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AUTHOR	Horton, Robert L.; And Others
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ABSTRACT

This unit is designed to stimulate interest in math, engineering, aerospace, and physics through the exploration of rocketry science. It serves as a ready source of information dealing with the subject of rocketry and provides directions for completing a variety of hands-on rocketry science experiments, including the design, construction, and launch of 2-liter bottle rockets. The teaching outline consists of four parts: introduce new knowledge; summarize learning; bring closure to session; and review previous session when starting new session. Sections include: Exploring the Motion of Rockets, Building on the Basics, and Let's Get Launching. (JRH)

4-H 501 GPM

ROCKETS AWAY!

A fun approach to exploring the science of rocketry.

Teachers Edition

THE OHIO STATE UNIVERSITY
EXTENSION

ROCKETS AWAY!

Teachers Edition

A fun approach to exploring the science of rocketry.

Featuring a variety of experiments & activities including the construction and launching of 2-liter bottle rockets

Written by:
Robert L. Horton, Ph.D.
Extension 4-H Specialist
Science Education

Bob Newman
Educator, Simpson Middle School
Mansfield, Ohio

Conn Dandareau
Educator, Simpson Middle School
Mansfield, Ohio

Mike Blevins
Project Consultant
Columbus, Ohio

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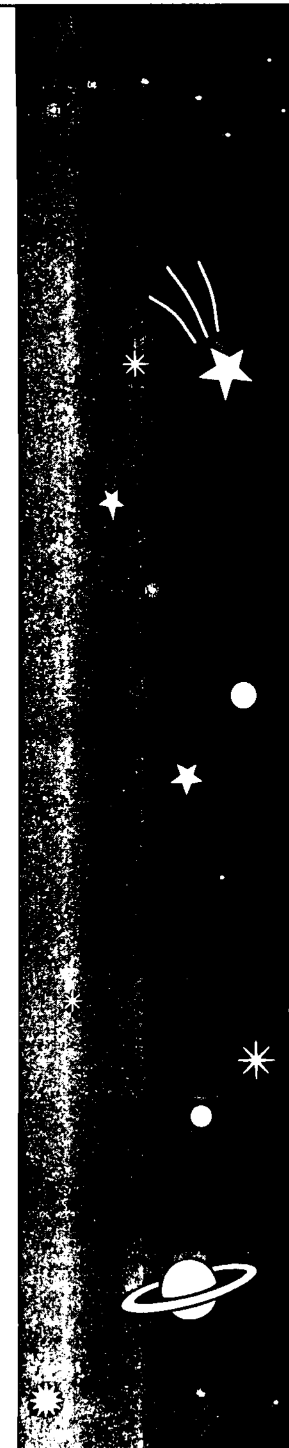

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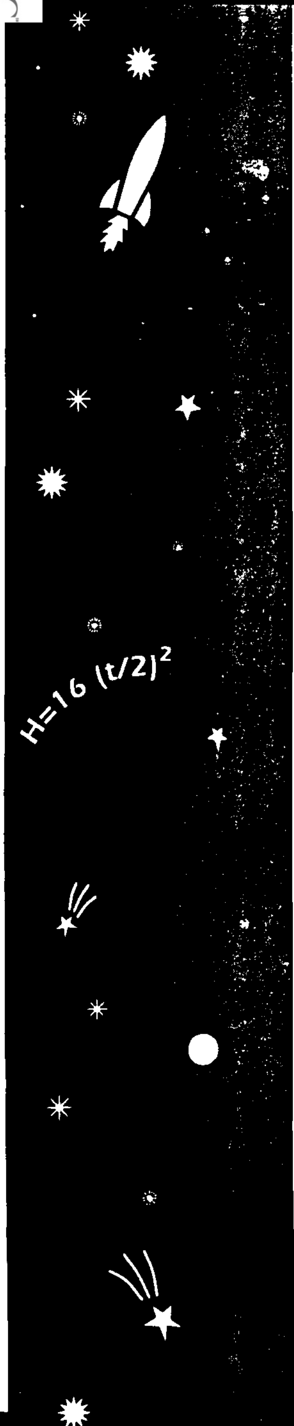


About the Unit

This unit is designed to stimulate interest in math, engineering, aerospace, and physics through the exploration of rocketry science. It will serve as ready source of information dealing with the subject of rocketry, as well as provide directions for completing a variety of hands-on rocketry science experiments. This includes the design, construction and launch of 2-liter bottle rockets as detailed in section three. The benefit to using 2-liter bottle rockets is that there is no need for expensive solid rocket engines, nor is there the large investment of time in the design and construction of the rockets. In addition, 2-liter bottle rockets can easily be modified to accommodate a variety of experiments, or to improve their overall performance.

As you begin each session, be sure to include a proper introduction and discussion of information to be covered. This will help the class prepare for the learning that follows. For best results, conduct experiments as demonstrations with group members as active participants. Or, if you wish, provide an opportunity for group members to conduct experiments on their own or in teams. This is especially important in lessons 2 & 3 where group members construct and fly experimental rockets.

Once an activity is completed, allow time for processing. Use the guiding questions as provided to help group members relate what they observed and experienced. When processing an activity, try not to focus on answers being "right" or "wrong." Rather, accept all answers as possible solutions. Then, help the group see why a particular answer may be more appropriate than others, especially if the answer you were looking for was not given.

Plan on at least two hours to complete sessions 1 & 2. This includes performing all of the recommended experiments along with time for group discussion. Session 3 should be extended over a longer period of time in order for group members to complete all five problems. Time permitting, you may wish to explore some of the Digging Deeper and Going Beyond activities in each lesson.

Teaching Outline - The following is a recommended outline for conducting a series of sessions on this subject.

•Introduce new knowledge - Rely heavily on showing rather than telling. Refer to the examples in each lesson, or use your own to get your message across. As you teach, focus on improving the learner as a person, as well as helping the group learn new things.

•Summarize Learning - Have the group talk about what they learned and what they liked doing. Focus on the positive, especially if things didn't work as you planned.

•Bring closure to Session - Provide an overview of what will be covered during the next session. Try building excitement for what's to come by giving the group a problem to solve or maybe even a question to be answered.

•When starting next time . . . review previous session.

This will help the learners have a common starting place for the current session and lead into new information.

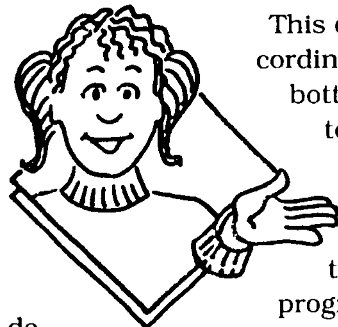
Getting Started With the Unit

Step 1: Obtain the required materials listed for each experiment. When conducting as a group, plan on having learners work in teams of 2-3 whenever possible. This will help cut down on the amount of supplies needed as well as facilitate cooperative learning among group members.

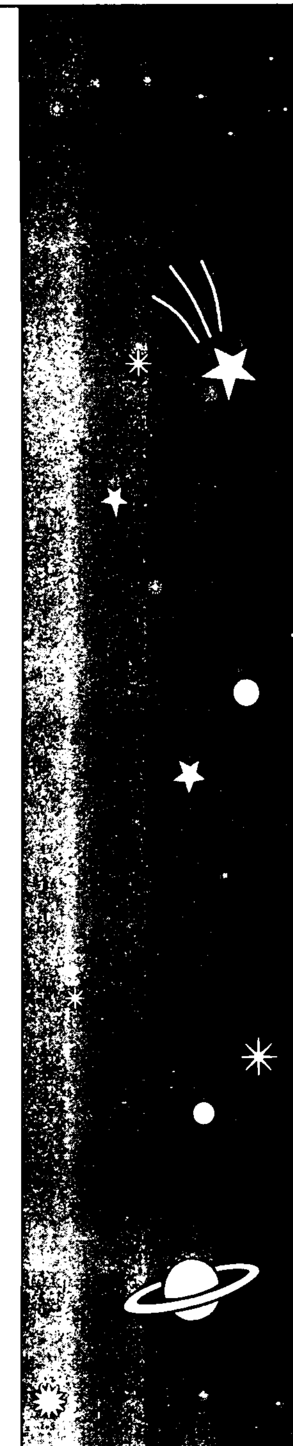
Step 2: Rocketry equipment - Lesson three is designed to help learners apply what they learned in the previous two lessons in a unique step-by-step problem solving approach. This includes the design, construction, and launching of 2-liter bottle rockets. Be sure to photocopy the appropriate pages from this lesson and distribute them to group members. This lesson works best when group members can work on their own or in teams to design and build their 2-liter bottle rockets.

Step 3: Optional Computer Assisted Instruction

For learners with access to an IBM compatible computer, an optional program is available to teach them about the proper design and flight configurations of 2-liter bottle rockets. This simulation program will help them solve problems like determining the proper design for a nose cone and tail fin, testing the proper ratio between fuel capacity and water pressure for maximum range, or determining the ideal weight for a 2-liter bottle rocket.

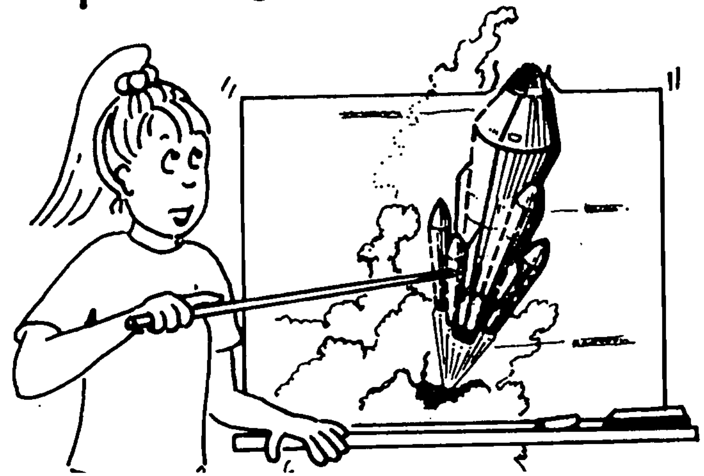


This diskette also contains a program for recording and analyzing launch data using 2 liter bottle rockets. This is a must for learners interested in perfecting the design of their 2 liter bottle rocket. As learners enter data based on the amount of water and pressure used for each launch, including the time it took from launch to landing, the program will determine altitude and speed of the rocket as well as predict ideal water/pressure ratios for future launches.



$H=16(t/2)^2$

I. Exploring the Motion of Rockets



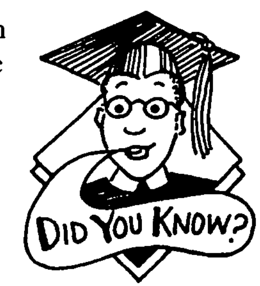
Rocket Run-Down

- **The science of rockets began with the discoveries of Isaac Newton.**
- **Rockets rely on the unbalancing of forces for motion.**
- **Rockets will speed up when mass is decreased or thrust is increased.**
- **A rocket's forward motion is a reaction to the rapid discharge from its engines.**
- **Gravity is a force held constant against the performance of rockets.**

Background

A rocket in its simplest form is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape in one direction, and in doing so provides a thrust that propels the rocket skyward in the opposite direction. Most historians believe that rockets were invented by the Chinese around the 11th century AD. These early rockets were used by the Chinese to repel invaders, such as the Mongols.

By the thirteenth century the use of rockets had spread to the Middle Eastern countries where they were known as "Chinese Fire Arrows." These early rockets were little more than tubes stuffed with gunpowder. When the gunpowder was ignited, it exploded and produced hot gasses that "pushed" the rockets into flight. Eventually, the use of rockets for both warfare and entertainment spread worldwide. However, it has been only since the last three hundred years that rocket experimenters have actually understood the scientific principles behind the motion of rockets.



Did you Know - Rockets were used in many battles including one famous battle against the United States during the War of 1812. During the battle, at Baltimore's Fort McHenry, a young poet named Francis Scott Key watched the rocket bombardment and wrote a poem about "the rocket's red glare/the bombs bursting in air." Later, set to music, that poem became the American national anthem, The Star-Spangled Banner.

Discussion

Begin by discussing the movement of objects both in the atmosphere and in space. Have a toy rocket and a wind-up balsa wood glider on hand to illustrate key points. Start the group thinking by asking the question . . . "How do rockets move?" Help the group understand that rockets do not move like conventional aircraft which pull themselves along through the atmosphere. To demonstrate this point, wind up your balsa wood glider and release it skyward. Point out that the glider stays aloft as long as the propeller keeps turning.

Compare this to the movement of a rocket. Tie a string around the mid section of your rocket and twirl it over your head. Explain that a rocket's movement is not caused by the pushing or pulling of its engines against the atmosphere. If this were the case, rockets would be unable to travel the airless void of space. Rather, a rocket relies upon a different type of "sustained force" to achieve motion. In the case of the rocket circling above your head, its action is the result of the movement in your wrist. As long as your wrist continues to twirl, the rocket will continue to move.

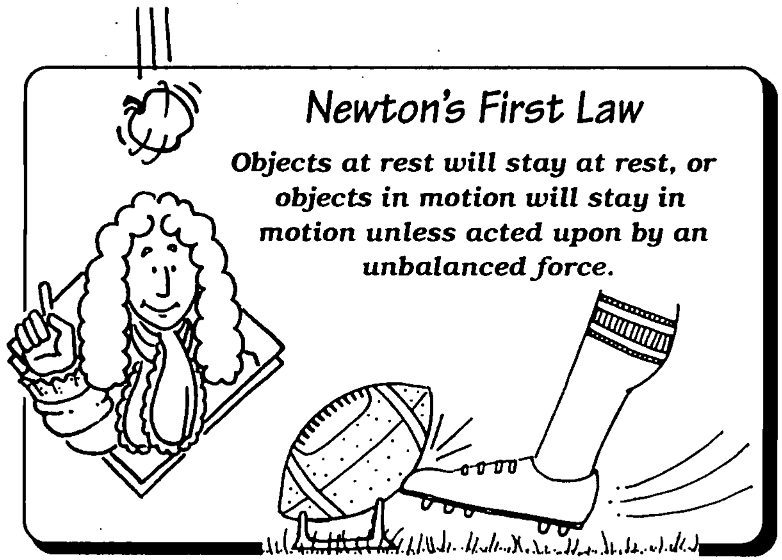
Explain that the remainder of the lesson will focus on helping the group explore the science behind the term "rocket motion." In fact, they may be surprised to learn that rocketry got its start with the publishing of a book in 1687 by an English scientist named Sir Isaac Newton. In his work, Newton stated that three important scientific principles govern the motion of all objects, whether on earth or in space. Over time, these principles have become known as Newton's laws of motion.

Let's Explore

The following collection of experiments have been designed to familiarize your group with each of Newton's three laws. The activities may be presented as student assisted demonstrations, or in the form of small group exercises. Whenever possible, encourage group members to collect, analyze and compare data. Also, utilize the guiding questions to help group members process their observations as well as apply what they learned to real life situations.

Newton's First Law

Objects at rest will stay at rest, or objects in motion will stay in motion unless acted upon by an unbalanced force.



Explain that during a rocket's flight, forces become balanced and unbalanced all the time. A small model rocket sitting on the launch pad experiences a balance of forces. The surface of the pad provides a balanced force against the mass of the rocket being pulled down by gravity. When the engine ignites, its thrust unbalance the forces, allowing the rocket to travel upward. This thrust continues until the engine's fuel is exhausted. Once this occurs, the rocket becomes susceptible to the forces of gravity and atmospheric friction. These unbalanced forces act upon the rocket's forward motion causing it to slow and eventually fall back to earth.

Experiment - Testing Gravity

Materials: popcorn

Distribute popcorn to the group. Have the group place several pieces in their hand. Explain that as the popcorn rests in their hand it is being acted upon by forces. The force of gravity is trying to pull the popcorn downward, while at the same time your hand is pushing against the popcorn trying to hold it up. Now try unbalancing the forces by letting the popcorn fall from your hand into your mouth. Once done, have the group describe what they did to have the popcorn fall from their hand. You may even wish to have the group members write down the steps they used to unbalance the forces acting on the popcorn.

Explanation: Help the group see that by unbalancing forces, the popcorn was transformed from a state of rest to a state of motion.

Guiding Questions

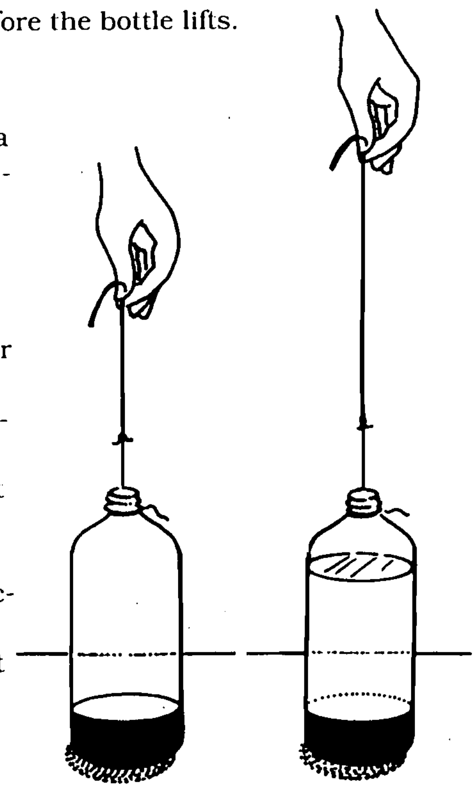
- **What force returned the popcorn again to a state of rest? (*the wall of your stomach*)**
- **How was the motionless popcorn like a rocket on a launch pad? (*both require an unbalancing of forces to make them move*)**
- **What force keeps a rocket motionless on a launch pad? (*the force of the launch pad acting against the force of gravity*)**
- **Could you repeat the experiment in the weightlessness of space? (*yes*)**
- **What would you do differently? (*push the popcorn towards your mouth*)**

Experiment - Let's Get Lifting

Materials: 16oz soft drink bottle
string
rubber band
water

Divide the group into teams. Have each team take an empty 16oz soft drink bottle and tie a string around its neck. Next, take a rubber band and cut it so that it can be attached to the opposite end of the string. Now, instruct the teams to pull the rubber band and measure how much it stretches before the empty bottle lifts. Next, have each team take the same bottle and fill it with water. Again, pull on the rubber band and measure how much it stretches before the bottle lifts.

Explanation: As the teams observed, a certain amount of unbalanced force was needed to lift the bottle. However, the greater the *mass* of the object, the greater the unbalanced force needed to lift it. Obviously, the idea of mass is an important factor to consider when calculating the unbalanced force necessary to lift or move the mass of an object like a rocket.



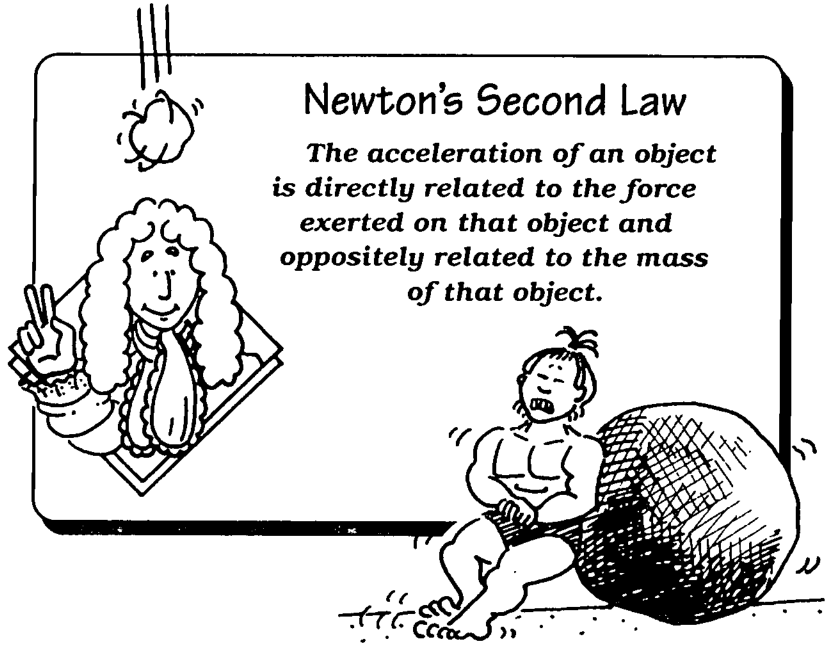
Guiding Questions

- **Would the experiment work the same in the weightlessness of space? (*No, the absence of gravity would reduce the force necessary to move the bottle.*)**
- **On earth, would the same amount of force be needed to pull the bottle across a desk? (*the force should be less since you are acting against friction rather than gravity.*)**

Word to Know – Mass: the amount of matter in an object

Newton's Second Law

The acceleration of an object is directly related to the force exerted on that object and oppositely related to the mass of that object.



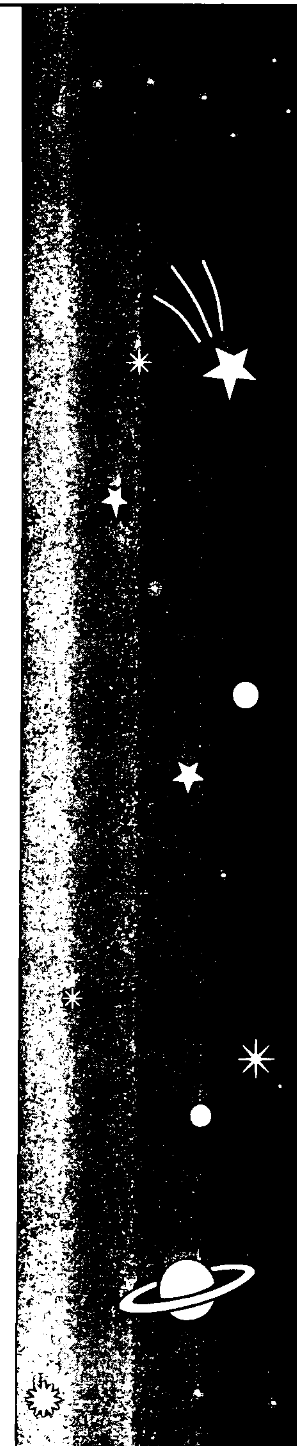
Start by pointing out the usefulness of this law when designing efficient rockets. To enable rockets to *accelerate* to higher elevations with greater payloads, designers must minimize the rocket's *mass* while maximizing the amount of *force* exerted from its engines. This is typically accomplished by igniting engines in stages. This allows for spent engines to be separated away from the main rocket, thereby decreasing the rocket's mass while increasing its acceleration.

Experiment - Getting the Jump on Gravity

Break the group into teams of two for this experiment. Explain to the group that they are about to experience Newton's first two laws. First, have the teams pretend that they are a rocket on a launch pad. As they stand with their arms at their side, have them talk about the balance of forces that hold them steady. After a few moments, suggest that the teams prepare themselves for liftoff. This is accomplished by having team members crouch down with their hands touching the floor. At the count of three, have each team member jump into the air.

After the jump, discuss what forces became unbalanced to cause them to move skyward. Also discuss what forces caused them to return to earth. Use this discussion to lead them to the application of Newton's second law. Point out that in order to increase acceleration, they either have to decrease mass or increase thrust. Suggest that team members stand back to back with their arms locked and repeat the experiment as before. *"Surly the doubling of leg power will improve acceleration!"* However, as the teams will quickly discover, the doubling of their thrust was negated by the doubling of their mass.

See if the teams can figure out how to increase their thrust without increasing their mass. For example, have one team member jump into the air while being lifted from the waist by one or two others.

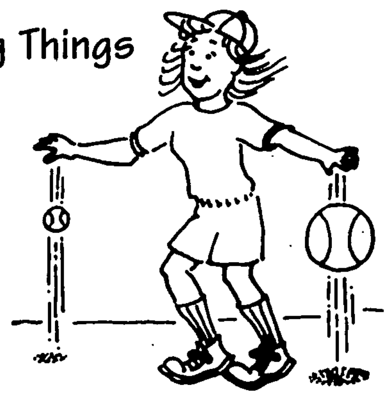


$H=16(t/2)^2$

Guiding Questions

- **Are there challenges when designing larger rocket engines to produce greater thrust? (*yes*)**
- **How did it feel to be lifted skyward by several people? (*somewhat weightless*)**
- **Was the job of lifting easier as more people joined in? (*yes*)**

Experiment - Bouncing Things



Materials: Basketball
Tennis ball

Ask a group member to help you by bouncing a basketball. At the same time, begin bouncing a tennis ball. Talk about the difference in mass between the tennis ball and the basket ball.

Also mention that the tennis ball could be thrown faster than the basketball using the same amount of thrust. Lastly, compare the difference in force it takes to bounce them equal heights.

Explanation: By now, you realize that it takes far more force to bounce a basketball than a tennis ball. Of course, the basketball is heavier than a tennis ball, but it is not the weight that makes it harder to bounce. If there were no gravity, so that both were weightless, the basketball would still be harder to bounce. This is because the basketball has a greater amount of material in it (*mass*). Therefor, according to Newton's Second law, the greater an object's mass, the greater its resistance to acceleration.

Digging Deeper

Extend the experiment by placing the tennis ball on top of the basketball and dropping them from a height of about 5 feet. If done properly, the tennis ball should "shoot up" into the air while the basketball barely leaves the ground. In fact, the height will be so great that it will be impossible to match with a single bounce of the tennis ball. Try modifying the experiment by applying greater force as you drop the balls.

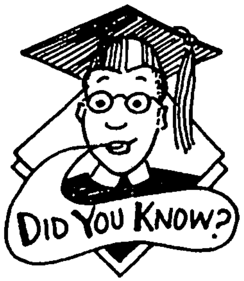
Explanation: Far more energy is required to make the basketball bounce the same distance as the tennis ball. This is because the basketball has more mass. (*Newton's second law*) When the tennis ball is placed on the basketball, a transfer of energy from the basketball to the tennis ball takes place. This is the same principle that's used in the staging of rockets. When separated, much of the energy in the massive lower stages is transferred to the lighter upper stages resulting in greater acceleration.

Guiding Questions

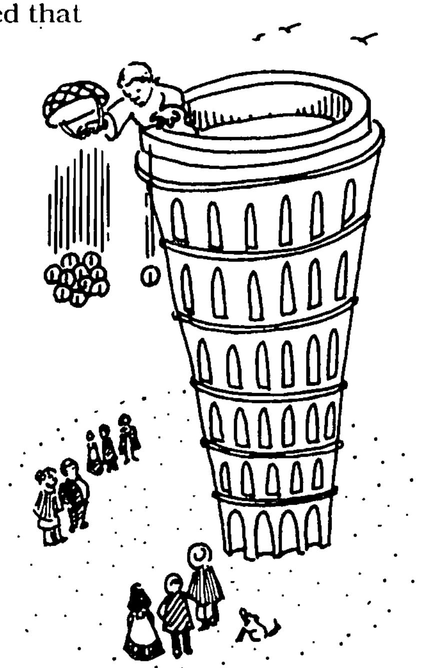
- **Why is it easier to throw a tennis ball than a basketball? (*less mass*)**
- **What would be easier to slow down, a tennis ball or a basketball? (*a tennis ball*)**
- **On a single bounce, can you match the distance the tennis ball traveled when it was on the basketball? (*not likely*)**

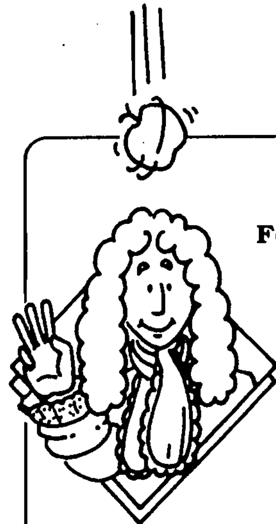
Did You Know - the larger the mass of an object in motion the greater the unbalanced force needed to stop it. That's why its so difficult to stop a freight train once it gets moving. Its moving mass possesses a tremendous amount of *inertia*.

Word to Know - Inertia: A resistance to a change in motion. The greater the mass of a moving object, the greater its inertia.



Did You Know? - If the force to bounce a tennis ball and a basketball 10 feet into the air differs, why then will they return to earth at the same time? - - In 1590, a man by the name of Galileo (*Gal-uh-LEE-oh*) Galilei, from Pisa Italy, discovered that gravity pulls all objects to earth with the same acceleration (32ft/second) regardless of their mass. It is said that he simultaneously dropped a 10 pound weight and a 1 pound weight from the top of the Leaning Tower of Pisa. A crowd of students and professors looked on as both weights hit the ground at the same time. Galileo explained that what he did was . . . "*no different than dropping ten 1 pound weights at the same time as the 1 pound weight.*"

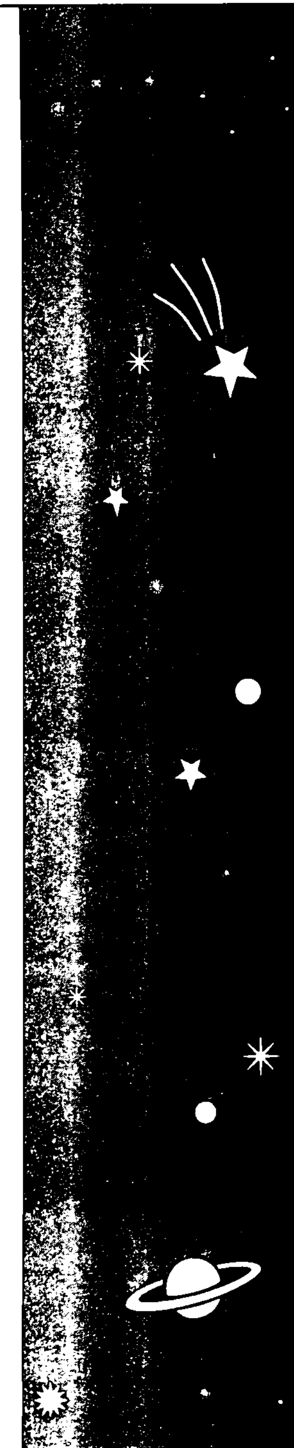


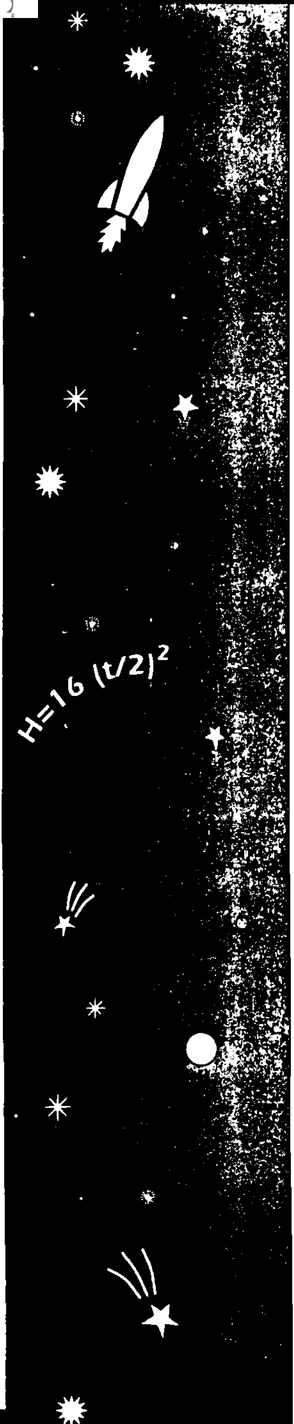


Newton's Third Law

For every action there is always an opposite and equal reaction.

Explain to the group that with rockets, the *action* is the expelling of gas out of the engine. The *reaction* is the movement of the rocket in the opposite direction. Of course you might believe that a rocket moves by pushing off against the surrounding air. However, if this were the case, space travel would be impossible due to the absence of air in space.





Experiment - Kicking Into Action

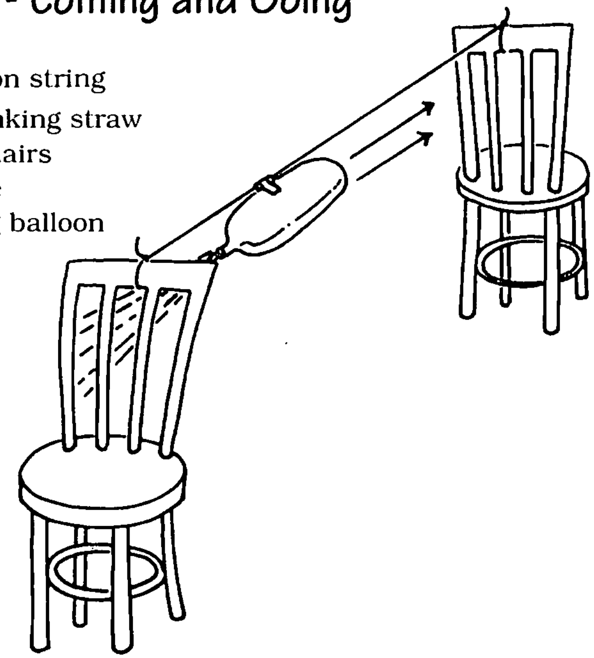
The best way for the group to understand the principle of "action-reaction" is to experience it themselves. Begin by finding a smooth surface on which to stretch out. While lying on their backs with their arms at their side, have them kick their feet forward. If the surface is smooth enough, they should begin moving in the opposite direction of their kicks.

Questions to Answer

- **How is water spraying from a garden hose similar to this experiment? (*force of water from the nozzle tends to push hose in opposite direction*)**
- **How is your kicking like the thrust from a rocket's engine? (*the engine's thrust moves the rocket forward*)**
- **What happens if you held a stack of books on your stomach? (*It would it take more energy to move the same distance as before*)**
- **How is adding weight an example of Newton's second law of motion? (*increasing the mass decreases the acceleration*)**

Experiment - Coming and Going

Materials: Nylon string
Drinking straw
2 chairs
tape
long balloon



Have a couple of group members help you with the next experiment.

Using an 8' piece of nylon string, thread it through a 1" piece of drinking straw. Suspend the string between two chairs or a wide doorway as shown. Next, inflate a long balloon and attach it to the 1" straw with a piece of tape. Starting at one end of the string, release the balloon and observe how it travels along the string.

Explanation - Help the group see that the action of the air leaving the balloon in one direction provides the movement of the balloon in the opposite direction.

Guiding Questions

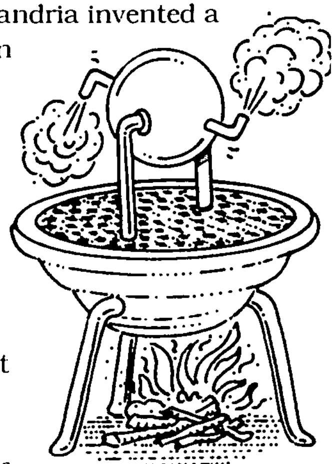
- **Would the size or shape of the balloon effect its performance? (*yes*)**
- **Would adding weight to the balloon effect its performance? (*yes*)**

Let's summarize

Take this time to summarize what the group has learned so far. Remind then, that for a rocket to lift off from a launch pad, force must be exerted (first law) to unbalance the present forces at work. The rate at which the rocket leaves the launch pad (second law) will be determined by the mass of the rocket and its fuel, along with the force that is produced when the fuel is burned. The reaction, or motion, of the rocket away from the launch pad (third law) is equal to and opposite from the action or thrust of the engine.

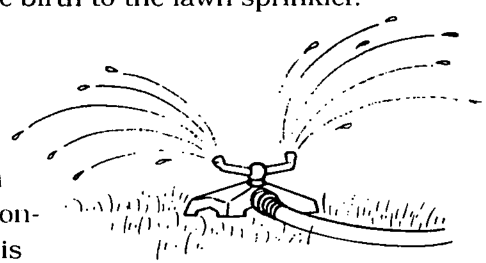
Going Beyond: Build you own Hero Engine

Explain to the group that around 700BC, a Greek man by the name of Heron of Alexandria invented a rocket like device later to be known as a "Hero Engine." Heron mounted a sphere on top of a water kettle. A fire mounted below the kettle turned the water into steam, and the gas traveled through pipes to the sphere. Two L-shaped tubes on opposite sides of sphere allowed the gas to escape, and in doing so gave a thrust to the sphere causing it to rotate.

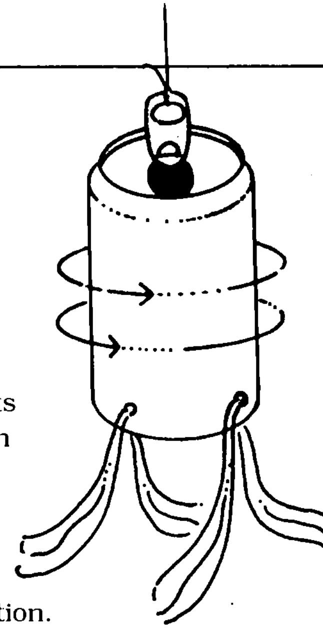


Little did Heron know that his engine was an excellent example of Newton's three laws of motion. Also, little did he know that his invention would give birth to the lawn sprinkler.

Use the following instructions to create your own Hero type engine. Time permitting, use this as a team activity or a group demonstration. Either way, this activity does a nice job of tying in Newton's three laws.



Materials: aluminum can
nail
hammer
nylon string
bucket
water



1. Lay an aluminum can on its side. Using a nail, carefully punch four equally spaced holes just above and around the bottom rim. Before removing the nail, push it slightly to the right so that the hole is in a slanted direction.

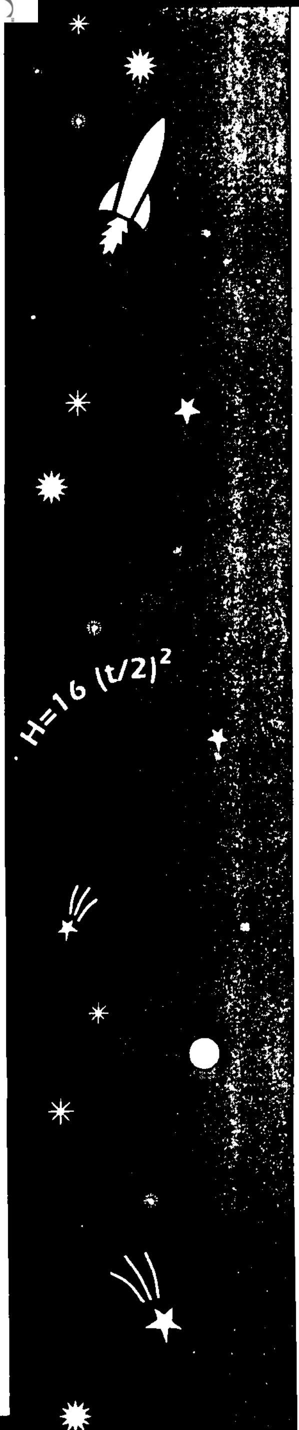
2. Bend the can's opener lever straight up and tie a short length of nylon string to it.

3. Immerse the can in water until it is filled. As the can is lifted by its string, watch how water leaving the can through the holes starts it spinning.

Explanation: 1st Law - The can spins because gravity pulling water through the holes creates an imbalance of forces on the can. 2nd Law - The rate of *acceleration* will vary with the *mass* of the can and the water in it. It will also vary with the *force* at which the water leaves the holes. This force is dependent upon on the number and size of holes used, along with the volume of water above the holes. 3rd Law - The can rotates opposite from the direction of the water leaving the can.

Guiding Questions:

- **If you added weight to the can would it take a longer or shorter period of time for the can to start spinning? (*longer*)**
- **Once the weighted can started to spin, would it take a longer or shorter period of time for it to stop? (*longer*)**



II. Building On The Basics

Rocket Run-down

- Rockets do not rely on the dynamics of flight for travel.
- Rocket engines use nozzles to increase and direct thrust.
- Rockets are long and balanced for reasons of efficiency and stability.
- In the atmosphere, fins are used to balance, control and stabilize rockets.
- Rockets are streamlined to maximize performance within the atmosphere.

Background

Over a long and exciting history, rockets have evolved into mighty vehicles capable of launching spacecraft beyond the reaches of our planet. Rockets have brought us many wonders. They have carried astronauts to the moon, given us images from the edges of the solar system, and placed satellites into orbit providing instantaneous global communications. Few experiences can compare with the excitement and thrill of watching a rocket powered vehicle like the Space Shuttle thunder into space. Yet, with all of these developments taking place around us, people still fail to comprehend the basic principles of rocketry. For example, the following are six of the most commonly asked questions of NASA scientists.

Commonly Asked Questions

Q. Do rockets really fly?

Q. Why do rocket engines have nozzles?

Q. Why are rockets so long?

Q. If rockets don't fly, why do they have fins?

Q. Why are rockets so streamlined?

Q. Why must rockets be balanced?

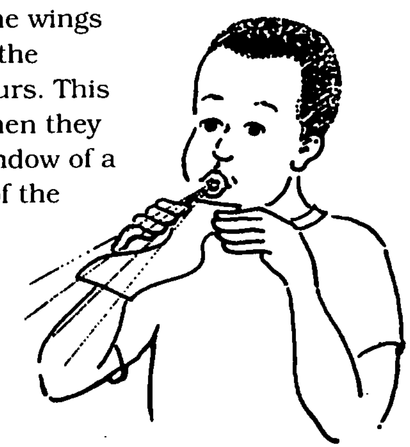
Use this lesson to help your group explore the answers to these questions while preparing them for additional learning. The answers to the questions may be explored through the use of student assisted demonstrations or actual hands-on involvement.

Discussion

Introduce the six questions to your group. Explain that they will be exploring the answers to these questions through a series of hands-on experiments. Be sure to emphasize that the goal of this lesson is to search for answers rather than memorize solutions.

Q: Do Rockets Really Fly?

A: Air is all around us. Our planet is surrounded by a layer of air called the atmosphere held in place by gravity. Although air can't be seen, it has substance. In fact, air has so much substance that it can hold up aircraft the size of a school bus through a force known as *lift*. On an airplane, lift is produced as the plane builds up speed for takeoff. As the plane races down the runway, the underside of its wings begin to rest upon an ever increasing force of air rushing beneath them. When the pressure of air under the wings is great enough to support the weight of the plane, lift occurs. This is same force people feel when they stick their hand out the window of a fast moving car. The force of the air hitting the palm of their hand can actually provide enough pressure to support it in mid air.



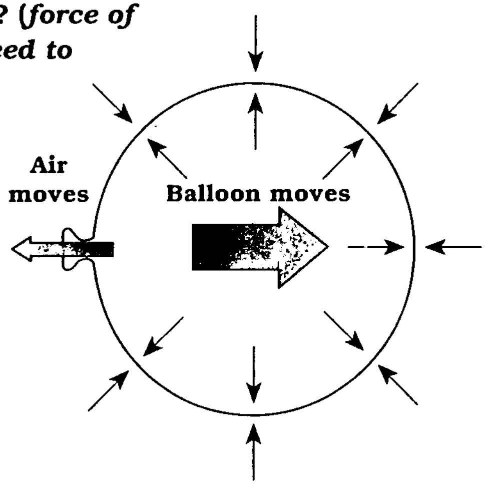
Experiment - Try a Little Lift

Materials: Strips of paper 2"x8"

Help your group see that an air stream has lifting power by blowing on a piece of paper. Cut a strip of paper 2 inches by 8 inches. Holding one end against their chin, have them blow on the strip. As they blow, an air stream forms and the strip flies up. Blow harder, and it flies higher. Stop blowing and it stops flying.

Guiding Questions

- **What would happen if you increased the size of the paper? (*force of air would need to increase*)**
- **Why is lift less of a factor for rockets. (*Rockets don't rely on a cushion of air for flight*)**



Digging Deeper

Although air is essential for the flight of airplanes and jets, the reverse can be said about wingless rockets. As you recall from the discussion of Newton's third law, the force of gas leaving a rocket's engine provides an equal and opposite force which lifts the rocket skyward. Compared to airplanes and jets which rely upon the atmosphere to lift and pull themselves along, rockets move without the need of atmosphere. This is especially essential for traveling the weightlessness of space where atmosphere is nonexistent.

Experiment - Action/Reaction

Materials: 5" balloons

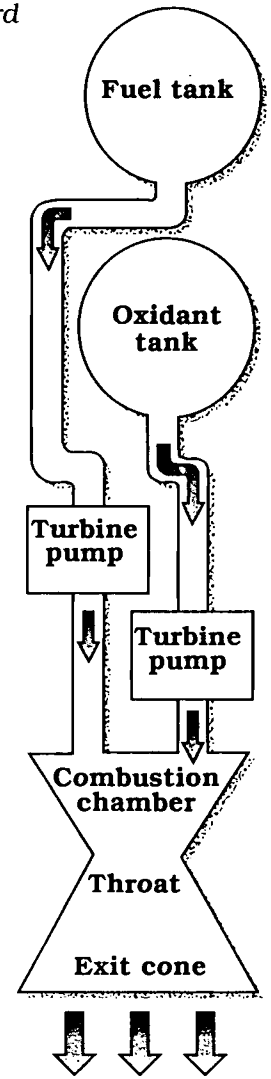
Take a 5 inch balloon and inflate it to capacity. Now, release the balloon and watch its movements. As the group will note, the air rushing from the balloon's open end provides an equal and opposite reaction of forward motion. (*Newton's 3rd Law*)

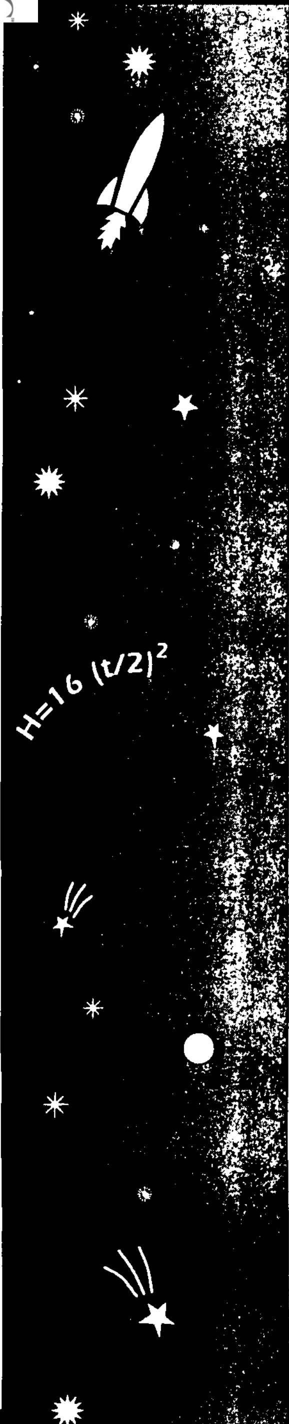
Guiding Questions

- **What would happen if you increased the size of the balloon? (*should see similar results*)**
- **What would happen if you added weight to the balloon? (*acceleration would decrease - Newton's 2nd law*)**

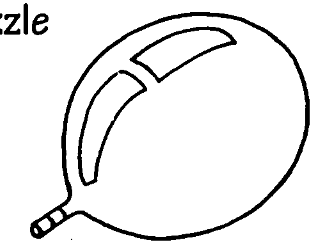
Q: Why Do Rocket Engines Have Nozzles?

A: The purpose of the nozzle is to increase the acceleration of the gases as they leave the rocket, thereby maximizing the thrust. It does this by cutting down the opening through which the gases can escape. The nozzle in a solid-propellant engine is an opening at the back of the rocket that permits the hot expanding gases to escape. The narrow part of the nozzle is the throat. Just beyond the throat is the exit cone.





Experiment - Add a Nozzle



Materials: drinking straws
scissors
tape
5" balloon

Using the 5 inch balloon from the earlier experiment insert a 1 inch piece of plastic drinking straw into its open end. Be sure the "rolled" end of the balloon is clipped off so that the balloon can be taped securely to the straw. Inflate the balloon then release it with the straw attached. Have the group note the change in the balloon's movement. Rather than flying wildly, it now moves in circles. As the group can see, the straw increases and directs the flow of air from the balloon.

Guiding Questions

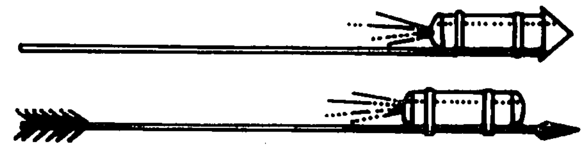
- **What would happen if you added length to the nozzle? (*Performance would eventually decrease*)**
- **What would happen if you decreased the diameter of the nozzle? (*Performance would eventually decrease*)**

Digging Deeper - Nozzles in everyday use.

If possible, help the group see how a nozzle works using a garden hose. Turn on the water and watch how it flows from the hose. Now put on a spray nozzle and observe the change in water leaving the hose. Try setting the nozzle down on a smooth surface while the water is running. Chances are the hose will begin to move. Can the group guess which of Newton's three laws of motion are at work? (*3rd law, action/reaction*)

Q: Why Are Rockets So Long?

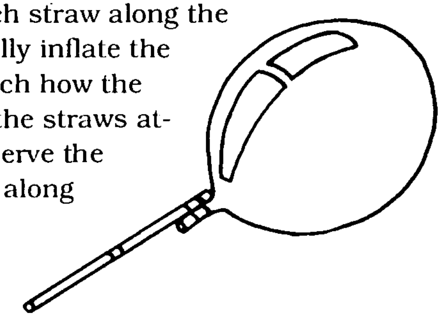
A: Building an efficient rocket engine is only part of the problem to producing a successful rocket. The rocket must also be stable in flight. Making a rocket stable requires some form of control system. The simplest of all controls is a stick. The Chinese fire-arrows were simple rockets mounted on the ends of sticks.



Experiment - Add a Stick

Materials: straws
tape
5" balloon

Take a plastic drinking straw and insert its end into another plastic straw. Cut one of the straws so that the total length of the two straws combined is 13 inches. Using the balloon with the nozzle attached from the earlier experiment, tape the 13 inch straw along the length of the nozzle. Carefully inflate the balloon then release it. Watch how the balloon rocket moves with the straws attached. Have the group observe the rocket's upward movement along with its slight rotation.

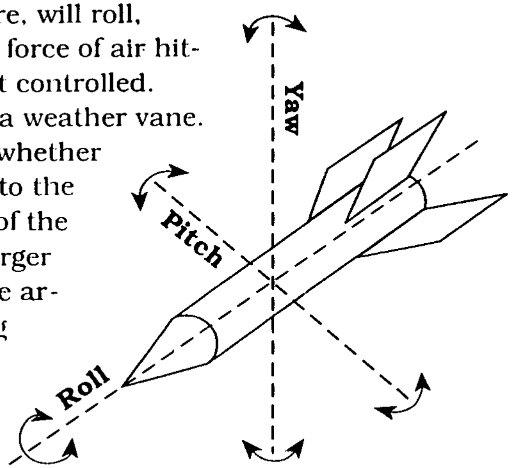


Guiding Questions

- **What would happen if you increased the length of the straw. (*the added weight would eventually decrease performance*)**
- **Why are the sticks on bottle rockets so long? (*To provide maximum control for safety*)**

Q: If Rockets Don't Fly, Why Do They Have Fins?

A: Rockets are stabilized by the effects of air movement on their fins which function as controls. Even a rocket, long in stature, will roll, pitch, and yaw if the force of air hitting its surface is not controlled. Think of a rocket as a weather vane. The reason that the whether vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail than the head, and therefore the tail is pushed away.

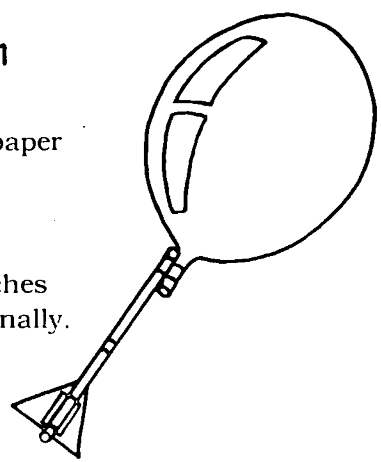


For a rocket to fly properly, pitch and yaw axes are the most important to control because any movement in either of these two directions will cause the rocket to go off course. The roll axis does not affect the flight path. In fact, a rolling motion will help stabilize the rocket the same way a properly passed football is stabilized by rolling in flight. However this rolling motion does tend to use up some of the energy needed for forward motion.

Experiment - Add a Fin

Materials: 3" squares of paper
tape
scissors

Take a piece of paper 3 inches square and cut it in half diagonally. (*The large "Post-Its" work well for this experiment.*)



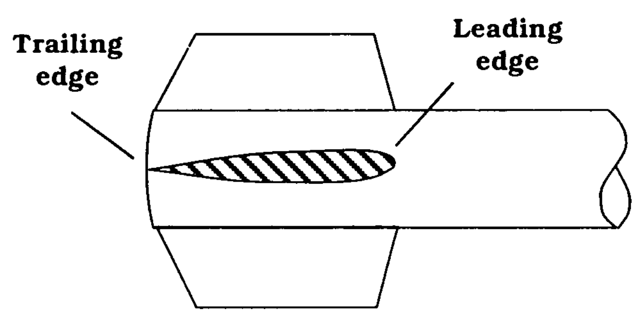
Using the balloon and straws from the earlier activity, tape the pieces of paper to the bottom of the straw as shown. Inflate the balloon then release it. Have group members note how the fins seem to help stabilize the flight of the balloon, especially its rolling motion.

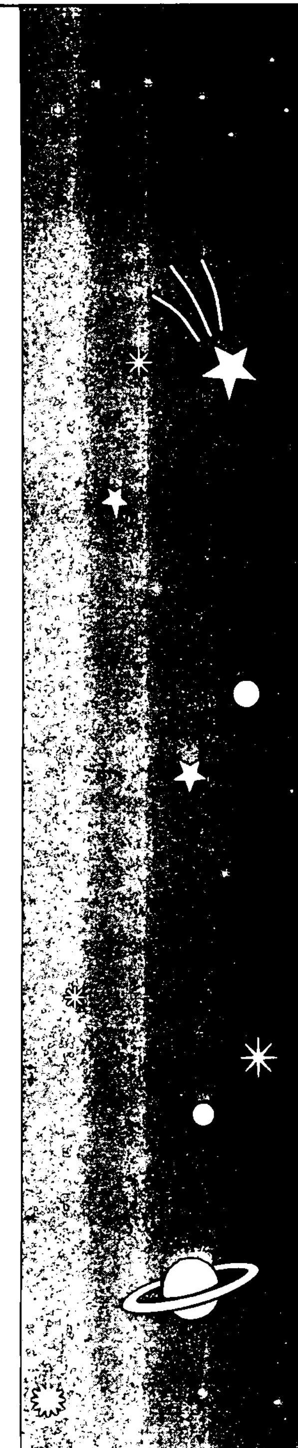
Guiding questions

- **Are there certain fin configurations that work better than others? (*yes*)**
- **What works better, two or four fins? (*two seem to work better due to less drag*)**
- **What happens if you used two balloons instead of one? (*greater thrust should increase performance - Newton's second law.*)**

Q: Why are rockets so Streamlined?

A: When a rocket is moving, friction from the atmosphere slows it down. Any part of the rocket that sticks out contributes to the problem. To reduce the amount of friction (or drag) on a rocket, it should be designed to slice cleanly through the air. A properly designed rocket is said to be *streamlined*. This means that air passing around the outside of an object flows in smooth lines. Poorly designed rockets, ones that produce drag, cause the air to tumble. The proper term for tumbling air is *turbulence*.

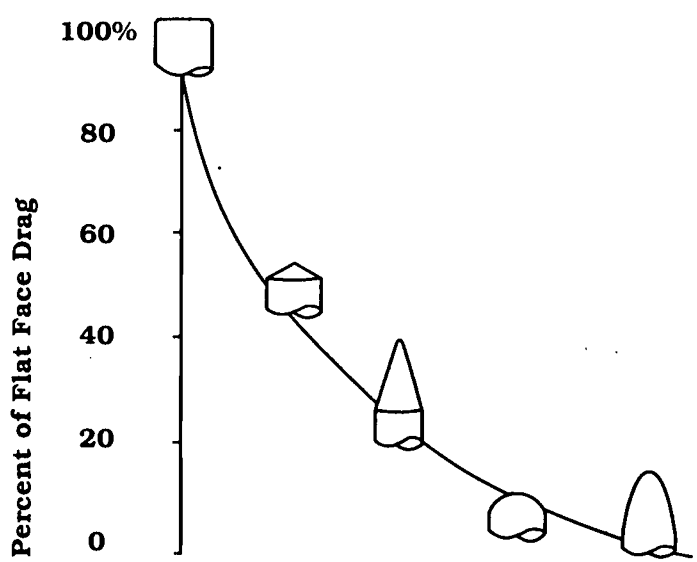




$H=16\,(t/2)^2$

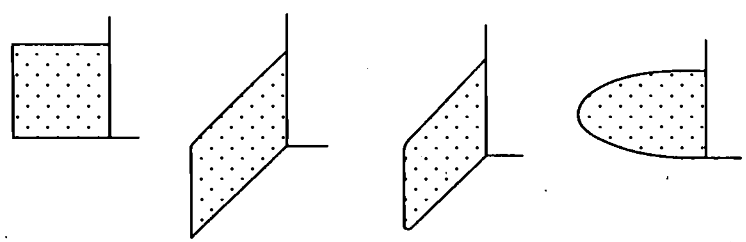
Nose Cones

The shape of the nose cone has a great effect on the amount of drag that a rocket experiences. A parabolic nose cone creates the lease amount of drag. A good length to width ratio is three to one.



Fins

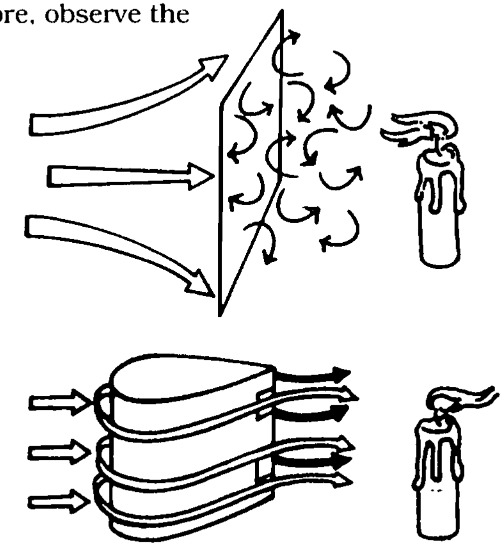
A swept back fin creates less drag than a straight or forward-swept fin. Also rounded corners on a fin create less drag than sharp corners.



Experiment - testing turbulence

Materials: construction paper
scissors

Cut a 2 inch square from a piece of construction paper. Hold the square about 2 inches in front of a burning candle and about 4 inches from you as shown in the illustration. Blow hard against the square and observe the movement of the flame. If the group sees any unusual movement in the flame they are observing turbulence. Now, take a 2 inch by 4 inch piece of construction paper and fold it into the shape of a wing as shown in the illustration. Blowing as before, observe the movement of the flame.



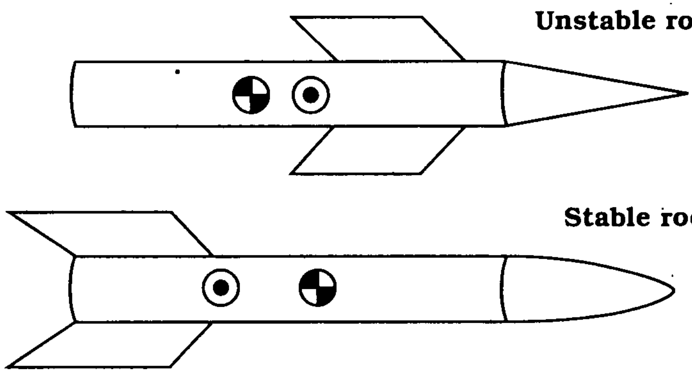
As the group will note, smooth, rounded surfaces produce less turbulence than flat ones. Of course, once in space, the shape of the rocket matters little. For example, our earth, which travels around the sun at a speed of 66,600 mph, has more in common with a bowling ball than a rocket.

Guiding Questions

- **Does the size of the paper generate more or less turbulence? (*Depends on the shape of the leading edge*)**
- **Does the smoothness of the paper generate more or less turbulence? (*May tend to produce less*)**

Q: Why must rockets be balanced?

A: There is an imaginary point in any rocket where there is exactly the same surface area on one side of the point as on the other. This spot is called the Center of Pressure (◉). There is also a spot in any rocket where all of its mass is perfectly balanced. This spot is known as its Center of Gravity (◐). In order for a rocket to remain stable while in the air or in the weightlessness of space, the ◉ and ◐ should be no closer than one-half the distance equal to the largest diameter of the body. If they are in the same place, or very near each other, the rocket will try to rotate about its center of gravity.



Experiment - Broom Launch

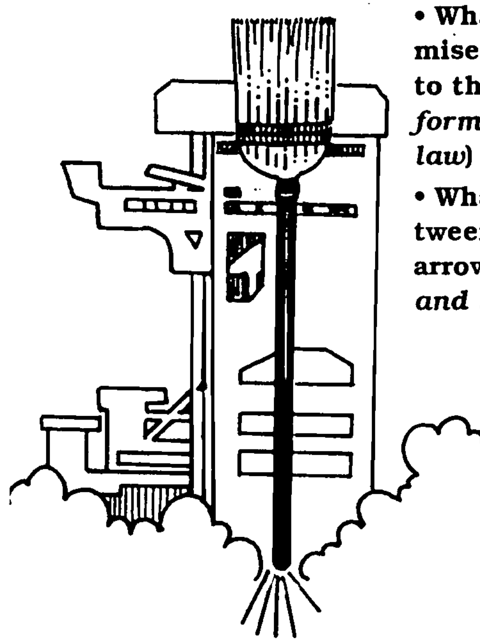
Materials: Broom

If you tried to toss the head of a broom into the air, it would begin to tumble around its center of gravity. That's because the center of gravity of a broom head and the center of pressure used to lift it are too close together. A rule of thumb is that the distance between the two points should be no less that 1/2 the largest diameter of the body.

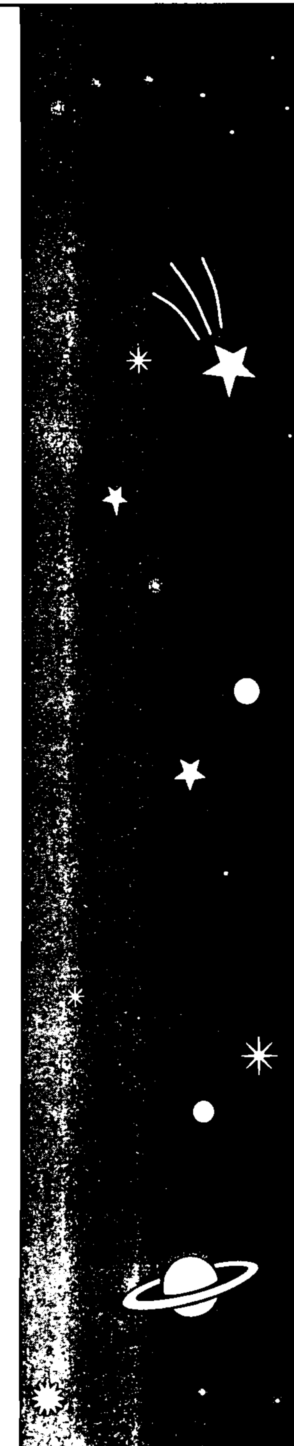
Test this by tossing an entire broom into the air. As the group will observe, the broom handle stabilizes the broom head by shifting the center of gravity away from the center of pressure. You can toss the broom all you want but it is difficult to spin it end over end. Not bad stability if it were a rocket. In fact, it would take an incredible amount of "unnatural" lateral pressure against its lower end to throw this type of rocket off course.

Guiding Questions

- **Where is the broom's center of gravity? (*its balancing point*)**
- **Where is the brooms center of pressure? (*the point at which a silhouette of the broom balances*)**
- **Does the length of the broom handle make a difference in the broom's stability? (*yes*)**
- **If the weight of the broom head was increased, would it become more or less stable? (*more stable*)**

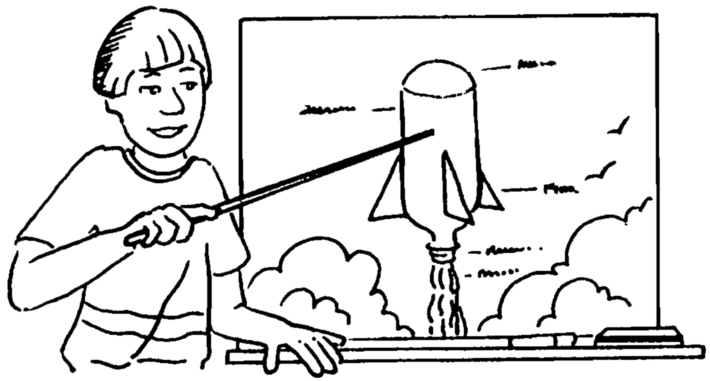


- **What do you compromise when adding weight to the broom head? (*performance - Newton's 2nd law*)**
- **What are similarities between the broom and an arrow? (*weight at the top and length*)**



$H=16(t/2)^2$

III. Let's Get Launching



Rocket Run-down

- ***Rockets need to be properly weighted for maximum stability.***
- ***Rockets need to be properly designed for maximum performance.***
- ***The altitude and velocity of model rockets can be determined mathematically.***
- ***Rocket fuel needs to be properly formulated and weighted to provide maximum thrust.***

Background

This lesson is designed to help the group apply what they learned in the previous two lessons through a unique step-by-step problem solving approach. This includes the design, construction, and launching of 2-liter bottle rockets. Be sure to photocopy the appropriate pages from this lesson and distribute them to group members. Time permitting, group members should be allowed to work at their own pace in teams of 2-3. You may need to have additional launchers on hand to cut down on the amount of wait time. Eventually, a friendly competition will occur between the groups to determine who built the best rocket. When this happens, use this as an opportunity for cooperative learning to take place.

For learners with access to an IBM compatible computer, an optional program is available to teach them about the proper design and flight configurations of 2-liter bottle rockets. This simulation program will help them solve problems like determining the proper design for a nose cone and tail fin, testing the proper ratio between fuel capacity and water pressure for maximum range, or determining the ideal weight for a 2-liter bottle rocket.

This diskette also contains a program for recording and analyzing launch data using 2 liter bottle rockets. This is a must for learners interested in perfecting the design of their 2 liter bottle rocket. As learners enter data based on the amount of water and pressure used for each launch, including the time it took from launch to landing, the program will determine altitude and speed of the rocket as well as predict ideal water/pressure ratios for future launches.

Discussion

Explain to the group that they are now going to build and test their own rockets. This will allow them to apply what they experienced in the previous two sessions. Begin by providing group members with a demonstration launch of a 2-liter bottle rocket. The instructions in this section provide you with all the information you need to design and build a successful 2-liter rocket.

During your demonstration launch, be sure to review with the group the *Warning and Operating Instructions* that came with the launcher. Stress the importance of "common sense" around the rockets. Just because the rocket uses a "friendly" fuel mixture of water and air pressure, doesn't mean they ignore the potential danger of the rocket under pressure. This discussion should also include an overview of the following launch procedures:

-Periodically check the pressure with a tire gauge.
- Do not exceed 140lbs of pressure
- Never look down on the rocket during or after pressurization
- Never aim the rocket at people, buildings, or other structures
-Always set up the rocket well away from any trees electrical wires, or buildings
- Be sure the launcher is firmly fastened to the ground
- Be sure to have an audible countdown to zero before pulling the launch pin.

Demonstration Launch - Is it a Rocket or an Engine?

Prepare to launch your bottle with no water and about 20 pounds of pressure. This should be done with the plastic base cap attached to the bottom of your bottle. Following proper safety procedures launch your bottle, then discuss the following Guiding Questions with the group.

Guiding Questions

Q. Did the bottle go straight up? (yes)

Q. Did it appear to be stable? (somewhat)

If the group could answer "yes" to either of these questions they probably could think of the bottle as a rocket. However, try filling the bottle with 25oz of water and pressurizing it to 70 lbs. After the launch, discuss the same questions.

Guiding Questions

Q. Did the bottle go straight up? (no)

Q. Did it appear to be stable? (no)

Chances are the group answered no to the above questions. What they need to realize is that the more thrust they apply to the bottle the less stable it becomes; making it more like an engine in need of a rocket.

Now launch a bottle that's been properly designed to perform as a rocket. Use this demonstration as a goal for the teams to achieve or even exceed. To accomplish this goal, start by photocopying and distributing the following "Rockets Away" section to group members. This section will provide them a step-by-step process for building a successful rocket while applying the principles learned in earlier lessons. Encourage team members to keep a journal of their observations.

Evaluating Performance

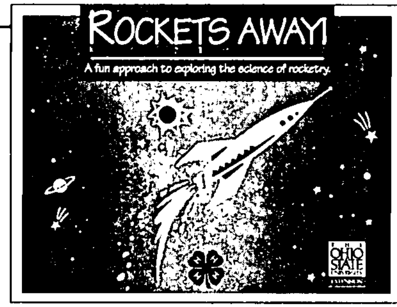
Once the teams have gathered some initial data on their rocket's performance, get them back together for some discussion. Have each team present their findings to the group. To highlight their findings, you may wish to have each team post their best launch results on an enlarged version of the "Record of Performance" chart found on page 25. Once the teams have reported, lead them in a discussion using the following questions.

- **Does more water mean better performance?**
- **Does more air mean better performance?**
- **Why did some rockets fly better than others?**
- **What happened when no water was used to launch the rocket?**
- **If you plotted the performance of your rocket at 70lbs of pressure with varying amounts of water, what would be the shape of the curve?**
- **Under the same conditions, would this curve look differently at different pressures?**

Extending the Learning

Time permitting, have the group complete the Digging Deeper and Going Beyond sections of the handout. These sections are designed to lead teams to further experimentation with their 2-liter bottle rocket.

Let's Get Building



As you observed from the initial demonstrations, as thrust from the bottle increased, the less stable the rocket became; making it more like an engine in need of a rocket. This reaction is similar to the releasing of an inflated balloon. To improve performance, you must first overcome the following problem in your rocket's design:

Check list

✔ **Center of pressure too close to the center of gravity.**

✔ **Too much resistance to wind.**

PROBLEM 1 - Center of Pressure too Close to the Center of Gravity

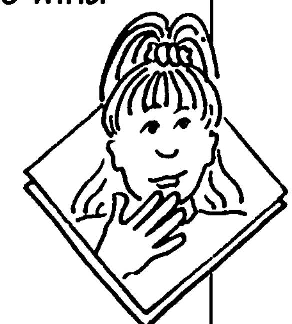
Materials: 2-liter soft drink bottle
duct tape
2 - 2 1/2" (*outside diameter) flat washers*
cardboard
scissors

Step 1: One way to change the center of gravity of an object is to increase its length. Just like you did with the balloon rocket. However center of gravity can also be changed by adding weight to one end. To do this, attach (*with duct tape*) two 2 1/2" (*outside diameter*) flat washers, or an equivalent of 6oz, to the rounded end of your bottle. Be sure to remove the plastic base cap (*if any*) before attaching the washers to your bottle.

Step 2: Once in place, test your rocket's center of gravity. Do this by seeing where it balances along your finger. Once determined, mark that spot on the rocket with a piece of tape. Now test the rocket's center of pressure by cutting a silhouette of the rocket out of cardboard and balancing it on your finger. The point where the silhouette balances is your rocket's center of pressure. [Remember, the distance between the center of gravity and center of pressure should be no closer than one-half the distance equal to the largest diameter of the body.]

Explanation - The mass of the washers at the top of the bottle moves the bottle's center of gravity away from its center of pressure. Because the mass of the washers is safely away from the rocket's center of pressure, the washers tend to "pull" the rest of the rocket behind them.

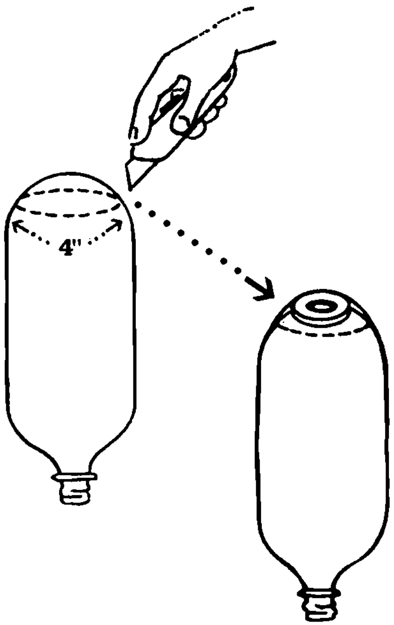
PROBLEM 2: Too much resistance to wind

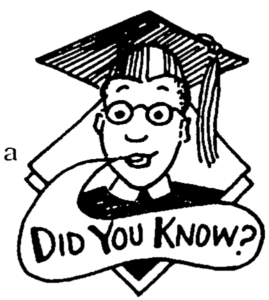


Materials: 2-liter soft drink bottle
scissors
exacto-type knife
8"x8" corrugated cardboard
duct tape
bobby pins
ruler

There are two factors to consider when talking about wind resistance; drag and turbulence. Drag is caused when the surface of the rocket resists the flow of air moving over its surface. If you removed the label from the bottle, and taped sparingly, you should encounter minimal drag on the surface of your rocket. Turbulence, on the other hand is caused when irregularly shaped surfaces or features trap the flow of air moving across the surface of the rocket. Let's try focusing our attention on deceasing the amount of turbulence caused by the rocket's design.

Step 1: Inspect your rocket for any likely causes of turbulence. What should come to your immediate attention is the irregularity caused by the attachment of weight to your rocket's nose section. This is an obvious generator of turbulence. To correct this problem, fasten a nose cone to your rocket. This can be done by cutting the rounded bottom from another 2-liter bottle and attaching to the end of your rocket. This will help soften the flow of air over the top of your rocket. Just be sure to scrape off any hot glue that may have remained after you removed the bottle's plastic base cap.

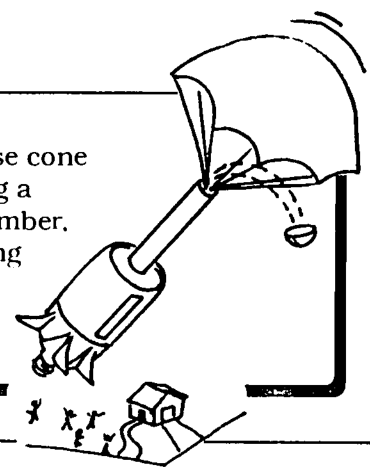




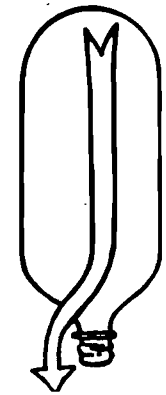
Did You Know - Ever wonder why a real rocket has a pointed nose? It is to provide stability as the rocket breaks the sound barrier. However, the best nose cone designfor a low velocity model rocket is a aparable.

Challenge

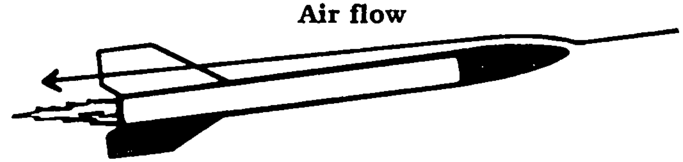
Think of a way for the nose cone to pop off on decent, releasing a parashute or streamer. Remember, your rocket will be accelerating back to earth at a velocity of 32 feet/second.



Step 2: Next, consider the neck of your 2-liter bottle rocket as a possible culprit of turbulence. What do you think happens once the air flowing along the surface of your rocket reaches this point? As this rush of air comes together at the neck end of the bottle it does so in a swirling motion, causing the base to swivel as well.



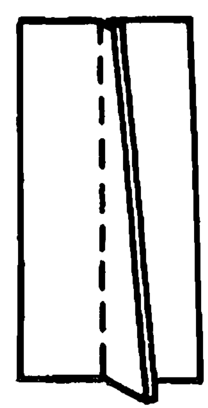
To control this movement, try adding fins to the base of your rocket. This will also assure that any deflecting forces on the rocket's nose cone will be counterbalanced by the by the aerodynamic stability of the tail fins. (*Just as fins were added to stabilize the bottom of your balloon rocket.*)

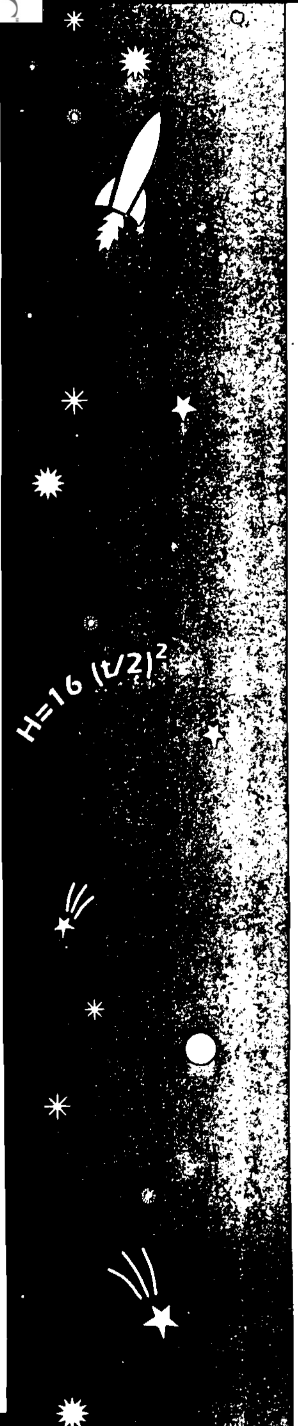


When properly designed, the deflecting force upon the nose of the rocket is counterbalanced by the aerodynamic forces on the fins.

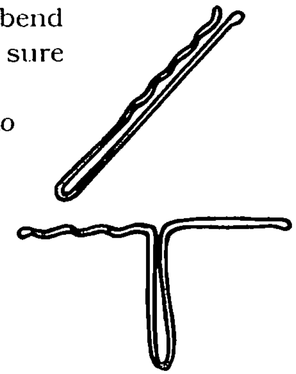
Step 3: Building Tail Fins

Using an exacto-type knife and the pattern on the following page, cut out three tail fins from an 8"x8" piece of corrugated cardboard. Be sure the pattern is placed parallel to the corrugated "ribbing" of the cardboard. Once cut, split open the 1" section of cardboard that extends beneath the triangular portion of the fin. When opened, this portion should be at a right angle to the fin.

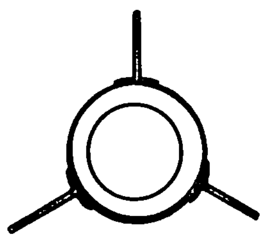




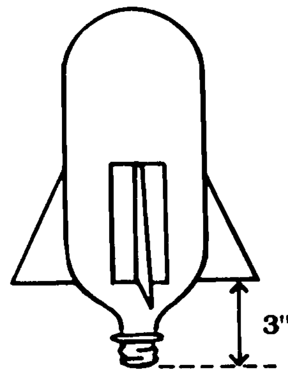
Next, take two bobby pins and bend them into the shape of a "T". Make sure the top of the "T" is at least 1 1/2" wide. Insert the two bobby pins into one of the fins so that the "T" portion of the bobby pin rests against the extended portion of the fin. The bobby pins are used to stiffen the fins during flight. Repeat this step for each fin.



Once completed, mount your fins with duct tape to your bottle as shown. (*Be sure your fins are properly aligned and spaced. The bottom of your fins should be about 3" away from the "open" end of your bottle.*)

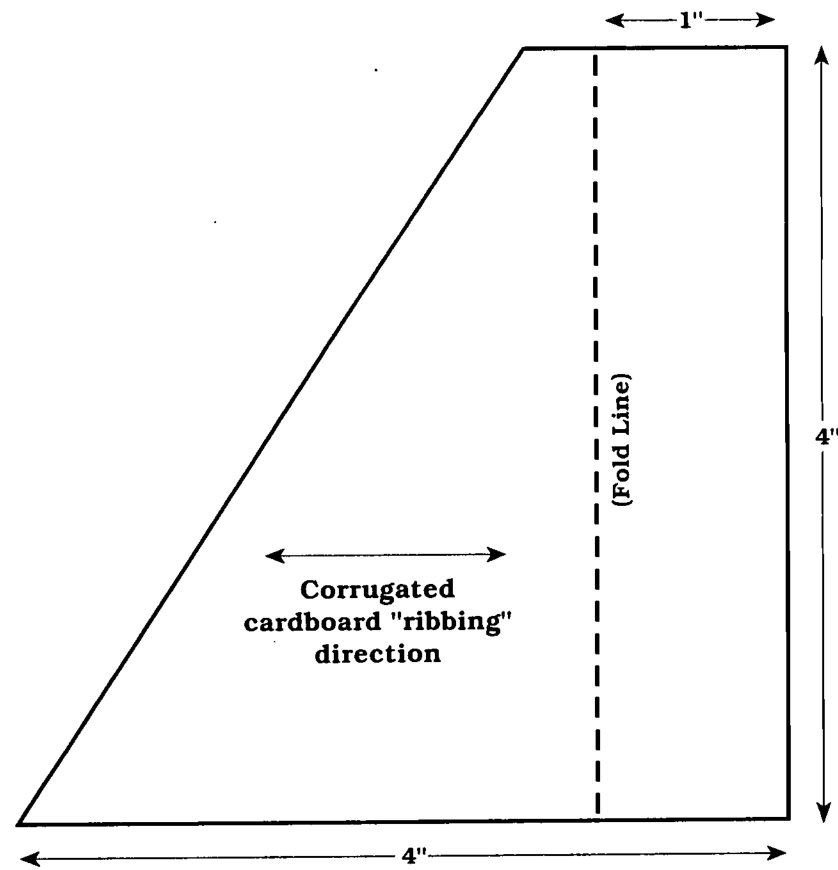


Fins, top view



Fins, side view

Fin pattern:



Moving Upward

Before you begin to test the initial performance of your rocket, you most likely will want a standard for comparison. The best measures of performance are altitude and velocity. Your challenge is to come up with a reliable method for obtaining this data. This leads you to your last problem before liftoff.

PROBLEM 3 - Measuring the altitude and velocity of your rocket

Materials: Calculator

One method of finding out how high your rocket went is to time the interval in seconds between launch and landing. Once known, you can determine the altitude of you rocket using the following formula H=16(t/2)2; where H is the altitude, and t is the time in seconds. For example, let's say it took 4 seconds from launch to landing. You would first divide 4 by 2, which would give you 2. You would then square 2, giving 4 (*you square a number by multiplying it by itself*), and multiplying this by 16. In this example, your rocket would have reached an approximate height of 64 feet.

To determine your rocket's velocity, take the number of seconds it took from launch to landing and divide it by 2. Then take the height that it traveled and divide it by the number of seconds you just calculated. This will give you a number called "feet per second". To convert this number into miles per hour multiply it by 0.68.

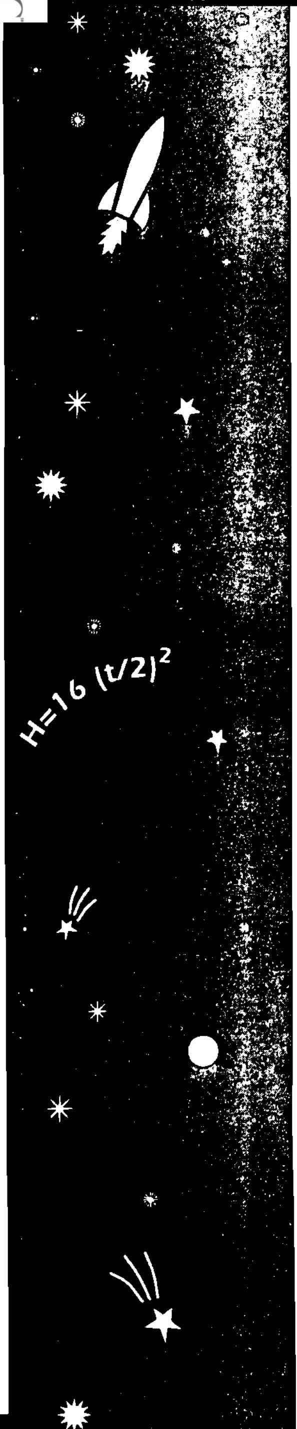
Using the first example, the rocket took 4 seconds from liftoff to landing. Next, divide this number by 2 which would give you 2 seconds. You would then take the height it traveled (*64 feet*) and divide it by 2 seconds, giving you a speed of 32 feet/second. Multiply 32 by a factor of 0.68 and you get an average velocity of 21.76 miles per hour.

Let's Get Launching

Proceed to the launch area with your rocket. Before you launch observe the following procedures:

- Periodically check the pressure with a tire gauge.
- Do not exceed 140lbs of pressure
- Never look down on the rocket during or after pressurization
- Never aim your rocket at people, buildings, or other structures
- Always set up your rocket well away from any trees, electrical wires, or buildings
- Be sure the launcher is firmly fastened to the ground
- Be sure to have an audible countdown to zero before pulling the launch pin.

Try several launches at varying amounts of water and pressure. A good place to start is about 25 ounces of water and 75 lbs. As you launch your rocket include in your observations the number of seconds from launch to landing as well as any signs of instability. Use the chart below to record your data.



Record of Launches

	Onces of Water	Air Pressure	Height	Velocity
Launch #1				
Launch #2				
Launch #3				
Launch #4				
Launch #5				
Launch #6				
Launch #7				
Launch #8				
Launch #9				
Launch #10				

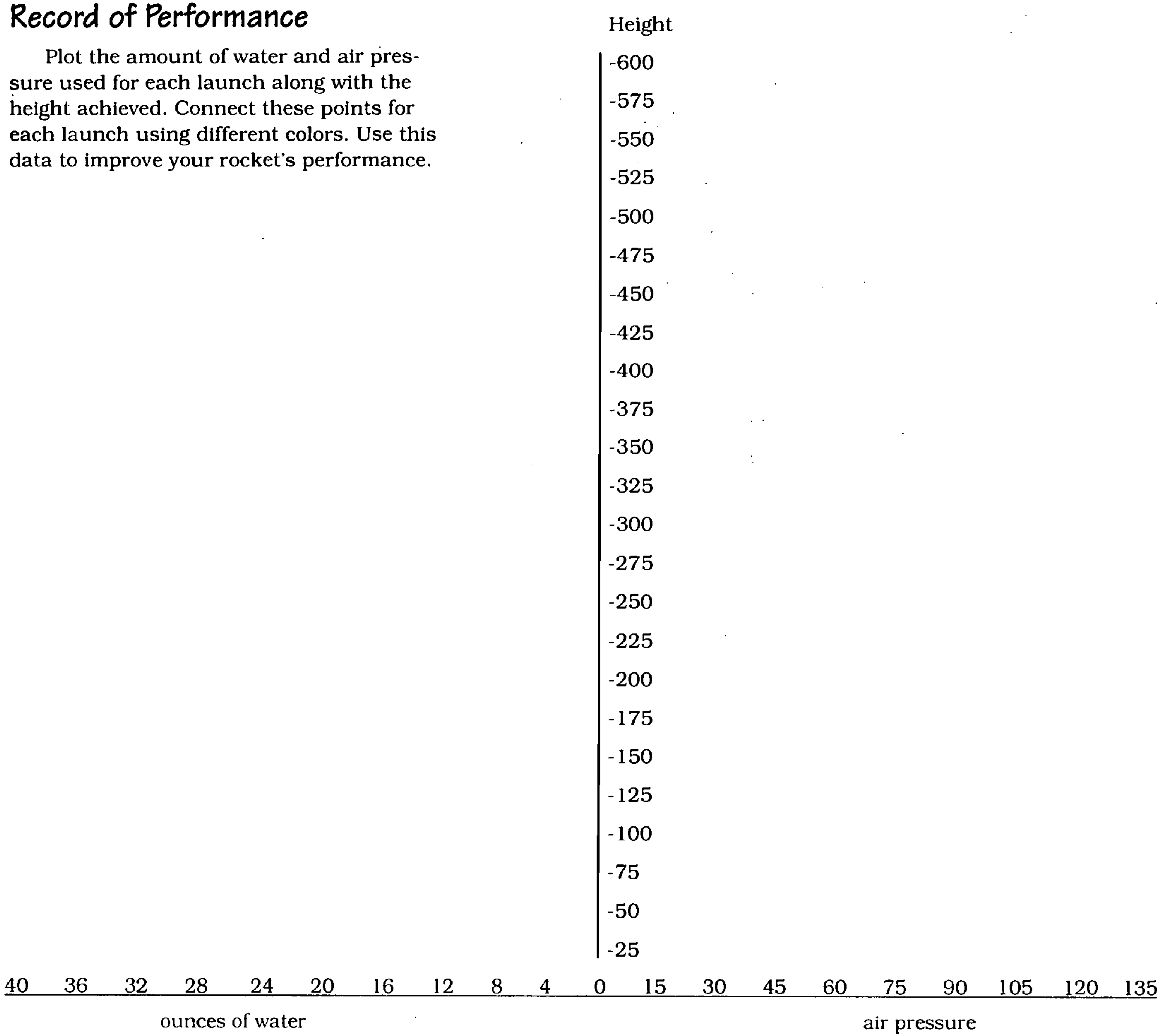
Evaluating Performance

Once you completed your launches and calculations, record the performance of your rocket in the chart below. Share this information with your group in order to make some assumptions about how 2-liter bottles perform. When discussing your data, consider the following questions:

- Does more water mean better performance?
- Does more air mean better performance?
- Why did some rockets fly better than others?
- What happened when no water was used to launch the rocket?
- If you plotted the performance of your rocket at 70lbs of pressure with varying amounts of water, what would be the shape of the curve?
- Under the same conditions, would this curve look differently at different pressures?

Record of Performance

Plot the amount of water and air pressure used for each launch along with the height achieved. Connect these points for each launch using different colors. Use this data to improve your rocket's performance.



Digging Deeper

Let's Continue

Based on your initial launches, you're probably wondering how to make your rocket go as fast as possible. To do this you need to consider Newton's second law of motion. This is the law which says that in order to increase the acceleration of an object you either need to decrease its mass or increase the amount of thrust used against the object. Therefore, to increase the performance of your rocket you need to overcome the following problems:

Check list

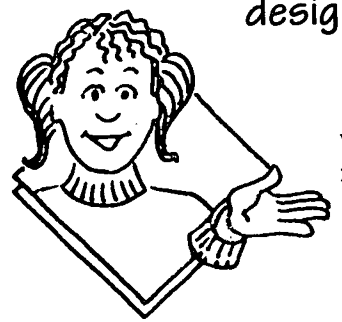
- ✔ **Minimizing the rocket's weight without compromising stability.**
- ✔ **Improving the rocket's design.**

PROBLEM 4 - Decrease rocket weight without compromising stability.

The best way to decrease the weight of your rocket is to remove one of the washers you added to shift the center of gravity away from its center of pressure. However, with less "moving mass" you may increase the rocket's susceptibility to air turbulence. You also risk moving the rocket's center of gravity too close to its center of pressure. Try adjusting the weight at the top of your rocket while maintaining stability and performance.

54

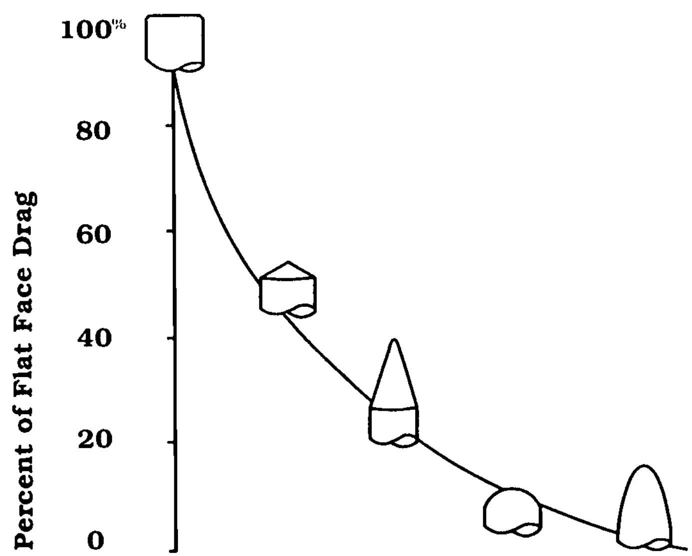
PROBLEM 5: Improving your rocket's design



Consider the following facts when improving upon your rocket's design:

• Nose Cones

The shape of the nose cone has a great effect on the amount of drag that a rocket experiences. A parabolic nose cone creates the least amount of drag. A good length to width ratio is three to one.



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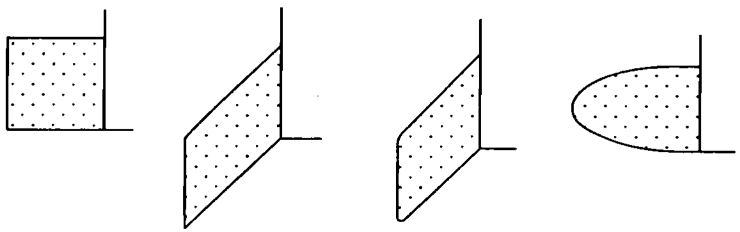
• Fins

A swept back fin creates less drag than a straight or forward-swept fin. Also rounded corners on a fin create less drag than sharp corners.

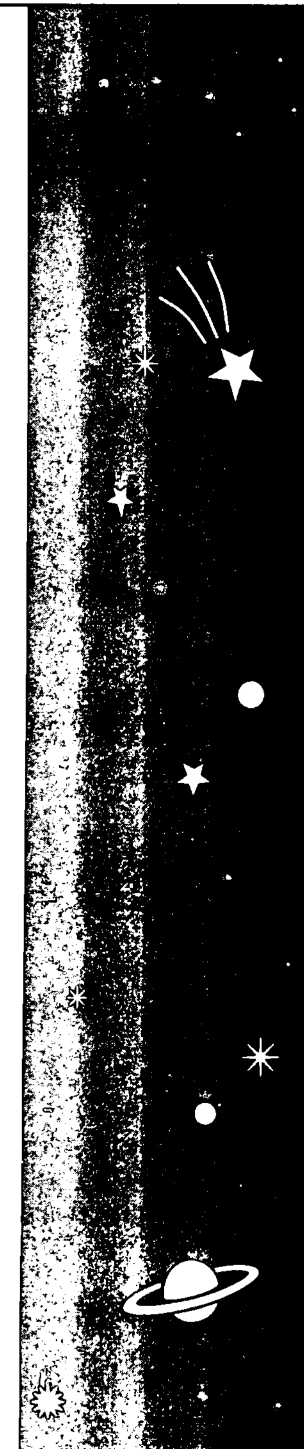


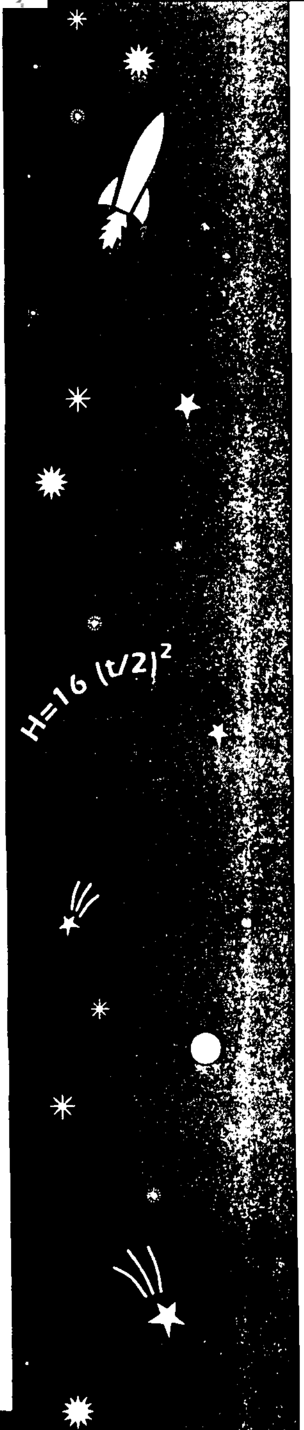
• Center of Gravity

Another alternative to minimizing the weight of an object while moving its center of gravity away from its center of pressure is to make it longer; just like the Chinese did with their fire arrows.

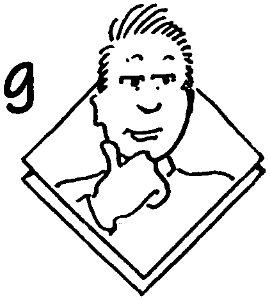
• Surface

Smooth surfaces cause less drag than rough surfaces.





Going Beyond - Rocket Staging



Materials: 16oz tall plastic cup
2-liter bottle with base cap

Have you ever wondered why rockets are assembled in stages? To enable rockets to accelerate to higher elevations with greater payloads, designers must minimize the rocket's mass while maximizing the amount of force exerted from its engines. This is typically accomplished by igniting engines in stages. This allows depleted engines to be separated away from the main rocket, thereby decreasing the rocket's mass while increasing its acceleration. Try the following activity to explore this method further.

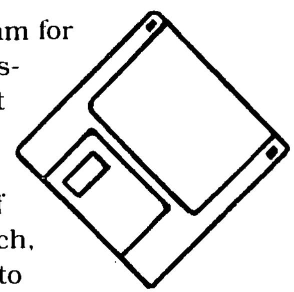
Activity: Take an empty 2 liter bottle, (*with its base cap in place*), fill it with 20 ounces of water, and place it on the launcher. Pressurize the bottle to 50 lbs. Now take something like a plastic sports bottle or a tall 16oz plastic drinking cup. Fill the container with 12 ounces of water and place it on top of the bottle. Now, launch the bottle and note what happens.

Explanation - What you should have observed is an example of rocket staging. Once the bottle ran out of thrust, its reduced mass made it more susceptible to the forces of wind and gravity. However, if you noticed the water filled container, it should have continued to climb just like the second stage of a rocket. This is because the container had more "mass in motion" (*kinetic energy*) which allowed it to resist the forces of wind and gravity for a longer period. This experiment can be likened to a train traveling along side a car at 50 mph. Although both are traveling at the same rate of speed, the train would take a lot longer to stop due to its enormous mass.

58

Computer Assistance

For groups with access to a computer, an IBM compatible program is available to assist in perfecting your 2-liter bottle rocket. This simulation program will help you solve problems like determining the proper design for a nose cone and tail fin, testing the proper ratio between fuel capacity and water pressure for maximum range, and determining the ideal weight for a 2-liter bottle rocket.



This diskette also contains a program for recording and analyzing launch data using 2 liter bottle rockets. This is a must for groups interested in perfecting the design of their 2 liter bottle rocket. As data is entered based on the amount of water and pressure used for each launch, including the time it took from launch to landing, the program will automatically determine altitude and speed of the rocket as well as predict ideal water/pressure ratios for future launches.

59

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