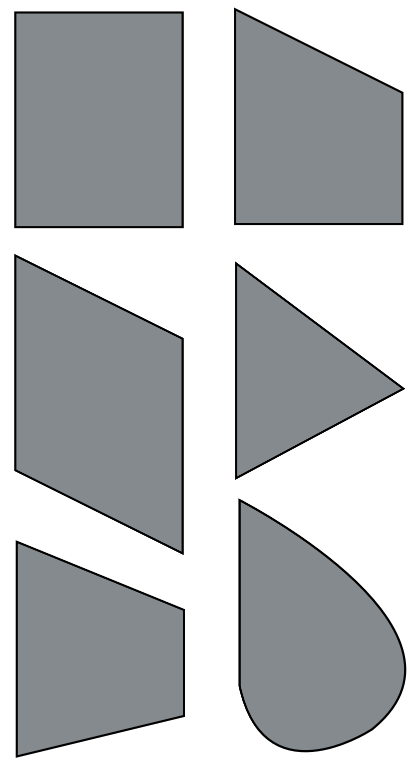
Procedure Three-Piece Pop! Rocket

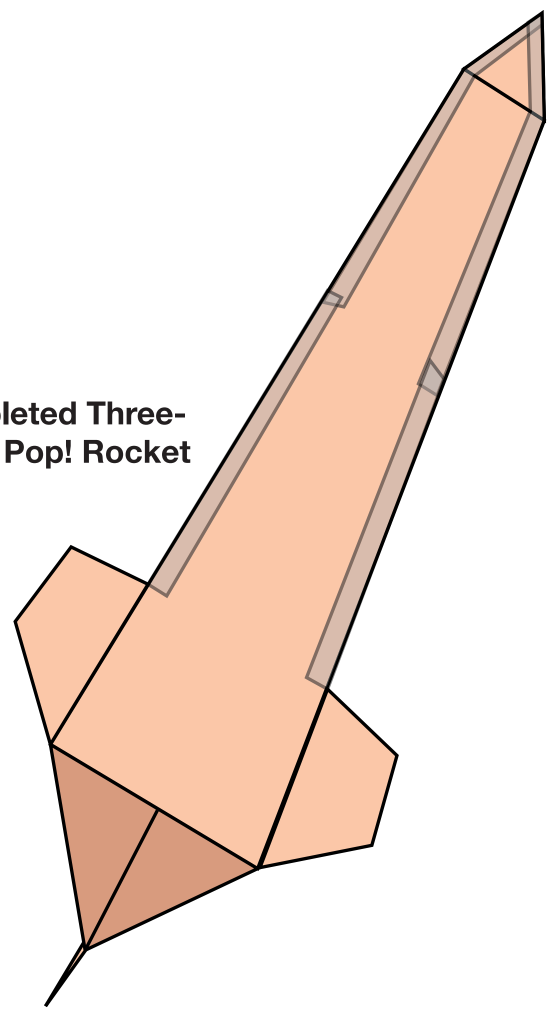
1. If using a computer with an illustration program for designing Pop! Rockets, draw a vertical rectangle that is 3 cm wide and 22 cm long. The nose cone triangle can either be an isosceles or equilateral triangle. Add fins to the sides of the bottom of the rectangle. Keep in mind that the size of the paper limits the size of the fins.
2. After completing one rocket pattern, copy it two times and fit all the pieces on the paper with two patterns pointing up and one pointing down. If the fins are too large for a single sheet of paper, create two patterns on one page and the third on a second page.
3. When the patterns are complete, students can add decorations to their rockets or wait until the patterns are printed and then decorate them.
4. Cut out the three pieces and press the edge of a ruler to the fold lines for the fins and nose cone to get a straight fold. Fold the fins outward.



5. Tape a penny securely to the inside of one of the nose cone triangles.
6. Slide the pieces together and match up the sides of the rocket body. Run a strip of tape along the seams. Do not tape the fins or nose cone pieces yet.
7. Pick up the rocket, bring the two side pieces together, and tape the seam. It may be helpful to insert the PVC pipe into the rocket before taping.
8. Use glue stick or tape to join adjacent fins pieces together to make three fins. If desired, the fins can be left untaped to make six fins.

Ideas for Different Fin Shapes





Completed Three-Piece Pop! Rocket

9. Push the PVC pipe inside the rocket body up to the position of the nose cone. Use the pipe for support while taping. Fold the three triangles inward and tape the seams.
10. The rocket is ready for launch. Follow the launch instructions for the Pop! Rocket Launcher (page 63).

Procedure One-Piece Pop! Rocket

1. Print the pattern on the next page on card stock paper.
2. Use a ruler and the edge of a penny to score the fold lines. To do so, place the ruler along a dashed line and run the edge of the penny (held at an angle) across the paper to make a small groove. The groove will insure that the fold line is both accurate and straight.
3. Cut out the pattern on the solid lines.
4. Tape a penny to the inside of one of the nose cone triangles.
5. Fold the three rectangles into a triangular prism shape with the large tab inside. Tape the seam.

6. Fold the triangles inward to form the nose cone. The tabs should be inside. They will provide support for taping.
7. Bend the fins outward. The rocket is ready for flight.

Discussion

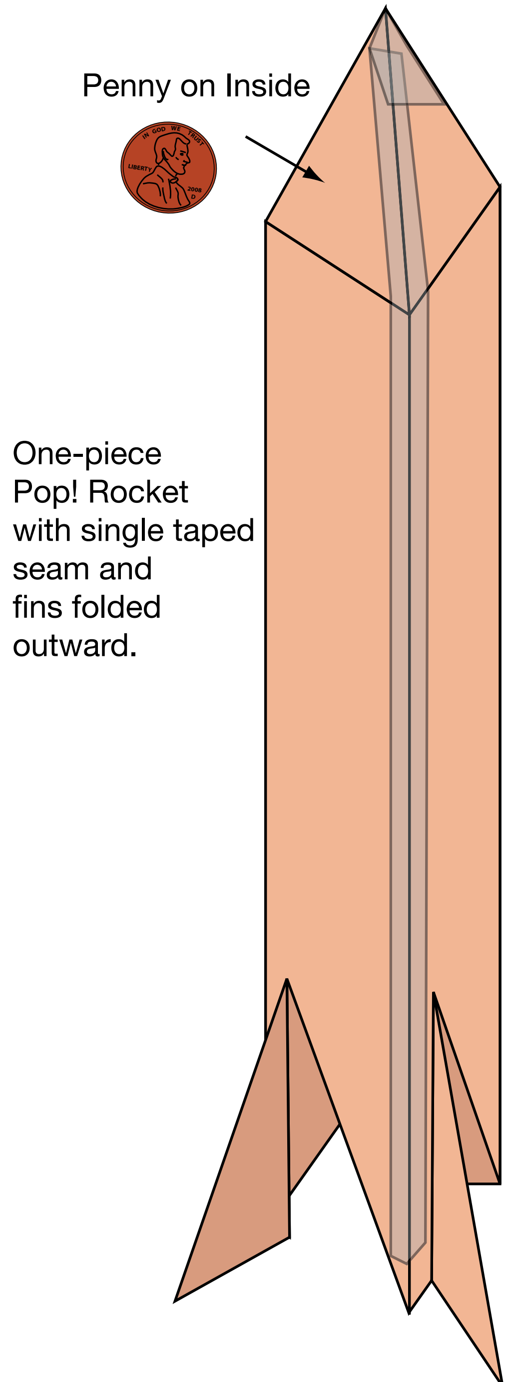
What are the parts of a rocket?

The pointy upper end of the rocket is the nose cone. It helps the rocket spread apart the air as the rocket flies. The nose cone can be compared to the pointed bow of a boat that spreads water apart as it sails forward. Astronauts and spacecraft are usually placed in or near the nose cone. (Note: The space shuttle is a little different in design. However, the astronauts still ride in the cone-shaped front of the Orbiter.)

The body of the rocket is the tube-shaped (triangular-shaped in this activity) part of the rocket that holds the rocket fuel.

Engines are where the rocket fuel is burned. These are found at the lower end of the rocket body. The engines push the rocket into space.

Fins are the tiny wings at the lower end of the rocket body. They help the rocket fly straight.



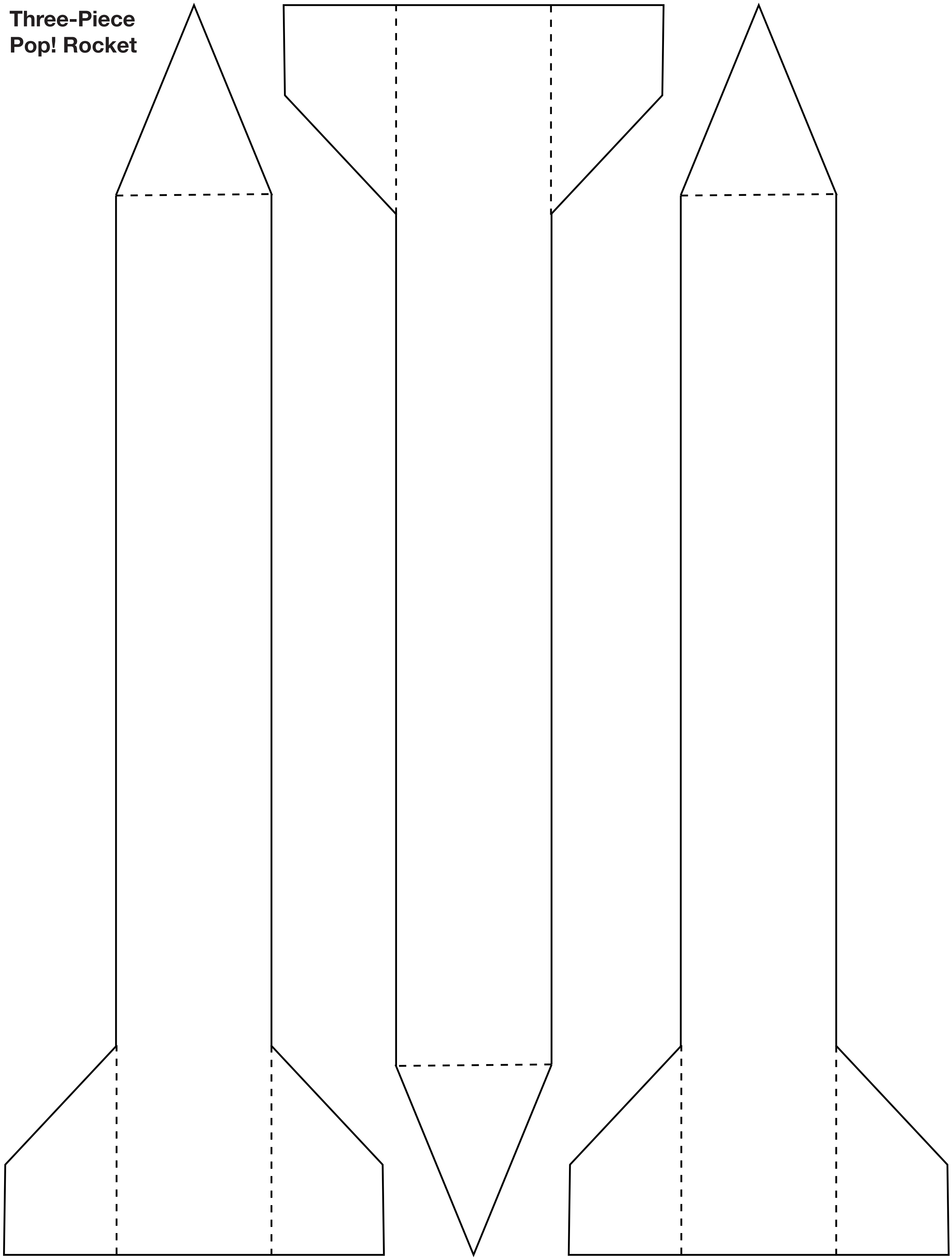
Assessment

- Ask students to write or tell a short story describing their rocket and how they flew.
- Have students draw pictures of their rockets flying through space.

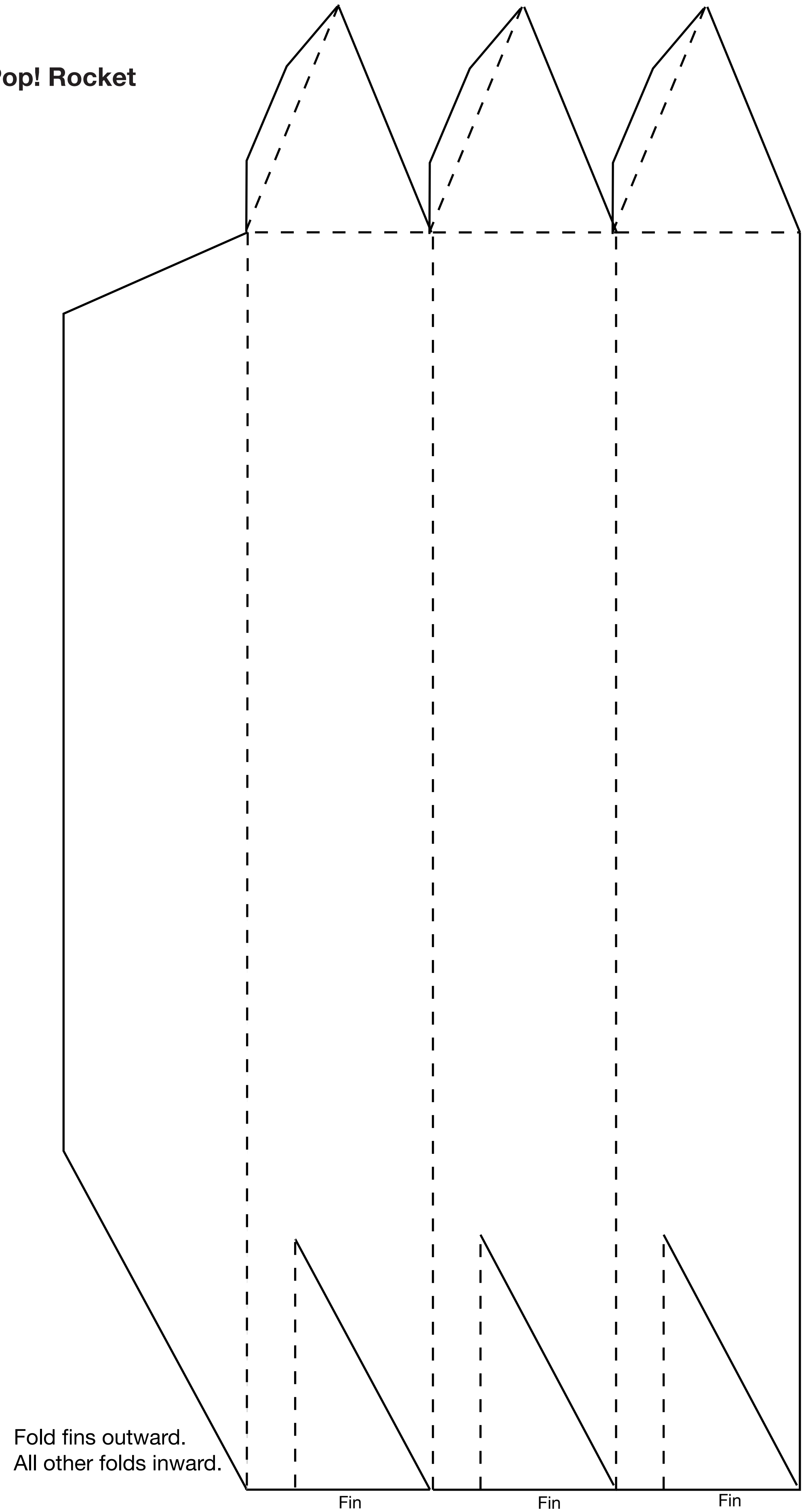
Extensions

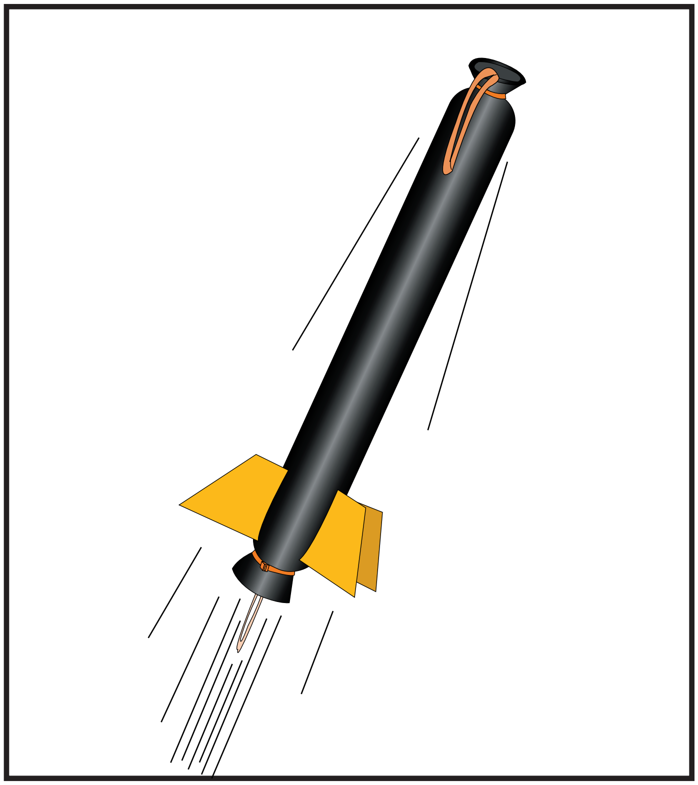
- Compare rockets to an arrow, a weather vane, or a dart. Bring one or more of these objects to class and compare them to the shape of the students' rockets.
- Show pictures of different rockets and compare them to students' rockets.

Three-Piece Pop! Rocket



One-Piece Pop! Rocket





Rocket Activity

Foam Rocket

Objective
Students will learn about rocket stability and trajectory with rubber band-powered foam rockets.

Description
Students will construct rockets made from pipe insulating foam and use them to investigate the trajectory relationship between launch angle and range in a controlled investigation.

National Science Content Standards

Unifying Concepts and Processes
- Evidence, models, and explanation
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Abilities of technological design

National Mathematics Content Standards
- Number and Operations
- Algebra
- Geometry
- Measurement
- Data Analysis and Probability

National Mathematics Process Standards
- Reasoning and Proof
- Communication
- Connections

Materials
30 cm-long piece of polyethylene foam pipe insulation (for 1/2” size pipe)
Rubber band (size 64)
Styrofoam food tray
3 8” plastic cable wraps
75 cm of ordinary string
Scissors
Meter stick
Press tack
Washer or nut
Quadrant plans printed on card stock
Rocket construction instructions
Experiment data sheet
Masking tape
Launch record sheet
For class - tape measure

Management
Select a large room with a high ceiling for the launch range, such as a cafeteria or gymnasium. Place markers on the floor at 1 meter intervals starting at 5 meters and going to 20 meters. If it is a calm day, the investigation can be conducted outside. Although the rockets can be launched outside on windy days, the wind becomes an uncontrollable variable that will invalidate the results. Prepare some sample rocket fins to show how they are constructed. Refer to the construction

page for details. Before conducting the investigation, review the concept of control. In this investigation, control will be how much the rubber band is stretched when launching the rockets. The experimental variable will be the angle of launch. Students will compare the launch angle with the distance the rocket travels. Organize students into teams of three. One student is the launcher. The second student confirms the launch angle and gives the launch command. The third student measures the launch distance, records it, and returns the rocket to the launch site for the next flight. The experiment is repeated twice more with students switching roles. The distances flown will be averaged, and students will predict what the best launch angle should be to obtain the greatest distance from the launch site.

Background

The foam rocket flies ballistically. It receives its entire thrust from the force produced by the elastic rubber band. The rubber band is stretched. When the rocket is released, the rubber band quickly returns to its original length, launching the foam rocket in the process. Technically, the foam rocket is a rocket in appearance only. 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. The ability to fly foam rockets repeatedly (without refueling) makes them ideal for classroom investigations on rocket motion.

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. In this activity, the launcher is a meter stick held by the student.

Tip Be sure the range-measuring student measures where the rocket touches down and not where the rocket ends up after sliding or bouncing along the floor.

In flight, foam rockets are stabilized by their fins. The fins, like feathers on an arrow, keep the rocket pointed in the desired direction. If launched straight up, the foam rocket will point upward until it reaches the top of its flight. Both gravity and air drag put act as brakes. At the very top of the flight, the rocket momentarily becomes unstable. It flops over as air catches the fins and becomes stable again when it falls back nose forward.

When the foam rocket is launched at an angle of less than 90 degrees, it generally remains stable through the entire flight. Its path is an arc whose shape is determined by the launch angle. For high launch angles, the arc is steep, and for low angles, it is broad.

When launching a ballistic rocket straight up (neglecting air currents) the rocket will fall straight back to its launch site when its upward motion stops. If the rocket is launched at an angle of less than 90 degrees, it will land at some distance from the launch site. How far away from the launch site is dependent on four things. These are:

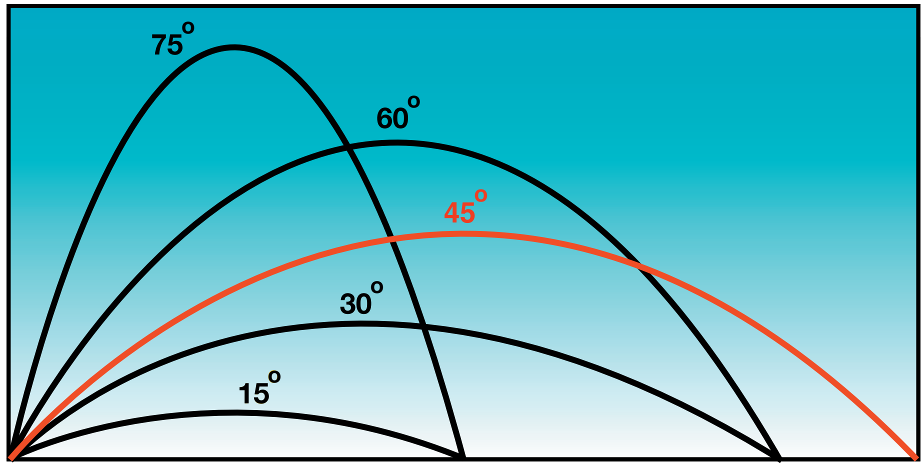
gravity
launch angle
initial velocity
atmospheric drag

Gravity causes the foam rocket to decelerate as it climbs upward and then causes it to accelerate as it falls back to the ground. The launch angle works with gravity to shape the flight path. Initial velocity and drag affects the flight time.

In the investigation, students will compare the launch angle to the range or distance the foam rocket lands from the launch site. Launch angle is the independent variable. Gravity can be ignored because the acceleration of gravity will remain the same for all flight tests.

Atmospheric drag can be ignored because the same rocket will be flown repeatedly. Although students will not know the initial velocity, they will control for it by stretching the rubber band the same amount for each flight. The dependent variable in the experiment is the distance the rocket travels.

Assuming student teams are careful in their control of launch angles and in the stretching of the launch band, they will observe that their farthest flights will come from launches with an angle of 45 degrees. They will also observe that launches of 30 degrees, for example, will produce the same range as launches of 60 degrees. Twenty degrees will produce the same result as 70 degrees, etc. (Note: Range distances will not be exact because of slight differences in launching even when teams are very careful to be consistent. However, repeated launches can be averaged so that the ranges more closely agree with the illustration.



Launch angle vs. range for rockets with the same initial launch velocity

Procedures Constructing a Foam Rocket

1. Using scissors, cut one 30-cm length of pipe foam for each team.
2. Cut four equally spaced slits at one end of the tube. The slits should be about 8 to 10 cm long. The fins will be mounted through these slits.
3. Tie a string loop that is about 30 cm long.
4. Slip one end of a cable wrap through the string loop and through the rubber launch band. Join the cable wrap to form a loop and tighten it down to a circle approximately 1 to 2 cm in diameter. The end of the wrap can be trimmed off with scissors or left.
5. Thread the cable wrap with string and rubber launch band through the hole in the foam tube. The string should stick out the rear end of the rocket and the rubber band out the nose. Position the plastic loop about 3 cm back from the nose.
6. Tighten the second cable wrap securely around the nose of the rocket. It should be positioned so that the cable wrap loop inside the rocket is unable to be pulled out the nose when the rubber band is stretched. ***Caution students not to pull on the string.*** The string should only be pulled during launches when the rubber band is held from the other end. Trim off the excess cable wrap end.
7. Cut fin pairs from the foam food tray or stiff cardboard. Refer to the fin diagram.