



Ares: Launch and Propulsion

An Educator Guide with Activities in Science and Mathematics



Educational Product	
Educators	Grades 5 – 12

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**This Educator Guide uses Traditional U.S. units of measure as the standard. Metric units follow in (parenthesis). In cases when a given formula is traditionally calculated in metric units, for mathematical correctness, it is presented in that manner.*

NOTE: The Ares vehicles are a preliminary design configuration and will be subject to change as the design progresses.

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Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Overview: Science Module

Introduction

In *Ares: Launch and Propulsion*, students become familiar with how rockets are launched. They also learn how and why specific rockets are chosen for various payloads. This module gives students a hands-on opportunity to experiment with variables that might affect the performance of a launch vehicle. Working in teams, students investigate one variable in detail by performing tests. By completing these tests, students will learn the various aspects involved in launching a rocket. In the assessment, students engage in a competition wherein they apply what they have learned about rockets to build a launch vehicle that flies as high as possible.

Curriculum Connections

This module contains fourteen hands-on activities for students. Through effective questioning, teachers facilitate students developing awareness of Newton's Laws of Motion as they apply to rockets. Correlations to National Standards are noted for each activity.

Teacher Guide Descriptions

Pop Rocket Variables: In this introductory activity, students study the concept of variables in relationship to launching pop rockets. Students will complete a concept map to demonstrate their knowledge of rockets.

Pop Goes Newton: Students continue to study the concept of variables in relation to launching pop rockets. The lesson has the students applying each of Newton's Laws of Motion to the "Pop Rocket Variable" activity.

The History of Rocketry: In this activity, students create a multiple tiered timeline on the history of rocketry from ancient times through the Ares Projects.

Launching Ares: The student activities in the "Launching Ares" section can be used to create interest in why the Ares missions are critical for returning to the Moon. Students work in groups to determine how to transport construction items and determine the payload and sequence for the transportation.

Investigating Water Rockets: In both the abbreviated and comprehensive approach students will get a complete overview of the safety issues with building and launching rockets. Students will complete activities on measuring altitude, fin shape and size, propulsion, and more.

Fly Me High: During this performance assessment, students will work in their design groups to design, build, and test launch a water rocket. Students will share their findings with the rest of the class.

You Get What You Pay For: This optional activity incorporates an economic component into the module. Students will be given a budget of \$150,000 to spend on subcontractors and materials for construction.

Role of Student

Students will work in teams to learn about various aspects of launching a water rocket related to propulsion. Students will investigate the shape, size, number, and placement of fins, as well as the nose cone shapes. Students then take the information learned in the expert groups back to their design group in order to design and build a water rocket that will fly as high as possible.

Multimedia Files

NASA Ares I Crew Launch Vehicle: Video with Bob Armstrong.

NASA Ares V Cargo Launch Vehicle: Video with Bob Armstrong.

Why Two Rockets? Video with Bob Armstrong.

Getting Ready for Launch: Video with Joel Best.

Why Go to the Moon? Video with Joel Best.

Launch Period vs. Launch Window: Audio with Kris Walsh.

Mission Integration Managers: Audio with Kris Walsh.

The multimedia files were developed especially for this module and are to be used as background information for the teacher and in conjunction with the classroom lessons. They can be downloaded along with the module. The video segments are also available online at:

http://www.nasa.gov/mission_pages/constellation/ares/ares_education.html

Interaction/Synthesis

In this phase of the learning cycle, student/peer interactions are emphasized. These activities contain work to be done in expert groups, with the whole class participating in the safety rules found in the appendices. Once students have had time to explore the rocket variables in these activities, they return to their original design groups to build and test their water rockets.

Teachers have two options for implementing this Interaction/Synthesis activity: a comprehensive version in which each design (expert) team studies different variables and a more abbreviated version with fewer variables to investigate, some of which are studied collectively as a class, thereby requiring less class time and teacher preparation. The following synopsis of the two approaches will enable teachers to choose what best meets their needs.

Interaction/Synthesis Assessment	Comprehensive Approach	Abbreviated Approach
Safety Rules/Safety Checklist	Yes	Yes
Measuring Altitude	Yes	Yes
Nose Cone Group	Yes	No (While the nose cone is not tested, it should be constructed for the final assessment)
Fin Number and Placement	Yes	No
Fin Shape and Size	Yes	Yes
Volume of Water	Yes Individually in expert groups	Yes As a class
Pressure of Water	Yes	No
Weather or Not	Yes	No
You Get What You Pay For	Optional	No
Fly Me High (Assessment)	Yes	Yes

In the assessment activity, “Fly Me High,” students are asked to combine what they have learned in this module with the skills needed to launch a water rocket to as high an altitude as possible. In the optional activity, “You Get What You Pay For,” students are responsible for building a budget for the activities undertaken in both the Interaction/Synthesis and assessment sections of this module.

Curriculum Connections

National Science Standards Addressed

Grades 5–8

Science as Inquiry

- Understandings about scientific inquiry.
- Abilities necessary to do scientific inquiry.

Physical Science

- Properties and changes of properties in matter.
- Motion and forces.
- Interactions of matter and energy.

Science and Technology

- Understandings about science and technology.
- Abilities of technological design.

History and Nature of Science

- History of science.
- Science as a human endeavor.

Science in Personal and Social Perspectives

- Science, technology, and society.
- Personal health.

Grades 9–12

Science as Inquiry

- Understandings about scientific inquiry.
- Abilities necessary to do scientific inquiry.

Physical Science

- Structure and properties of matter.
- Chemical reactions.
- Motion and forces.

Science and Technology

- Understandings about science and technology.
- Abilities of technological design.

History and Nature of Science

- Historical perspectives.
- Science in personal and social perspectives.
- Personal and community health.

Mathematics Standards Addressed

Grades 6–8

Number and Operations

- Compute fluently and make reasonable estimates.

Measurement Standard

- Understand measurable attributes of objects and the units, systems, and processes of measurement.
- Apply appropriate techniques, tools, and formulas to determine measurements.

Problem Solving Standard

- Solve problems that arise in mathematics and in other contexts.

Grades 9–12

Measurement Standard

- Understand measurable attributes of objects and the units, systems, and processes of measurement.

Problem Solving

- Solve problems that arise in mathematics and in other contexts.

National Educational Technology Standards Addressed

Grades 6–8

Technology Standards

- Use content specific tools, software, and simulations to support learning and research.
- Collaborate with peers, experts, and others using telecommunications and collaborative tools to investigate curriculum-related problems, issues, and information, and to develop solutions or products or audiences inside and outside the classroom.

Grades K–12

Technology Standards

- Technology productivity tools.

Technology Research Tools

- Students use technology to locate, evaluate, and collect information from a variety of sources.

Technology Problem-solving and Decision-making Tools

- Students use technology resources for solving problems and making informed decisions.

Economic Standards Addressed

Grades 6–8

- Understands that scarcity of productive resources requires choices that generate opportunity costs.
- Knows that all decisions involve opportunity costs and that effective economic decision-making involves weighing the costs and benefits associated with alternative choices.
- Understands that the evaluation of choices and opportunity costs is subjective and differs across individuals and societies.

History Standards Addressed

Grades 6–8

Historical Understanding

- Understands and knows how to analyze chronological relationships and patterns.
- Knows how to construct and interpret multiple-tier time lines.

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Rocket Principles

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

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

One of the interesting facts about the historical development of rockets is that while rockets and rocket-powered devices have been in use for more than 2000 years, it has been only in the last 300 years that rocket experimenters have had a scientific basis for understanding how they work.

The science of rocketry began with the publication of a book in 1687 by the great English scientist Sir Isaac Newton. His book, entitled *Philosophiae Naturalis Principia Mathematica* (*Principia: Mathematical Principles of Natural Philosophy*), described physical principles in nature. Today, Newton's work is usually just called the *Principia*.

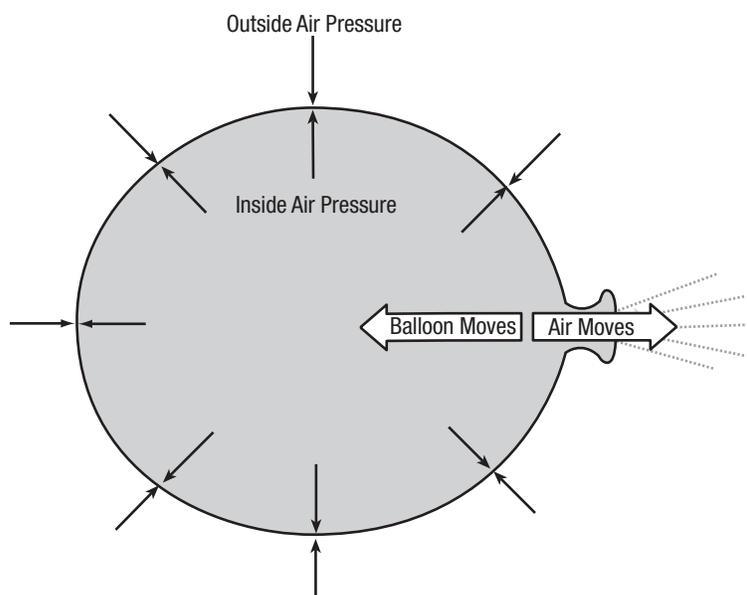
In the *Principia*, Newton stated three important scientific principles that govern the motion of all objects, whether on Earth or in space. Knowing these principles, now called Newton's Laws of Motion, rocketeers have been able to construct the modern giant rockets such as the Saturn V and the Space Shuttle of the 20th century. Here now, in simple form, are Newton's Laws of Motion:

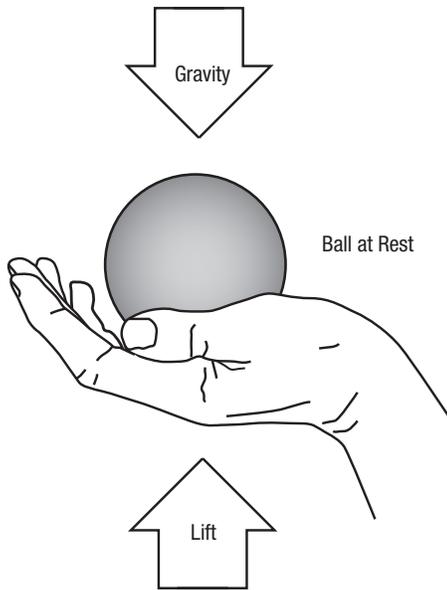
1. Objects at rest will stay at rest, and objects in motion will stay in motion in a straight line, unless acted upon by an unbalanced force.
2. **Force** is equal to **mass** times **acceleration**. $F = ma$
3. For every action, there is always an opposite and equal reaction. As will be explained shortly, all three laws are really simple statements of how things move. But with them, precise determinations of rocket performance can be made.

Newton's First Law

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

Rest and motion can be thought of as being opposite to each other. Rest is the state of an object when it is not changing position in relation to its surroundings. If you are sitting still in a chair, you can be said to be at rest. This term, however, is relative. Your chair may actually be one of many seats on a speeding airplane. The important





thing to remember here is that you are not moving in relation to your immediate surroundings. If rest were defined as a total absence of motion, it would not exist in nature. Even if you were sitting in your chair at home, you would still be moving, because your chair is actually sitting on the surface of a spinning planet that is orbiting a star. The star is moving through a rotating galaxy that is, itself, moving through the universe. While sitting “still,” you are, in fact, traveling at a speed of hundreds of miles or kilometers per second.

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

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

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

Objects in space also react to forces. A spacecraft moving through the solar system is in constant motion. The spacecraft will travel in a straight line if the forces on it are in balance. This happens only when the spacecraft is very far from any large gravity source, such as Earth or the other planets and their Moons. If the spacecraft comes near a large body in space, the gravity of that body will unbalance the forces and curve the path of the spacecraft. This happens, in particular, when a satellite is sent by a rocket on a path that is tangent to the planned orbit about a planet. The unbalanced gravitational force causes the satellite's path to change to an arc. The arc is a combination of the satellite's fall inward toward the planet's center and its forward motion. When these two motions are just right, the shape of the satellite's path matches the shape of the body it is traveling around. Consequently, an orbit is produced. Since the gravitational force changes with height above a planet, each altitude has its own unique velocity that results in a circular orbit. Obviously, controlling velocity is extremely important for maintaining the circular orbit of the spacecraft. Unless another unbalanced force, such as friction with gas molecules in orbit or the firing of a rocket engine in the opposite direction, slows down the spacecraft, it will orbit the planet forever.

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

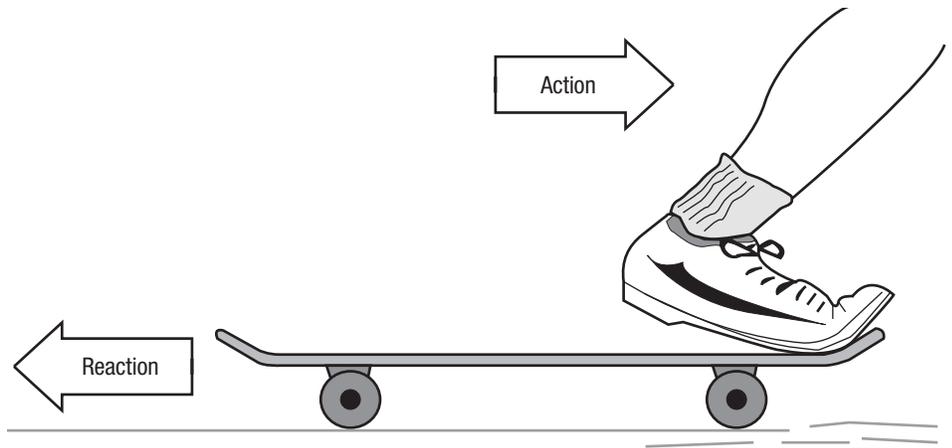
Newton's Third Law

For the time being, we will skip the Second Law and go directly to the third. This law states that every action has an equal and opposite reaction.

Rockets can lift off from a launch pad only when it expels gas out of its engine. The rocket pushes on the gas, and the gas in turn pushes on the rocket. The whole process is very similar to riding a skateboard. Imagine that a skateboard and rider are in a state of rest (not moving). The rider jumps off the skateboard. In the Third Law, the jumping is called an action. The skateboard responds to that action by traveling some distance in the opposite direction. The skateboard's opposite motion is called a reaction. When the distance traveled by the rider and the skateboard are compared, it would appear that the skateboard has had a much greater reaction than the action of the rider.

This is not the case. The reason the skateboard has traveled farther is that it has less mass than the rider. This concept will be better explained in a discussion of the Second Law.

With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the weight of the rocket. While on the pad, the weight of the rocket is



balanced by the force of the ground pushing against it. Small amounts of thrust result in less force required by the ground to keep the rocket balanced. Only when the thrust is greater than the weight of the rocket does the force become unbalanced and the rocket lifts off. In space, where unbalanced force is used to maintain the orbit, even tiny thrusts will cause a change in the unbalanced force and result in the rocket changing speed or direction.

One of the most commonly asked questions about rockets is how they can work in space where there is no air for them to push against. The answer to this question comes from the Third Law. Imagine the skateboard again. On the ground, the only part air plays in the motions of the rider and the skateboard is to slow them down. Moving through the air causes friction, or as scientists call it, drag. The surrounding air impedes the action-reaction. As a result rockets actually work better in space than they do in air. As the exhaust gas leaves the rocket engine it must push away the surrounding air; this uses up some of the energy of the rocket. In space, the exhaust gases can escape freely.

Newton's Second Law

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

$$F = ma$$

The equation reads “force equals mass times acceleration.” To explain this law, we will use an old-style cannon as an example. When the cannon is fired, an explosion propels a cannonball out the open end of the barrel. It flies a mile or kilometer or two to its target. At the same time, the cannon itself is pushed backward a few yards or meters. This is action and reaction at work (Third Law). The force acting on the cannon and the ball is the same. The Second Law determines what happens to the cannon and the ball.

Look at the following two equations.

Force equals the **mass** of the cannon times the **acceleration** of the cannon.

$$F = ma$$

Force equals the **mass** of the ball times the **acceleration** of the ball.

$$F = ma$$

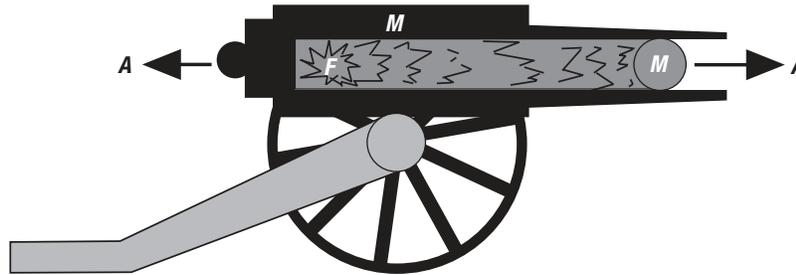
The first equation refers to the cannon and the second to the cannonball. In the first equation, the mass is the cannon itself, and the acceleration is the movement of the cannon. In the second equation, the mass is the cannonball, and the acceleration is its movement. Because the force (exploding gun powder) is the same for the two equations, the equations can be combined and rewritten as follows:

The **mass** of the cannon times the **acceleration** of the cannon equals the **mass** of the ball times the **acceleration** of the ball.

$$ma = ma$$

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

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



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

Newton's Second Law of Motion is especially useful when designing efficient rockets. To enable a rocket to climb into low Earth orbit, it is necessary to achieve a speed in excess of 17,398 miles (28,000 kilometers) per hour. A speed of over 25,010 miles (40,250 kilometers) per hour, called "escape velocity," enables a rocket to leave Earth and travel out into deep space. Attaining space flight speeds require the rocket engine to achieve the greatest action force possible in the shortest time. In other words, the engine must burn a large mass of fuel and push the resulting gas out of the engine as rapidly as possible. Ways of doing this will be described in the next chapter. Newton's Second Law of Motion can be restated in the following way: the greater the mass of rocket fuel burned and the faster the gas produced can escape the engine, the greater the thrust of the rocket.

Putting Newton's Laws of Motion Together

An unbalanced force must be exerted for a rocket to lift off from a launch pad or for a craft in space to change speed or direction (First Law). The amount of thrust (force) produced by a rocket engine will be determined by the rate at which the mass of the rocket fuel burns and the speed of the gas escaping the rocket (Second Law). The reaction, or motion, of the rocket is equal to and in the opposite direction of the action, or thrust, from the engine (Third Law).

Bottle rockets are excellent devices for investigating Newton's Three Laws of Motion. The rocket will remain on the launch pad until an unbalanced force is exerted propelling the rocket upward (First Law). The amount of force depends upon how much air you pumped inside the rocket (Second Law). You can increase the force further by adding a small amount of water to the rocket. This increases the mass the rocket expels by the air pressure. Finally, the action force of the air (and water) as it rushes out the nozzle creates an equal and opposite reaction force propelling the rocket upward (Third Law).

Ares: Launch and Propulsion

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Practical Rocketry

The first rockets ever built, the fire-arrows of the Chinese, were not very reliable. Fire-arrows flew on erratic courses and often landed in the wrong place. Being a rocketeer in the days of the fire-arrows must have been an exciting, but also a highly dangerous activity. Today, rockets are much more reliable. They fly on precise courses and are capable of going fast enough to escape the gravitational pull of Earth. Modern rockets are also more efficient today because we have an understanding of the scientific principles behind rocketry. Our understanding has led us to develop a wide variety of advanced rocket hardware and devise new propellants that can be used for longer trips and more powerful takeoffs.

Rocket Engines and Their Propellants

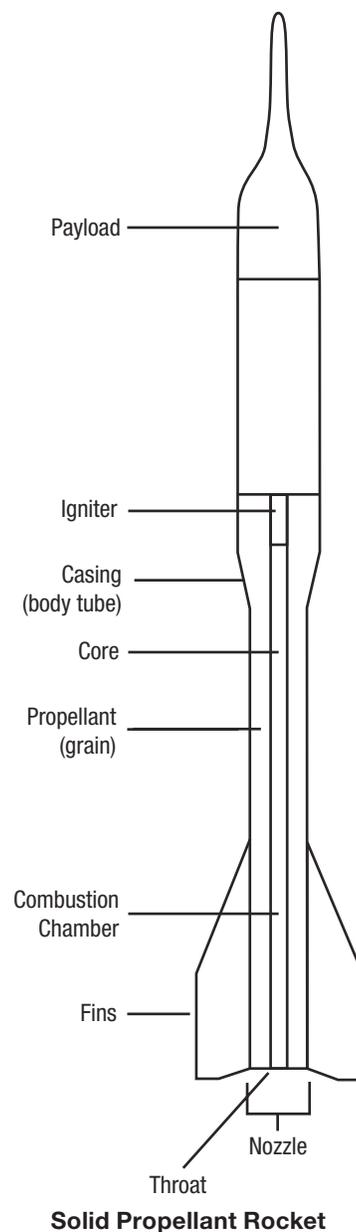
Most rockets today operate with either solid or liquid propellants. Ares uses both. The word propellant does not mean simply fuel, as you might think; it means both fuel and oxidizer. The fuel is the chemical the rocket burns, but for burning to take place, an oxidizer (oxygen) must be present. Jet engines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

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

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

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

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





Ares I

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

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

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

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

One especially good method of reducing the weight of liquid engines is to make the exit cone of the nozzle out of very lightweight metals. However, the extremely hot, fast-moving gases that pass through the cone would quickly melt thin metal. Therefore, a cooling system is needed. A highly effective, though complex, cooling system that is used with some liquid engines takes advantage of the low temperature of

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

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

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

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



Ares I

Ares V

liquid hydrogen. Hydrogen becomes a liquid when it is chilled to 423 degrees below zero (-253° C). Before injecting the hydrogen into the combustion chamber, it is first circulated through small tubes that lace the walls of the exit cone. In a cutaway view, the exit cone wall looks like the edge of corrugated cardboard. The hydrogen in the tubes absorbs the excess heat entering the cone walls and prevents it from melting the walls away. It also makes the hydrogen more energetic because of the heat it picks up. We call this kind of cooling system regenerative cooling.

Engine Thrust Control

Controlling the thrust of an engine is very important to launching payloads (cargoes) into orbit. Thrusting for too short or too long of a period of time will cause a satellite to be placed in the wrong orbit. This could cause it to go too far into space to be useful or make the satellite fall back to Earth. Thrusting in the wrong direction or at the wrong time will result in a similar situation.

A computer in the rocket's guidance system determines when that thrust is needed and turns the engine on or off appropriately. Liquid engines do this by simply starting or stopping the flow of propellants into the combustion chamber. On more complicated flights, such as going to the Moon, the engines must be started and stopped several times.

Some liquid-propellant engines control the amount of engine thrust by varying the amount of propellant that enters the combustion chamber. Typically the engine thrust varies for controlling the acceleration experienced by astronauts or to limit the aerodynamic forces on a vehicle.

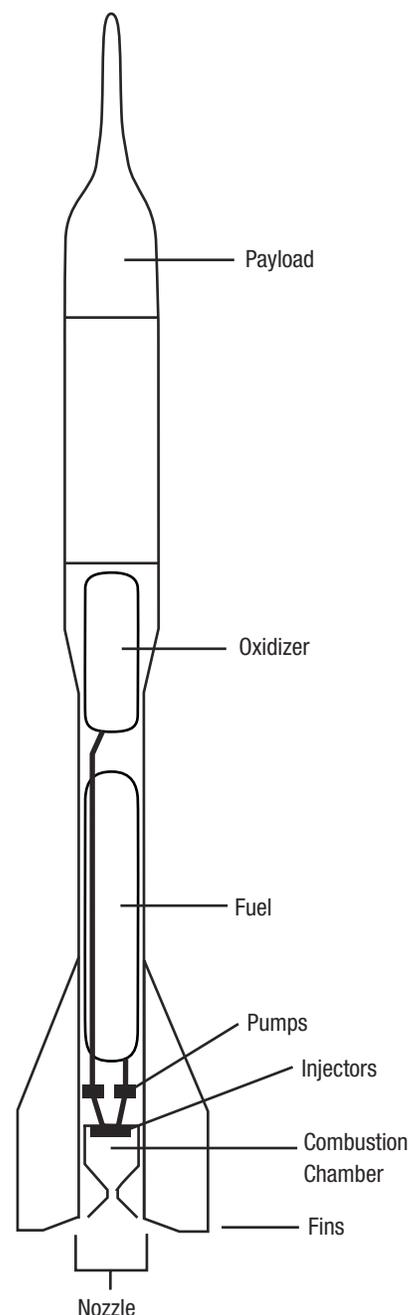
Solid-propellant rockets are not as easy to control as liquid rockets. Once started, the propellants burn until they are gone. They are very difficult to stop or slow down part way into the burn. Sometimes fire extinguishers are built into the engine to stop the rocket in flight, but using them is a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

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

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

Stability and Control Systems

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



Liquid Propellant Rocket

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

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

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

In flight, spinning or tumbling takes place around one or more of three axes. They are called roll, pitch, and yaw. The point where all three of these axes intersect is the CM. For rocket flight, the pitch and yaw axes are the most important because any movement in either of these two directions can cause the rocket to go off course.

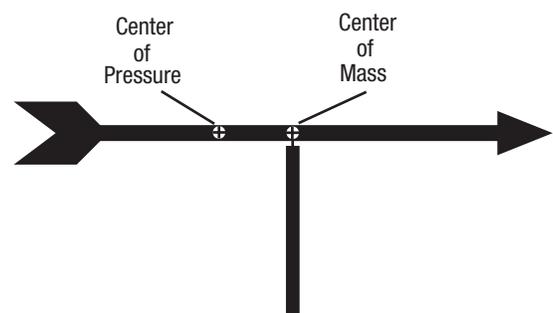
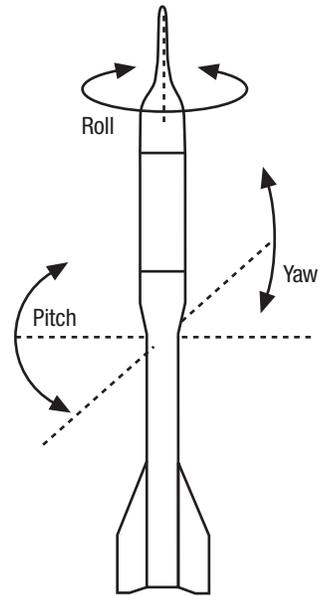
The roll axis is the least important because movement along this axis will not affect the flight path. In fact, a rolling motion will help stabilize the rocket in the same way a properly passed football is stabilized by rolling (spiraling) it in flight. Although a poorly passed football may still fly to its mark even if it tumbles rather than rolls, a rocket will not. The action-reaction energy of a football pass will be completely expended by the thrower the moment the ball leaves the hand. With rockets, thrust from the engine is still being produced while the rocket is in flight. Unstable motions about the pitch and yaw axes will cause the rocket to leave the planned course. To prevent this, a control system is needed to prevent, or at least minimize, unstable motions.

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

The reason that the weather vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail than the head, and the tail is pushed away. There is a point on the arrow where the surface area is the same on one side as the other. This spot is called the CP. The CP is not in the same place as the CM. If it were, then neither end of the arrow would be favored by the wind nor would the arrow point. The CP is between the center of mass and the tail end of the arrow. This means that the tail end has more surface area than the head end.

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

Control systems for rockets are intended to keep a rocket stable in flight and to steer it. Small rockets usually require only a stabilizing control system. Large rockets, such as the ones that launch



satellites into orbit, require a system that not only stabilizes the rocket, but also enable it to change course while in flight.

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

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

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

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

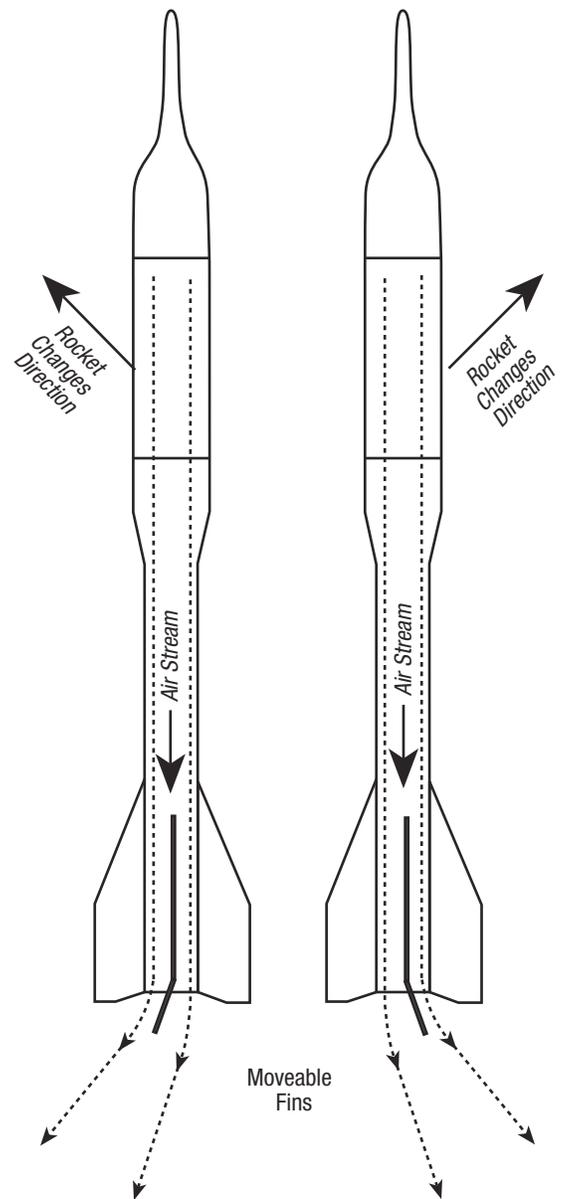
An important improvement in rocketry came with the replacement of sticks by clusters of lightweight fins mounted around the lower end near the nozzle. Fins could be made out of lightweight materials and be streamlined in shape. They gave rockets a dart-like appearance. The large surface area of the fins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

With the start of modern rocketry in the 20th century, new ways were sought to improve rocket stability and at the same time reduce overall rocket weight. The answer to this was the development of active controls. Active control systems included vanes, movable fins, canards, gimballed nozzles, vernier rockets, fuel injection, and attitude-control rockets. Tilting fins and canards are quite similar to each other in appearance. The only real difference between them is their location on the rockets: canards are mounted on the front end of the rocket, while the tilting fins are at the rear. In flight, the fins and canards tilt like rudders to deflect the air flow and cause the rocket to change course. Motion sensors on the rocket detect unplanned directional changes, and corrections can be made by slight tilting of the fins and canards. The advantage of these two devices is size and weight. They are smaller and lighter and produce less drag than the large fins.

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

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

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



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

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

Mass

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

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

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

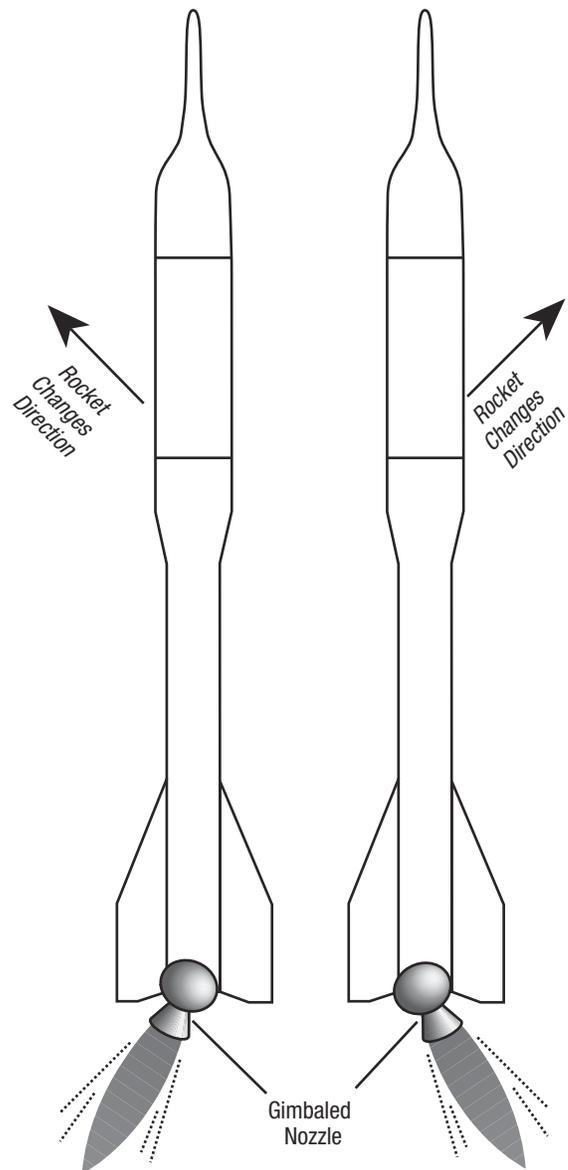
Payloads may be satellites, astronauts, or spacecraft that will travel to other planets or Moons. In determining the effectiveness of a rocket design, rocketeers speak in terms of mass fraction (MF). The mass of the propellants of the rocket divided by the total mass of the rocket gives MF:

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

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

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

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



Ares: Launch and Propulsion

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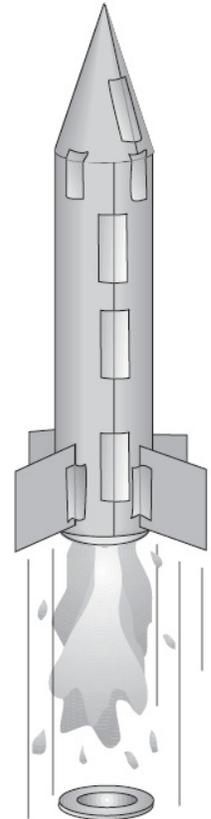
Teacher Guide

Pop Rocket Variables

Background Information

In this introductory activity, students study the concept of variables in relationship to launching pop rockets. The lesson starts by having the teacher direct a discussion assessing what the students know about rockets. This allows them the opportunity to share experiences they have had with them. Then, students will complete a concept map for a “rocket,” which will allow them to demonstrate their prior knowledge about rockets. As an optional activity, to stimulate further discussion and conversation about the history of rocketry, the class may view excerpts from the movie *October Sky*. After these preliminary activities, students discuss the idea that variables are the factors involved in an experiment. Then, using a film canister with water and an antacid tablet, the teacher may demonstrate how a pop rocket works. Students will then use a variable wheel to make operational definitions and list all of the variables that may affect the flight of the pop rocket.

The variable wheel (page 3) is a technique that students can use to graphically represent the factors involved in an experiment. The variable wheel is simply a circle with the responding variable (dependent variable) written in the center. The spokes that extend out from this circle are factors that would affect the responding variable. Once students have written as many factors on the spokes as they can generate, they will choose the one variable that they will plan to test. The other factors they listed then become variables that should be kept constant during the experiment. With the variables identified, the next step is for students to operationally define both the responding and the manipulated (independent) variables. This operational definition, as explained in the teacher procedure, should describe how the manipulated variable will be changed and how the responding variable will be measured.



A variable is a changing factor, trait, or condition. There are three types of variables:

- the independent or manipulated variable,
- the dependant or responding variable,
- and the controlled variable.

In these activities, students choose one factor to test. This is known as the manipulated or independent variable.

After choosing a variable to test, students write a research question and complete their investigation.

Following the investigation, students read the Student Text, “Variables and Operational Definitions.” This text uses a Super Bowl pizza party to describe how events or items affect the ultimate outcome of a particular effort, including those events over which our control ranges from a great deal to none.

National Science Standards Addressed

Grades 5–8

Science as Inquiry

- Abilities necessary to do scientific inquiry.
- Understandings about scientific inquiry.

Physical Science

- Properties and changes of properties in matter.
- Motion and forces.

Science and Technology

- Abilities of technological design.
- Understandings about science and technology.

Science in Personal and Social Perspectives

- Science technology and society.
- History and nature of science
(For optional *October Sky* activity).
- History of science.

Grades 9–12

Science as Inquiry

- Abilities necessary to do scientific inquiry.
- Understandings about scientific inquiry.

Physical Science

- Chemical reactions.
- Motion and forces.

Science and Technology

- Abilities of technological design.
- Understandings about science and technology.
- History and nature of science
(For optional *October Sky* activity).
- Historical perspectives.

Materials

For each group of three to four students:

- Student activity, “Pop Rocket Variables,” page 6.
- Student text, “Variables and Operational Definitions,” page 12.
- Plastic 35 mm film canister with an internal-sealing lid.
- Effervescent antacid tablet.
- Paper towels.
- Water.
- Eye protection.
- Computer with Internet access connected to a video projector.
- (Optional) *October Sky* VHS or DVD with television or video projection.

Procedure

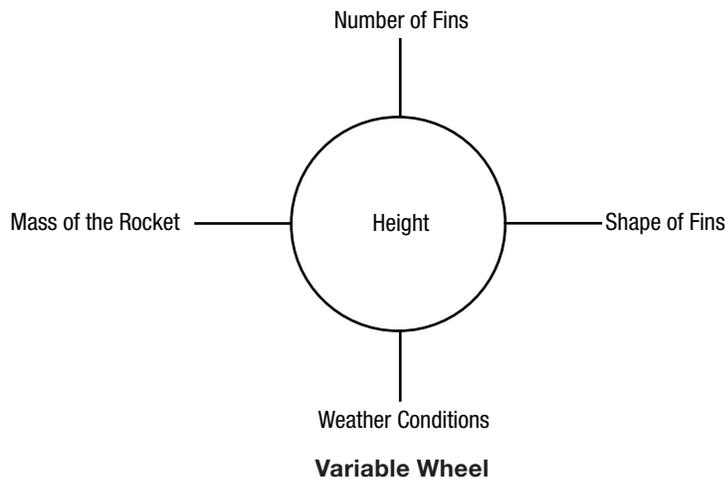
1. Distribute the student activity, “Pop Rocket Variables.” Students will return to this activity sheet throughout the class discussion and experiment.
2. Start this activity by asking the students to brainstorm what they know about rockets (#1 on student activity sheet) and what questions they have (#2 on student activity sheet). You may want to have students work in small groups of three or four to generate their lists.
3. Allow time for students to share their prior knowledge (#1 on student activity) about rockets with the rest of the class. During this time, record the students’ thoughts on the board or on chart paper. If there is shared information that not everyone agrees with, record this in the form of a question. Use another area to record questions that the students may have about rockets (#2 on student activity sheet).
4. Next, direct students’ attention to the “Rocket Concept Definition Map” on their handout. Concept definition mapping is a way to teach students how to find the meaning of a concept by describing what it is, describing its properties, comparing it with other concepts, and providing examples. Prior to having students complete this, you may want to model the technique by using a word they are familiar with, like the word “book.” See Appendix A to this teacher guide for an example of a completed “concept definition map” for “Rocket.”
5. Allow students time to use their brainstorming words to complete the concept map either individually or in their small groups. Circulate around the room asking questions to help students clarify why and how they are putting the concept map together.

6. Have students present their completed concept maps to the class. Instruct the class to ask the presenters questions to help clarify the ideas presented. Presenters should respond and defend their ideas.
7. Direct students to the variable wheel (#4) on their handout. In the ensuing discussion, you will model how to create a variable wheel. Instruct students to complete the variable wheel during the discussion.
8. Introduce the concept of a variable wheel by asking the following: “What do we usually measure when a rocket is launched?” (Most students will probably respond: “The height that the rocket will travel.”)

Then, share the following information with your students: “The variable that is measured is called the ‘dependent variable’ or the ‘responding variable’ because the result depends on other factors.” Place the word “height” in the middle of the circle in the variable wheel.

9. Continue the discussion by asking students: “What factors would be involved that would affect the height the rocket would travel?” (Expect many different answers to this. Students may suggest that the amount or type of fuel would be a factor, the weather conditions, the mass of the rocket, and the shape and number of fins. Some may also suggest the shape of the rocket or the nose cone.)

Explain to students that the factors they listed are called ‘independent variables’ or ‘manipulated variables’ since the experimenter can manipulate them. Place these variables on the spokes of the variable wheel. Refer to the example below.



10. Ask student groups to choose one of these variables and write an operational definition for it. If students are not familiar with operational definitions, provide an explanation and example, such as the following:
 - Explanation:** “An operational definition is the way a measurement will be performed.”
 - Example:** “We will measure the height of the rocket by using three fins, then with four fins, and then with five fins, each time making sure that the distances between the fins are equal.”
11. Keeping in mind that all of the variables mentioned in the variable wheel affect the height the rocket will travel, ask students to respond to questions 6–8 on their handout. Then, allow time for them to share their responses. Suggested responses are in parenthesis below:
 - Question # 6:** Why is it important to keep all variables constant except the manipulated variable? In other words, when conducting an experiment, why is it important to test only one variable at a time? (Students may suggest that if more than one variable is tested at the same time, it will be difficult to determine which manipulated variable is affecting the responding variable.)
 - Question #7:** What variables are the most difficult to keep constant? (Students may suggest that weather conditions can change without notice.)
 - Question #8:** What should be done if a variable cannot be kept constant during an experiment? (Students may suggest making a note in the report describing the factors that were not kept constant and why. Other students may suggest repeating the experiment so that these variables can be kept as constant as possible.)

12. Instruct students to use the completed variable wheel in #4 of their student activity sheet to assist them in writing the research question for #9. You may want to provide the following explanation: “One way of using a variable wheel to determine a research question is to circle the manipulated variable that you wish to test. The variables not circled then become variables that are kept constant during the experiment.”

Model the process by circling the variable “Number of Fins” in the wheel, and then provide the following example of a research question: “How do the number of fins affect the height that my rocket will travel?”

Explain that in the research question, only the manipulated and responding variables need to be included. It is understood that the experimenter will try to keep the other variables constant. Also, explain that the questions should not be worded in such a way that they can be answered with a “yes” or “no” response.

13. Tell students that now they will have a chance to complete an experiment in which they get to measure how a certain variable affects the height of a pop rocket. Demonstrate how the pop rocket works by using the following procedure:
- Put on eye protection.
 - Fill the canister one-third full of water.
 - Place one-half of an antacid tablet in the canister.
 - Snap the lid on tight.
 - Place the canister upside down on a flat surface (with the lid resting on the surface).
 - Stand back.
14. Ask students to fill in their variable wheel for the pop rocket (#10 on the activity sheet). They should then choose a variable that they want to test.
15. Direct students to get into groups based on the variable they are testing. (Students who want to test the same variable should be in the same group.)
16. Ask the groups to write a research question (#11 on handout) for their pop rocket experiment.
17. Instruct students to determine the operational definition or how the height of the pop rocket will be measured. During this experiment, qualitative measures would work fine. Determining methods for measuring height will be investigated further in the assessment portion of this module. They should note the operational definition in #12 on the student activity sheet and they should outline the procedure they will use to complete the experiment.
18. Once they have recorded their procedure, ask them to create a data table on which to record the data. Remind students that it is a good idea to test each variable with more than one trial.
19. Circulate around the room assisting students who have questions. Look over student plans before providing the materials for them to complete the experiments.
20. Distribute materials to the groups so they can conduct their experiments.
21. Ask the students to use their data to write an answer or conclusion to their research question. This should be included in #13 on the student activity sheet.
22. Tell students to save the results from their experiments as they will be referring to them in the next activity. If you prefer, collect the completed sheets; however, they will need to be returned to the students prior to the next activity.

Optional Activity

Develop students' understanding of the history of rocketry by showing select excerpts from the feature film *October Sky*. Detailed procedures for facilitating this optional viewing activity can be found in Appendix B of this teacher guide.

Alternate Strategy Tip

In order to give students more experiences with operational definitions, see the activities on this concept in the Teaching Science Process Skills resource listed in the teacher resources section at the end of this section.

23. Assign the student text, "Variables and Operational Definitions," page 12, to be read as a review of this activity with pop rockets. Instruct students to respond to the post-reading questions on a separate sheet of paper. Possible student responses are included in parenthesis below:

- **Question #1:** Cause is to effect as manipulated variable is to "responding variable." (Explanation: The manipulated variable is deliberately changed in an experiment to cause an effect. The effect or response is called the responding variable.)
- **Question #2:** In your own words, describe the differences between a manipulated variable, a constant variable, and a responding variable. Give examples to demonstrate your understanding of each. (Responses will vary. Look for clear examples to illustrate student understanding of each type of variable.)
- **Question #3:** Why is it important to have a clear operational definition before conducting a scientific experiment? (Operational definitions ensure a consistency in measurement not only during the initial experiment, but any time an experiment is repeated.)
- **Question #4:** Why is a planning tool like the variable wheel useful in a scientific experiment? How can it contribute to more accurate results? (It helps the scientist think through all the possible variables that could affect an experiment. In doing so, the experimenter can get a better handle on which variables need to be kept constant.)

Teacher Resources

Film

Gordon, C., Franco, L. (Producers), and Johnston, J. (Director). (1999). *October Sky* (Motion picture). Universal City, CA: Universal Pictures.

Publications

Hickam, H., *Rocket Boys*, Delacorte Press, New York, NY, 1998.

Rockets: A Teacher's Guide with Activities in Science, Mathematics, and Technology, NASA EG-2003-01-108-HQ, Office of Human Resources and Education, Washington, D.C., 2003.

Ramig, J. E., Bailer, J., and Ramsey, J. M., *Teaching Science Process Skills*, 192 pp., Good Apple, Torrance, California, 1995.

Schwartz, R., "Learning to Learn Vocabulary in Content Area Textbooks," *Journal of Reading*, Vol. 32, pp. 108–117, 1988.

Web sites

Fiftieth Anniversary of Sputnik:

<http://www.hq.nasa.gov/office/pao/History/sputnik/>

Teaching Tip

Examples of variables that students test may include the following:

- The amount of water.
- Temperature of the water.
- Amount of antacid tablet used.
- Number of canisters used.
- The size of particles of crushed antacids.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics

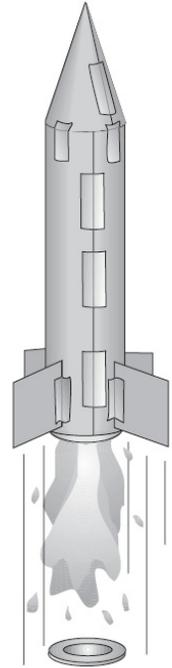


Student Activity

Pop Rocket Variables

Procedure

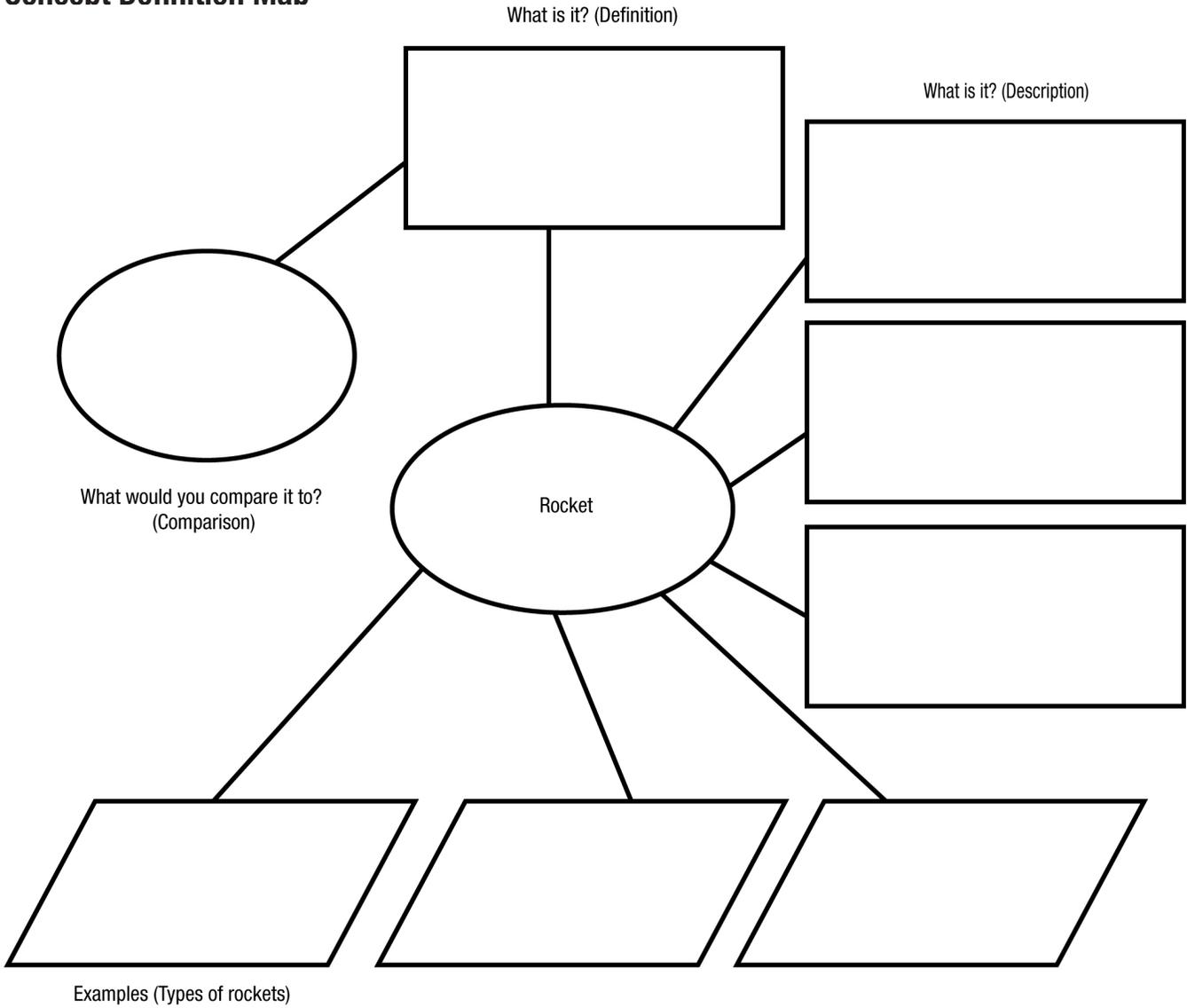
1. In your small groups or individually, write down as much as you can to reflect what your group knows about rockets. (Sentence fragments are acceptable.)



2. Now, think about what you want to know about rockets. Write down a list of questions you or your group may have.

3. Either in small groups or individually, complete the rocket concept definition map below.

Concept Definition Map

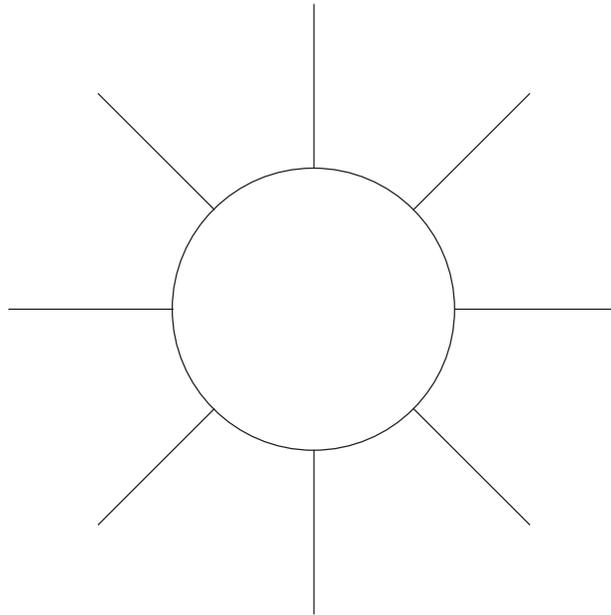


4. Variables are the factors involved with a scientific experiment. A variable wheel, like the one pictured below, is a technique you can use to show the different factors involved in a particular experiment. Your teacher will discuss the components of a variable wheel. During the discussion, label the variable wheel and keep in mind the following definitions of variables.

Responding Variable: The factor that is affected and measured in an experiment. It is called “responding” or “dependent variable” because the result depends on other factors.

Manipulated Variable (also called independent variable): The factor that is deliberately changed during an experiment in order to cause an effect, one that impacts the responding variable.

Constant Variable: While an experiment often has many variables that can be manipulated, only one should be manipulated at a time. All other variables should be controlled or kept constant in order to minimize their effects.



5. Every experiment should begin with an operational definition: a description of how the select independent or manipulated variable will be changed and how the effect or responding/dependent variable will be measured. Write your group's operational definitions for one of the manipulated variables from the variable wheel above.

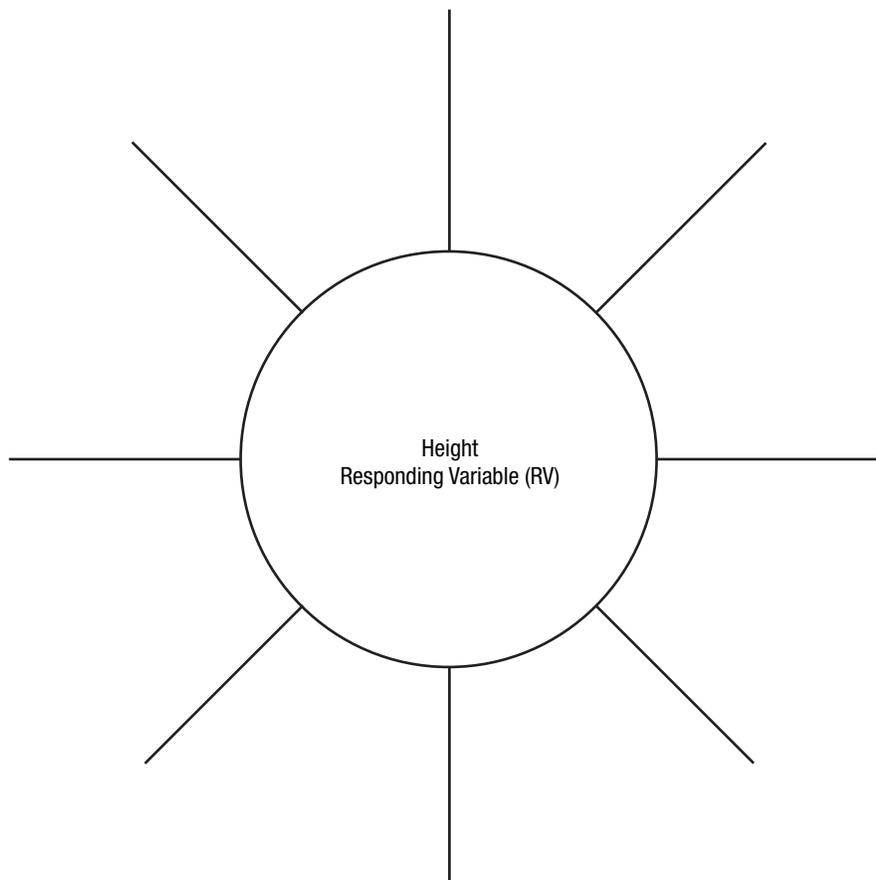
6. When conducting an experiment, why is it important to test only one variable at a time?

7. Which variables in the wheel above would be the most difficult to keep constant?

8. What should be done if a variable cannot be kept constant during an experiment?

9. Using the completed variable wheel from #4, write a practice research question.

10. Your teacher will demonstrate how to launch a pop rocket using a film canister, an antacid tablet, and water. After watching the demonstration, complete the variable wheel below to show all the factors that could affect the height of the pop rocket (the responding variable).



11. Now, as a group, write a research question to guide your pop rocket experiment.

12. Complete the operational definition, outline the procedure, and label both the operational definition and the procedure for the pop rocket variable experiment. This should be approved before you launch.

13. Use this space to continue with your procedure, results (data table), and conclusion. The conclusion should answer the research question and be based on the results in your data table. Label the procedure, results, and conclusion. You may use the back of this sheet if you need more space.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Text

Variables and Operational Definitions



All of your friends come over to your house for a Super Bowl party. After the first quarter, they tell you that they are hungry. Everyone thinks pizza will satisfy his or her appetite. Before you call the local pizza shop, you ask everyone what their favorite toppings are. Everyone agrees on sausage, pepperoni, extra cheese, olives, and ham. Based on this information, you call in your order.

The desired end result for everyone at your party is the same. They want to satisfy their hunger by eating pizza. We will call the desired end result “a good pizza.”

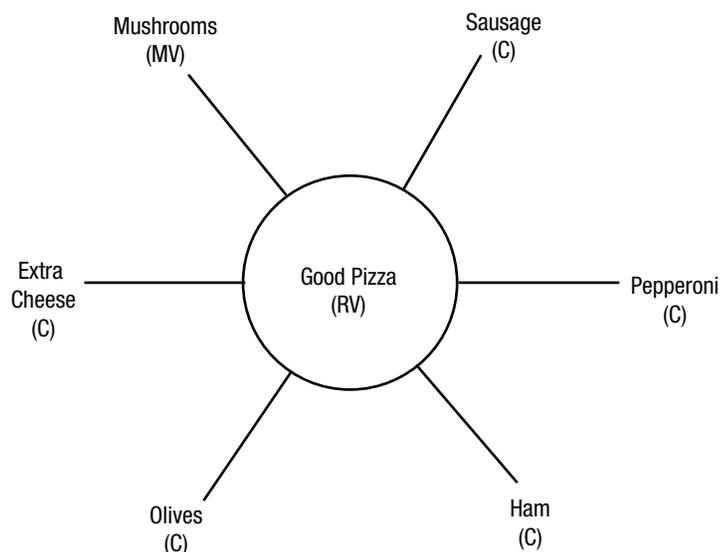
The variables are the factors involved in an experiment, in this case, a party.

The manipulated variable (labeled “MV” in the graphic below) in an experiment is the variable that is deliberately changed during the experiment to cause an effect.

An experiment often has several variables that may be manipulated, but only one should be manipulated at a time. The remaining variables should be kept constant (labeled “C”). The manipulated variable in this experiment is one of the various toppings. The responding variable (labeled “RV”) is the factor that is affected in the experiment. The responding variable in this case is the friend’s perception of a good pizza. We can illustrate this with the use of a variable wheel.

The variable wheel has the responding variable in the center of the circle and the manipulating variables on the spokes. Let us say you wanted to play a trick on your friends, and you order mushrooms on the pizzas to find out if they still considered it a good meal. We put this in the form of a question: “How does adding mushrooms affect my friends’ perception of a good pizza during a Super Bowl party?” In this case, you would order the pizzas with the toppings of their choice AND mushrooms. As you might imagine, some people might like this; some would be ambivalent; and some would be upset and even pick them off.

How could you measure your friends’ perception of a good pizza? One way might be to observe their expressions as they see the pizza and eat the meal. Another way would be to listen for any verbal feedback. Yet another would be to observe their actions. A more formal way would be to give them a short survey about their reaction to the mushrooms on the pizza. All of these ways of measuring your friends’ perceptions of a good pizza are examples of operational definitions. Operational definitions are how we intend to measure the variables in an experiment.



Having too many variables makes measuring the results more difficult or even impossible. In the case of the pizza experiment, let us say your operational definition of a good pizza is to observe the expression on your friends' faces. Instead of ordering the pizzas with the toppings of their choice, you added mushrooms to the pizzas. Let's say you decided to add pineapple in addition to mushrooms. Because there would be more than one variable being tested at the same time, it is very difficult to determine which of the variables (toppings) affected whether a person considers it a good pizza. In this case, it is important to keep all variables, except the manipulated variable, constant during the experiment. This way, it is easy for the experimenter to determine if that variable is the one that causes an effect for better or worse.

Some variables are hard to keep constant. For instance, let us say that some of the people at your party are rooting for the winning team, and some are rooting for the losing team. The people rooting for the winning team may perceive their pizza to be better than the people who are rooting for the losing team. Even though you are not trying to measure them all, other variables may also contribute to your friends' perceptions of a good, average, or bad pizza. Other variables might include such things as the thickness of the crust of the pizza, the temperature of the pizza, or the flavor of the pizza sauce. Environmental factors may contribute to the perceptions of your friends as well. Environmental factors might include such things as whether it is too hot or too cold in the room, the noise level, is it too loud or too quiet, and even an individual's attitude about attending your party.

When planning an experiment, it is difficult to know all of the variables that might contribute to the result of your study. Using the variable wheel or listing the factors that might affect your experiment before you begin will help you be aware of these variables and deal with them during your experiment.

Throughout the rocket activities in this module, the responding variable will focus on the height that the rockets will fly. The manipulated variables are what you will be working on to affect the rocket's height. As you build your rockets, you will notice that some variables have a greater effect than others. Your job during the Interaction/Synthesis phase of this module will be to operationally define the manipulated variables that will be used in launching a water bottle rocket and then measure the effect on the responding variable of height.

Post-Reading Questions

1. Complete the analogy and explain why your choice is the best fit.

Cause is to effect as manipulated variable is to _____.

- a. constant
- b. operational definition
- c. independent variable
- d. responding variable

Explanation:

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

Pop Goes Newton

Background Information

In this activity, students continue to study the concept of variables in relation to launching pop rockets. The lesson has the students applying each of Newton's Laws of Motion to the "Pop Rocket Variable" activity.

The activity demonstrated each of Newton's Laws of Motion. The film canister sat on the floor before lift off, demonstrating that objects at rest remain at rest unless acted on by an unbalanced force (First Law). The liftoff demonstrated that the pressure of the gas generated by the water-antacid reaction caused an unbalanced force, which resulted in upward movement. This movement continued until the force of gravity caused the canister to move downward, demonstrating once again that objects in motion remain in motion unless acted upon by an unbalanced force (First Law). The force of the floor or ground pushing up on the canister at rest and the canister pushing down on the ground demonstrated that for every action there is an equal and opposite reaction (Third Law). Also, the canister traveled upward with a force that is equal and opposite to the downward force propelling the water, bubbles, and lid. Finally, the acceleration of the canister is directly proportional to the amount of force on the canister and inversely proportional to the mass of the water, gas, and canister, thereby demonstrating that acceleration equals force divided by mass or $a = F/m$ (Second Law). Students will analyze each step in the "Pop Rocket Variables" activity and match them with the appropriate Law of Motion.



Sir Isaac Newton

The National Science Education Standards call for students to use evidence to develop descriptions, explanations, predictions, and models: "Students should base their explanations on what they observed, and as they develop cognitive skills, they should be able to differentiate explanation from descriptions – providing causes for effects and establishing relationships based on evidence and logical argument" (National Research Council, 1996). In this activity, students make detailed descriptions of events from the "Pop Rocket Variables" activity. Then, they state the law that corresponds with the description followed by an explanation.

National Science Standards Addressed

Grades 5–8

Science as Inquiry

Abilities necessary to do scientific inquiry.

Physical Science

Motion and forces.

Science and Technology

Understandings about science and technology.

Science in Personal and Social Perspectives

Science technology and society.

History and Nature of Science

History of science.

Grades 9–12

Science as Inquiry

Abilities necessary to do scientific inquiry.

Physical Science

Motion and forces.

Science and Technology

Understandings about science and technology.

History and Nature of Science

Historical perspectives.

Materials

For each group of three to four students:

- Student activity, “Pop Goes Newton,” page 17.
- Student text, “Newton’s Laws of Motion,” page 21.
- Completed student activity, “Pop Rocket Variables” from previous lesson (Briefing).
- (Optional) Video, *Liftoff to Learning: Newton in Space*.

Procedure

1. Distribute the student text “Newton’s Laws of Motion” and assign this to be read before the students begin the student activity. Review the concepts in the text by having students explain Newton’s three laws using their own words and examples from their everyday lives as requested in the post-reading section of the student text.
2. Distribute the student activity, “Pop Goes Newton,” to each person in the class. You may choose to have students work on this activity in groups or individually. Review the background information and explain that they are going to be taking another look at the “Pop Rocket Variable” activity and applying what they have read about Newton’s laws to that activity.
3. Show students the procedure on the student activity and point out the example item that has been done for them. Ask if there are any questions. Allow students time to complete the activity. Circulate around the room offering assistance to those who have questions or need help.
4. Once everyone has finished the activity, have student volunteers read their descriptions, laws, and explanations. During this time, challenge students to listen to the descriptions and explanations, allowing those who are listening to ask questions or seek clarification on what has been read.
5. Conclude the activity by having students write in their journals about what they have learned today. Instruct them to use their student activity sheets to summarize Newton’s Three Laws of Motion in their own words.

Alternate Strategy Tip

Before the students read the student text, show them the short (12 minute) NASA video *Newton In Space*. This short video shows Newton’s Laws of Motion in an everyday fun context. The video is available at:

<http://quest.nasa.gov/space/teachers/liftoff/newton.html>

A higher resolution version of the video is available for a nominal fee at:

<http://quest.nasa.gov/space/teachers/liftoff/>

Teacher Resources

Publications

Rockets: A Teacher’s Guide with Activities in Science, Mathematics, and Technology, NASA EG-2003-01-108-HQ, Office of Human Resources and Education, Washington, DC, 2003.

National Research Council, (2000). *Inquiry and the National Science Education Standards*, National Academy Press, Washington, DC, 2000.

National Research Council (1996). *The National Science Education Standards*. National Academy Press, Washington, DC.

Web sites

NASA video and instructional resources for *Newton in Space*:
<http://quest.nasa.gov/space/teachers/liftoff/newton.html>

Pop Goes Newton, page 17 Teacher Answer Key

1. First Law
2. First Law
3. Third Law
4. Third Law
5. Second Law
6. First Law
7. First Law
8. First Law

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Activity

Pop Goes Newton

Background Information

Read the student text, “Newton’s Laws of Motion and Rockets,” before beginning this activity. A summary of information from that text follows. You may refer to this when completing the procedure.

Newton’s First Law of Motion:

- Objects at rest tend to stay at rest unless acted on by an unbalanced force.
- Objects in motion tend to stay in motion in a straight line unless acted on by an unbalanced force.

Newton’s Second Law of Motion:

- As force is increased, acceleration increases. As mass is increased, acceleration decreases.
- Therefore, force equals mass times acceleration ($F = ma$).

Newton’s Third Law of Motion:

- For every action or force there is an equal, opposite, and simultaneous reaction or force.



Sir Isaac Newton

Procedure

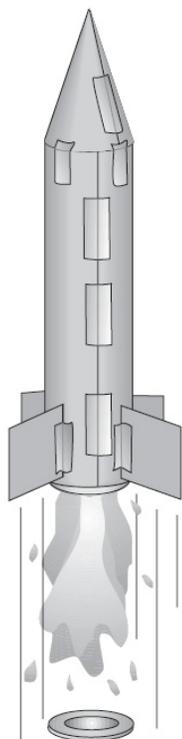
For each of the following events from the pop rocket experiment, write a detailed description of the event followed by the appropriate law that applies, and then provide a detailed explanation. The first one is done for you.

1. **Event:** The empty film canister is sitting on the lab table.

Description: The translucent film canister is sitting on the table with the cap securely fastened on top of it. There is nothing in the canister except air.

Law: 1. Objects at rest tend to stay at rest unless acted on by an unbalanced force.

Explanation: The film canister is not moving since the forces acting on it are balanced. The force of gravity pulling on the film canister is equal to the force the table is pushing on the film canister.



2. **Event:** A certain amount of water and an antacid tablet is placed into the film canister.

Description:

Law:

Explanation:

3. **Event:** The canister is placed on the table, and the rocket lifts off.

Description:

Law:

Explanation:

4. **Event:** The rocket travels upward with a force generated by the gas forming in the canister that causes the lid to blow off.

Description:

Law:

Explanation:

5. **Event:** The acceleration is directly proportional to the force and inversely proportional to the mass of the propellant.

Description:

Law:

Explanation:

6. **Event:** The canister stops upward motion.

Description:

Law:

Explanation:

7. **Event:** The canister falls back to the ground.

Description:

Law:

Explanation:

8. **Event:** The canister is found lying on the ground.

Description:

Law:

Explanation:

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Text

Newton's Laws of Motion and Rockets

Sir Isaac Newton

Isaac Newton was born in Lincolnshire, England on January 4, 1643. His father died before he was born, and his grandmother raised him as an orphan; he did not have a happy childhood. During this time, Newton went to school in Grantham, England, where he was proficient at mechanics. Newton's job was to run the family farm, but he enjoyed problem solving, experimenting, and devising mechanical models more than farming. Because of this interest, he attended Trinity College in Cambridge and lived there until 1696. The years between 1669 and 1687, when he was a professor at Cambridge, were highly productive for Newton. During this time, he worked with the problem of gravitation and before the autumn of 1684, he wrote the first book of the Principia: *Mathematical Principles of Natural Philosophy*. He read his notes on the Laws of Motion during his lectures. These now famous "Laws of Motion," as they relate to rockets, are discussed below.



Sir Isaac Newton

In 1696, Newton moved to London and was appointed to a high paying position first as Warden of the Royal Mint and then Master in 1699. He showed little interest in research during this time of his life. In 1703, he was elected president of the Royal Society and was re-elected each year until his death. In 1705, Queen Anne knighted him. This made him the first scientist ever to be knighted. However, the last portion of his life was not an easy one. It was dominated in many ways by the controversy with the German mathematician Gottfried Wilhelm Leibniz over who had invented calculus. Newton never married. He lived modestly and died on March 20, 1727.

Newton's First Law of Motion

Newton's First Law of Motion states that a body moving uniformly will remain moving in a straight line unless it is acted upon by some outside force. Similarly, a body that is at rest will remain at rest unless acted upon by an outside force. Newton's First Law of Motion can be described in one word: "inertia." The word inertia comes from Latin and literally means "laziness." Things that have inertia are lazy. Lazy things like to keep doing what they are already doing. If something (either animate or inanimate) is not moving, an external force is necessary to get it to do what it is not doing, in this case, move. If something is already moving, it is too lazy to change what it is doing, and thus an external force is necessary to stop it from moving or to make it change its direction. A body has more of a tendency to exhibit strong inertia when it is more massive. If inertia is strong, then mass is larger. When inertia is weak, then mass is smaller.

Is it good or bad for a rocket to be lazy? The answer to this is dependent on what you are already doing. If a rocket has been launched, then having inertia is good because the rocket, being lazy, wants to keep doing what it is already doing. Drag, a force caused by moving through air, is trying to prevent it from moving. So, in this case, the more inertia the better.

Sometimes it is bad for a rocket to be lazy. This occurs just before launch. A force must be used to overcome this form of laziness. This is the propulsive force (thrust) provided by something shooting out the back of the rocket. A rocket can be so lazy (have so much mass) that it is incapable of overcoming its inertia. In this case, it is a bad

thing to be lazy. How do you correct this? You correct this by lowering the mass of the rocket. A rocket should have a propulsive force that far exceeds the mass of the rocket.

The best rockets have a small mass and are aerodynamic, which decreases the resistance or drag force working against the rocket in motion. Thus, they have a high thrust-to-mass ratio. Once moving, the drag force — which involves the mass density of the air, the shape of the leading edge of the rocket, and the surface drag (based on surface area roughness) — should be minimized, so that acceleration (in this case the rate at which the rocket is slowed down or decelerated) is minimized.

Newton's Second Law of Motion

As mentioned previously, several forces act upon the rocket. A force is necessary to overcome the rocket's tendency to do what it is already doing. If the rocket is sitting lazily on the pad, then a force must be used to make it move. A launch involves a propulsive force. The rocket can be made to move more rapidly by either increasing the propulsive force and/or decreasing the rocket's mass.

How rapidly a rocket increases speed off the launch pad is called acceleration. Rocket acceleration equals the force applied, divided by the mass of the rocket ($a = F/m$). As force is increased, acceleration increases. As mass is increased, the acceleration decreases. This basically describes Newton's Second Law of Motion. Algebraically re-arranging the equation results in the classic description of Newton's Second Law of Motion: Force equals mass times acceleration.

$$F = ma$$

When a rocket is being launched (during the thrust phase of the mission), the acceleration rate should be maximized. Because $a = F/m$, the propulsive force must be maximized. The student or engineer must find ways to do this. The energy available to do work on the rocket is a function of the product of the pressure provided times the volume of air available. Generally, students will not be able to control the air pressure. However, there are ways to gain a propulsive advantage over the air pressure by decreasing the mass of the rocket, by increasing the thrust of the rocket engine, and/or by increasing the efficiency of the rocket engine. The thrust of a rocket engine is usually related to the size (diameter and length) of the engine, size and shape of the rocket nozzle, design of the components (such as the injector), and the pressure of the propellants that are injected into the combustion chamber. The efficiency of an engine, which is like miles per gallon in an automobile, can be maximized by careful attention to the choice of propellants, the shape of the nozzle, and the design of the injector and combustion chamber of the engine itself.

Drag only occurs while the rocket is moving. Drag is the force that makes the rocket change its speed by slowing it down. Drag increases the rate at which the rocket slows down. Once the thrust force is no longer applied, the speed at which the rocket is moving can be kept fairly constant by minimizing the drag force. Note that drag becomes significantly higher as speed increases. Specifically, drag is proportional to the square of the velocity: (Force of Drag = $0.5 \times [\text{coefficient of drag}] \times [\text{air density}] \times [\text{cross-sectional area}] \times [\text{velocity}^2]$).

Newton's Third Law of Motion

For every action or force there is an equal, opposite, and simultaneous reaction or force. When you hit a table with your hand, the table hits you back with a force equal to the force you applied to it, resulting in pain or even damage to your hand.



Ares V



Ares V Booster Separation

A rocket is able to lift off the pad because the acceleration imparted by the expanding exhaust is able to overcome the inertia of the rocket sitting on the pad. This is the same for a jet as it accelerates down the runway. The rocket continues to accelerate because the propellant use drives the mass of the rocket down, while the thrust of the engine continues unabated, leading to a very fast ride at burnout.

Review

Newton's First Law of Motion:

- Objects at rest tend to stay at rest unless acted on by an unbalanced force.
- Objects in motion tend to stay in motion in a straight line unless acted on by an unbalanced force.

Newton's Second Law of Motion:

- As force is increased, acceleration increases. As mass is increased, acceleration decreases.
- Therefore, force equals mass times acceleration ($F = ma$).

Newton's Third Law of Motion:

- For every action or force there is an equal, opposite, and simultaneous reaction or force.

Post-Reading Reflection

Demonstrate your understanding of Newton's Laws of Motion by describing each law in your own words and drawing a picture to help you remember the law. Then, provide an example from your everyday life to help illustrate each law.

1. First Law of Motion

Description in Your Own Words	Drawing to Help You Remember the Law	Example From Your Everyday Life

2. Second Law of Motion

Description in Your Own Words	Drawing to Help You Remember the Law	Example From Your Everyday Life

3. Third Law of Motion

Description in Your Own Words	Drawing to Help You Remember the Law	Example From Your Everyday Life

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

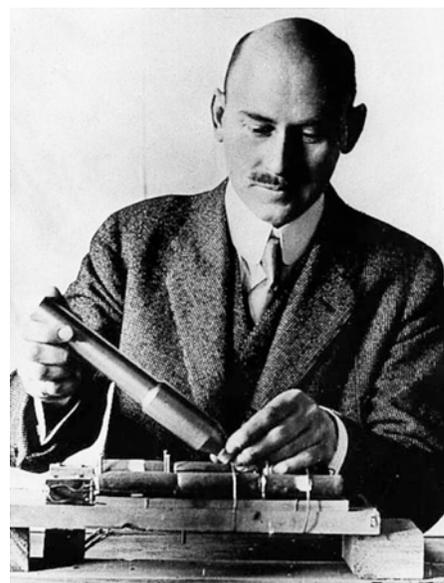
The History of Rocketry

Background Information

The design of today's rockets are the result of thousands of years of experimentation and research. Beginning 2000 years ago as a steam-powered toy, rockets have evolved into sophisticated vehicles capable of launching spacecraft into the solar system.

The Ares I Crew Launch Vehicle, slated to begin operations by 2015, and the Ares V Cargo Launch Vehicle, scheduled to fly by 2020 are designed to be safe, reliable, sustainable space transportation systems built on previous knowledge and space flight hardware from the Apollo-Saturn and Space Shuttle Programs. Ares I and Ares V will replace the Space Shuttle, which will be retired by 2010. The launch vehicles were named after Ares, the ancient Greek name for Mars. Using the latest technology, as well as lessons learned over years of research and experience, these rockets will take human beings to the Moon, Mars, and beyond.

In this activity, students create a multiple tiered timeline on the history of rocketry from ancient times through the Ares Projects.



Robert Goddard is considered one of the fathers of modern rocketry.

National Science Standards Addressed

Grades 5–8

Science as Inquiry

Understandings about scientific inquiry.

Science and Technology

Understandings about science and technology.

Science in Personal and Social Perspectives

Science technology and society.

History and Nature of Science

History of science.

Grades 9–12

Science as Inquiry

Understandings about scientific inquiry.

Science and Technology

Understandings about science and technology.

History and Nature of Science

Historical perspectives.

History Standards Addressed

Grades 6–8

Historical Understanding

Standard 1: Understands and knows how to analyze chronological relationships and patterns.

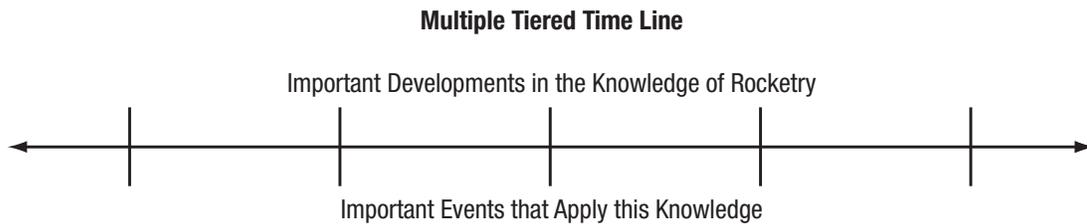
Benchmark 2: Knows how to construct and interpret multiple tier time lines.

Materials

- Student text, “From Earth to the Moon and Beyond,” page 34.
- Printed copies or online access to “Brief History of Rockets:”
http://exploration.grc.nasa.gov/education/rocket/TRCRocket/history_of_rockets.html
- Construction paper, yardsticks, and markers (optional).

Procedure

1. Explain to students that spacecraft are lifted into space using rockets and that current rocket design is the result of thousands of years of experimentation and research. Divide students into groups of six. Give each student a copy of a “Brief History of Rockets:”
http://exploration.grc.nasa.gov/education/rocket/TRCRocket/history_of_rockets.html



2. Ask each group to read the “Brief History of Rockets” and then create a time line of 10 to 15 important events. On one side of the time line, have students record important events in the scientific knowledge about rockets. On the other side, have them identify important events that show how scientists applied that knowledge (e.g., the first launch of a liquid-fueled rocket). Have students update their time lines by reading the student text, “From Earth to the Moon and Beyond.”
3. Ask the groups what events they chose and why. Explore with them why they chose some events and not others.
4. Ask the entire class to create a single time line of the 10 to 15 most important events in the history of rocketry. Again, ask them to record important developments in the knowledge of rocketry on one side and important events in the application of that knowledge on the other side.

Going Further

- Ask students to write an essay on the history of rocketry.
- Have students write a report on a specific event in the history of rocketry.
- Ask students to identify other events that occurred in the same year as an important event in the history of rocketry.
- Ask students to prepare a report on the use of rockets since the creation of NASA.

Teacher Resources

Web sites

Marshall Space Flight Center Offers a Timeline of Rocket History:
<http://history.msfc.nasa.gov/rocketry/index.html>

Rockets Teacher's Guide with Activities:
<http://exploration.grc.nasa.gov/education/rocket/TRCRocket/Intro.html>

Orders of Magnitude: A History of the NACA and NASA, 1915-1990:
<http://www.hq.nasa.gov/office/pao/History/SP-4406/contents.html>

Alternate Strategy Tip

Expand this activity by incorporating another timeline showing what was happening in Europe, Asia, and other parts of the world at the times when significant rocketry events were occurring.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

Launching Ares

Introduction

America is returning to the Moon in preparation for human exploration on Mars. This preparation includes building an outpost at one of the lunar poles to serve as a scientific experimental station and training ground for a Mars expedition.

NASA's Constellation Program will design the next generation of launch vehicles that will carry space explorers back to the Moon and onward to Mars and other destinations. Unlike our Shuttle missions to the International Space Station, which carry both personnel and equipment in one launch vehicle, NASA's lunar exploration plan will use two separate launch vehicles. Initially, the Ares I Crew Launch Vehicle will carry four-person crews of astronauts aboard the Orion Crew Exploration Vehicle, to the Moon for periods up to ten days to construct and inhabit the lunar outpost. The Ares I will also be able to take a crew of six to the International Space Station. The Ares V Cargo Launch Vehicle will carry large payloads of heavy equipment, including the Earth departure stage, which houses the lunar lander, Altair, to low-Earth orbit and beyond.

Engineers are building on a foundation of almost fifty years of proven space technology to build Ares I, which will incorporate a reusable solid fuel rocket derived from the Space Shuttle solid rocket booster, and a J-2X rocket engine, derived from the J-2 engine used on Saturn IB and Saturn V rockets. In fact, the Ares I and Ares V were named after the Saturn IB and Saturn V rockets to pay homage to this heritage.

Ares V will also incorporate tested and proven technology. Its core stage will have two 5.5-segment reusable solid rocket boosters to provide the necessary lift-off thrust. These are derivatives of the Space Shuttle solid rocket boosters. The core stage also has a liquid-fueled central booster element with six RS-68 rocket engines, which are a modified version of those used in the Delta IV launcher. The J-2X main engine, which will propel the Earth departure stage, is the next generation of the J-2 upper stage engine used in the Saturn IB and Saturn V.

The student activities in "Launching Ares" consist of three parts: 1) the "Ground Challenge," 2) "From Earth to the Moon and Beyond," and 3) the "Moon Challenge." In the "Ground Challenge" student activity, students are tasked with planning the most efficient method of transporting personnel, common construction materials, and supplies to a scientific experimental station located in a remote area here on Earth. Their options will include the types of ground transportation vehicles that are the latest versions of proven vehicles normally found in a construction company's inventory, no one of which meets all the requirements for the project. The "Ground Challenge" is designed to give students a better understanding of the decision-making process that led to the determination to use two types of Ares launch vehicles for future scientific exploration on the Moon and Mars.

In part 2 of "Launching Ares," students read the text "From Earth to the Moon and Beyond," page 34, which offers a historical context for U.S. space exploration. It includes a discussion of the Apollo and Space Shuttle programs, as well as a closer look at Ares, the next generation of launch vehicles. The text features links to videos and reading comprehension reinforcement, as well as reflection questions to assist students in identifying the main ideas.

The “Ground Challenge Activity,” page 43, provides students with a decision-making simulation that involves ground-based vehicles and distances with which they have some familiarity. That exercise will prepare them for the subsequent “Moon Challenge Activity,” page 47, in which they consider the launch vehicle requirements for transporting personnel and construction materials to a lunar habitat and experimental station. In part 3, students use their decision-making skills to determine what personal supplies are both needed and feasible for a lunar mission. They will then plan the most efficient method of using an Ares rocket system to transport equipment, personnel, supplies, and experimental equipment to the Moon.

Objective: The objective for these activities is for students to use a decision-making process similar to that used by NASA scientists and engineers to accomplish the following:

- Match vehicle capacities with requirements to select the best possible transportation option for completing each stage of a transportation project.
- Determine which supplies are vital for traveling through and living in a limited space in a “challenging” environment.

National Science Standards Addressed

Grades 5–8

Science as Inquiry

Abilities necessary to do scientific inquiry.

Science and Technology

Abilities of technological design.

Understanding about science and technology.

History and Nature of Science

Science as a human endeavor.

History of science.

Grades 9–12

Science as Inquiry

Abilities necessary to do scientific inquiry.

Understandings about scientific inquiry.

Science and Technology

Abilities of technological design.

Understandings about science and technology.

History and Nature of Science

Science as a human endeavor.

Nature of scientific knowledge.

Historical perspectives.

Principles and Standards for School Mathematics Addressed

Number and Operations Standard for Grades 6–8

Compute Fluently and Make Reasonable Estimates

Select appropriate methods and tools for computing with fractions and decimals from among mental computations, estimation, calculators, or computers, and paper and pencil, depending on the situation, and apply the selected methods.

Measurement Standard for Grades 6–8

Understand Measurable Attributes of Objects and the Units, Systems, and Processes of Measurement

Understand both metric and customary systems of measurement.

Problem Solving Standard for Grades 6–8

Solve Problems that Arise in Mathematics and in other Contexts

Measurement Standard for Grades 9–12

Understand Measurable Attributes of Objects and the Units, Systems, and Processes of Measurement

Make decisions about units and scales that are appropriate for problem situations involving measurement.

Problem Solving for Grades 9–12

Solve Problems that Arise in Mathematics and in other Contexts

Materials

- *Return to the Moon: The Journey Begins Now*, available in the video archives at: http://www.nasa.gov/mission_pages/constellation/main/index.html
- Mission Integration Managers: Audio with Kris Walsh.
- Getting Ready for Launch: Video with Joel Best.

Copies of the following for each student or group of students:

- Student activity, “Ground Challenge,” page 43.
- Student text, “From Earth to the Moon and Beyond,” page 34.
- Student activity, “Moon Challenge,” page 47.
- Pieces of colored construction paper labeled with the names of different types of equipment and supplies to be transported. The labels include their masses and dimensions and the stage numbers in which they are needed. (See Appendix D and E for label templates.)

Optional materials: Especially helpful for kinesthetic learners, construct manipulative representations of the various transportation vehicles using different sized boxes, labeled with their maximum payload capacities (see label templates in Appendix D):

- Pickup truck: Personal checkbook boxes approximately 3 1/2 by 6 inches (9 by 15 centimeters).
- Club cab pickup: Business checkbook boxes approximately 3 1/2 by 8 inches (9 by 20 centimeters).
- SUV: Select a box that has dimensions similar to those representing the pickup truck but with more depth.
- Trailers: Flat box similar to audiotape box approximately 3 by 4 inches (8 by 10 centimeters).
- Tractor-trailer: Shoebox.
- Tape or twist-ties to hook the trailers to the pickup trucks.
- Template labels can be placed on top of the boxes to represent the materials to be carried by a specific vehicle in a specific stage.
- Masking tape to mark off a 12-foot (approximately 3.7-meter) diameter circle on the classroom floor.

Procedure

Part I: Ground Challenge Simulation

1. Introduce the “Ground Challenge Simulation Activity” by telling students that the types of ground transportation that we use today — including automobiles, SUVs, pickup trucks, and tractor-trailer rigs — are the result of many years of experimentation and redesign of older models of these vehicles. Through the years, engineers evaluated older models, retained the best features, and improved those that had not proven acceptable or reliable to produce newer models. The construction project that students will be considering in this activity would not have been possible using the trucks available sixty years ago. They did not have the payload/cargo capacity, safety, technology, or the reliability required by this project simulation.
2. Distribute copies of the “Ground Challenge” student activity with the accompanying reporting sheet. Point out the goal of the activity as described in paragraph two of the student handout. Make sure that students understand that they should include at least two different options for transporting people, construction materials, and equipment to the site. For each option, students should provide a rationale describing the benefits and limitations of each. Divide the class into work groups, and give them any additional instructions you wish to include, such as ways to divide the work, the time schedule for completing the reporting sheet, and the method you have selected for sharing-out after they have finished.
3. Move around the room, answering questions that arise during group work and asking questions that provide guidance as students work on the challenge activity.
4. During the follow-up session, give each group the opportunity to share the decisions recorded on their Ground Challenge Activity report sheets. (See Appendix C for two possible options to give you an idea of the types of responses students may have; however, many others are possible.) This report should include their rationale, but it also could include the criteria (other than mass) they used for making the decisions.

5. Continue by asking questions like the following:
 - a) Did all members of your group agree with your final decisions? If not, how did you decide what to include?
 - b) What factors, other than payload capacities and mass of equipment and personnel, might play a role in making transportation decisions?
 - c) If you were the president of the company making the final transportation decisions based on the report sheets of these “employee committees,” what vehicles would you decide to use for Trip 1? Trip 2? Trip 3? Trip 4? On what basis did you make this decision (your own preferences or group preference)?

Part 2: From Earth to the Moon and Beyond

1. Distribute copies of the “From Earth to the Moon and Beyond” student text. Optional: Prior to the reading assignment, establish the context of NASA’s Constellation Program by showing the short animation, *Return to the Moon: The Journey Begins Now*, available in the video archives at the following URL: http://www.nasa.gov/mission_pages/constellation/main/index.html. Then, explain to the students that they will be reading a text that investigates past journeys to the Moon, as well as the future of solar system exploration.
2. Comprehension and reflection questions are interspersed throughout the text to assist students in identifying main ideas and recalling important information. Below are some suggested responses to the review questions:
 - a. What sparked human transportation into space? (President Kennedy’s 1961 challenge to Congress to support efforts to send an astronaut to the Moon and back by the end of the decade was a catalyst. Teachers may want to provide additional information about Sputnik, Yuri Gagarin, and the Cold War context of the Space Race between the United States and the Soviet Union.)
 - b. How did the Apollo program contribute to space science and engineering? (Specific examples from the text include: lunar surface experiments that contributed to our understanding of soil mechanics, meteoroids, solar wind, and magnetic fields, to name a few; the engineering feats of the Saturn V rocket made human travel to space possible, and the first space station was launched into orbit during the Apollo era.)
 - c. What was unique about the Space Shuttle system? (Many of the hardware components were reusable.)
 - d. What were some of the Space Shuttle program’s significant accomplishments? (Specific examples mentioned in the text include: the launch and repair of the Hubble Space Telescope as well as building and servicing the International Space Station.)
 - e. What happened to two of the orbiters during the Space Shuttle era? (Astronaut lives were lost during two accidents involving orbiters: *Challenger* and *Columbia*.)
 - f. Match the launch vehicle components with their functions:

 C Solid Rocket Boosters

 G Fuel Tank

 B J-2X Engine

 D Instrument Unit

 A Orion Crew Exploration Vehicle

 H Launch Abort System

 F RS-68 Engines

 E Lunar Lander

A Houses the astronauts during both the ascent to the Moon and the descent back to Earth.

B After lift-off, this powers Altair, the lunar lander, and the Orion Crew Exploration Vehicle to the Moon (Earth departure).

C Provides the first stage thrust for Ares I and Ares V.

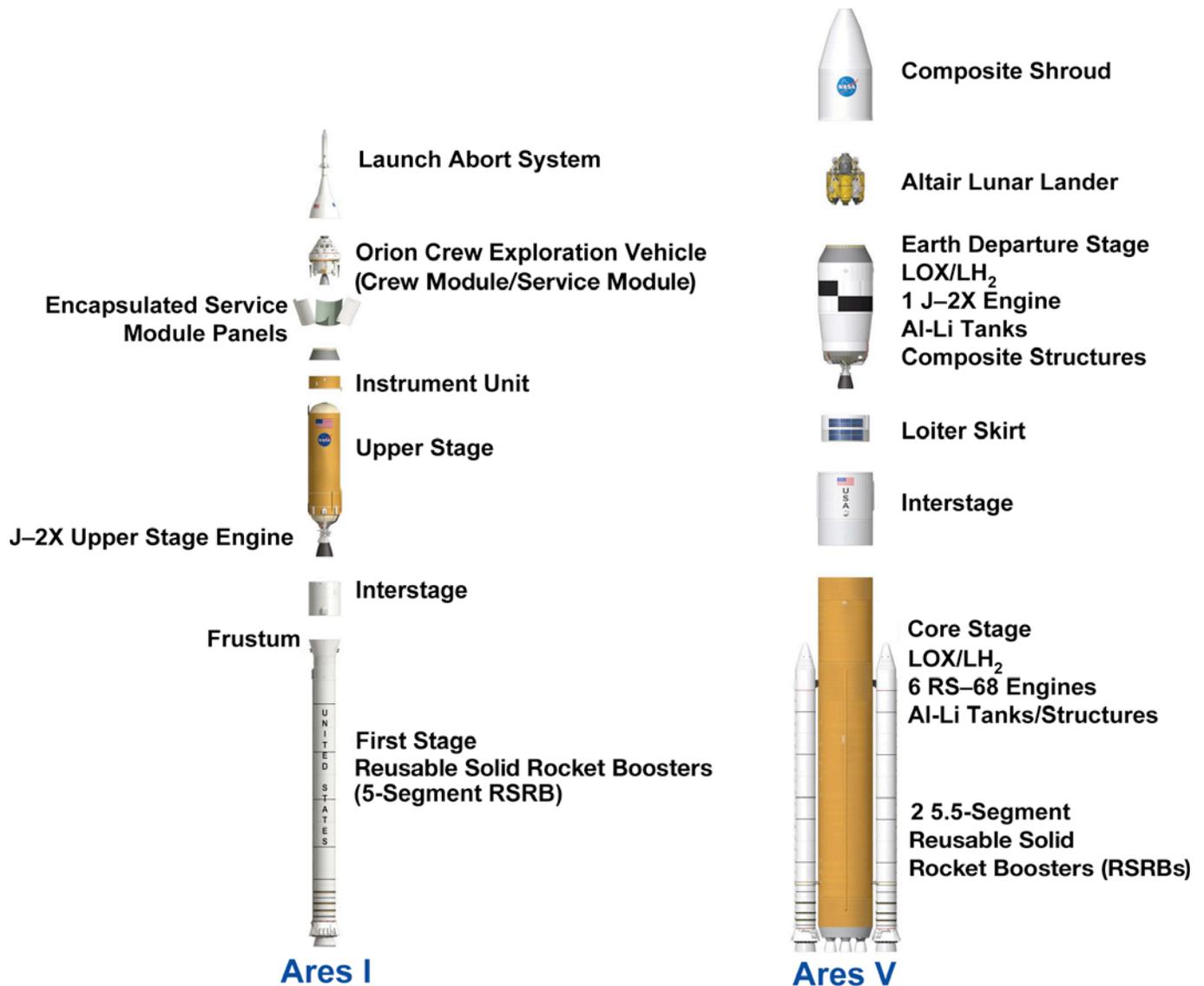
D Where the “brains” of the rocket are housed.

E Houses the equipment and eventually transports the astronauts to their final lunar destination. It can land anywhere on the Moon and can support a crew of four for up to seven days.

F Powers the core stage or lift-off on the Ares V.

G The LOX/LH2 fuels the upper stage in both vehicles.

H Allows the astronauts to escape from the launch vehicle if dangers arise.



- g. Which Ares launch vehicle components are based on similar technology used during the Apollo (Saturn) and Space Shuttle programs? (The J2-X engine and solid rocket boosters.)
- h. What is the purpose for having two different Ares launch vehicles? (Separating the crew from the cargo improves safety to the astronauts.)
- i. Based on the comparison table, how do changing characteristics of the various space vehicles reflect NASA's goal to improve safety? (Ares I is a less complicated and lighter vehicle than the others. The crew is located on top of the rocket, thereby enhancing the safety to the astronauts on board compared with the Space Shuttle.)
- j. If the crew of astronauts travel on Ares I and the cargo is onboard Ares V, how do these two payloads eventually connect? (When Orion, the spacecraft aboard Ares I that carries the crew, reaches Earth orbit, it docks with the Earth departure stage of Ares V, which carries the Altair lunar lander. The crew transfers to the lunar lander for the final descent onto the lunar surface.)
- k. What is the main difference between the lunar sortie and the lunar outpost missions? (Sortie missions are short-term, preliminary planning missions to explore potential lunar outpost sites in preparation for the longer missions. Outpost missions are long-term missions that require more permanent habitats. During

these lunar outpost missions, astronauts can conduct long-term science and technology investigations.

Ultimately, these more permanent outpost sites will make travel beyond the Moon and on to Mars possible.)

- I. The inflatable lunar habitat consists of a small airlock unit attached to a larger habitat. What is the function of this airlock feature? (Safeguards astronauts by helping them to transition from the harsh atmospheric conditions on the Moon to the controlled atmosphere within the habitat.)
3. Use the text as the basis for a discussion in which you help students compare the “Ground Challenge” to a space challenge of transporting construction equipment to the Moon for the establishment of a human habitat and an experimental station. Ask questions similar to the following. Accept student answers without comment except to ask for clarification.
 - a. How would planning for the construction of an experimental station on the Moon be similar to the planning that goes into the construction of a similar building on the ground? How might it be different?
 - b. How are the transportation vehicles available for a trip to the Moon similar to those you used to transport building and living supplies to the ground station? How are they different?
 - c. What equipment and supplies (in addition to those you moved to the ground station), would you have to transport to the Moon?
 - d. How would the use of inflatable, expandable structures change the ground challenge of transporting building materials to a scientific exploration station?

Part 3: The Moon Challenge Activity



1. To lead into the Moon Challenge activity, play  and discuss “Mission Integration Managers” with Kris Walsh. Discuss the excitement of preparing for a mission and the role of the mission manager. Then play the video “Getting Ready for Launch” with Joel Best to lead into a discussion of some of the things that might be involved in preparing for a space mission.
2. Call students’ attention to the last section of the student text, which describes the “Moon Challenge.” Ask what other questions they have about the “Moon Challenge.” You may wish to record student questions on chart paper or on an overhead transparency to keep them for future reference.
3. Use masking tape to mark off a 12-foot (3.7 meter) diameter circle on the classroom floor. Ask students if they know why you are doing this. (Students may recall that the lunar habitat in the “From Earth to the Moon and Beyond” student text is 12 feet (3.7 meters) in diameter.) Tell students that any personal supplies they decided to take to the Moon must fit in a habitat this size. Prompt students further by asking the following:
 - How many astronauts will be sharing this living space? (at least 4)
 - How does this size space compare with the living space in the International Space Station (ISS)?” (Students may indicate that it is larger than the lunar habitat.) Inform students that the space station is about 120 feet (36.6 meters) long; fully assembled, it will be approximately 354 by 243 feet (108 by 74 meters), about the length of a football field. You may wish to show them the indicated height of the habitat. Some of them may be aware that personal supplies are “Velcroed®” to the walls of the Space Shuttle.
4. Distribute copies of the “Moon Challenge” student activity with the accompanying report sheet. Divide the class into work groups and give them any additional instructions you wish to include, such as ways to divide the challenge work, the time schedule for completing the report sheet, and the method you have selected for sharing-out after they have finished.
5. Move around the room, answering questions that arise during group work and asking questions that provide guidance as students work on the challenge activity.
6. During the follow-up session, give each group the opportunity to share the decisions recorded on their “Moon Challenge” activity report sheets. This report should include their rationale, but it could also include the criteria (other than mass) that they used for making the decisions.
7. After you listen to the personal supply decisions, students should answer the conclusion questions found at the end of the student activity sheet:
 - a. Why do you think that you were required to transport the lunar habitat in the first trip? (Answers could

- include: The sooner the habitat is constructed, the sooner it would be possible for astronauts to live in it rather than in the very small lunar lander. Or, the habitat is necessary to protect supplies and equipment from the environment.)
- b. If students did not transport the power supply, the Atmospheric Revitalization System (ARS), and the Water Recovery System (WRS) in the second trip, ask them why not? (To help you make the students aware of the necessity of the ARS and WRS for astronaut survival, see the hotlinks to “Space Water” and “Space Breathing” available at the following URL: <http://spaceflight.nasa.gov/living/index.html>)
 - c. If students selected electrical equipment — such as a refrigerator, microwave, coffee maker, toaster, washing machine and dryer — ask them to consider how much power supply these appliances would use. Do you think the solar panel will supply that much electricity? (To find out what electrical appliances the astronauts on the ISS have, you may want students to look at the links for “Eating and Drinking” and “Doing Laundry” available at the following URL: <http://spaceflight.nasa.gov/living/index.html>. Or, you might want to search for some pertinent parts of the site so that you will be ready to help them decide whether or not these were wise choices in terms of space and use of power supplies.)
 - d. If students decided to take beds, desks, a kitchen cabinet, or a wardrobe to the Moon, ask them how they would arrange these items in the 12-foot (3.7-meter) diameter circle. (For more details, go to “Space Sleep” available at: <http://spaceflight.nasa.gov/living/index.html>. This will supply some insights into where and how astronauts sleep and eat in space, and how they will sleep and eat on the Moon.)
 - e. Explain some of the obstacles NASA faces in planning lunar missions with limited budgets? (Answers could include that budgets can limit the amount and type of equipment and supplies that can be transported to the Moon. When faced with budget constraints, mission planners must consider only those things that are most important for the survival of the crew and those that are necessary to accomplish mission objectives.)
 - f. Why is communication important when planning missions? (Answers could include that communication is essential because mission planners must communicate with engineers and mission operations personnel to ensure that the proper payload and supplies are being built and installed in a way to optimize space and mass constraints and are optimized for astronauts to successfully accomplish mission objectives. Students also might suggest that problems with communication could result in a mission failure or even loss of life.)
8. As a class, go through the personal supply list in the “Moon Challenge” activity sheet and decide which of the items on the list are necessary for astronaut survival on the Moon. Ask students how their decisions changed now that they are more aware of the space limitations and the way in which ISS astronauts live?
 9. Finally, ask them if anyone would like to go to the Moon as a part of NASA's Vision for Space Exploration? Why or why not?

Teacher Resources

Shuttle History and Missions:

<http://aerospacescholars.jsc.nasa.gov/HAS/Modules/Shuttle-to-Station/2/4.cfm>

This NASA site features a host of interesting information about Living in Space:

<http://spaceflight.nasa.gov/living/index.html>

Sputnik and the Dawn of the Space Age:

<http://www.hq.nasa.gov/office/pao/History/sputnik/>

NASA Johnson Space Center Fact Sheets:

<http://www.nasa.gov/centers/johnson/about/factsheets/index.html>

NASA's Constellation Program page features several engaging and informative online videos:

http://www.nasa.gov/mission_pages/constellation/main/index.html

Constellation Program: America's Fleet of Next-Generation Launch Vehicles: The Ares I Crew Launch Vehicle:

http://www.nasa.gov/pdf/151419main_ares1_factsheet.pdf

NASA Facts: Fact Sheet:

http://www.nasa.gov/pdf/183996main_FS-Transition.pdf

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Text

From Earth to the Moon and Beyond

Currently, NASA engineers are making decisions regarding not only transport vehicles, but also how to supply essentials like oxygen and water to support human life over long periods of time until these astronauts learn to “live off the land.” This is a goal for twenty-first century spaceflight. Before we learn about America’s next generation of rockets that will propel us to the Moon and beyond, we will review two of the most recent human transport systems that have lifted humans off the face of the planet — Apollo and the Space Shuttle.

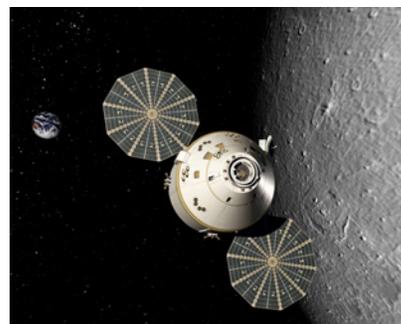
Transporting Humans to Space: A Look Back in NASA History

On May 25, 1961, President John F. Kennedy presented a challenge to a joint session of the United States Congress. “I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth.” This challenge mobilized the scientific and engineering communities who were determined to accomplish this goal. After successfully testing rockets and capsules that could keep humans alive in space with the Mercury and Gemini programs, the Apollo program was born.

Highlights of the Apollo Program

The Apollo program included a large number of un-crewed test missions and eleven crewed missions. The eleven crewed missions included two Earth-orbiting missions, two lunar-orbiting missions, a lunar swing-by, and six Moon-landing missions. To accomplish the goal that President Kennedy outlined in 1961, the Apollo program was designed to land humans on the Moon and bring them safely back to Earth. Six of the missions — Apollo 11, 12, 14, 15, 16, and 17 — achieved this goal.

The lunar-surface experiments conducted during the Apollo era included: soil mechanics, meteoroids, seismic, heat flow, lunar ranging, magnetic fields, and solar wind experiments. The rocket that propelled the astronauts to the Moon was the gigantic Saturn V. This is the most powerful rocket ever flown. It was launched thirteen times between 1967 and 1973. In total, the Saturn V carried 27 astronauts into space. The final launch of a Saturn V placed Skylab, the first U.S. space station, into orbit around the Earth.



Earth to Moon in the 21st Century



John F. Kennedy addresses Congress



The Space Transport System

The Space Shuttle Program

In 1981, a new system of launch vehicles made its debut with the Space Transportation System (STS) commonly called the Space Shuttle program. The purpose of the Shuttle is to deliver payloads into Earth orbit and to dock with satellites and the International Space Station (ISS). The Space Shuttle system is unique because almost all of the components are reusable (the exception is the external fuel tank). The system consists of four primary elements: an orbiter spacecraft, two solid rocket boosters (SRB), an external tank to house fuel and oxidizer, and three Space Shuttle main engines. The orbiter acts like a rocket upon ascent, a spacecraft while in orbit, and a glider as it returns to Earth.

Five orbiters have flown into space: *Columbia*, *Challenger*, *Discovery*, *Atlantis*, and *Endeavour*. One orbiter was lost due to an accident during ascent (*Challenger* in 1986) and one during descent (*Columbia* in 2003). While the Space Shuttle contributes to many significant accomplishments for human spaceflight, including the launch and repair of the Hubble Space Telescope and missions to build and service the space station, in 2004 NASA was charged with developing new vehicles to explore the Moon, Mars, and beyond.

Ares: The Next Generation

The next generation of launch vehicles is called Ares, named after the Greek God whose Roman counterpart is Mars. The Ares launch system is part of NASA's Constellation Program and is designed for trips to the International Space Station, the Moon, and eventually to Mars and other destinations. The Ares launch vehicles include the Ares I Crew Launch Vehicle and the Ares V Cargo Launch Vehicle. These rockets capitalize on technologies previously used with the Saturn V, and the Space Shuttle, as well as other rockets.

Future astronauts will ride the Orion Crew Exploration Vehicle to orbit on Ares I, which uses a single five-segment solid rocket booster, a derivative of the Space Shuttle's solid rocket booster, for its first stage. A liquid oxygen/liquid hydrogen J-2X engine derived from the J-2 engine used on Apollo's second and third stages will power the crew exploration vehicle's upper stage.

Ares V, a heavy-lift launch vehicle, will use a 10-meter-diameter core stage powered by six RS-68 liquid oxygen/liquid hydrogen engines, and two 5.5-segment solid propellant rocket boosters for the first stage. The upper stage, known as the Earth departure stage, will use the same J-2X engine as the Ares I. This versatile system will be used to launch the Altair lunar lander and other large cargo into Earth orbit and send it to the Moon. For the lunar mission, the Orion crew vehicle, launched by Ares I, will rendezvous with the Earth departure stage and Altair for the lunar trip. The J-2X, which put the Earth departure stage in Earth orbit, will ignite a second time to send the Altair/Orion vehicle to the Moon.



Artist's concept of Ares I (left) and Ares V (right).

To learn more about the Ares I and Ares V rockets, go to http://www.nasa.gov/mission_pages/constellation/ares/ares_education.html to see the following videos featuring Bob Armstrong and Joel Best from NASA's Marshall Space Flight Center.

Ares I Video

In this video, Bob Armstrong discusses the Ares I Crew Launch Vehicle. The Ares I is a two-stage vehicle that stands over 328-feet.

Ares V Video

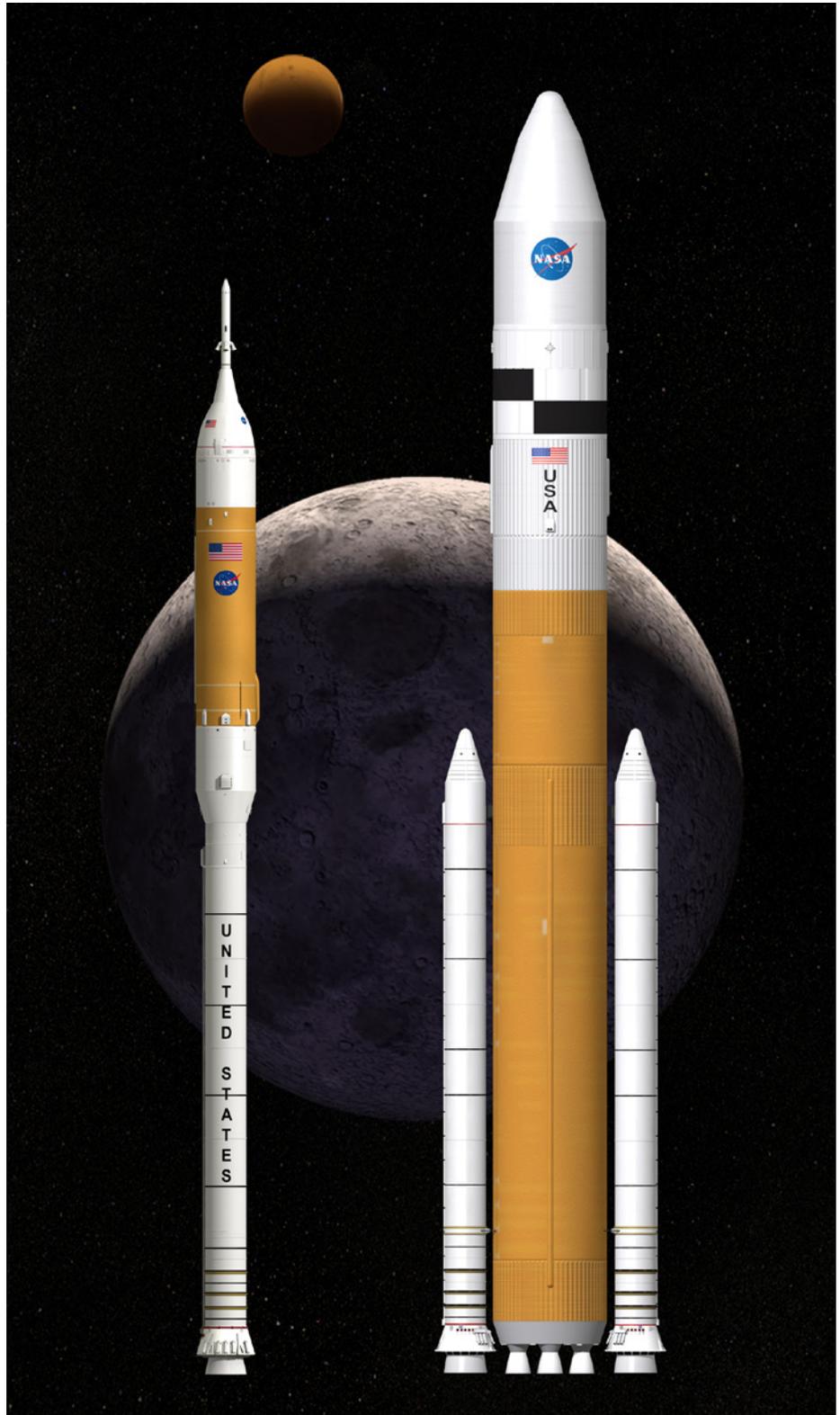
This video introduces the Ares V Cargo Launch Vehicle. The Ares V is the sister vehicle of the crew launch vehicle, the Ares I. The Ares V will be the largest rocket ever built.

Why Two Rockets? Video

The Shuttle system involves launching astronauts, supplies, and cargo (in the payload bay) into low-Earth orbit. Following the tragic losses of the crew in the *Challenger* and *Columbia* orbiters, NASA review panels determined that future launch systems should separate crew from cargo. In doing so, the rocket that launches the crew (Ares I) will be a simpler design and feature a special evacuation system for the astronauts to escape in the event of an emergency with the launch vehicle. Learn more as this video discusses why there are two rockets instead of one.

Why Go to the Moon? Video

Joel Best discusses why NASA wants to return to the Moon in this video. In the beginning missions, four-person crews will make several seven-day trips to the Moon. Eventually there will be a lunar outpost developed on the Moon with permanent living and working quarters.



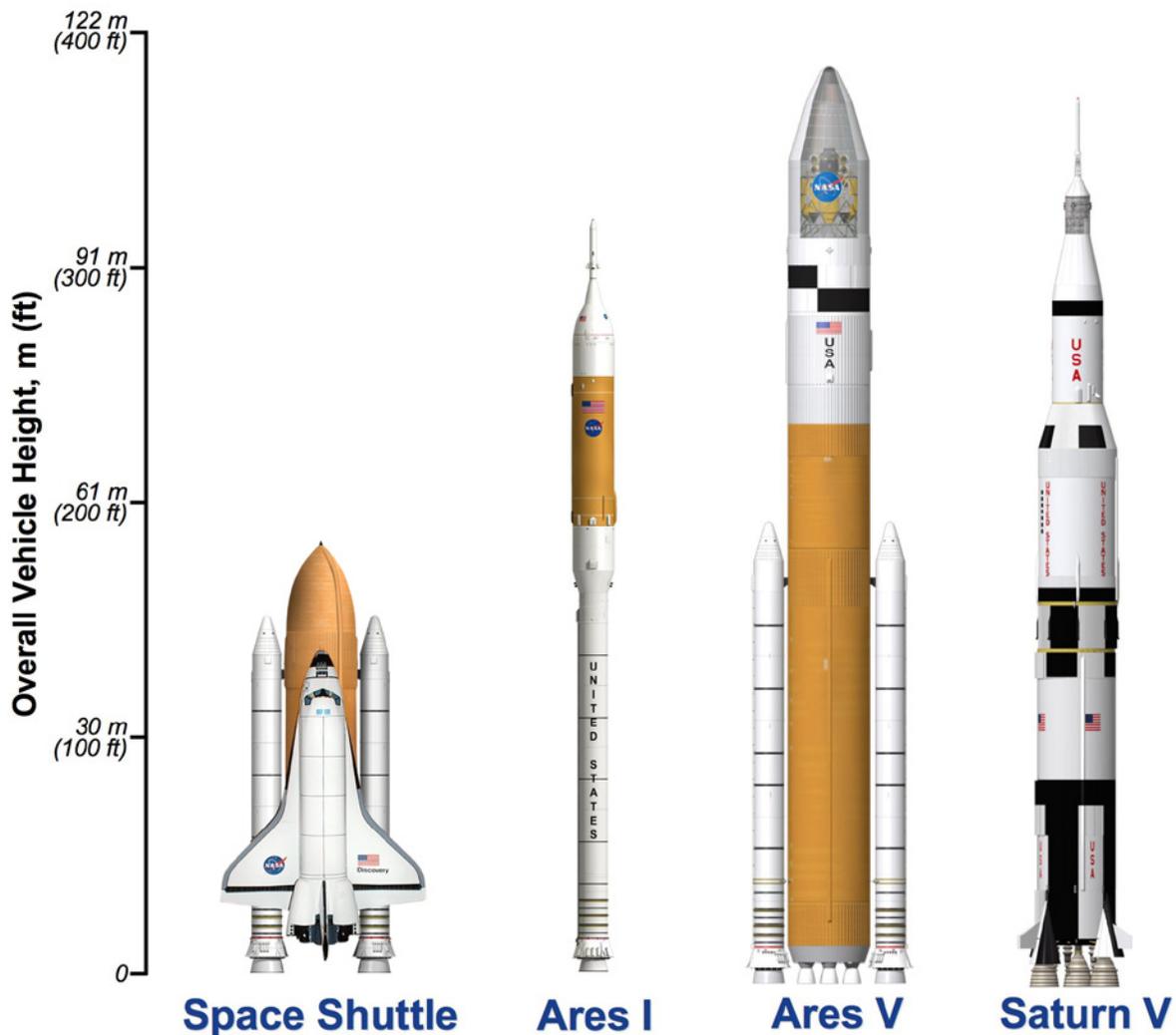
Ares I

Ares V

Space Vehicle Comparisons

The table and diagram below contain comparisons of the recent rockets used to launch humans into space.

Comparison of Space Vehicles				
	Saturn V	Space Shuttle	Ares I	Ares V
Height	363 ft. (111 m)	149.6 ft. (45.6 m)	325 ft. (99 m) As tall as a 32-story building	381 ft. (116 m) As tall as a 38-story building
Weight A fully fueled 747 weighs 1 million lb (4.5 million kg)	6.69 million lb (3 million kg)	4.4 million lb (2 million kg)	2 million lb (907,000 kg)	8.2 million lb (3.7 million kg)
Payload	260,150 lb (118,100 kg)	53,700 lb (24,360 kg)	56,200 lb (25,000 kg) 28 one-ton pickup trucks worth of payload	413,807 lb (187,699 kg) 207 one-ton pickup trucks worth of payload
Number of Astronauts	Up to 3 astronauts	Up to 7 astronauts	4 to 6 astronauts	Not Applicable
Location of Astronauts	In capsule on top of third stage	In orbiter attached to side of launch vehicle	In crew vehicle on top of second stage	Not Applicable



Review Questions

1. What sparked America's human exploration of space?
2. How did the Apollo program contribute to space science and engineering?
3. What was unique about the Space Shuttle system?
4. What were some of the Space Shuttle program's significant accomplishments?
5. What happened to two of the orbiters during the Space Shuttle era?

6. Match the launch vehicle components with their functions:

_____ Solid Rocket Boosters

_____ Fuel Tank

_____ J-2X Engine

_____ Instrument Unit

_____ Orion Crew Exploration Vehicle

_____ Launch Abort System

_____ RS-68 Engines

_____ Lunar Lander

A Houses the astronauts during both the ascent to the Moon and the descent back to Earth.

B After lift-off, this powers Altair, the lunar lander, and the Orion Crew Exploration Vehicle to the Moon (Earth departure).

C Provides the first stage thrust for Ares I and Ares V.

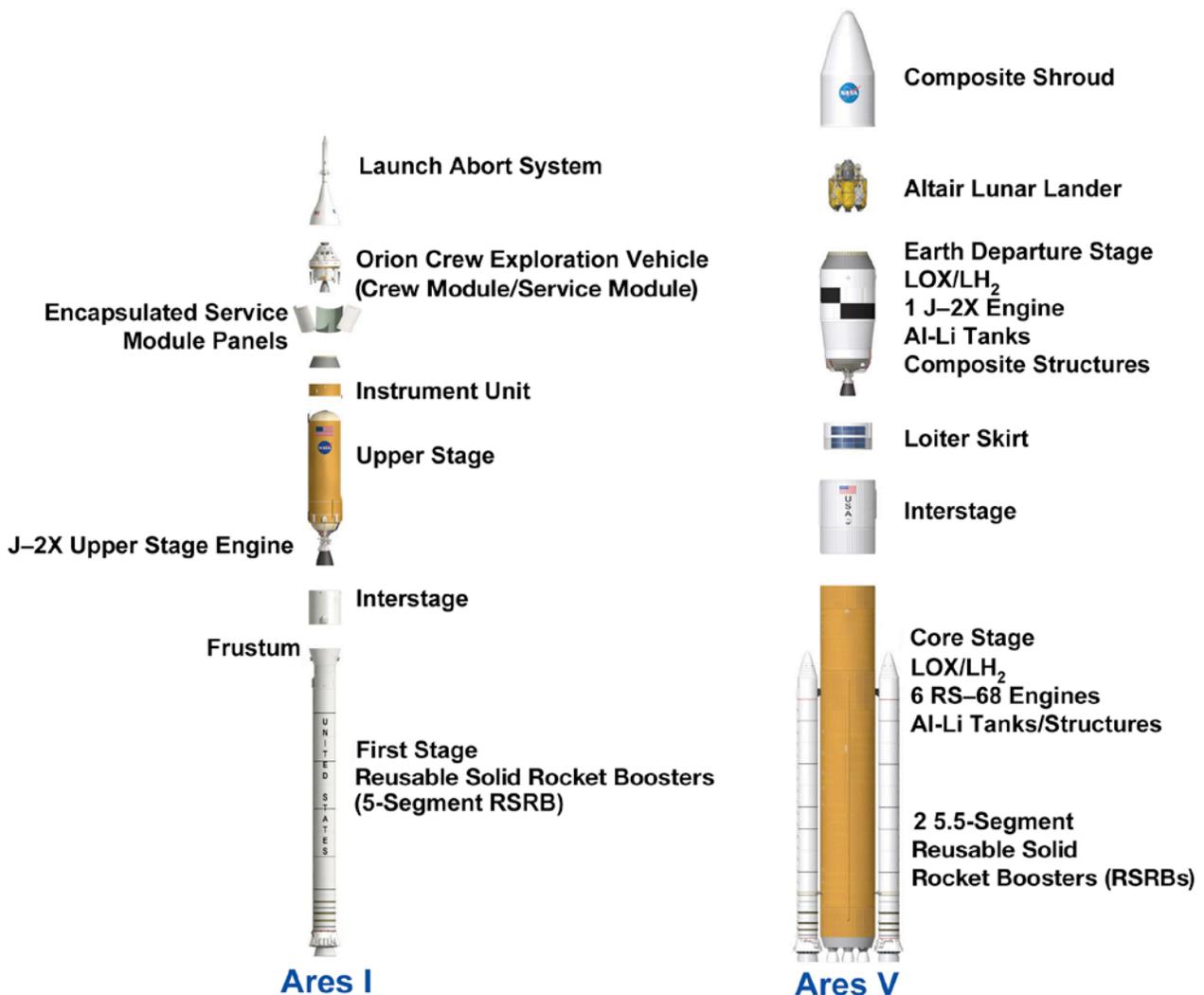
D Where the “brains” of the rocket are housed.

E Houses the equipment and eventually transports the astronauts to their final lunar destination. It can land anywhere on the Moon and can support a crew of four for up to seven days.

F Powers the core stage or lift-off on the Ares V.

G The LOX/LH₂ fuels the upper stage in both vehicles.

H Allows the astronauts to escape from the launch vehicle if dangers arise.



7. What Ares launch vehicle components are based on similar technology used during the Apollo (Saturn) and Space Shuttle programs?
8. What is the purpose for having two different Ares launch vehicles?

Lunar Transportation

Until now, NASA missions that transported astronauts to the Moon have used the Saturn V rocket to launch the Apollo command module and the lunar excursion module (LEM) into orbit. The Space Shuttle, lifted into space by its solid rocket boosters (SRB), has been used to launch and repair the Hubble Space Telescope, conduct science experiments in microgravity, and to service the International Space Station. Both the Apollo and Space Shuttle missions were relatively short-term, with no permanent habitat being constructed.

To complete the lunar and Mars exploration missions, it will be necessary to transport habitat components, survival supplies, and scientific equipment to the Moon's surface to support a permanent outpost station. Therefore, NASA engineers are making decisions regarding not only transport vehicles, but also how to supply essentials like oxygen and water to support human life over long periods of time until the astronauts learn to "live off the land."

In the "Ground Challenge," you made decisions using currently available ground transportation vehicles, but you were aware that the current models of these vehicles had been developed and improved over the last century. NASA engineers are designing a space transportation system built on a foundation of legacy knowledge and heritage hardware from the Apollo-Saturn and Space Shuttle programs.

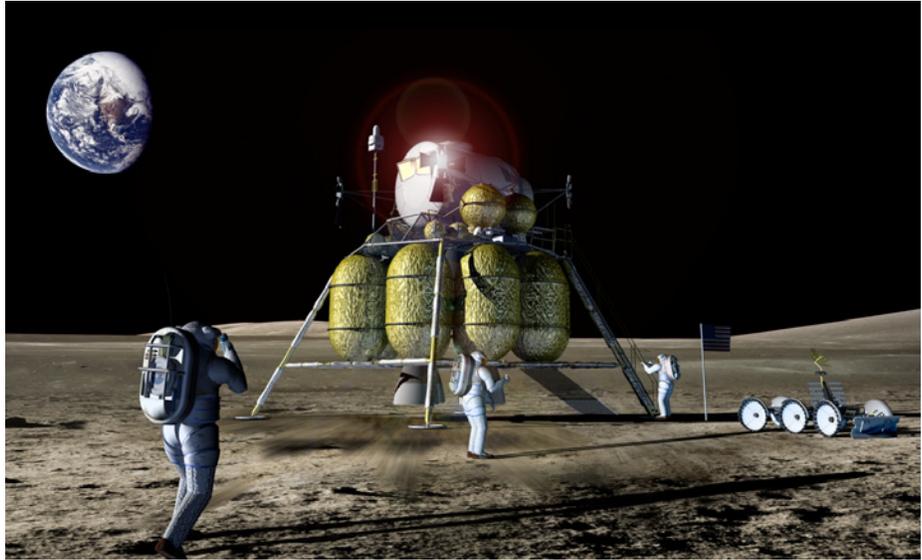
The Ares I is designed to lift the Orion Crew Exploration Vehicle (CEV), which carries the crew and supplies, into low-Earth orbit. Orion can carry six crewmembers and supplies to the International Space Station. In a trip to the Moon, however, four crewmembers and their supplies will be used. This will allow for more supplies and more room for the astronauts on this longer journey. The Ares V launches the lunar lander, Orion, into orbit. On the way to the Moon, Orion docks with the Earth departure stage carrying the lunar lander, Altair, which takes the crew to the Moon. Upon arrival, all four astronauts will be able to go down to the surface in the Altair. When they return, the bottom half of the Altair (the descent portion) stays on the Moon. The top half (the lander ascent stage) lifts off and re-docks with Orion. Altair is then ejected. Orion's service module fires its engines and sends the Orion crew capsule back toward Earth. The service module separates, and the Orion crew module lands on Earth using a combination of a heat shield, which has been protected by the service module during the other phases of the journey, parachutes, and airbags for cushioning. The Orion crew capsule will land on land, probably at Dryden Flight Research Center at Edwards Air Force Base in California.



Inflation Structures Project Leader Karen Whitley stands in the center of the 12-foot (3.65 meter) diameter inflatable lunar habitat at NASA Langley Research Center, Hampton, Va.

Lunar Living — Camping on the Moon

As part of its Global Exploration Strategy, NASA plans to build an outpost on the surface of the Moon — a base camp that would be busy when visitors are there, but that can be abandoned for long periods without long-term harm. Based at the outpost, astronauts will learn to use the Moon's natural resources to live off the land, make preparations for a journey to Mars, and conduct a wide range of scientific investigations. The first mission could begin by 2020.



Artist's concept of the lunar lander and astronauts on the moon.

Lunar Sortie Missions

Until permanent living quarters and power supplies are operational and Moon rovers are delivered, four-person crews will make several seven-day “sortie missions” to the Moon. A sortie is a short single mission flight. They will be based in a lunar lander that has a kitchen and sleeping areas, as well as medical care, storage, and waste collection facilities.

They will be able to conduct exploration missions at any location on the Moon. Sortie missions may be used to explore potential lunar outpost sites before more permanent building materials are delivered.

Lunar Outpost Mission

For longer lunar missions, more permanent living and working quarters are needed to allow astronaut crews to conduct long-term surface science, to learn to spend more time outside the habitat, and to test technology for future use. The lunar outpost housing will be delivered and constructed at a permanent surface location. It will provide larger and more comfortable crew accommodations than those in the lunar landers.

As the outpost construction takes place, mission lengths will be extended to an entire lunar day (28 Earth days), and then to permanent crew rotations that eventually would grow to six months on the lunar surface. The outpost habitat will be reused over multiple expeditions, and as a result will function during active periods when the crew is present and be placed in a dormant mode when it is not in use. Ultimately, the goal of the lunar outpost is continuous presence of surface crews.

The longest that any of the Apollo Mission astronauts stayed on the Moon was 75 hours (about three days). Therefore, the first step in making a lunar outpost a reality will be to determine what accommodations will be necessary for humans to live and work safely on the Moon's surface over an extended period of time.

Lunar Habitat

One possible type of lunar habitat being considered consists of inflatable, expandable structures as building blocks for a lunar base. According to Chris Moore, NASA Exploration Technology Development Program Executive, “Inflatables can be used as connectors or tunnels between crew quarters and can provide radiation shelter if covered with lunar soil.” The photograph shows a “planetary surface habitat and airlock unit.” The larger structure, which is 12 feet (3.7 meters) in diameter, is made of self-healing, radiation protective materials. There is a small inflatable structure attached to the larger structure that serves as an airlock. Both cylinders are pressurized and connected by an airtight door.

Whether the final selection of the lunar habitat is inflatable or constructed in some other way, it will be designed for extreme living and working conditions. There are plans to test the possible structures in the harsh environment of the Antarctic.



The “planetary surface habitat and airlock unit” has been delivered to NASA Langley for ground-based evaluation of emerging technologies such as health monitoring of flexible structures.

Moon Challenge

Based on your performance on the “Ground Challenge,” you have demonstrated your ability to build a research facility. In the “Moon Challenge” activity, you are asked to determine the supplies needed for a scientific experimental station to be launched by the Ares rocket system, transported to, and constructed on the Moon. You should use the “Moon Challenge” student activity sheet to begin the planning process.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Activity

Ground Challenge

Background Information

Your Ares construction company has contracted to construct a scientific experimental station, living quarters for personnel operating the station, and a power plant to provide electricity, water, and a clean air supply for the complex. This complex will be located in a remote, high-altitude desert one thousand miles from your company's headquarters.

In this "Ground Challenge," using the transportation vehicles your company has available, you will plan the most efficient method of transporting personnel, common construction materials, and supplies for a scientific experimental station to a remote area here on Earth. **You should plan at least two different transportation options. A rationale for benefits and limitations for each option should be presented.**

This construction will take place in four stages, as outlined in the table below; each stage requires a separate trip to deliver personnel with specialized capabilities. The complex is contracted to be operational in seven months, after which a group of scientists will take charge of maintaining the complex. By this time, you will have transported a solar-powered vehicle to the complex, which you will leave for their use.

The total mass of supplies and equipment that must be transported during the first two trips is 16,430 pounds (7,450 kilograms). The remaining supplies and equipment, totaling 14,500 pounds (6,580 kilograms), must be on site during the next two construction trips. During this time, teams of four people will be rotated every seven days, but transport vehicles may stay on site for as long as one month. The supplies can be transported before the trip in which they will be used.

Delivery Schedule

Ground Challenge: Schedule for delivery of manpower, supplies, and equipment			
Trip #	Labor for	Supplies for	Estimated Mass
1	Setting up 20 ft by 50 ft (6.1 by 15.2 m) building to accommodate: <ul style="list-style-type: none">• Personnel housing• Water production equipment• Power equipment and supplies• Housing for experimental equipment including air conditioning	20 ft by 50 ft (6.1 by 15.2 m) metal building outside walls/roof/foundation/floor inside partition walls to house: <ul style="list-style-type: none">• Personnel housing/food (will have to take bedding and one week's supply of food with them)• Water production/storage• Equipment (one week's supply)• Power equipment storage and supplies• Experimental research area	<ul style="list-style-type: none">• Building: 6,000 lb (2,722 kg)• Insulation: 200 lb (91 kg)• Foundation materials: 2,000 lb (907 kg)• Flooring sections: 1,000 lb (454 kg)• Interior wall finish: 500 lb (227 kg)• Lumber: 400 lb (181 kg)• Construction equipment: 500 lb (227 kg)• Sleeping bags• Food/Water for the team for one week: 250 lb (113 kg) Total: 10,850 lb (4,922 kg)

Ground Challenge: Schedule for Delivery of Manpower, Supplies, and Equipment			
Trip number	Labor for	Supplies for	Estimated Mass
2	Finish inside construction to create: <ul style="list-style-type: none"> • Personnel housing area • Operational power supply, • Operational water supply 	<ul style="list-style-type: none"> • Supply equipment (generator or solar panels) and supplies • Laboratory area for experimental research 	<ul style="list-style-type: none"> • Cabinetry materials: 1,000 lb (454 kg) • Plumbing supplies (include water supply): 1,750 lb (794 kg) • Electrical supplies (include air-conditioning): 1,000 lb (454 kg) • Power supply: 1,000 lb (454 kg) • Tools and construction equipment: 500 lb (227 kg) • Sleeping bags • Food/water for the team for one week: 250 lb (114 kg) Total: 5,500 lb (2,497 kg)
3	Install air conditioning in experimental research area	<ul style="list-style-type: none"> • Air conditioning equipment/supplies for experimental research equipment • 4 by 4 solar-powered vehicle 	<ul style="list-style-type: none"> • Food supply/staples for 6 months: 5,000 lb (2,268 kg) • Vehicle: 2,000 lb (907 kg) Total: 7,000 lb (3,175 kg)
4	Set up experimental equipment	Equipment	7,500 lb (3,402 kg) (This mass can be broke into parts if needed.)

Transportation Choices

Your company has the following types of transport vehicles available for this project:

- One full-sized pickup truck with a 1,750-pound (794-kilogram) maximum payload capacity and a towing capacity of 5,000 pounds (2,268 kilograms). This truck can hold three people, whose weight is considered part of the maximum payload. The bed of the pickup is 4 by 8 feet (1.2 by 2.4 meters).
- One club cab pickup that can hold four people and has a total maximum payload capacity of 2,000 pounds (907 kilograms) and a towing capacity of 6,000 pounds (2,721 kilograms). The bed of the pickup is 4 by 6.5 feet (1.2 by 1.9 meters).
- Two trailers that can be towed by either pickup truck; one with a maximum of 6,000 pounds (2,721 kilograms) payload capacity, another with a maximum payload capacity of 3,000 pounds (1,361 kilograms). Both trailers are 12 feet (3.7 meters) long.
- One SUV that can hold seven passengers and their luggage/food/water supply for a seven-day stay, or four passengers (and luggage) plus 750 pounds (340 kilograms) of construction equipment or tools.
- One tractor-flat-bed-trailer rig that can carry a maximum payload of 40,000 pounds (18,144 kilograms). The trailer can remain on-site for two months, but the tractor will return to company headquarters at the end of one week. The flat-bed trailer measures 48 feet (14.6 meters) long by 8.5 feet (2.6 meters) wide.

Ground Challenge Reporting Sheet

Directions: Plan at least two efficient methods of transporting personnel and equipment to the construction site so that the complex will be completed as scheduled. The maximum number of trips you can make is four. Efficiency is defined as hauling as much as possible during each trip with the smallest vehicles possible. Note your transportation choices for each of the four trips. Offer two possible options in the tables below and provide a clear rationale to support your decisions.

Option 1 Trip	Transportation Choices
Trip 1	
Trip 2	
Trip 3	
Trip 4	
Rationale for Option 1	

Option 2 Trip	Transportation Choices
Trip 1	
Trip 2	
Trip 3	
Trip 4	
Rationale for Option 2	

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Activity

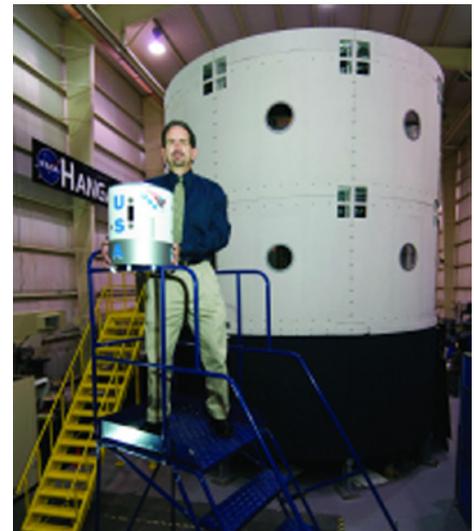
Moon Challenge

Background

Based on your performance on the “Ground Challenge,” your Ares Construction Company has demonstrated its ability to build a research facility on Earth. In this “Moon Challenge,” you will determine what personal supplies are needed and can be accommodated in a lunar scientific experimental station. Then, using the Ares rocket system, you will plan the most efficient method for transporting the habitat and life-support equipment, personal supplies, and experimental equipment to the Moon.

Habitat Size Constraints

The “From Earth to the Moon and Beyond” student text showed one model of the lunar habitat, measuring 12 feet (3.7 meters) in diameter. Another housing possibility, shown to the right, is a three-level vertical lunar habitation model. The lowest level of this vertical structure has an airlock for entering and leaving the structure. The second level includes living and recreational space, and the top level houses the scientific workspace. If the man in the photo is 6 feet (1.8 meters) tall, you can estimate the size of the structure.



Larry Toups stands in front of the Lunar Habitation Vertical Mockup at Johnson Space Center. He is holding a model of the structure.

Payload Constraints

The total mass of the payload for Ares I Crew Exploration Vehicle (CEV) is estimated to be 56,217 pounds (25,500 kilograms). The main payload for the Ares V is the Altair lunar lander, which will weigh an estimated 99,208 pounds (45,000 kilograms). The combined payload for both Ares I and Ares V is estimated to be about 155,425 pounds (70,500 kilograms). You will be allowed approximately 8,000 pounds (3,630 kilograms) for supplies to establish your lunar outpost. Assume each mission to be four weeks in duration. Your task is to design a delivery schedule for at least four missions to carry the needed equipment to the Moon.

For planning purposes, assume that each mission would include between four and six astronauts. Keep in mind that the greater the number of astronauts flying on a given mission, the greater the number of supplies that will be needed to sustain them.

On the next page are estimated weights for items you may choose to take. Be sure to include the lunar habitat (7,000 pounds or 3,175 kilograms) on the first mission. The experimental equipment and lunar rover may be transported in subsequent missions.

Supply Estimates

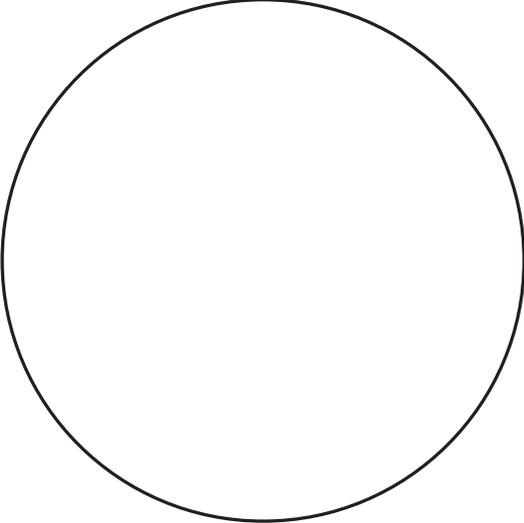
Supplies for	Approximate Mass
Lunar Habitat	7,000 lb (3,175 kg)
Personnel Food and Water: You will have to take a four-week supply of food/water and possibly bring food/supplies for future missions.	Food/Water for one week 250 lb (110 kg)
Personnel Supplies: Kitchen Cabinet Mini Refrigerator Refrigerator Microwave Lunar Dust Buster Electric Coffee Maker Toaster (4-slice capacity) Toaster (2-slice capacity) Washing Machine Dryer Bunk Bed Single Bed Table Tool Set (160 piece) Tool Set (300 piece) Books (3) Bookshelves CD Player Video Game Set Desk (office size) Desk (small) Chair (1) Sleeping Bag Foot Locker (trunk) Wardrobe Treadmill Medical Kit Extension Ladder	40 lb (18 kg) 70 lb (30 kg) 315 lb (145 kg) 70 lb (30 kg) 10 lb (4.5 kg) 5 lb (2.5 kg) 7 lb (3 kg) 4 lb (2 kg) 200 lb (90 kg) 150 lb (70 kg) 280 lb (125 kg) 150 lb (70 kg) 110 lb (50 kg) 29 lb (13 kg) 65 lb (30 kg) 3 lb (1.4 kg) 35 lb (15.9 kg) 35 lb (15.9 kg) 6 lb (2.7 kg) 150 lb (68 kg) 70 lb (32 kg) 20 lb (9 kg) 7 lb (3 kg) 30 lb (13.6 kg) 140 lb (64 kg) 154 lb (70 kg) 7 lb (3.2 kg) 70 lb (32 kg)
Power Supply Equipment: 50-watt Solar Panel Power-boost Generator Atmospheric Revitalization System and Water Recovery System	25 lb (11.3 kg) 174 lb (79 kg) 6,000 lb (2722 kg)
Apollo Style Lunar Roving Vehicle	460 lb (209 kg)
Experimental Equipment	7,500 lb (3400 kg)

Moon Challenge Reporting Sheet

Directions: Referring to the Supply Estimates list, determine which supplies will be transported during each of the four lunar missions. Itemize the mass for each supply and provide totals for each mission in the “Total Mass” column. Then, provide a rationale for your supply selection.

Mission	Number and Type of Supply and Mass	Total Mass (Must not exceed 8,000 pounds or 3629 kilograms)
1	1 Lunar Habitat	
Rationale		
2		
Rationale		
3		
Rationale		
4		
Rationale		

Conclusion Questions

1. Why do you think that you were required to transport the lunar habitat in the first trip?
2. Did you transport the power supply, the Atmospheric Revitalization System (ARS), and the Water Recovery System (WRS) in the second trip?
Why or why not? (See the hotlinks to “Space Water” and “Space Breathing” available at: <http://spaceflight.nasa.gov/living/index.html>)
3. Did you select electrical equipment — such as a refrigerator, microwave, coffee maker, toaster, washing machine, or dryer?
How much of the power supply will these appliances use?
Do you think the solar panel will supply that much electricity? (To find out what electrical appliances the astronauts have on the International Space Station, you may want to look at the links for “Eating and Drinking” and “Doing Laundry” available at: <http://spaceflight.nasa.gov/living/index.html>)
4. If you decided to take beds, desks, a kitchen cabinet, or a wardrobe to the Moon, how would you arrange these items in the 12-foot (3.7 meter) diameter circle? (For more details, go to “Space Sleep” available at: <http://spaceflight.nasa.gov/living/index.html>. This will supply some insights into where and how astronauts sleep and eat in space, and how they will sleep and eat on the Moon.)

5. Explain some of the obstacles NASA faces in planning lunar missions with limited budgets.
6. Why is communication important when planning missions?

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

Investigating Water Rockets: Abbreviated Approach

Background Information

This teacher's guide represents an alternate approach to conducting the Interaction/Synthesis section of this module in a shorter time frame and with less teacher preparation than is required if each group studies different variables in design (expert) teams. However, the safety aspects of this approach are still important and are noted below for the instructor and students to follow. The following table is a synopsis of the two approaches, so you will be able to make a decision that best meets your needs:

Interaction/Synthesis and Assessment	Comprehensive Approach	Abbreviated Approach
Safety Rules/Safety Checklist	Yes	Yes
Measuring Altitude	Yes	Yes
Nose Cone Group	Yes	No (While the nose cone is not tested, it should be constructed for the final assessment.)
Fin Number and Placement	Yes	No
Fin Shape and Size	Yes	Yes
Propulsion Volume of Water	Yes Individually in expert groups	Yes As a class
Pressure of Water	Yes	No
Weather or Not	Yes	No
You Get What You Pay For	Optional	No
Fly Me High (Assessment)	Yes	Yes

A critically important issue for these sessions is safety. Water bottle rocketry is fun, and it can be a great vehicle for understanding many scientific concepts; however, all safety precautions must be followed.

During this session, students will get a complete overview of the safety issues involved with building and launching bottle rockets. Safety is a major issue. Be certain that you study the accompanying "Safety Rules" with your students and that you monitor strict safety regulations during all launches. Instruct students to refer to the "Safety Checklist" each time they build or launch. Specific information is included in this unit.

In addition to learning about safety precautions, students will build an altitude tracker and practice using it in preparation for the upcoming rocket launches. The altitude tracker makes use of simple trigonometry to determine the altitude a rocket reaches in flight. For most accurate readings, at least four altitude readings should be taken. These reading stations should be at a distance of 33 feet (10 meters) from the launch pad at each position including north, east, south, and west. Once a rocket is launched, the four student spotters (standing at reading stations) should follow the path of the rocket through the altitude tracker sighting tube. When the rocket reaches its highest point (apex), each spotter should hold the weighted string in the position that it naturally falls and read and record the angle. Once the four angles are gathered, the high and the low angles should be omitted. The two remaining

angles should be averaged. Students should then find the angle on the conversion chart, identifying the height that the rocket reached.

The teacher's guide in this section is divided into information for teachers to interact with student groups. Each group will be working on the same type of testing at the same time. The teacher's role becomes that of a facilitator of learning, rather than the source of knowledge. Encourage them to ask questions and find answers for themselves throughout the process. Your close supervision is required during the test launches. We recommend that you schedule test launches on one specific day of the week or when a critical mass is ready to test their variable. You may want to recruit the assistance of another adult to assist in this process.

National Science Standards Addressed

See: Investigating Water Rockets: Comprehensive Approach

Materials

Activity 1: What Do I Need to Know Before Launch?

- "Appendix J Safety Rules," page 124.
- "Appendix K Safety Checklist," page 126.
- Student activity, "Measuring Altitude," page 62.
- "NASA Altitude Tracker," page 123. (This pattern can be copied or glued onto tag board.)
- Thread, lightweight string, or fishing line.
- Cellophane tape.
- Small washer or 1–2 ounce (28–57 gram) fishing sinker.
- Scissors.
- Rope or string to measure out range (33 feet or 10 meters).
- Angle-to-Height Conversion Chart, page 64.
- Tennis ball per pair of students.

Activity 2: Propulsion for Entire Class

- Student activity, "Altitude vs. Water Volume," page 84.
- Several two-liter plastic soft drink bottles.
- Water.
- Graduated cylinders (one-liter).
- Tire pump or air compressor.
- Safety glasses.
- Altitude trackers.
- Conversion chart, page 64.
- Rope to measure out range (33 feet or 10 meters).
- Compass to determine north, south, east, or west.
- Launcher (see Appendix G) or search the Internet to purchase a launcher.

Activity 3: Fin Shape

- Student activity, "Investigating Fin Shape or Size," page 72.
- Paper towel tubes.
- Tag board (for fins).
- Ruler.
- Cellophane tape and/or glue.
- Scissors.
- Safety glasses.
- Launching mechanism (vacuum with blower or leaf blower).
- Yard (or meter) stick for measuring distances.
- Arrows: some with and some without feathers.

Preparation

1. Gather materials for all of the activities.
2. Make copies of “Student Activity” pages. The Altitude Tracker needs to be copied on heavy weight paper.
3. Make a sample altitude tracker to use as an example.
4. Construct a water bottle rocket launcher or search the Internet to purchase a pre-made launcher. Instructions for construction of the launcher are located in Appendix G.

Activity 1: What Do I Need to Know Before Launch?

Procedure

1. Read through all the “Safety Rules,” page 124, with the students and then refer to the “Safety Checklist,” on page 126. Students should sign the safety rules. If you have already discussed the safety rules with the students, ask them to point out the safety issues to you as they read through the directions for “Constructing an Altitude Tracker,” which is included in the “Measuring Altitude” student activity on page 62.
2. Have each student construct an altitude tracker. The altitude tracker pattern can be found in Appendix I.
3. Have students complete the student activity, “Measuring Altitude,” in their small groups.

Activity 2: Propulsion for Entire Class

Working as a class, students will determine the best water volume to make a two-liter bottle go the specified height (98 feet or 30 meters). The goal of this investigation is to gather evidence regarding optimum water volume based on their observations.

Background Information:

A water bottle rocket is a two-liter soda bottle filled with compressed air and water. During launch, when the pump valve is opened, the compressed air and water are released, sending the rocket in an upward direction. Students will have the opportunity to experience Newton's Three Laws of Motion as well as expand their conceptual understanding of motion, force, mass, and momentum.

For a detailed explanation of how these Three Laws of Motion apply to water bottle rockets, see the student text, “Newton's Laws of Motion and Rockets,” on page 21.

Procedure:

1. While this activity will be completed as a class, students are each responsible for completing the student activity sheets, “Altitude vs. Water Volume,” beginning on page 84. The following procedure will help you to facilitate this whole-class activity:
 - a. Remove the labels from the bottles.
 - b. Fill bottles with pre-determined volumes of water and cap the bottles. To streamline the procedure, have a group of students measure volumes of water that would have the bottle completely full, three-quarters full, half-full, one-quarter full, and empty.
 - c. Put one bottle at a time on the launch pad and apply 50 psi of pressure.
 - d. Use a compass to determine locations. Have an altitude tracker spotter positioned at each of these four positions (north, east, south, and west).
 - e. Each spotter will use the altitude tracker to measure the angle of the highest point of flight.
 - f. Each angle should be recorded; the high and low angles should be omitted.
 - g. Two more trials should be made for that volume of water.
 - h. Average the remaining angles (once the high and low angles for each of the three trials have been omitted) to come up with an average angle.
 - i. Use the conversion chart, located in the “Measuring Altitude” student activity, to determine the height.
 - j. Repeat the same procedure for the other volumes of water.

2. Once students have conducted the test, they may wish to look at manipulating other variables. Watch as they unknowingly transform into research scientists attempting to answer questions that they ask themselves. Listen carefully; many will (in their descriptions) be describing Newton's Laws of Motion.

At just the right teachable moment, these laws can be explained and made understandable to very young students. Typical student statements that set the stage for new understandings include the following:

- a. Why did the rocket that was full of water barely take off? (It was too heavy [massive] — Newton's First Law.)
 - b. The rocket did not have enough "oomph" (force) to make it take off. Why? (There was not enough force for the relatively huge mass — Newton's Second Law.)
 - c. The water went one way and the rocket went the other way (Newton's Third Law).
3. Questions that might be asked to get the students thinking in the right direction include the following:
 - a. What happens to the rocket as the water inside the bottle goes down?
 - b. If you could eject the water twice as fast from the rocket, what effect would this have on the rocket?
 4. At the end of the lesson, ask each student to write a conclusion, using their own words, describing what makes the bottle rockets fly.

Activity 3: Fin Shape

Students working in groups will examine two variables related to fins. Students may investigate various fin shapes including rectangle, triangle, semicircle, or polygon — each in various sizes. Students should keep the number and placement location on the rocket constant. The goal for this exercise is to gather evidence, based on research and observations, for the best fin design to allow the rocket to be stable during flight.

Background Information

A rocket with no fins is much more difficult to control than a rocket with fins. The size and shape of the fins, as well as their number and placement, are critical to achieving adequate stability without adding too much weight. For more information on stability and control systems, see page xiv at the beginning of this guide.

Procedure

1. Distribute the "Investigating Fin Shape or Size" student activity on page 72. Divide the students into small groups and instruct each group to complete the investigations on this sheet.
2. When the groups have completed the investigations, look at their plans. It is important that students examine each variable (i.e., fin shape, fin size) during separate tests.
3. Time should be provided for students to discuss their results and conclusions.
4. Individual students should write a conclusion summarizing what they have learned about the aerodynamics of fins through their research and observations. They need to make their explanation clear enough so that other people can understand it.

Teacher Resources

Publications

Rockets: A Teacher's Guide with Activities in Science, Mathematics, and Technology, NASA EG-2003-01-108-HQ, Office of Human Resources and Education, Washington, DC, 2003.

<http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Rockets.html>

Web sites

NASA's Beginner's Guide to Rockets — good for teachers and students:

<http://exploration.grc.nasa.gov/education/rocket/bgmr.html>

Rocket Index from NASA Glenn Research Center:

<http://exploration.grc.nasa.gov/education/rocket/shortr.html>

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

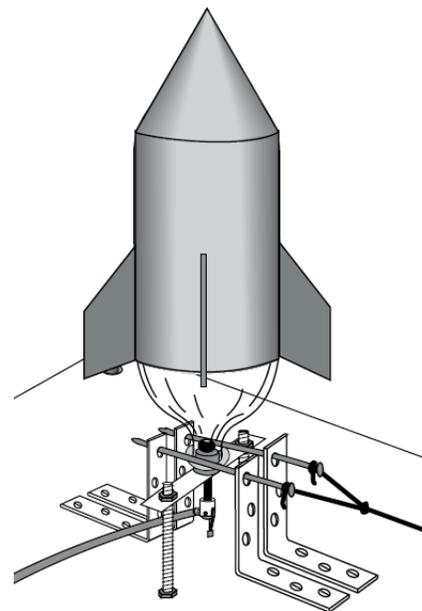
Investigating Water Rockets: Comprehensive Approach

Background Information

A critically important issue for these sessions is safety. Water bottle rocketry is fun, and it can be a great vehicle for understanding many scientific concepts; however, all safety precautions must be followed.

During this session, students will get a complete overview of the safety issues involved with building and launching bottle rockets. Safety is a major issue. Be certain that you study the accompanying “Safety Rules” (page 124) with your students and monitor strict safety regulations during all launches. Instruct students to refer to the “Safety Checklist” (page 126) each time they build or launch. Specific information is included in this unit.

In addition to learning about safety precautions, students will build an altitude tracker and practice using it in preparation for the upcoming rocket launches. The altitude tracker makes use of simple trigonometry to determine the altitude a rocket reaches in flight. For most accurate readings, at least four altitude readings should be taken. These reading stations should be a distance of 33 feet (10 meters) from the launch pad — one at each compass position — including north, east, south, and west. Once a rocket is launched, the four student spotters (standing at reading stations) should follow the path of the rocket through the altitude tracker sighting tube. When the rocket reaches its highest point (apex), each spotter should hold the weighted string in the position that it naturally falls and read and record the angle. Once the four angles are gathered, the high and the low angles should be omitted. The two remaining angles should be averaged. Students should then find the angle on the conversion chart, identifying the height that the rocket reached.



Students will work in the same collaborative (design) groups for “What Do I Need to Know Before Launch?” as they did for the other parts of the module. This will allow you to observe and experience what they know and do not know about rocketry and provide the motivation for them to want to learn more. Students work in design groups to discuss the first attempt at launching rockets; they will also assign expert roles. In expert groups, students will gain specific knowledge about one of the variables of successful rocket launching. They will bring this information back to their design group and that group will put together a newly designed rocket using each individual’s expertise. After additional testing, they will launch in the competition to find who can launch a water rocket the highest.

The teacher guide in this section is divided into information for teachers to use in their interactions with the specific expert groups. The teacher’s role becomes that of a facilitator of learning rather than the source of knowledge. With your supervision, your students can complete the activities within the expert learning group sessions. Encourage them to ask questions and find answers for themselves throughout the process. Your close supervision is required during the test launches. We recommend that you schedule test launches on one specific day of the week or when a critical mass is ready to test their variable. You may want to recruit the assistance of another adult to assist in this process.

Prior to the launch activity, students explore the safe parameters (weather conditions, etc.) that are guidelines used to determine if a launch can take place at a given time. Students use a simple fault-tree analysis to make decisions regarding a launch. This will include using technology to monitor the conditions at the local launch site to determine whether the launch should be conducted.

National Science Standards Addressed

Grades 5–8

Science as Inquiry

Abilities necessary to do scientific inquiry.

Physical Science

Motion and forces.

Science and Technology

Abilities of technological design.

Understandings about science and technology.

Science in Personal and Social Perspectives

Personal health.

Grades 9–12

Science as Inquiry

Abilities necessary to do scientific inquiry.

Physical Science

Motion and forces.

Science and Technology

Abilities of technological design.

Understandings about science and technology.

Science in Personal and Social Perspectives

Personal and community health.

Principles And Standards For School Mathematics Addressed

Measurement Standard for Grades 6–8

Understand measurable attributes of objects and the units, systems, and processes of measurement

Understand both metric and customary systems of measurement.

Apply appropriate techniques, tools, and formulas to determine measurements

Select and apply techniques and tools to accurately find length and angle measures to appropriate levels of precision.

Problem Solving Standard for Grades 6–8

Solve problems that arise in mathematics and in other contexts

Measurement Standard for Grades 9–12

Understand measurable attributes of objects and the units, systems, and processes of measurement

Make decisions about units and scales that are appropriate for problem situations involving measurement.

Problem Solving for Grades 9–12

Solve problems that arise in mathematics and in other contexts.

National Educational Technology Standards Addressed

Technology Standards for Students K–12

Technology Productivity Tools

Students use technology tools to enhance learning, increase productivity, and promote creativity.

Technology Research Tools

Students use technology to locate, evaluate, and collect information from a variety of sources.

Technology Problem-solving and Decision-making Tools

Students use technology resources for solving problems and making informed decisions.

Technology Standards for Students 6–8

Use content specific tools, software, and simulations to support learning and research.

Collaborate with peers, experts, and others using telecommunications and collaborative tools to investigate curriculum-related problems, issues, and information, and to develop solutions or products or audiences inside and outside the classroom.

Materials

Activity 1: What Do I Need to Know Before Launch?

- “Appendix J: Safety Rules,” page 124.
- “Appendix K: Safety Checklist,” page 126.
- Student activity, “Measuring Altitude,” page 62.
- “NASA Altitude Tracker,” page 123. (This pattern can be copied or glued onto tag board.)
- Thread, lightweight string, or fishing line.
- Cellophane tape.

- Small washer or 1–2 ounce (28–57 gram) fishing sinker.
- Scissors.
- Rope or string to measure out range (33 feet or 10 meters).
- Angle-to-Height Conversion Chart, page 64.
- Tennis ball per pair of students.

Activity 2: Nose Cone Experts

- Student activity, “What a Drag,” page 65.
- Paper towel tube.
- “Appendix L: Nose Cone Pattern,” page 127.
- Yard (or meter) stick.
- Several two-liter plastic soft drink bottles.
- Modeling clay.
- Card stock.
- Leaf blower or vacuum set to blow.
- Books to make a path.
- Long hall or open area.

Activity 3: Fin Experts (two groups)

- Student activity, “Flying Straight,” page 68, for students in both groups.
- Student activity, “Investigating Fin Shape or Size,” page 72, for one group. (Optional for students needing more structure.)
- Student activity, “Investigating Fin Number and Placement,” page 78 for the second group. (Optional for students needing more structure.)
- Paper towel tubes.
- Tag board (for fins).
- Ruler.
- Cellophane tape and/or glue.
- Scissors.
- Safety glasses.
- Launching mechanism (vacuum with blower or leaf blower).
- Yard (or meter) stick for measuring distances.
- Arrows: both with and without feathers.

Activity 4: Propulsion Experts

- Student activity, “Fly Like an Eagle,” page 81.
- Student activity, “Altitude vs. Water Volume,” page 84. (Optional for students needing more structure.)
- Student activity, “Altitude vs. Water Pressure,” page 87. (Optional for students needing more structure.)
- Several two-liter plastic soft drink bottles.
- Water.
- Graduated cylinders (one-liter).
- Tire pump or air compressor.
- Safety glasses.
- “NASA Altitude Tracker,” page 123.
- Conversion charts, page 64.
- Rope to measure out range (33 feet or 10 meters).
- Compass to determine north, south, east, or west.
- Launcher (see Appendix G) or search Internet to purchase a launcher.

Activity 5: Weather or Not

- Copy of the student activity, “Weather or Not,” page 90.
- Access to a computer with the Internet.
- Weather instruments for measuring wind speed, direction, visibility, and temperature.

Teacher Tip

Jigsaw is a type of structure for use in cooperative learning activities in which students work with one group of students for a defined task. After completing the defined task, students then disperse and join into new groups. These new groups are jigsaw groups comprised of representative members from each of the original groups. For example, if the original groups are identified as groups 1, 2, or 3, each jigsaw group would be comprised of members from groups 1, 2, and 3. This is an effective and efficient way of taking larger content, breaking it into smaller parts for in-depth investigation, and piecing the parts together again so that all participants gain some exposure to the larger content.

Alternate Strategy Tip

Refer to the teacher guide “You Get What You Pay For,” page 105, to include an economics component for the interaction and the assessment sections.

Preparation

1. Gather materials for all of the activities.
2. Make copies of “Student Activity” pages. The Altitude Tracker needs to be copied on heavy weight paper.
3. Make a sample altitude tracker to use as an example. The altitude tracker pattern can be found in Appendix I.
4. Construct a water bottle rocket launcher or search the Internet to purchase a pre-made launcher. Instructions for construction of the launcher are located in Appendix G.

Activity 1: What Do I Need to Know Before Launch?

Procedure

1. Read through all “Safety Rules” with students and refer to the “Safety Checklist.” Students should sign the safety rules. If you have already discussed the safety rules with students, ask them to point out the safety issues to you as they read through the directions for “Constructing an Altitude Tracker” included in the “Measuring Altitude” student activity.
2. Have each student construct an altitude tracker.
3. Have students complete the student activity, “Measuring Altitude,” in their design groups.
4. Using a jigsaw method (see teacher tip box on previous page), divide your design groups into four expert groups. These include the following:
 - a. Nose cone.
 - b. Fin numbers and placement.
 - c. Fin size and shape.
 - d. Propulsion.

Once the expert groups have been assembled, provide student activity sheets and instructions to the four groups.

Activity 2: The Nose Cone Experts

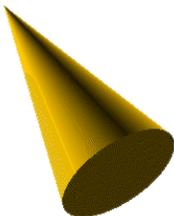
Description

Types of nose cones include the parabolic, the conical (cone), and the elliptical. Students working in this expert group will experiment with different nose cone shapes to determine the advantages and disadvantages of each type.

Background

Aerodynamics is the branch of science that deals with the motion of air and the forces on bodies moving through the air. There are four forces that act on a rocket. They are lift, drag, weight, and thrust. For a graphic illustration of these forces, go to: <http://exploration.grc.nasa.gov/education/rocket/rktfor.html>

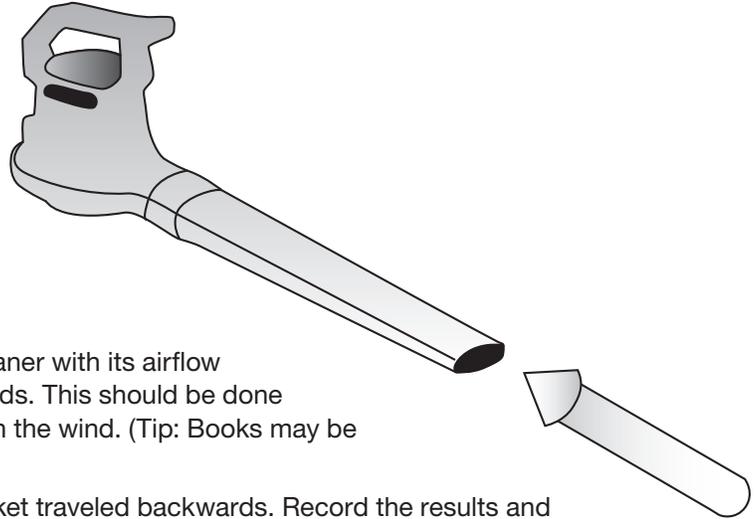
Drag is a force that opposes the upward movement of the rocket. It is generated by every part of the rocket. Drag is a sort of aerodynamic friction between the surface of the rocket and the air. Factors that affect drag include the size and shape of the rocket; the velocity and the inclination of flow; and the mass, viscosity and compressibility of the air. For an interesting

Types of Nose Cones		
Parabolic	A parabolic cone has a smooth curved surface and a sharp pointed nose.	
Elliptical	An elliptical cone is similar to the parabolic cone except the nose is blunted and not sharp. If the nose cone were cut in half, perpendicular to the base, the resulting cross-section would be half of an ellipse.	
Conical (cone)	A very common nose cone shape is a simple cone. The sides of the cone are straight lines.	

computer simulation where you can manipulate an airfoil's thickness, the air speed, altitude, and angle, go to <http://exploration.grc.nasa.gov/education/rocket/rktsim1.html>

Procedure

1. To allow them to build on their past experiences with aerodynamics, students in this expert group will complete questions 1–4 of the student activity sheet, “What a Drag.”
2. Students construct nose cones by cutting out two different nose cone shapes from card stock. (A template for one is available in Appendix L. The students will also do one of their own design.) They will then attach the nose cones onto paper towel tubes.
3. Use a commercial leaf blower or a vacuum cleaner with its airflow reversed to “blow” to force the rocket backwards. This should be done on a narrow track to keep the rocket in line with the wind. (Tip: Books may be lined up to make this track.)
4. Students should measure the distance the rocket traveled backwards. Record the results and complete the nose cone expert report on the “What a Drag” sheet. When students have completed the expert group work, instruct them to begin the student activity “Weather or Not.”



Activity 3: The Fin Experts

Description

Students working in these expert groups will examine the variables related to fins. One group will investigate shape and size, while the other will explore fin number and placement. Students in the first group investigate various fin shapes including rectangle, triangle, semicircle, or polygon — each in various sizes. The second group investigates three, four, or six fins placed in an even or uneven pattern. The goal for the fin experts is to gather evidence, based on research and observations, as to what makes for the most effective fin design for allowing the rocket to remain stable during flight. They will then share their collective findings with their own design team.

Teaching Tip

You may want to further divide the fin shape and size group into two groups. One group should investigate shape; the other should investigate size.

Background Information

A rocket with no fins is much more difficult to control than a rocket with fins. The size and shape of the fins, as well as their number and placement, are critical to achieve adequate stability while not adding too much weight. For more information on stability and control systems, see page xiv at the front of this guide.

Procedure

1. Have students complete the student activity “Flying Straight.” They will probably want to know:
 - Does fin shape make a difference?
 - Does fin size make a difference?
 - Would more fins work better?
2. Students capable of designing their own investigation should complete “Flying Straight,” numbers 12–14.
3. Students who need more structure should complete the student activity “Investigating Fin Shape or Size” or “Investigating Fin Number and Placement,” depending on their designated expert group. Distribute the “Investigating Fin Shape or Size” activity and instruct one group to complete the investigations on this sheet. Distribute the student activity, “Investigating Fin Number and Placement,” to the other group.

- When the groups have completed the investigations, look at their plans. It is important that students examine at least these three separate variables: fin shape, fin size, and fin number/placement. Some students may be ready to conduct their own experiments; other students may require more structure.
- Time should be provided for students to discuss their results and conclusions.
- (Optional) Individual students should write a summary of what they have learned through their research and observations about the aerodynamics of fins. They need to make their explanation clear enough so that other people in their design group can understand it. Have students exchange papers and complete a short peer review.
- Each of the two groups that investigated fins should write a group paper summarizing their findings, based on evidence gathered during their research and observations. That summary should be shared with other members of the design team. When students have completed the expert group work, instruct them to begin the student activity, "Weather or Not."

Activity 4: The Propulsion Experts

Description

Students working in this expert group will determine the best water volume and the best launch pressure to make a plain two-liter bottle go the specified height (98 feet or 30 meters). The goal of the propulsion experts is to gather evidence regarding optimum pressure and water volume, based on research and observations, and then share their collective findings with their own design group.

Background Information

A water bottle rocket is a two-liter soda bottle filled with compressed air and water. During launch, when the pump valve is opened, the compressed air and water are released, sending the rocket in an upward direction. Students will have the opportunity to experience Newton's Three Laws of Motion and expand their conceptual understanding of motion, force, mass, and momentum.

For a detailed explanation of how these Three Laws of Motion apply to water bottle rockets, see the student text "Newton's Laws of Motion and Rockets."

Procedure

- Have students complete the student activity "Fly Like an Eagle." They will probably want to know the following:
 - What volume of water works best?
 - Will the bottle rocket fly without water?
 - If a little water works, will a lot work better?
 - Will it fly best when it is totally full?
 - Does the launch pressure matter?
- Look at their plans. It is important that students in this expert group examine at least two variables: volume of water and launch pressure. Some students may be ready to conduct their own experiments; other students may require more structure. The student activities "Altitude vs. Water Volume" and "Altitude vs. Water Pressure" are available to use as a guide. Once students have tested the variables (volume of water and launch pressure) independently, they may wish to look at manipulating other variables. They may also want to look at various volumes of water at various pressures. Watch as they unknowingly transform into research scientists attempting to answer questions that they ask themselves. Listen carefully; many will (in their descriptions) be describing Newton's Laws of Motion. At just the right teachable moment, these laws can be explained and made understandable to very young students. Typical student statements that set the stage for new understandings include the following:
 - Why did the rocket that was full of water barely take off? (It was too heavy [massive] — Newton's First Law.)
 - The rocket did not have enough "oomph" (force) to make it take off. Why? (There was not enough force for the relatively huge mass — Newton's Second Law.)
 - The water went one way and the rocket went the other way (Newton's Third Law).

3. Questions that might be asked to get the students thinking in the right direction include the following:
 - Why did the rocket that was full of water barely take off?
 - What happens to the rocket as the water inside the bottle goes down?
 - If you could eject the water twice as fast from the rocket, what effect would this have on the rocket?
4. (Optional) At the end of the lesson, ask each student to write a summary, using their own words, describing what makes the bottle rockets fly. They need to make their explanation clear enough for other people in their design group to understand it. Have students exchange papers and complete a short peer review.
5. Finally, ask students to write a group paper, to be shared with their design group, which explains what makes a rocket fly best. When students have completed the expert group work, instruct them to begin the student activity “Weather or Not.”

Activity 5: Weather or Not

Procedure

1. Distribute a copy of the student activity, “Weather or Not,” to each student.

Play the following audio clip of Kris Walsh



(Appendix H)

explaining launch period and launch window. Instruct students to read the background information and work in their design groups to develop weather criteria for determining if a launch should take place. Circulate around the room offering assistance to groups who might need it.

2. Listen to students to determine the best way to come to a consensus on the weather conditions necessary to launch a water rocket. Using this method, synthesize the student criteria into a class launch criterion to be used during the competition in the assessment section.

Alternate Strategy Tip

Have weather instruments available for students to take real-time weather data and record this in the classroom. This will allow students to read weather instruments and at the same time find weather information at your launch site.

Teacher Resources

Publications

Rockets: A Teacher's Guide with Activities in Science, Mathematics, and Technology, NASA EG-2003-01-108-HQ, Office of Human Resources and Education, Washington, D.C., 2003.

<http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Rockets.html>

Web sites

NASA Beginner's Guide to Rockets — good for teachers and students:

<http://exploration.grc.nasa.gov/education/rocket/bgmr.html>

Rocket Index from NASA Glenn Research Center:

<http://exploration.grc.nasa.gov/education/rocket/shortr.html>

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Student Activity

Measuring Altitude

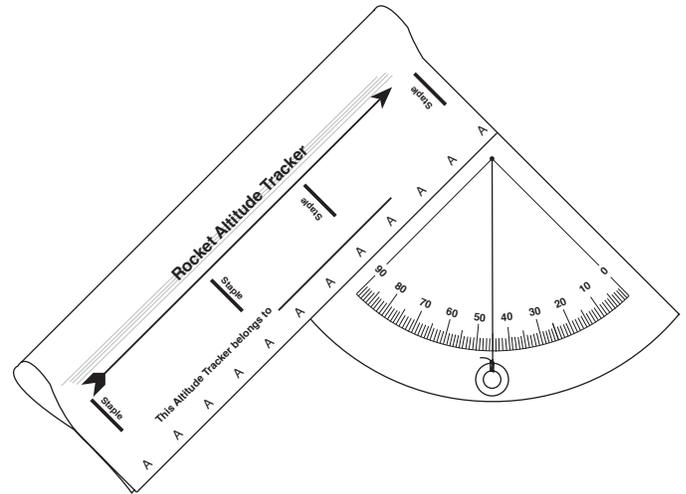
Materials

- “NASA Altitude Tracker Pattern,” page 123.
- Scissors.
- Pin or small nail.
- Thread, lightweight string, or fishing line.
- Cellophane tape.
- Small washer or 1–2 ounce (28–57 gram) fishing sinker.

Constructing the Altitude Tracker Scope

Procedure

1. Give each student an altitude tracker pattern located on page 123, Appendix I.
2. Cut out the pattern on the dark outside lines.
3. Curl (do not fold) the B edge of the pattern to the back until it lines up with the A edge.
4. Staple the edges together where marked. If done correctly, the As and Bs will be on the outside of the tracker.
5. Punch a small hole through the apex of the protractor quadrant on the pattern (black dot).
6. Slip a thread or lightweight string through the hole. Knot the thread or string on the backside.
7. Complete the tracker by hanging a small washer from the other end of the thread.



Measuring Altitude

1. Find an object whose height you would like to know but cannot measure directly.
2. Stand 33 feet (10 meters) from the object that you will be measuring.
3. Hold the tracker like a pistol and look through the sighting tube to locate the highest point of the object.
4. While the object is still in your sight, hold the string in the position that it naturally falls because of the weight.
5. Record the angle on the chart below.

6. Use the conversion chart to convert the angle into height in feet (meters) and record the height on the chart below.
7. Try this process with at least five other objects or until you feel that you have mastered the art of measuring the altitude of stationary objects.
8. Challenge: Stationary objects are easy; just wait until you try to track a rocket moving at 65 miles (105 kilometers) per hour! Now, have someone toss a tennis ball into the air and see if you can follow the path of the tennis ball through the sighting tube. Remember, the person with the tracker should be 33 feet (10 meters) away from the person throwing the ball. When the tennis ball reaches its highest point (apex), capture the angle by holding the string in the position that it naturally falls because of the weight. Do this several times until you become proficient at tracking the ball. Record the angle and height on the chart below.

Object	Angle (degrees)	Height (feet or meters)

9. Write a summary describing the process of finding the height of an object using an altitude tracker.

Angle-to-Height Conversion Chart

Angle (at 10 m or 32.8 ft)	Height (ft)	Height (m)	Angle (at 10 m or 32.8 ft)	Height (ft)	Height (m)
0	0	0.0	45	32.8	10.0
1	0.7	.2	46	33.8	10.3
2	1.3	.4	47	35.1	10.7
3	1.6	.5	48	36.4	11.1
4	2.3	.7	49	37.7	11.5
5	3	.9	50	39	11.9
6	3.3	1.0	51	40.4	12.3
7	3.9	1.2	52	41.7	12.7
8	4.6	1.4	53	43.3	13.2
9	5.2	1.6	54	45.3	13.8
10	5.9	1.8	55	46.9	14.3
11	6.2	1.9	56	48.6	14.8
12	6.9	2.1	57	50.5	15.4
13	7.5	2.3	58	52.5	16.0
14	8.2	2.5	59	54.5	16.6
15	8.9	2.7	60	56.8	17.3
16	9.5	2.9	61	59.1	18.0
17	9.8	3.0	62	61.7	18.8
18	10.5	3.2	63	64.3	19.6
19	11.2	3.4	64	67.3	20.5
20	11.8	3.6	65	70.2	21.4
21	12.5	3.8	66	73.5	22.4
22	13.1	4.0	67	77.1	23.5
23	13.8	4.2	68	81	24.7
24	14.8	4.5	69	85.3	26.0
25	15.4	4.7	70	89.9	27.4
26	16.1	4.9	71	95.1	29.0
27	16.7	5.1	72	101	30.8
28	17.4	5.3	73	107.3	32.7
29	18.0	5.5	74	114.5	34.9
30	19.0	5.8	75	122.4	37.3
31	19.7	6.0	76	131.6	40.1
32	20.3	6.2	77	142.1	43.3
33	21.3	6.5	78	154.2	47.0
34	22	6.7	79	168.6	51.4
35	23	7.0	80	186	56.7
36	23.6	7.2	81	207	63.1
37	24.6	7.5	82	233.3	71.1
38	25.6	7.8	83	267.1	81.4
39	26.6	8.1	84	312	95.1
40	27.6	8.4	85	374	114.0
41	28.5	8.7	86	469.2	143.0
42	29.5	9.0	87	626.6	191.0
43	30.5	9.3	88	938.3	286.0
44	31.5	9.6	89	1879.9	573.0

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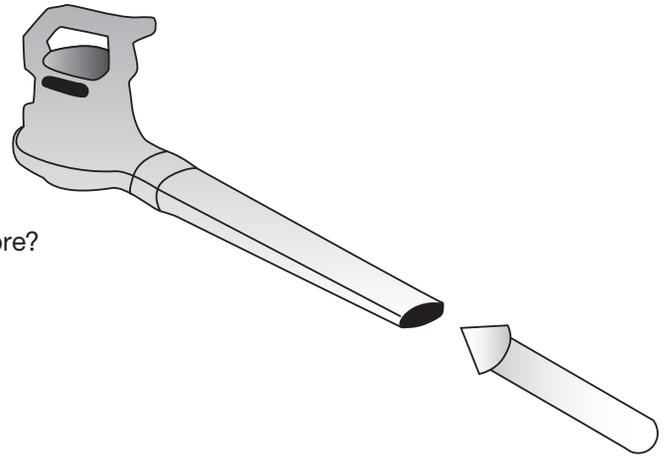
Student Activity

What a Drag!

Procedure

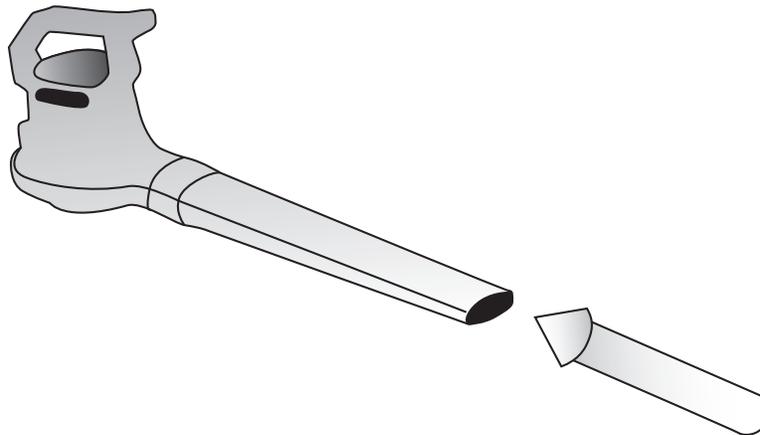
Directions: In your expert groups, complete the following.

1. What is the first thing you think of when you hear the word “aerodynamic?” Where have you heard the term before?
2. Using the resources on the Internet or in your library, find information on aerodynamics and the importance of using wind tunnels. Give several examples.
3. What is drag as it relates to aerodynamics? What are some things that can be done to an object to decrease its drag?
4. What are the parts of a rocket that may result in drag?



5. Using the pattern in Appendix L to get started, cut out the conical nose cone pattern from card stock and design a nose cone of your own. Assemble the nose cones and attach them onto paper towel tubes. The tubes will be tested with the leaf blower as shown below.
6. List the variables that need to be controlled in this activity.

7. Use a commercial leaf blower or vacuum set to blow air to force the rocket backwards. To keep the rocket in line with the wind, this should be done between two rows of books, or against a curb. Place the nose cone design structure in front of the blower, as shown below. While holding the blower, turn the blower on until the nose cone design structure stops moving. Be sure to maintain the same distance from the blower and paper towel tubes for each test. The blower should be turned on to the same power level and the same amount of time for each test.



Leaf blower and paper towel tube with nose cone

8. Measure the distance the rocket traveled backwards. Record results in the data table below.
9. Set up a data table, similar to what is below, to record your results in your journal.

Shape of Nose Cone	Distance Traveled			
	Trial 1	Trial 2	Trial 3	Average
Cone Shaped				
My Design				

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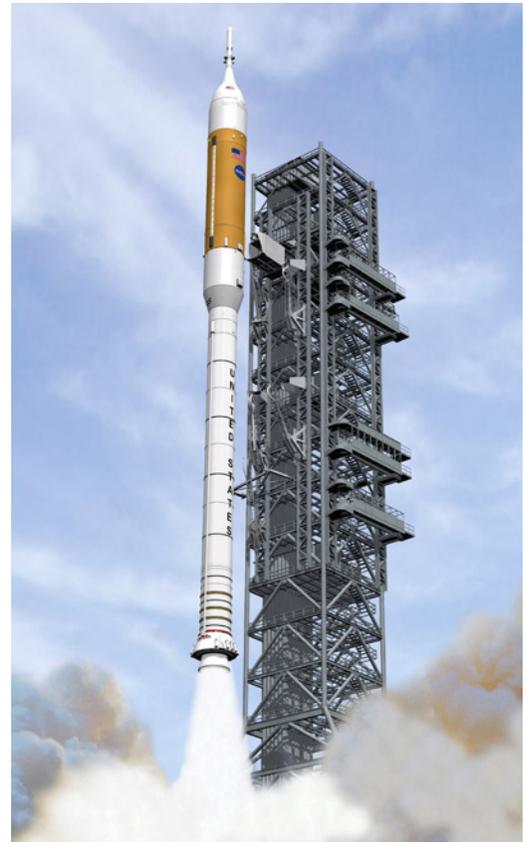
Student Activity

Flying Straight

Procedure

1. What questions occur to you about the fins of a rocket?

2. Think about rocket fins. What effect do you think fins have on a rocket?



The Ares I will not have fins. Roll control monitors, which turn (or gimbal) the nozzle of the engine to direct the air flow, will be used to control the direction of the vehicle.

3. Have you ever stuck your hand out of the car window at 55 miles (88 kilometers) per hour? What did you notice?

4. What happened when you moved your hand around?

5. What would happen to a rocket with a nose that moved around like your hand?

6. Look at an arrow. What is there about the structure of the arrow that allows it to fly through the air with such incredible stability? How is an arrow similar to a rocket? Why does it fly straight?

7. Balance an arrow on one of your fingers. Lay the arrow on top of a student's two outstretched index fingers. Have the student slowly bring her or his fingers together. Where is most of the mass of the arrow? Friction will cause the arrow to slide on the lightest side until a balance point is found. The balance point is much closer to the front than it is to the back. You have just discovered where the arrow's transverse center of mass lies.

8. Next, examine why an arrow has feathers toward the back. Using an arrow without feathers, lightly toss it underhanded across an area where you do not hit other students. Do the same with an arrow with its feathers intact. What differences did you see?

13. List all the things that have to stay the same to ensure that the test is fair (controlled variables).

14. Have your teacher or supervisor approve your plan and schedule a time for testing.

Teacher Signature _____

Testing Time _____

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Student Activity

Investigating Fin Shape or Size

Fin Shape

Problem: Which fin shape is the most stable? Remember that right now you are testing for fin shape; all other variables (including fin size, fin number, and fin placement) should remain constant.

Background: Fins are used to stabilize the rocket. As you would expect, fins with their thin edges facing into the wind have very little drag. However, increasing the thickness, the surface area, or the number of fins can increase the drag.

Procedure

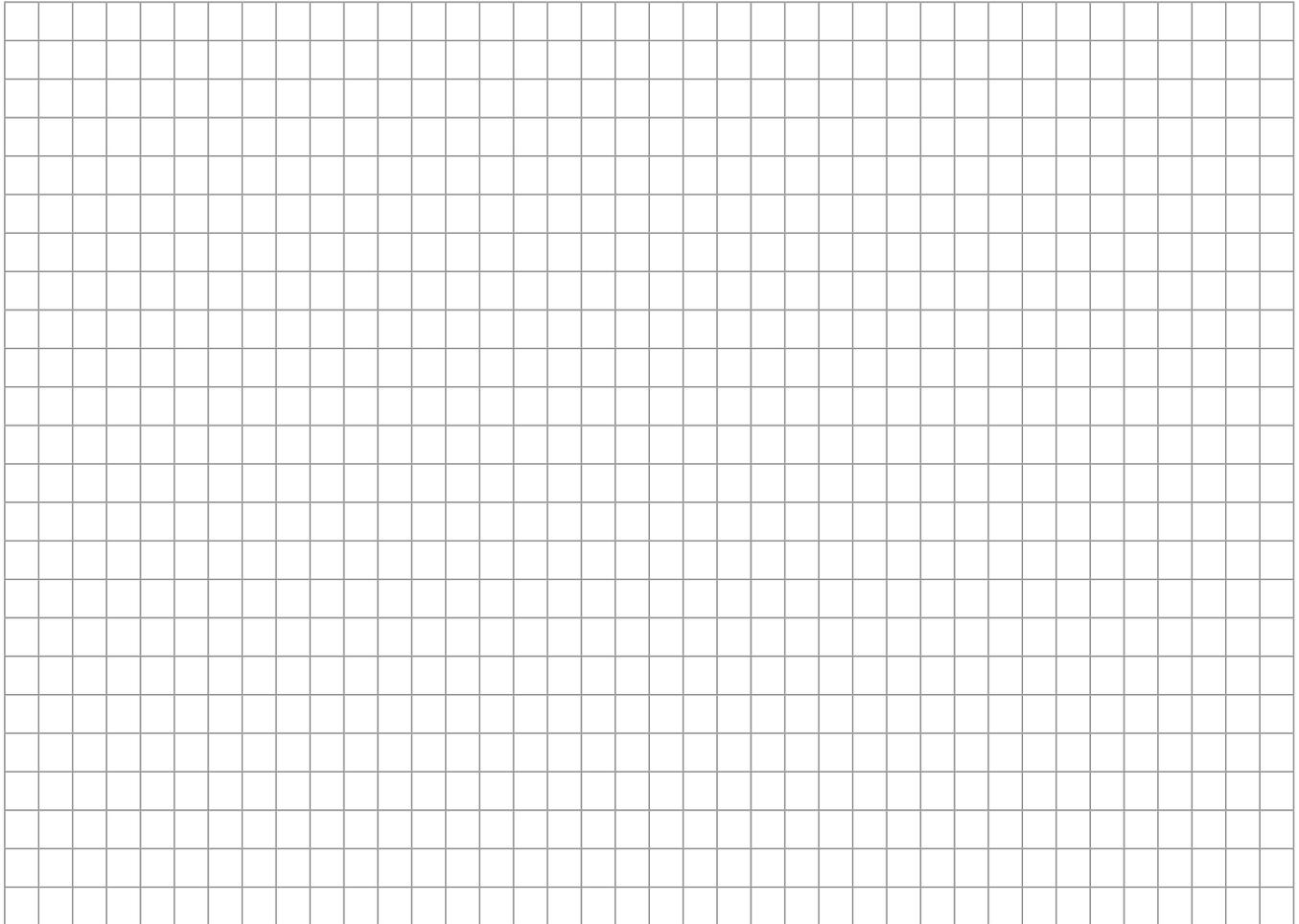
1. Using tag board, design several shapes of fins that could be attached to a paper towel tube. The fins should be the same size, but different shapes.
2. Make three to four fins of each shape that you designed.
3. Construct a simple rocket using the paper towel tube, without a nose cone covering, and use tape to attach the fins you have designed.
4. Draw a diagram of your fin shape on your data table.
5. Put your rocket on the ground so it faces a leaf blower or vacuum cleaner. Direct the air from the leaf blower or vacuum cleaner toward the rocket. Turn on the blower until the rocket starts moving.
6. Using the blower, “launch” your rocket three times, recording each of the three distances on the data table. Be sure to maintain the same distance from the blower and paper towel tubes for each test. The blower should be turned on to the same power level and the same amount of time for each test.
7. Determine the average distance and record it.
8. Record any other observations on the data table.
9. Complete the same procedure with at least two other fin shapes.
10. Graph your results.
11. Using your data as a basis, write your conclusions.

Data

Diagram of Fin Shape	Trial 1 Distance (in/cm)	Trial 2 Distance (in/cm)	Trial 3 Distance (in/cm)	Average Distance (in/cm)	Flight Observations

Results

(Graph Distance vs. Fin Shape)



Conclusion

What did you determine about fin shape from your activities? Support your conclusions with specific data.

Fin Size

Problem: Which fin size is the most stable? Remember that right now you are testing for fin size; all other variables (including fin shape, fin number and fin placement) should remain constant.

Background: Fins are used to stabilize the rocket. As you would expect, fins with their thin edges facing into the wind have very little drag. However, increasing the thickness, the surface area, or the number of fins can increase the drag.

What sizes of fins will you test? List three or four different sizes.

Procedure

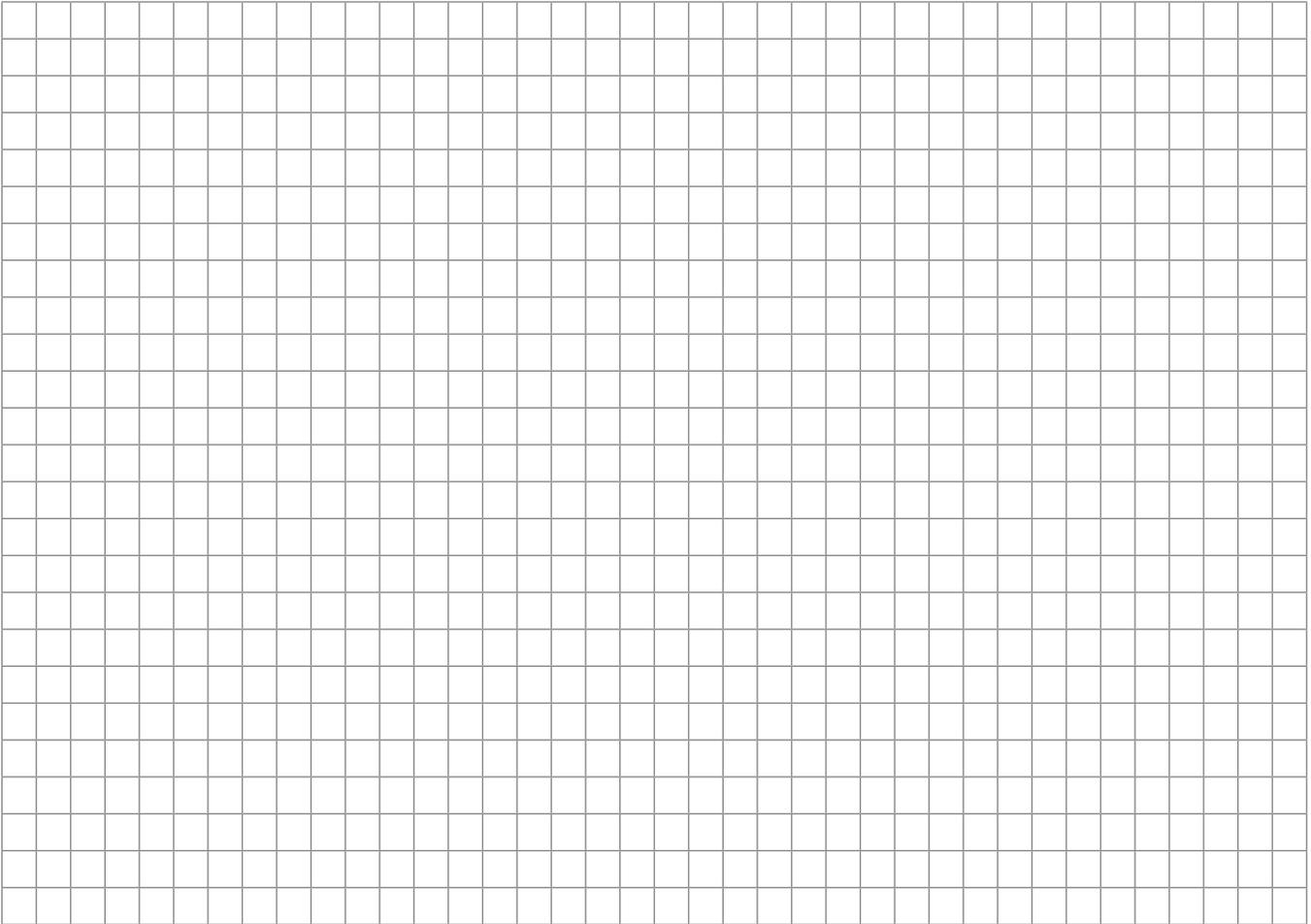
1. Using tag board, design several fins of different sizes that could be attached to a paper towel tube. The fins should be the same shape but different sizes.
2. Make three to four fins of each size that you designed.
3. Construct a simple rocket using the paper towel tube and attach the fins you have designed.
4. Trace your fin size on your data table.
5. Put your rocket on the ground so it faces a leaf blower or vacuum cleaner. This should be done between two rows of books to keep the rocket in line with the wind. Direct the air from the leaf blower or vacuum cleaner toward the rocket. Turn on the blower until the rocket starts moving. Be sure to maintain the same distance from the blower and paper towel tubes for each test. The blower should be turned on to the same power level and the same amount of time for each test.
6. Using the blower, “launch” your rocket three times, recording each of the three distances on the data table.
7. Determine the average distance and record it.
8. Record any other observations on the data table.
9. Complete the same procedure with at least two other fin sizes.
10. Graph your results.
11. Write your conclusions based on your data.

Data

Diagram of Fin Size	Trial 1 Distance (in/cm)	Trial 2 Distance (in/cm)	Trial 3 Distance (in/cm)	Average Distance (in/cm)	Flight Observations

Results

(Graph Distance vs. Fin Size)



Conclusion

What did you find is the optimum fin size for stable flight? Support your conclusions with specific data from your activity.

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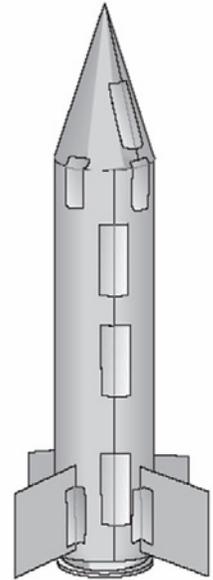
Student Activity

Investigating Fin Number and Placement

Fin Number And Placement

Problem: Which fin number and placement are the most stable? Remember that right now you are testing for fin number; all other variables (including fin shape and size) should remain constant. If time permits, try testing the same number of fins with different placements or spacing between them.

Background: Research information on fin number and placement at any of the Web sites or other resources you may have. Take notes in the space below.



What numbers and placement will you test?

Procedure

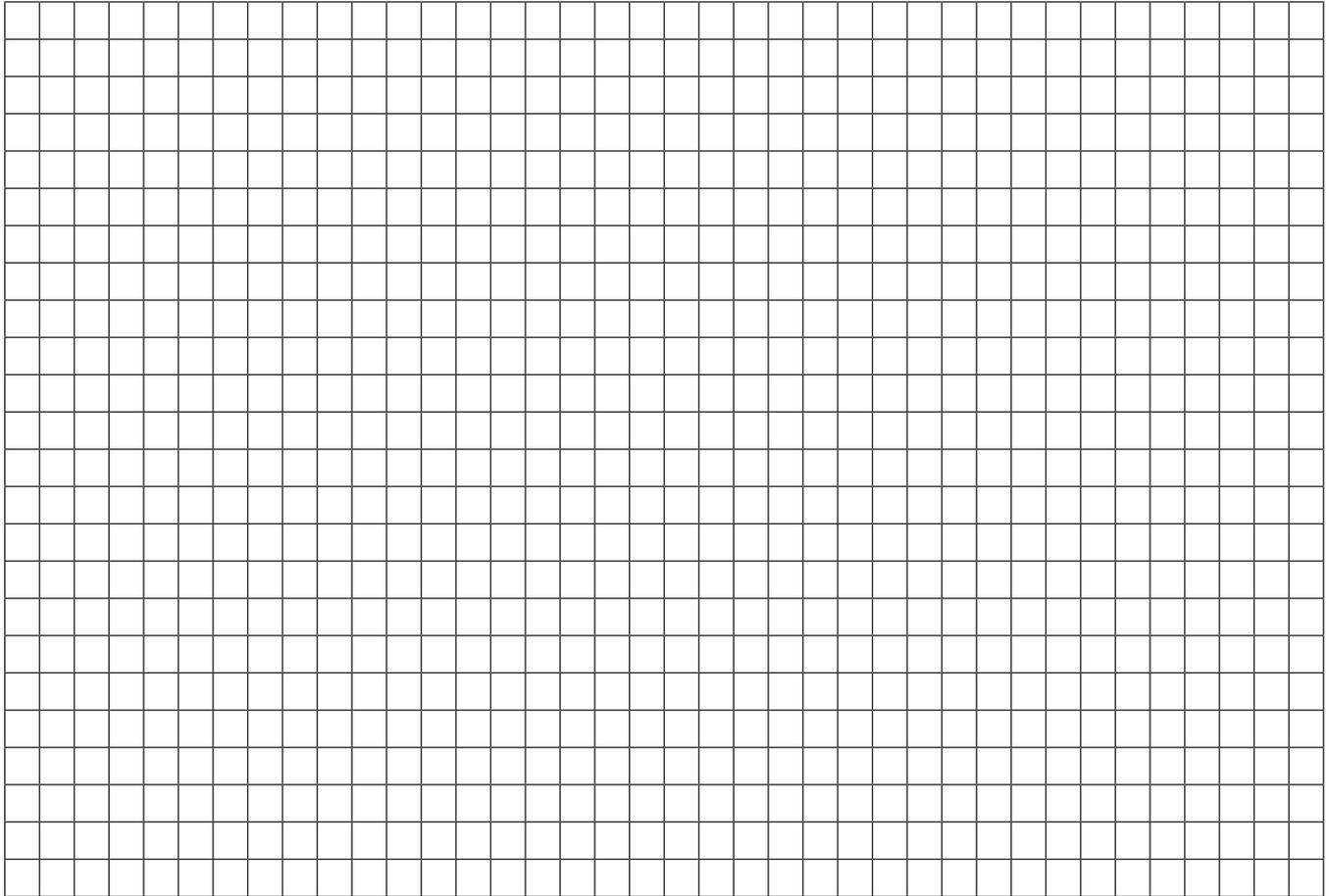
- Using tag board, design one type of fin that could be attached to a paper towel tube. The fins should all be the same size and shape.
- Make five or six fins that are identical.
- Construct a simple rocket using the paper towel tube and attach the fins you have designed.
- Record the number of fins and their placement on your data table.
- Put your rocket on the ground so it faces a leaf blower or vacuum cleaner. This should be done between two rows of books to keep the rocket in line with the wind. Direct the air from the leaf blower or vacuum cleaner toward the rocket. Turn on the blower until the rocket starts moving. Be sure to maintain the same distance from the blower and paper towel tubes for each test. The blower should be turned on to the same power level and the same amount of time for each test.
- Using the blower, “launch” your rocket three times, recording each of the three distances on the data table.
- Determine the average distance and record it.
- Record any other observations on the data table.
- Complete the same procedure with at least two other numbers of fins.
- Graph your results.
- Write your conclusions based on your data.

Data

Diagram of Fin Number and Their Placement	Trial 1 Distance (in/cm)	Trial 2 Distance (in/cm)	Trial 3 Distance (in/cm)	Average Distance (in/cm)	Flight Observations

Results

(Graph Distance vs. Fin Number and Placement)



Conclusion

What did you learn from these experiences? Support your understanding with data from the activities.

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Student Activity

Fly Like an Eagle

Procedure

1. What questions do you have about how a water rocket works?



2. Write a question that deals with finding out if the amount of water in the bottle affects how high a water rocket will travel.

3. Describe how you could vary the amounts of water in your bottle rocket (operational definitions).

8. Make a data table for recording the responding variable. Make sure that you test your water rocket more than one time with each amount of water.

9. Have your teacher or supervisor approve of your plan and schedule a time for testing.

Teacher Signature _____

Testing Time _____

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Student Activity

Altitude vs. Water Volume

Problem

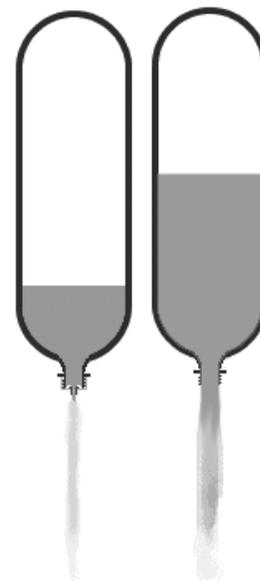
How much water should be added to the two-liter bottle to make it go the highest? Remember, right now you are testing for volume of water; all other variables (including launch pressure) should remain constant.

Background Information

Background information on “Rocket Principles” (pages viii-xi) and “Practical Rocketry” (pages xii-xvii) is available at the front of this guide.

Procedure

1. Fill bottles with pre-determined volumes of water and cap the bottles. Keep the water level the same each time you test for the optimal pressure.
2. Put one bottle at a time on the launch pad and apply 50 psi of pressure.
3. Use a compass to determine locations. Have an altitude tracker spotter positioned at each of these four positions (north, east, south, and west).
4. Each spotter will use the altitude tracker to measure the angle of the highest point of flight.
5. Each angle should be recorded; the high and low angles should be omitted.
6. Two more trials should be made for that volume of water.
7. Average the remaining angles (once the high and low angles for each of the three trials have been omitted) to come up with an average angle.
8. Use the conversion chart, located in the “Measuring Altitude” student activity, to determine the height.
9. Repeat the same procedure for the other volumes of water.
10. Graph your results.
11. Write your conclusion.

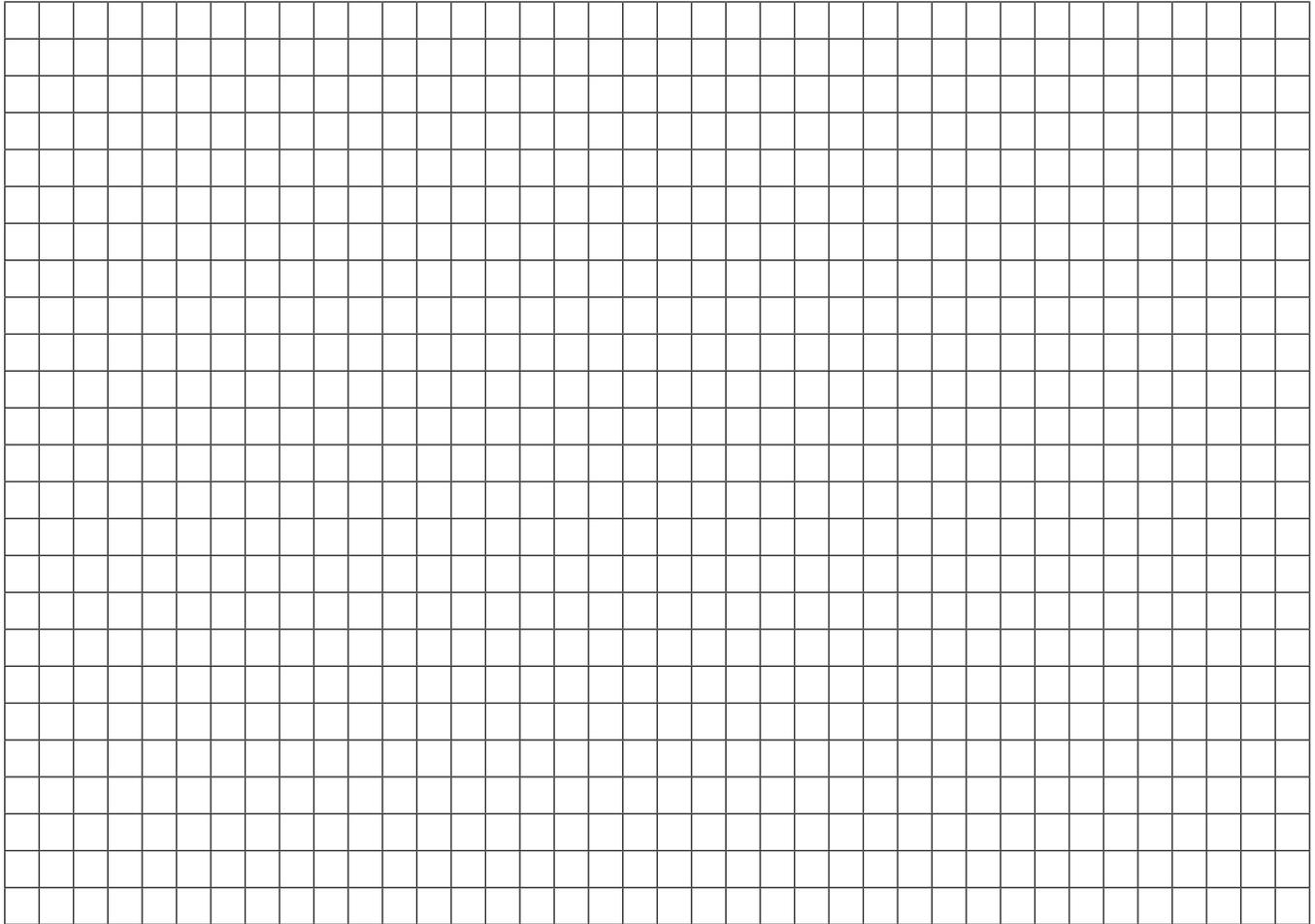


Data

Volume of Water (oz/mL)	Trial 1 Angles (degrees)	Trial 2 Angles (degrees)	Trial 3 Angles (degrees)	Average Angle (degrees)	Average Height (ft/m)
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		

Results

(Graph Altitude vs. Volume of Water)



Conclusion

What did you determine was the optimum volume of water needed to meet the specifications for your flight? Support your decision with data that you collected.

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Student Activity

Altitude vs. Water Pressure

Problem

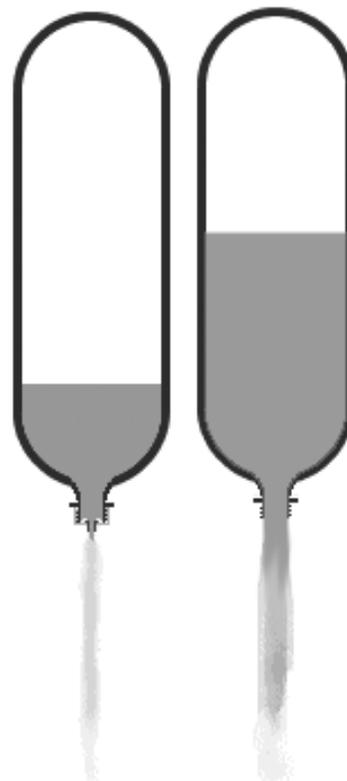
What launch pressure will make the two-liter bottle go to the specified height (98 feet or 30 meters)? Remember that right now you are testing for launch pressure; all other variables (including volume of water) should remain constant.

Background Information

Research additional information on Newton's Three Laws of Motion as they relate to the force necessary to lift the bottle off the launch pad to a height of 98 feet (30 meters). Include in your reading and research, concepts related to force (balanced and unbalanced), motion, mass, thrust, lift, acceleration, propellant, center of mass, roll, pitch, yaw, and center of pressure. Conduct an Internet search and take notes on these terms in a notebook or separate sheet of paper as directed by your teacher.

Procedure

1. Put one bottle at a time on the launch pad and apply the pre-determined amount of pressure.
2. Have an altitude tracker spotter positioned at each of the four positions (north, east, south, and west).
3. Each spotter will use the altitude tracker to measure the angle of the highest point of flight.
4. Each angle should be recorded; the high and low angles should be omitted.
5. Two more trials should be made for that launch pressure.
6. Average the remaining angles (once the high and low angles for each of the three trials have been omitted) to come up with an average angle.
7. Use the conversion chart, located in the "Measuring Altitude" student activity, to identify the height.
8. Repeat the same procedure for the other launch pressures.
9. Graph your results and write your conclusion.

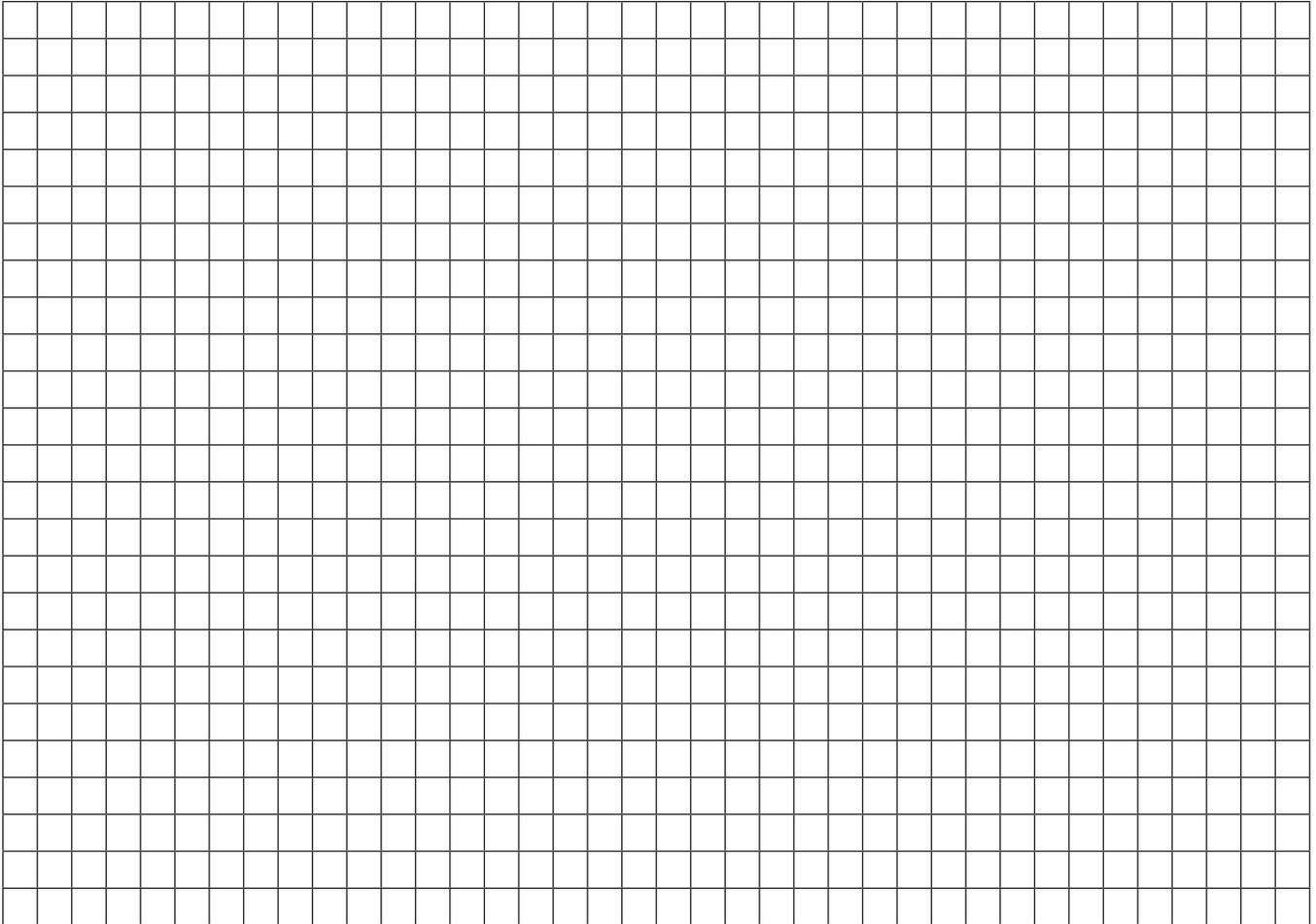


Data

Volume of Water (oz/mL)	Trial 1 Angles (degrees)	Trial 2 Angles (degrees)	Trial 3 Angles (degrees)	Average Angle (degrees)	Average Height (ft/m)
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		
	N E S W	N E S W	N E S W		

Results

(Graph Altitude vs. Launch Pressure)



Conclusion

What did you discover about launch pressure during your tests? Support your conclusion with data.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Activity

Weather or Not

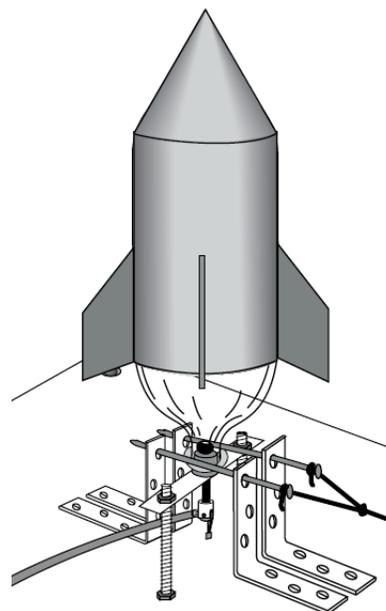
Background Information

In order to have a successful launch, not only do all of the rocket systems and subsystems have to be in order, but the conditions at the launch site and in the direction the rocket is moving toward have to be optimal for launch. The launch weather officer monitors cloud cover, knowing how close clouds can be to the launch site as well as how deep the clouds can be. The upper level winds are measured with balloons that go up six hours before launch. The balloons give a profile of the winds. This information is fed back to mission control and compared with the constraints of the rocket for that mission.

The launch period is the number of days the rocket can be launched into the proper orbit. For a low-Earth orbit, there is no concern; a launch can take be conducted on any given day. For missions going to Mars, the launch period is limited because of the energy that needs to be imparted to the spacecraft. The mission might use the gravitational pull of a planet or the Moon to get into the proper orbit. The launch team works with the spacecraft provider to determine the target. The rocket gets the spacecraft to the target with certain energy, and then the mission designers take over.

The launch window is the time period on the day of launch that a rocket can be launched. The launch window ranges from one second to one hour, and it changes on a day-to-day basis. If the launch window is twelve minutes or more, there is more flexibility. If there is more than one window and a problem occurs, the rocket could still fly that day. According to Boeing Mission Integration Officer Kristen Walsh, "If there is a problem with the launch countdown, then we can safe the vehicle, recycle, and attempt again that same day." If the launch window is less than 12 minutes, and there is a problem, then the delay will be for 24 hours.

In the next phase of this module, your design teams will take all of the information that you learned in your expert groups and apply it to building a water rocket that can fly as high as possible. For the launches that will take place in the competition, your teacher will set the launch period. The launch window should be twelve minutes. That means if your team cannot launch your water rocket in twelve minutes, you will have to launch during the next launch period. In this activity, your group will determine which weather conditions are acceptable for launch, and which weather conditions should cause a delay.



Procedure

- Using the information in the previous background section, work in your design groups to develop the weather constraints for launching a water rocket.
- For each of the following conditions, write the necessary conditions that the safety officers and the teacher will use to determine if a launch will occur. As you develop the conditions, include a rationale for each of the weather requirements.

Weather Constraints and Launch Criteria:

Weather Component	Conditions Necessary	Method of Measurement	Rationale
Wind Speed			
Wind Direction			
Visibility			
Temperature			
Precipitation			
Cloud Cover			

3. Use the Internet or your school’s weather instruments to determine the current weather conditions. Record the current conditions below and whether or not you should launch today based on your team’s criteria.

Current Conditions and Launch Decision

Weather Component	Today’s Conditions	Launch Decision (Yes or No)	Rationale
Wind Speed			
Wind Direction			
Visibility			
Temperature			
Precipitation			
Cloud Cover			

4. Take notes about other group’s criteria. What are the similarities and the differences? Think about how the class should come to a consensus for determining the conditions necessary for launch.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

Fly Me High

Background Information

During this performance assessment, students will work in their design groups to design, build, and test launch a water rocket. Students will begin by sharing with their groups what they each learned from their previous expert-group investigations (e.g., nose cone shape, fin shape and size, water volume, etc.). Such “expert” input will inform the design process of the group’s water rocket. Then, once the teacher has approved the designs, students may assemble the materials and begin building their rockets.

Students will have the opportunity to revise their initial designs based on their rocket’s performance during a practice launch. Just as actual rocket designers do not use the first design they create, your students will also be able to test their initial design before making revisions and deciding on the final design for the contest. Encourage students to refer back to earlier work and findings as they prepare for the contest.

Once students have completed construction and before the first test launch, the rockets should be put through a stability test. Design groups will determine the center of mass and the center of pressure for their test rockets. The center of mass is the point about which the rocket balances. Students could practice this by trying to balance a ruler on one finger. The center of pressure is the point where half of the surface area of a rocket is on one side and half is on the other. Students could model this by finding the mid-point of a ruler. A stable rocket has the center of mass in front of the center of pressure.

Once the design group has found these centers on their rocket, they should complete the swing test to verify their rocket’s stability. To perform the swing test, students attach a string loop, like a collar, around the rocket’s center of pressure. Next, they attach another string to this loop, like a leash. Then, they swing the rocket in a circle; if it is stable, the rocket should point in the direction it is being swung.



Ares I

National Science Standards Addressed

Grades 5–8

Science as Inquiry

Abilities necessary to do scientific inquiry.

Physical Science

Motion and forces.

Science and Technology

Abilities of technological design.

Understandings about science and technology.

Science in Personal and Social Perspectives

Personal health.

Grades 9–12

Science as Inquiry

Abilities necessary to do scientific inquiry.

Physical Science

Motion and forces.

Science and Technology

Abilities of technological design.

Understandings about science and technology.

Science in Personal and Social Perspectives

Personal and community health.

Principles and Standards for School Mathematics Addressed

Measurement Standard for Grades 6–8

Understand measurable attributes of objects and the units, systems, and processes of measurement

Understand both metric and customary systems of measurement.

Apply appropriate techniques, tools, and formulas to determine measurements

Select and apply techniques and tools to accurately find length and angle measures to appropriate levels of precision.

Problem Solving Standard for Grades 6–8

Solve problems that arise in mathematics and in other contexts

Measurement Standard for Grades 9–12

Understand measurable attributes of objects and the units, systems, and processes of measurement

Make decisions about units and scales that are appropriate for problem situations involving measurement.

Problem Solving for Grades 9–12

Solve problems that arise in mathematics and in other contexts

National Educational Technology Standards Addressed

Technology Standards for Students K–12

Technology Productivity Tools

Students use technology tools to enhance learning, increase productivity, and promote creativity.

Technology Research Tools

Students use technology to locate, evaluate, and collect information from a variety of sources.

Technology Problem-solving and Decision-making Tools

Students use technology resources for solving problems and making informed decisions.

Technology Standards for Students 6–8

Use content specific tools, software, and simulations to support learning and research.

Collaborate with peers, experts, and others using telecommunications and collaborative tools to investigate curriculum-related problems, issues, and information, and to develop solutions or products or audiences inside and outside the classroom.

Materials

- One or more two-liter plastic soft drink bottles.
- String.
- Safety goggles.
- Glue or tape.
- Cardboard or thick paper.
- Modeling clay.
- Scissors.
- Pens and decorating supplies.
- Scale.
- Measuring devices: rulers, yard or meter sticks, and measuring tape.
- Balance.

- Launch pad with secure pin and washers.
- Water.
- Safety goggles.
- Air pump or tank.
- Altitude tracker.
- Decorative decals.
- Background information on stability in rockets can be found in “Rocket Principles” (pages viii-xi) and “Practical Rocketry” (pages xii-xvii) at the front of this guide.
- “Appendix J: Safety Rules,” page 124.
- “Appendix K: Safety Checklist,” page 126.
- Student activity, “Fly Me High,” page 97.

Procedure

1. Explain to students that they will work in their design groups for this assessment activity. Each student will be expected to share what he/she learned in their respective expert groups (e.g., nose cone shape, fin shape and size, water volume — whichever variables are applicable) to help inform the overall design of their group's water rocket.
2. Assign the following jobs to students in each group. Review the role of each:
 - Safety Officer: Checks for safe practices and can stop a launch whenever unsafe practices are observed.
 - Loading Officer: Responsible for securing the rocket to the pad and charging the rocket with the appropriate air pressure.
 - Principal Investigator/Launch Officer: Makes final decisions about rocket design. Commences the countdown and launches the vehicle.
 - Downrange Officer: Observes the launch, measures the height of the rocket at apogee (the greatest distance from the ground), and records data. Spots the rocket and assures the safe landing of the rocket.
3. Distribute a copy of the “Appendix K: Safety Checklist” to each design team. Go over the list and answer any questions students may have. Review the following competition rules:
 - Only materials approved by the teacher may be used in the construction of any part of the bottle rocket system.
 - Safety rules and checklists must be followed at all times.
 - The rocket may not be pressurized over 50 psi.
4. Distribute the student activity, “Fly Me High.” Students should share their expertise and make recommendations for the design phase. The design group should complete the planning guide portion of the sheet to document their original design and the rationale for their design decisions. Final decisions for the designs of the rocket will be up to the Principal Investigator in each design group. The teacher should review and approve rocket designs before construction begins.
5. Allow students time to assemble the materials before construction. Students should measure the mass of the cone, body, and tail separately. Students in each group will construct their own rocket. Deadlines should be given for both test launches and final launches so that all group launches take place on the same days.
6. During the trial launch, students should assume their respective roles: Safety Officer, Loading Officer, Principal Investigator/Launch Officer, and Downrange Officer.
7. After the trial launch, when students return to the classroom, each group should review the results of the test launch, including the height the rocket reached. Students will then redesign the rocket with changes, as necessary, for the second official competition. On the student activity sheet, using evidence from the test-trial process, groups should document the modifications they make to their original design, as well as the rationale behind these changes. Again, students should be given a clear deadline in order to prepare the rocket for the official launch.

8. During the official competition, if you choose to declare one overall winner, independent judges (perhaps an older student or parent volunteer) should be used to measure, with an altitude tracker, the height to which the rockets travel. The group whose launch results in the highest altitude is the winner. The judge’s decision is final.

Student Evaluation Criteria

Criteria	Advanced (4)	Proficient (3)	Partially Proficient (2)	Novice (1)
Development of Rocket Design	<p>Designs are complete and detailed.</p> <p>Rationale demonstrates a sophisticated understanding of all the components/ variables of the rocket.</p>	<p>Designs are complete.</p> <p>Rationale demonstrates an understanding of most of the components/ variables of the rocket.</p> <p>No clear inaccuracies or misconceptions.</p>	<p>Designs are incomplete.</p> <p>Rationale demonstrates a basic understanding of components/ variables of the rocket design.</p> <p>May contain inaccurate or incomplete information.</p>	<p>Designs are missing important information.</p> <p>Rationale does not demonstrate a basic understanding of components/ variables of the rocket design.</p>
Construction and Testing of Rocket	<p>The design group easily constructs and tests the rocket based on their original designs.</p> <p>Revisions to their original design are carefully documented and based on evidence from the test-trial process.</p>	<p>The design group experiences minimal difficulty with constructing and testing the rocket based on their design.</p> <p>Revisions to their original design are based on evidence from the test-trial process.</p>	<p>The design group experiences difficulty with constructing and testing the rocket.</p> <p>Revisions to their original design are partially based on evidence from the test-trial process.</p>	<p>The design group experiences great difficulty constructing and testing the rocket.</p> <p>Revisions, if made, are not based on evidence from the test-trial process.</p>
Performs Assigned Duties During Launch	<p>Students exceed expectations as they follow their assigned roles and responsibilities.</p>	<p>Students consistently follow their assigned roles and responsibilities.</p>	<p>Students sometimes follow their assigned roles and responsibilities.</p>	<p>Students rarely follow their assigned roles and responsibilities.</p>
<p>Safety Officer: Checks for safe practices and can stop a launch whenever unsafe practices are observed.</p> <p>Loading Officer: Responsible for securing the rocket to the pad and charging the rocket with the appropriate air pressure.</p> <p>Principal Investigator/Launch Officer: Commences the countdown and launches the vehicle.</p> <p>Downrange Officer: Observes the launch, measures the height of the rocket at apogee (the greatest distance from the ground), and records data. Spots the rocket and assures the safe landing of the rocket.</p>				

Teacher Resources

Publication

Rockets: A Teacher’s Guide with Activities in Science, Mathematics, and Technology, NASA EG-2003-01-108-HQ, Office of Human Resources and Education, Washington, D.C., 2003.

<http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Rockets.html>

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Activity

Fly Me High

Procedure

1. In the design groups, everyone should share what was learned in their expert-group investigations (e.g., nose cone shape, fin shape and size, water volume, etc.). Group members should ask questions of the experts to help determine the design of the group's water rocket. During the launch, each student in the design group will assume one of the following roles:
 - **Safety Officer:** Checks for safe practices and can stop a launch whenever unsafe practices are observed.
 - **Loading Officer:** Responsible for securing the rocket to the pad and charging the rocket with the appropriate air pressure.
 - **Principal Investigator/Launch Officer:** Makes final decisions about rocket design. Commences the countdown and launches the vehicle.
 - **Downrange Officer:** Observes the launch, measures the height of the rocket at apogee (the greatest distance from the ground), and records data. Spots the rocket and assures the safe landing of the rocket.
2. Read "Appendix K: Safety Checklist." Review the following competition rules:
 - Only materials approved by the teacher may be used in construction of any part of the bottle rocket system.
 - Safety rules and checklists must be followed at all times.
 - The rocket may not be pressurized over 50 psi.
3. After everyone has shared information from the expert groups, your group should decide what variables should be tested during the design phase. During this time, experts in your group should have input into the design process for the component they investigated during their previous work. Write out your design specifications using the rubric that follows as a guide. Final decisions for the designs of the rocket will be up to the Principal Investigator in each design group. Your teacher should review and approve rocket designs before construction begins.

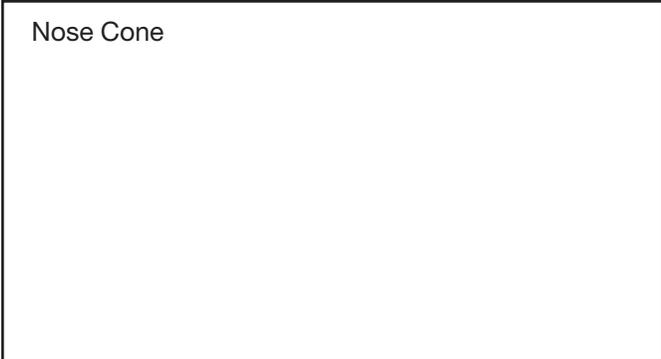


Ares I

Use the space below to plan your design:

Drawings.

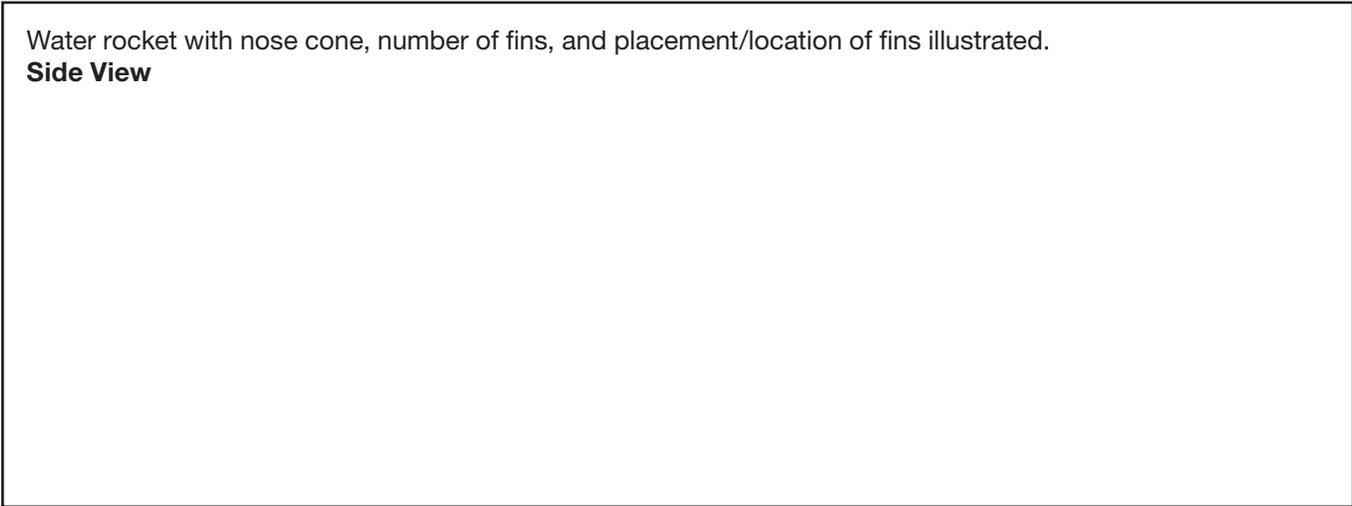
Nose Cone



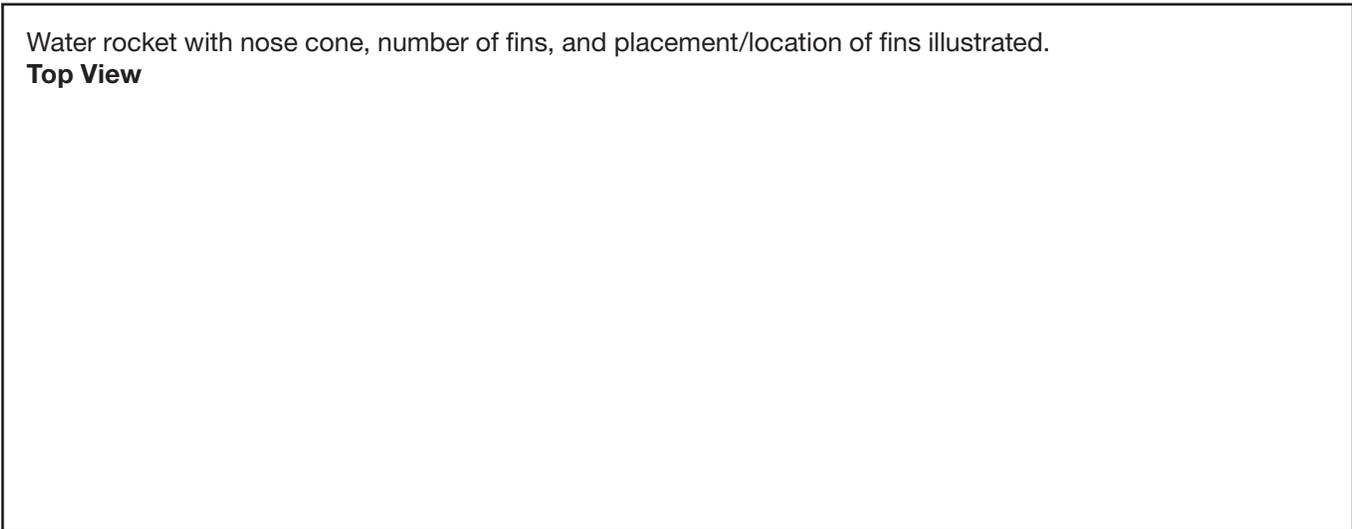
Fin Shape



Water rocket with nose cone, number of fins, and placement/location of fins illustrated.
Side View



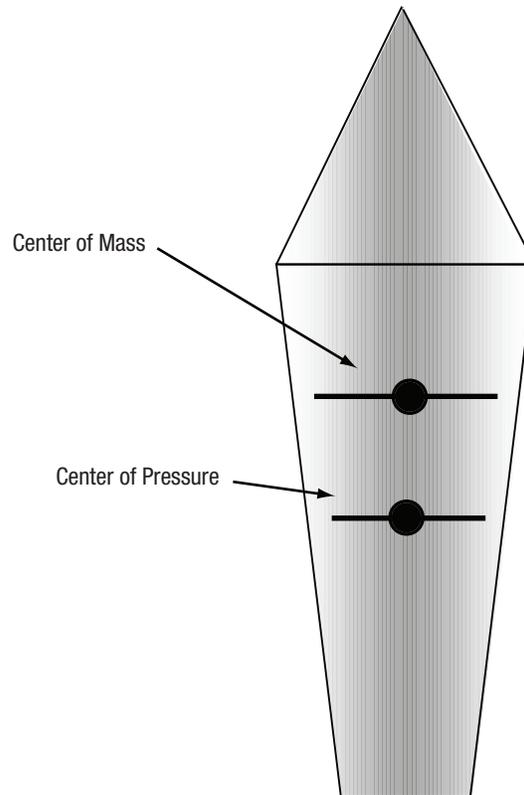
Water rocket with nose cone, number of fins, and placement/location of fins illustrated.
Top View



Take your measurements and record the data in the blanks below. Be sure to accurately measure all factors that are constant (such as the bottles) and those you will control (like the size and design of fins). Under the first column, list each rocket component and explain what influenced your design selection for that component. Finally, at the end, include a rationale for the complete rocket design.

Component and Rationale	Length	Width	Diameter	Mass
<p>Rationale for how components work together (overall design).</p>				

4. Assemble the materials before construction. Measure the mass of the cone, body, and tail. You will then construct the rocket. Make sure that you are ready for the test launch by the deadline.
5. Once construction is complete, perform a rocket stability determination using the directions below. Determine the center of mass and the center of pressure. Using the results from this test, your group can make adjustments to your rocket prior to the test launch.
 - a. Tie a string loop around the middle of your rocket. Tie a second string to the first so that you can pick it up. Slide the string loop into a position where the rocket balances. You may have to temporarily tape the nose cone in place to keep it from falling off.
 - b. Draw a straight line across a scale diagram of the rocket to show the ruler position. Mark the middle of the line with a dot. This is the rocket's center of mass.
 - c. Lay your rocket on a piece of cardboard. Carefully trace the rocket on the cardboard and cut it out.
 - d. Lay the cardboard cutout you just made perpendicular on the ruler and balance it.
 - e. Draw a straight line across the diagram of your rocket where the ruler is. Mark the middle of this line with a dot. This is the center of pressure of the rocket. See diagram.
6. Your group will be allowed one test launch and one final launch. After your test launch, you may make minor changes before the final launch competition. Before each launch, complete the prelaunch readiness review information that follows.



Prelaunch

Readiness Review

	Test Launch	Final Launch
Total Mass	_____ oz (mL)	_____ oz (mL)
Total Length	_____ in (cm)	_____ in (cm)
Width (at widest part)	_____ in (cm)	_____ in (cm)
Number of Fins	_____	_____
Length of Nose Cone	_____ in (cm)	_____ in (cm)
Volume of Water (fuel)	_____ oz (mL)	_____ oz (mL)
Center of Mass (from Nose Cone)	_____ in (cm)	_____ in (cm)
Center of Pressure	_____ in (cm)	_____ in (cm)
Does rocket pass swing test?	_____ Yes _____ No	_____ Yes _____ No

Flight Log

Company Name: _____

Safety Officer: _____

Loading Officer: _____

Principal Investigator/Launch Officer: _____

Downrange Officer: _____

Teacher: _____

Launch Conditions:

Test Launch

Final Launch

Launch Location: _____

Time: _____

Temperature: _____

Wind Conditions: _____

Launch Direction: _____

Maximum Altitude: _____

Notes from Day of Launch:

Recommendations for Future Launches:

After Test Launch

After Final Launch

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Teacher Guide

You Get What You Pay For

Background Information

This optional activity incorporates an economic component into the module and can be conducted prior to the other activities in the Interaction/Synthesis sections or with the assessment section of this module. Students will be given a budget of \$150,000 and an approved subcontractor list that has a listing of the materials and costs for construction. Teachers completing this aspect of the module should decide on either using “play” money, checks, or giving the student groups a spreadsheet that they can organize to keep track of their expenditures. Students are cautioned to spend their money wisely and thus save the teacher real money on materials used in this unit. Students are also warned that in order to participate in the final launch they must pay \$20,000, plus money for fuel. Students will not receive salary or benefits during this activity. Insurance will not be included either.



National Science Standards Addressed

Grades 5–8

Science and Technology

Understandings about science and technology.

Grades 9–12

Science and Technology

Understandings about science and technology.

Economic Standards Addressed

Grades 6–8

Understands that scarcity of productive resources requires choices that generate opportunity costs.

Knows that all decisions involve opportunity costs and that effective economic decision-making involves weighing the costs and benefits associated with alternative choices.

Understands that the evaluation of choices and opportunity costs is subjective and differs across individuals and societies.

Materials

- Spreadsheet or balance sheet.
- Calculator.
- Student activity, “You Get What You Pay For,” page 105.

Procedure

1. Distribute the student activity “You Get What You Pay For.” Have the students read over the directions at the top of the page. Instruct them to respond in writing to the group discussion question about their money-managing experiences. Then, ask them to share their answers with the rest of their group. Once students have had a chance to share within their groups, ask one or more students in each group to share with the class.
2. Prior to the group activities, have students complete the budgets for their expert group work, and the competition on their student activity sheet. They will need to build a preliminary budget for the activities. Since this is the first time to “spend money,” and they have little experience in building a water rocket, encourage students to keep their costs down. Students may use this time to consider the materials they would like to use for the expert group work.
3. If this activity is being done with the Interaction/Synthesis section, tell students that they will be working in groups to test various aspects of the rocket. Different groups will experiment with nose cone design, propulsion, and fin design. Since each person will be representing a different “competing team,” each person should be given a certain amount of “money” to contribute to the expert group to cover the costs of the materials used in testing. Students should then complete the expert group activities outlined in the Teacher Guide.
4. Make it clear to the students that each design group has the same budget. Though not realistic, it will give each group the same resources. Explain to the students that each person is expected to contribute funds to support the work done in the expert groups.
5. Finally, explain that the bulk of their budget should be geared for the launch of the water rocket. Make it clear that \$20,000 needs to be budgeted for the two launches (trial and official launches), and they need to have budgeted projected fuel costs.
6. Distribute expert group sheets to the groups. The groups can use these sheets to help them estimate their group budget.
7. Allow time for students to create their budgets. Circulate around the room assisting where necessary.
8. Encourage students to keep good records of their expenditures during the activities. At the completion of the activity, students should take the time to re-evaluate their actual payments versus their budgeted amounts. They should record whether they are over or under budget during each part and then reallocate funds appropriately.
9. You may want to assign the primary budget responsibilities to the Principal Investigators, as they will be responsible for acquiring materials throughout the module. You may also want to check the design groups’ budgets periodically to see how each group is handling their funds.
10. At the end of the activity, you may want to recognize the groups with a certificate for being fiscally responsible.

Ares: Launch and Propulsion

An Educator's Guide with Activities in Science and Mathematics



Student Activity

You Get What You Pay For

Background Information

In this activity, you will plan a budget for the construction and launch of your water rocket. Each group will be given a budget of \$150,000 and an approved subcontractor list that identifies materials and their costs for your consideration. Use your funds wisely and keep accurate records of all you spend. To pay for the use of the launcher, your group must have a minimum of \$20,000 for the last two launches (the test and final launches). Your group must also have money budgeted for fuel costs. (Fuel will cost \$30 per milliliter.) If your group has less than \$20,000 at the time of launch, your group will not be permitted to launch and will be disqualified. Complete the following activity in your group to create a budget that helps you to manage your funds.

Group Discussion

Think about any experiences you have had in managing money. Describe your successes and failures in the space below and then share with your group.



Part 1: Final Launch Budget

Below is the list of required materials needed for the final launch. Using a spreadsheet or balance sheet, plan the funds you would like to allocate for the first launch. You may use materials found on the Approved Subcontractor List in addition to the materials listed below. Create a budget for the final launch and testing. The budget for test and final launches should total at least \$20,000.

- One or more two-liter plastic soft drink bottles.
- Water for fuel.
- Safety goggles.
- Glue or tape.
- Cardboard or thick paper.
- Modeling clay.
- Scissors.
- Pens and decorating supplies.
- Materials for protecting the payload.
- Use of launcher.

Part 2: Expert Group Budget

Each person in your group should be allotted a certain budget that they can spend on materials, construction, and launching their rockets. The payload and propulsion groups should be given at least \$5,000 to purchase a bottle (with the labels removed) for their tests. Launch pad fees will not be assessed during the expert phase. Create a budget for each expert team. The expert groups will use funds for testing different aspects of the rocket. Since it is unknown at this time exactly what costs are, you will need to estimate. Use the expert group sheets to help estimate your group’s costs.

Budget	
Propulsion	
Nose cone	
Fin shape/size	
Fin number/placement	
Total	

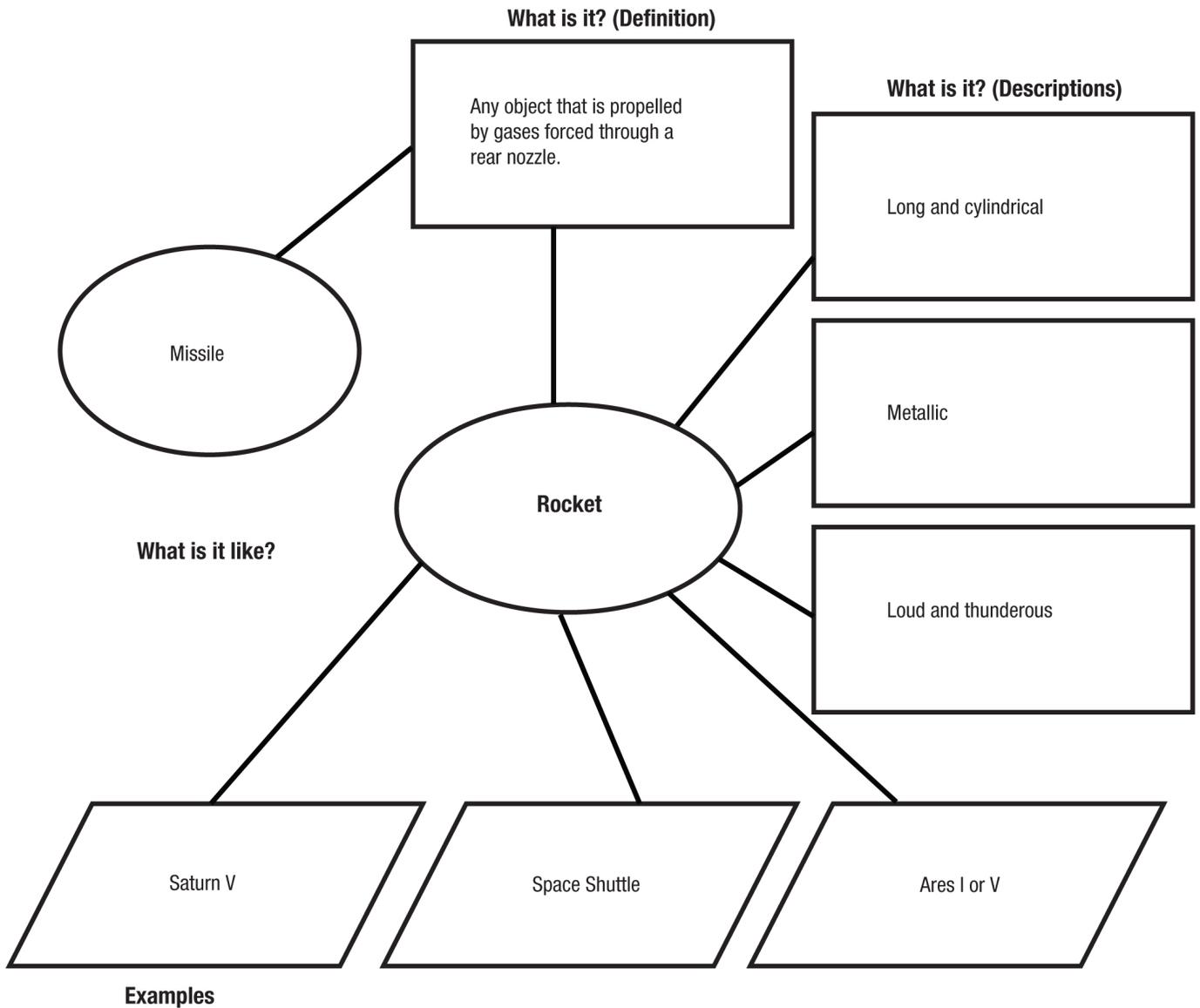
Approved Subcontractor List

Subcontractor	Materials	Price Per Unit
Bottle Neck Engine Corporation Ares Launch Center H2O Unlimited	Two-liter Bottle	\$20,000 per bottle
	Use of Launcher & Pump	\$10,000 per launch
	Fuel	\$30 per milliliter
Stick To It Tape and Glue	Duct Tape	\$5,000 per 2 inches (5 cm)
	Strapping Tape	\$5,000 per 2 inches (5 cm)
	Masking Tape	\$2,500 per 2 inches (5 cm)
	Cellophane Tape	\$1,000 per 2 inches (5 cm)
	Dental Floss	\$500 per 2 inches (5 cm)
	Glue Stick	\$2,000 per container
	Hot Glue Stick	\$5,000 per stick
	Low-temp. Glue Gun	\$1,000 per rental
Totally Tubular	Toilet Paper Tubes	\$50 per tube
	Wrapping Paper Tubes	\$100 per tube
	Paper Towel Tubes	\$150 per tube
Write-On Paper	Cardboard	\$2,500 per sheet
	Construction Paper	\$1,500 per sheet
	Egg Containers	\$1,000 per 6 count
	Popsicle Sticks	\$50 per stick
	Poster Board	\$10,000 per sheet
	Sand Paper	\$5,000 per sheet
	Typing Paper	\$1,000 per sheet
	Tag Board	\$3,000 per sheet
Put it Together Construction Materials Limited	Clay	\$500 per 100 grams
	Cotton Balls	\$50 per ball
	Graduated Cylinders	\$10 per cylinder
	Hole Punch	\$10 per punch rental
	Yard Sticks	\$10 per stick
	Ruler	\$5 per ruler
	Safety Goggles	Complimentary
	Scissors	\$5 per pair
	Small Washers	\$5 per washer
	Spring Scale	\$10 per scale
	Tape Measure	\$50 per tape rental
	Tennis Ball	\$100 per ball
	Long Stick	\$10 per stick
Color My World Paints	Decorative Decals	\$50 per decal
	Felt-Tipped Pens	\$50 per pack
	Magic Markers	\$10 per marker
	Paints	\$50 per color

Appendix A

Example of a Completed Concept Definition Map

(Adapted from Schwartz, 1988)



Appendix B

Optional Activity: Investigating the History of Rocketry with *October Sky*

1. Play the opening segment (Chapter 1 on the DVD, "The Age of Sputnik") to *October Sky*. This movie is about a boy who lives in a coal-mining town in West Virginia in 1957. Based on the book, *Rocket Boys*, by Homer Hickam, this true story details Homer's struggles as he dreamt of sending rockets to outer space. The first scene shows people listening to the news on the radio that the Union of Soviet Socialist Republic (USSR) had launched the first human-made satellite (Sputnik). Provide additional background information about the Cold War context and the events that took place in 1957 when the Soviet Union became the first country to launch a satellite into orbit. Ask students questions similar to the following:
 - How do you think Americans must have felt after hearing the news that a Cold War foe had just launched a satellite into space for the first time? (This symbolized to them that the Soviets were more advanced than the U.S. Many felt that Americans were falling behind technologically. Sputnik may have caused fear in the minds of some people.)
 - Why might this cause fear? (People thought that if the Soviets could launch a satellite into space, they could also launch a missile at the United States.)
 - According to the radio newscast, what was the response made by Dr. Wernher von Braun? (First, he said that there was no confirmed sighting of the satellite. Second, he said the United States was working on launching a satellite of their own.)
 - What was the long-term response from the United States? (The United States started emphasizing the subjects of mathematics and science in the nation's schools.)
2. Let your students listen to the sound of the beeping radio signal that Sputnik made. An audio clip is available at: <http://www.hq.nasa.gov/office/pao/History/sputnik/>
3. Sputnik inspired Homer Hickam to experiment with model rockets. His first experiment resulted in him blowing up his mother's fence. Show the segment where Homer and his friends experiment with launching rockets. Start the video at the 34-minute mark of the film where the worker says, "SAE 1020 bar stock..." (Chapter 6 on the DVD, "Rocket Roulette"). Show the next two minutes, and then ask the question below. (You may want to show this segment again after the question.)
 - As Homer Hickam and his friends experimented with model rockets, many of their first attempts failed. This happens with rocket scientists of all ages. They learn from their experiences. What two factors were they going to change during this segment? (Reduce the mass and increase the length.)
4. Show a short segment (one minute) starting at the 46-minute mark of the film (Chapter 9 on the DVD, "Up in Smoke"). Ask questions similar to the following:
 - Describe the launch of the rocket this time. (It was a successful launch.)
 - What did they measure once it was launched? (The time of descent.)
5. Homer and his friends were accused of starting a forest fire with their rocket. Show a one-minute segment starting at 75:30 (partway through Chapter 13, "Search for Auk 13," on the DVD). Homer uses mathematics to demonstrate that his rocket did not cause the fire.
 - What measurement did he use that helped to determine that the rocket was not the cause? (The time it took the rocket to fall.)

Appendix C

Possible Options for the Ground Challenge

Choose the most efficient method of transporting personnel and equipment to the construction site so that the complex will be completed as scheduled. The maximum number of trips you can make is four. Efficiency is defined as hauling as much as possible during each trip with the smallest vehicles possible. For each trip, determine two possible options to complete the stage. At each trip, four people arrive at the construction site and must leave at the end of the stage. Choose the best option and provide a rationale.

Note to Teachers: Payload masses and estimated masses of supplies and equipment are given in both metric and traditional U.S. units. When making the conversions, masses were rounded to the nearest fives and tens to make calculations easier for students.

The following tables represent two possible options for completing each stage of the construction. Student transportation choices may vary, but should be similar due to the limitations of the transportation vehicles.

Option 1	
Stage/Trip	Transportation Choices
Trip 1 Option 1	To the site: <ul style="list-style-type: none"> • Tractor flat-bed trailer to haul all equipment = 30,925 lb (14,027 kg) with two people. • Full-size pickup for food, water, personal belongings, and two people. Return home: <ul style="list-style-type: none"> • Leave the trailer; two people bring back the tractor, and two people bring back the pickup.
Trip 2 Option 1	To the site: <ul style="list-style-type: none"> • SUV or club cab to transport four people and food, water, and personal belongings. Return home: <ul style="list-style-type: none"> • SUV or club cab to transport four people and personal belongings.
Trip 3 Option 1	To the site: <ul style="list-style-type: none"> • SUV or club cab to transport four people and food, water, and personal belongings. Return home: <ul style="list-style-type: none"> • SUV or club cab to transport four people and personal belongings.
Trip 4 Option 1	To the site: <ul style="list-style-type: none"> • Two people bring the tractor back to the site. Two people bring the pickup with food, water, and personal belongings. Return home: <ul style="list-style-type: none"> • Tractor flat-bed trailer is brought back with two people. • Pickup with two people.
Rationale for Option 1	Everything is now on site with one trip in order to build the base.

Option 2	
Stage/Trip	Transportation Choices
Trip 1 Option 2	<p>To the site:</p> <ul style="list-style-type: none"> • One club-cab trailer with 6,000 lb (2,722 kg) building panels and two people. • One pickup trailer with foundation materials and flooring sections (3,000 lb) 1,361 kg with two people. • The remaining 1,850 lb (839 kg) can go in either bed along with the food, water, and personal belongings. <p>Returning home:</p> <ul style="list-style-type: none"> • Two people drive back each vehicle.
Trip 2 Option 2	<p>To the site:</p> <ul style="list-style-type: none"> • One club cab with 6,000 lb (2,722 kg) trailer for the total materials and four people with food, water, and personal belongings. <p>Returning home:</p> <ul style="list-style-type: none"> • Four people drive back club cab.
Trip 3 Option 2	<p>To the site:</p> <ul style="list-style-type: none"> • One club cab with 3,000 lb (1,361 kg) trailer for hauling solar-powered car, food, and supplies for six months. <p>Returning home:</p> <ul style="list-style-type: none"> • Four people drive club cab back.
Trip 4 Option 2	To the site: TBD by student:
Rationale for Option 2	It is more efficient not to use an under-utilized tractor-trailer and leave it behind after the first trip.

Appendix D

Label Templates for Available Vehicles

Pickup Truck – three-person cab
Maximum Payload Capacity: 1,750 pounds (794 kilograms)
Towing Capacity: 5,000 pounds (2,268 kilograms)
Size of Cargo Bed: 4 feet (1.2 meters) by 8 feet (2.4 meters)

Club Cab Pickup Truck – four-person cab
Maximum Payload Capacity: 2,000 pounds (907 kilograms)
Towing Capacity: 6,000 pounds (2,722 kg)
Size of Cargo Bed: 4 feet (1.2 meters) by 6.5 feet (2 meters)

Trailer
Maximum Payload Capacity: 6,000 pounds (2,722 kilograms)
Size: 8 feet (2.4 m) wide by 12 feet (3.7 meters) long

Trailer
Maximum Payload Capacity: 3,000 pounds (1,361 kilograms)
Size: 8 feet (2.4 meters) wide by 12 feet (3.7 meters) long

SUV
Capacity: Seven Passengers,
Luggage/food/water Supply for a Seven-day Stay
or
Four Passengers (and luggage) and
750 pounds (340 kilograms) of Construction Equipment or Tools

Tractor-flat-bed-trailer Rig
Maximum Payload: 40,000 pounds (18,144 kilograms)
Flat-bed Trailer Size:
48 feet (14.6 meters) long by 8.5 feet (2.6 meters) wide

Appendix E

Templates for Representing Equipment and Supplies

Trip 1

Building Materials: 6,000 pounds (2,722 kilograms)
Panels: 16 feet (5 meters) long by
4 feet (1.2 meters) wide

Trip 1

Insulation:
200 pounds (91 kilograms)
Rolls: 4 feet (1.2 meters) in diameter

Trip 1

Flooring Sections:
1,000 pounds (454 kilograms)
8 feet (2.4 meters) long by 2 feet
(0.6 meters) wide

Trip 1

Foundation Materials:
2,000 pounds (907 kg)
Concrete/steel Sections:
4 feet (1.2 meters) long
by 4 feet (1.2 meters) wide

Trip 1

Interior Wall Finish:
500 pounds (227 kg)
4 feet (1.2 meters) by 8 feet
(2.4 meters) panels

Trip 1

Food/Water for One Week:
250 pounds (113 kilograms)

Trip 1

Construction Equipment:
500 pounds (227 kilograms)

Trip 1

Lumber: 400 pounds (181 kilograms)
Includes 12 foot (3.7 meter) lengths

Trip 2

Cabinetry Materials:
1,000 pounds (454 kilograms)

Trip 2

Plumbing Supplies (include water supply):
1,750 pounds (794 kilograms)

Trip 2

Tools and Construction Equipment:
500 pounds (227 kilograms)

Trip 2

Electrical Supplies
(include air-conditioning):
1,000 pounds (454 kilograms)

Trip 2

Power Supply:
1,000 pounds (454 kilograms)

Trip 2

Food/water for One Week:
250 pounds (113 kilograms)

Trip 3

Solar-powered Vehicle:
2,000 pounds (907 kilograms)
6 feet (1.8 meters) by 15 feet (4.6 meters)

Trip 3

Food Supply/Staples for Six Months:
5,000 pounds (2,268 kilograms)

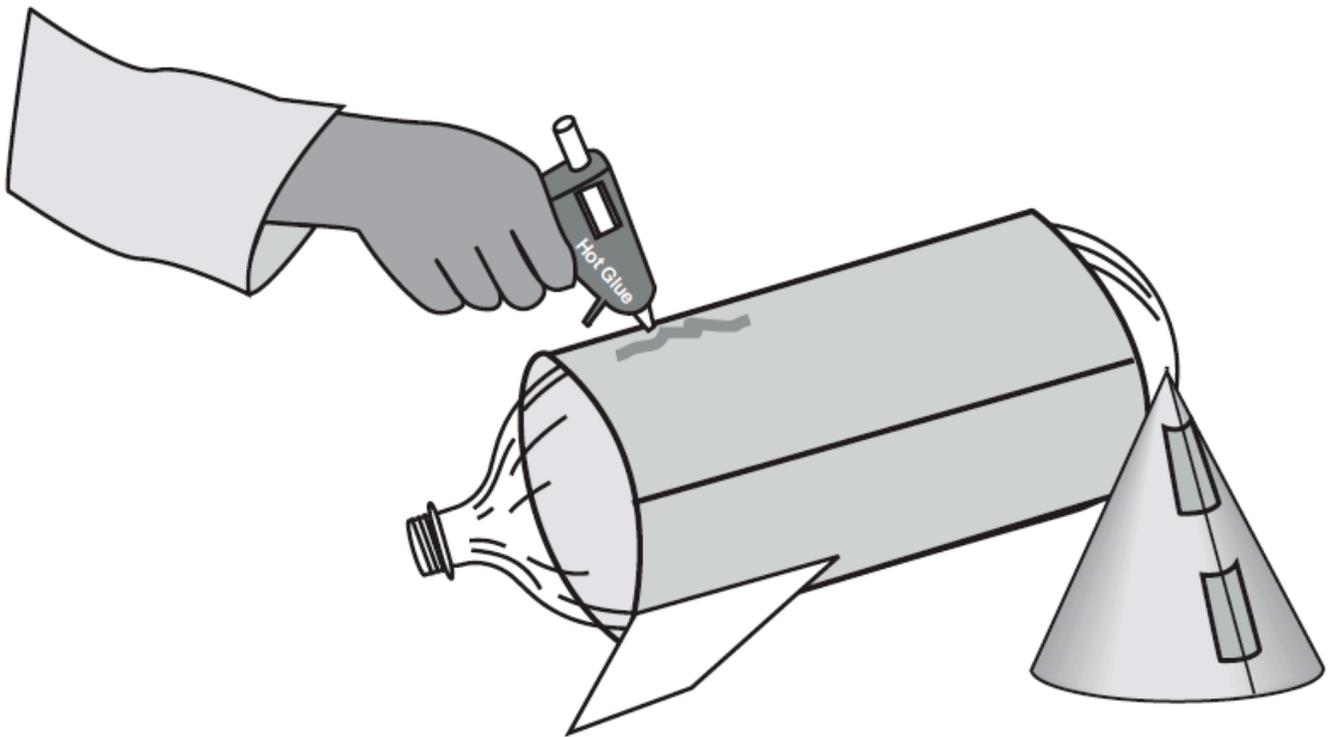
Trip 4

Experimental Equipment:
7,500 pounds (3,402 kilograms)

Appendix F

Building A Bottle Rocket

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



Appendix G

Water Bottle Rocket Launcher

Management

Consult the materials and tools list to determine what you will need to construct a single bottle rocket launcher. The launcher is simple and inexpensive to construct. Air pressure is provided by means of a hand-operated bicycle pump. The pump should have a pressure gauge for accurate comparisons between launches.

Most needed parts are available from hardware stores. In addition, you will need a tire valve from an auto parts store and a rubber bottle stopper from a school science experiment. The most difficult task is to drill a 0.375 inch hole in the mending plate called for in the materials list. An electric drill is a common household tool. If you do not have access to one, or do not wish to drill the holes in the metal mending plate, find someone who can do the job for you. Ask a teacher or student in your school's industrial arts shop, a fellow teacher or the parent of one of your students to help.

If you have each student construct a bottle rocket, having more than one launcher may be advisable. Because the rockets are projectiles, safely using more than one launcher will require careful planning and possibly additional supervision. Please refer to the launch safety instructions.



Materials and Tools

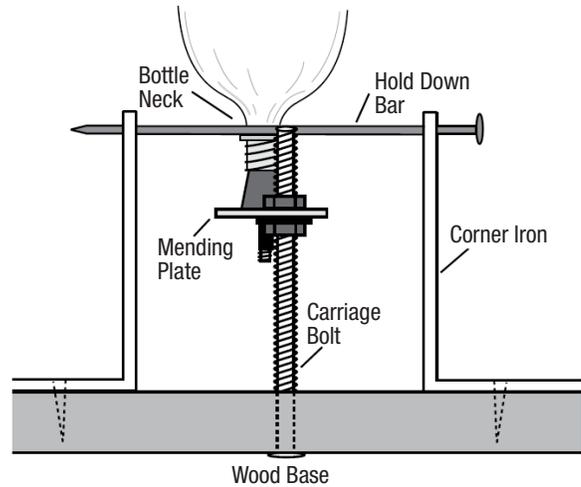
- Four 5 inch corner irons with 12.75 inch wood screws to fit.
- One 5 inch mounting plate.
- Two 6 inch spikes.
- Two 10 inch spikes or metal tent stakes.
- Two 5 inch by 0.25 inch carriage bolts with six 0.25 inch nuts.
- One 3 inch eyebolt with two nuts and washers.
- 0.75 inch diameter washers to fit bolts.
- One number 3 rubber stopper with a single hole.
- One Snap-in Tubeless Tire Valve (small 0.453 inch hole, 2 inches long).
- Wood board 12 by 18 by 0.75 inch (30.5 by 45.7 by 1.9 centimeter).
- One two-liter plastic bottle.
- Electric drill and bits including a 0.375 inch bit.
- Screwdriver.
- Pliers or open-end wrench to fit nuts.
- Vice.
- 12 feet (3.66 meters) of 0.25 inch cord.
- Bicycle pump with pressure gauge.

Background Information

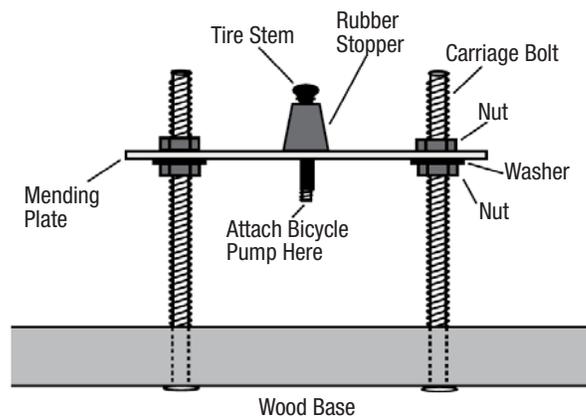
Like a balloon, air pressurizes the bottle rocket. When released from the launch platform, air escapes the bottle, providing an action force accompanied by an equal and opposite reaction force (Newton's Third Law of Motion). Increasing the pressure inside the bottle rocket produces greater thrust since a large quantity of air inside the bottle escapes with a higher acceleration (Newton's Second Law of Motion). Adding a small amount of water to the bottle increases the action force. The water expels from the bottle before the air does, turning the bottle rocket into a bigger version of a water rocket toy available in toy stores.

Construction Instructions

1. Prepare the rubber stopper by enlarging the hole with a drill. Grip the stopper lightly with a vice and gently enlarge the hole with a 0.375 inch bit and electric drill. The rubber will stretch during cutting, making the finished hole somewhat less than 0.375 inch.
2. Remove the stopper from the vice and push the needle valve end of the tire stem through the stopper from the narrow end to the wide end.
3. Prepare the mounting plate by drilling a 0.375 inch hole through the center of the plate. Hold the plate with a vice during drilling and put on eye protection. Enlarge the holes at the opposite ends of the plates, using a drill bit slightly larger than the holes to do this. The holes must be large enough to pass the carriage bolts through them.
4. Lay the mending plate in the center of the wood base and mark the centers of the two outside holes that you enlarged. Drill holes through the wood big enough to pass the carriage bolts through.
5. Push and twist the tire stem into the hole you drilled in the center of the mounting plate. The fat end of the stopper should rest on the plate.
6. Insert the carriage bolts through the wood base from the bottom up. Place a hex nut over each bolt and tighten the nut so that the bolt head pulls into the wood.
7. Screw a second nut over each bolt and spin it about half way down the bolt. Place a washer over each nut, and then slip the mounting plate over the two bolts.
8. Press the neck of a two-liter plastic bottle over the stopper. You will be using the bottle's wide neck lip for measuring in the next step.
9. Set up two corner irons so they look like book ends. Insert a spike through the top hole of each iron. Slide the irons near the bottle's neck so that the spike rests immediately above the wide neck lip. The spike will hold the bottle in place while you pump up the rocket. If the bottle is too low, adjust the nuts beneath the mounting plate on both sides to raise it.
10. Set up the other two corner irons as you did in the previous step. Place them on the opposite side of the bottle. When you have the irons aligned so that the spikes rest above and hold the bottle lip, mark the centers of the holes on the wood base. For more precise screwing, drill small pilot holes for each screw, and then screw the corner irons tightly to the base.
11. Install an eyebolt to the edge of the opposite holes for the hold down spikes. Drill a hole, and hold the bolt in place with washers and nuts on top and bottom.
12. Attach the launch pull cord to the head end of each spike. Run the cord through the eyebolt.
13. Make final adjustments to the launcher by attaching the pump to the tire stem and pumping up the bottle. Refer to the launching instructions for safety notes. If the air seeps out around the stopper, the stopper is too loose. Use a pair of pliers or a wrench to raise each side of the mounting plate in turn to press the stopper with slightly more force to the bottle's neck. When satisfied with the position, thread the remaining hex nuts over the mounting plate and tighten them to hold the plate in position.



Positioning Corner Irons

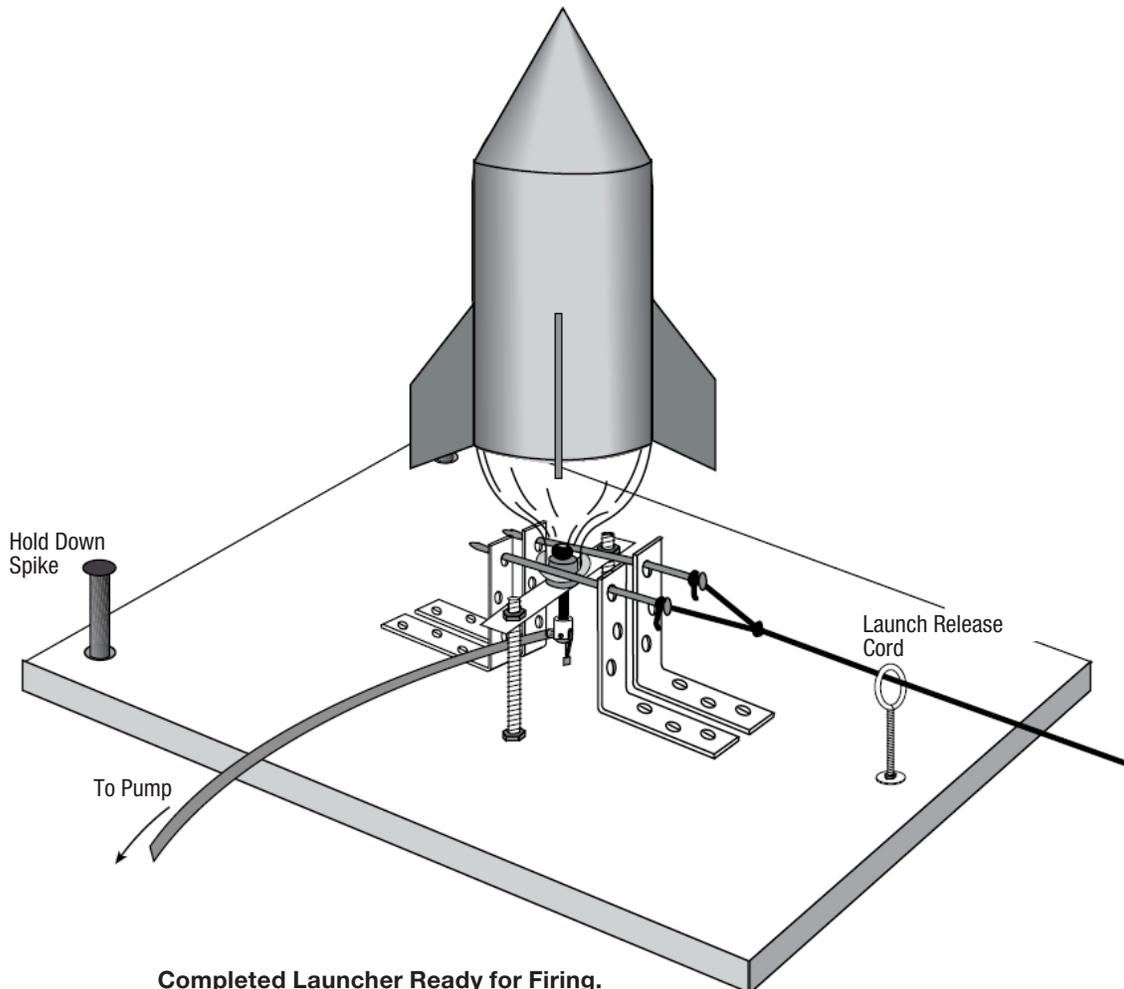


Attachment of Mending Plate and Stopper

14. Drill two holes through the wood base along one side. The holes should be large enough to pass large spikes or metal tent stakes. When the launch pad is set up on a grassy field, the stakes will hold the launcher in place when you yank the pull cord. The launcher is now complete.

Launch Instructions

1. Select a grassy field that measures approximately 100 feet (30.48 meters) across. Place the launcher in the center of the field, and anchor it in place with the spikes or tent stakes. Note: If it is a windy day, place the launcher closer to the side of the field from which the wind is coming so that the rocket will drift onto the field as it comes down.
2. Have each student or student group set up their rocket on the launch pad. Other students should stand back several feet (meters). It will be easier to keep observers away by roping off the launch site.
3. After the rocket is attached to the launcher, the student pumping the rocket should put on eye protection. The rocket should be pumped no higher than about 50 lb/in² (8.93 kg/cm²) of pressure.
4. When pressurization is complete, all students should stand in back of the rope for the countdown.
5. Before conducting the countdown, be sure the place where the rocket is expected to come down is clear of people. Launch the rocket when the recovery range is clear.
6. Only permit the students launching the rocket to retrieve it.



Appendix H

Transcripts

The multimedia files were developed especially for this module and are to be used as background information for the teacher and in conjunction with the classroom lessons. They are available online at:

http://www.nasa.gov/mission_pages/constellation/ares/ares_education.html

Ares I—Narrated by Bob Armstrong

(Runtime — 4:46 minutes)

I'm Bob Armstrong. I work at NASA's Marshall Space Flight Center in Huntsville, Alabama. Our office is tasked with designing, building, and testing this Nation's next generation of space launch vehicles. This vehicle here is the crew launch vehicle, or Ares I. It's the first in the stable of new launch vehicles for this country. It's an inline two-stage vehicle. It stands over 328 feet, which is a little taller than a 32-story building. It weighs, at liftoff, about 2 million pounds, which is about twice the mass of a 747 fully fueled aircraft. Its thrust at takeoff, 3.5 million pounds — which is 13 million times the propulsion capability of a 747 aircraft. This vehicle can place 48,000 pounds of payload into orbit, which is about 24, one-ton pickup-truck loads of cargo.

The first stage of this vehicle, shown here, is a solid rocket booster — similar to those that fly on the shuttle today. Although, this has got a fifth segment, where the Shuttle flies with four segments. We've upgraded it to give it a little more flight performance. The first stage burns for about two minutes. At that point, it is jettisoned. It is recovered under parachutes. Studies are under way to see if we might reuse that piece of hardware. Once the first stage is jettisoned, the second stage fires. Now, the second stage is made up of three components. The first component is where the fuel is housed — the tankage, if you will. It houses the fuel, the liquid hydrogen, in this case, and the oxidizer, the liquid oxygen. The second component is the engine — in this case, it's the J-2X. Now, the J-2X is housed under the inner stage adaptor here, so you can't see it. The J-2X is a modified, upgraded version of the J-2 that flew on the second and third stages of the Saturn V launch vehicle. Now, the third component of this upper stage is the instrument unit housed up here — that's where the avionics or the brains of this launch vehicle reside. This upper stage is a new design, being designed by an in-house NASA team.

Now, the payload is the crew exploration vehicle, and it sits on top of the launch vehicle. After the upper stage burns out, which is about at 450 seconds that it burns, it will be expended. Depending on the mission that it's flying, it can dock with the International Space Station — in that case, it will carry six crew. However, if it's one of two vehicles, setting up for a Moon mission, it would dock with the lander and the Earth departure stage that had been delivered there earlier by the Ares V, which is this vehicle's sister vehicle. A real important milestone is coming up in the April 2009 timeframe, and it's going to be a flight demonstrator test of this vehicle here. The vehicle will be made up with some flight hardware and some simulated hardware, but it's going to give us a good idea of how this vehicle will fly under real conditions. It's also going to help us understand how do we process this vehicle — on the ground, as well as launch this vehicle. April of 2009 is not far off, and we look forward to this big milestone.

Ares V—Narrated by Bob Armstrong

(Runtime — 4:47 minutes)

I'm Bob Armstrong. I work at NASA's Marshall Space Flight Center in Huntsville, Alabama. Our office is tasked with designing, building, and testing this nation's next generation of space launch vehicles that are going to take us back to the Moon. This vehicle next to me is the Ares V Cargo Launch Vehicle. It is the sister vehicle of the crew launch vehicle, the Ares I. This vehicle stands about 365 feet tall. It weighs, at liftoff, about seven million pounds, which is about seven times the weight of a 747 fully fueled aircraft. At liftoff, it generates over 10 million pounds of thrust. And when this vehicle lifts off, the solid rocket boosters, similar to the one that flies on the Ares I, the sister vehicle — there are five segments — they will be firing at liftoff. Also, the center core, which is a liquid oxygen and liquid hydrogen — the fuel is hydrogen core, will be firing.

On the bottom of that core are five RS-68 engines. The RS-68 engines are flying today on the Delta IV launch vehicle. At liftoff, these solids will fly for about two minutes. They will burn out, and they will be jettisoned, recovered under parachutes — studies are under way to see whether they will be reused or not. The liquid core will continue to burn, and at about 400,000 feet, it will be expended and burn up on re-entry. At that point, the upper stage engine, which is under this shroud — you can't see it — but it's the same engine that flies on the Ares I, the J-2X, will fire suborbitally. It will place the Earth departure stage and the lander in low-Earth orbit.

Once that is in orbit, we'll check it out — make sure everything is OK — and at that point, we'll launch the Ares I Crew Launch Vehicle. As its name implies, it's going to launch the crew. They will rendezvous with the lander and the Earth departure stage, which still contains fuel. Once they rendezvous and check everything out, the Earth departure stage will fire the J-2X Engine a second time and send the payload and the crew on a trajectory to the Moon. Then, the Earth departure stage is no longer needed. It is expended.

Now, when they get near the Moon, the crew will transfer from the crew exploration vehicle, or Orion, into the lander. We have four crew members on board. All four will take the lander and go down to the surface. That's a little different than Apollo — Apollo only allowed two to go down to the surface — one had to stay on orbit. This doubles our capability, and it's because of the size of the vehicles, as well as the autonomous capability of the crew exploration vehicle. So, while the crew goes to the surface, the crew exploration vehicle remains in lunar orbit. Now, one thing about the lander that is also different — we have the capability to land anywhere on the Moon, which is, in the Apollo days, we could only land in the equatorial areas. We also have twice the volume in the crew exploration vehicle than we did in the Apollo days, so there are some important differences.

Now, once the crew is done with its work on the Moon — initial stays will be about 10 days — they'll get back in the lander. The upper stage of the lander, the top part shown here, will fire, take the crew off the surface of the Moon, up to rendezvous with the Orion. At that point, the crew will transfer from the lander into the Orion. The lander will be expended. Some day down the road, we might want to reuse those landers if we can find water, ice on the Moon to use as potential fuel. After the crew transfers to the Orion, the Orion service module engine will fire sending them on a direct trajectory back to the Earth. When they get near the Earth, the service module, which is no longer needed, will be jettisoned and it will allow the capsule heat shield, which is under the service module to be used in a pristine state. The crew will re-enter through the atmosphere. The heat shield will protect them and the capsule from the extreme temperatures of re-entry. Parachutes will deploy much like on Apollo, but unlike Apollo, we're going to land on the land, as opposed to in the water. Landing on the land allows us to potentially reuse the capsule and it's much easier to recover the crew. We do not have to have a Navy to go out and get the crew. The Ares I Crew Launch Vehicle will be flying in the 2015 time frame. This vehicle, we plan on having flying in the 2018 time frame for a return to the Moon in the 2020 time frame.

Why Two Rockets?— Narrated by Bob Armstrong

(Runtime — 2:31 minutes)

I'm Bob Armstrong, and I work at NASA's Marshall Space Flight Center in Huntsville, Alabama. We're tasked with designing, building, and testing this nation's next generation of space transportation vehicles that are going to return us to the Moon.

Next to me are those two vehicles. The first one is the crew launch vehicle. It takes the crew into low-Earth orbit. It can supply the space station when it first comes on-line. Ultimately, it will be used in concert with its sister vehicle, the Ares V, or cargo launch vehicle to return us to the Moon.

Now, people ask, 'Why are you flying two vehicles instead of one, like they did in the Saturn V days?' There are numerous reasons for that — one of the most important, though, is safety reasons. Numerous panels that were convened following the *Challenger* and *Columbia* accidents pointed out the need to separate crew from cargo. On the Shuttle, we fly crew and cargo together.

For these vehicles, we've taken a different tact, and we've separated them. In a mission to the Moon, the cargo goes up on the 'cargo vehicle truck,' if you will, into low-Earth orbit, and it waits for the crew. So, once we get the cargo up there, we know it's working, we can send the crew up. This vehicle, the crew vehicle, as you can see, is a less complex vehicle, so it's likely to be more reliable. Additionally, we have a launch escape system called the launch abort system on this. If we do have a problem during launch, we can get the crew off safely to fly another day.

Another advantage of having separate crew and cargo: we've got this true 'work truck' here, if you will, that ahead of the crew or at anytime in between missions, we can deliver cargo — cargo such as habitats, rovers, in-situ resource utilization equipment — all kinds of equipment that we can deliver to the surface of the Moon without having the astronauts present, so we do not put them in any kind of danger.

Getting Ready For Launch — Narrated by Joel Best

(Runtime — 5:37 minutes)

Hi, I'm Joel Best. I work at the NASA Marshall Space Flight Center supporting the Ares I launch vehicle project. I work in the operations and supportability area, and what we do is we develop the operational concepts as well as the operations requirements for supporting the Ares I launch vehicle. We not only do ground operations, but we also do flight operations — the requirements for both of those areas.

The Ares I launch vehicle is comprised of three different elements: there's the upper stage, the first stage, and then the J-2X Engine. The J-2X Engine, the components are made out at the Pratt & Whitney Rocketdyne facility in Canoga Park, California. Those components are shipped to the Stennis Space Center, and they're put together there into what we know as the J-2X Engine. It is green run, test-fired, there at the Stennis Space Center, and then the engine is shipped to the Michoud Assembly Facility where the upper stage element is fabricated and manufactured.

Once the engine is integrated into the upper stage, that whole unit is shipped down to the Kennedy Space Center on a covered barge. Now the first stage, those are actual canisters that are reused over and over again, and they're filled out at the Utah facility by ATK Thiokol. Then they're shipped by rail in rail cars down to the Kennedy Space Center, and then they're put together down at Kennedy in the Vehicle Assembly Building. Once all the launch vehicle elements arrive at the Kennedy Space Center, the first stage elements are processed in an off-line hazardous facility and then they are sent over to the Vehicle Assembly Building. The upper stage with the J-2X Engine and inner stage already installed come in and they go straight to the Vehicle Assembly Building and wait for the first stage to get stacked.

Well, before any stacking can begin, a big thing called the mobile launcher — it's like a big barge — comes into the stacking cell; and then the first stage, piece by piece, is stacked on this mobile launcher; and then the upper stage is stacked on top of the first stage. Once, all of that is stacked, the Orion spacecraft with the LAS on top is put on top of the upper stage and then it's considered an integrated Orion-Ares launch vehicle stack. That, then, rolls out to the pad on this mobile launcher. The mobile launcher doesn't roll out on its own. There's a crawler transporter that comes in — it's like a big caterpillar. It's got treads like a bulldozer does. It comes in and it goes under the mobile launcher, picks it up, rolls it out of the VAB, and then goes down the crawlerway out to the launch pad — takes this whole integrated stack. And there's a launch umbilical tower that is part of the mobile launcher that holds everything in place. It not only allows you to get access to the whole integrated stack, but there's also a damping arm and a stiffening arm on there to hold it in place until it gets to the launch pad. Well, all this rolls out there, and it gets integrated into the launch pad — it gets hooked up and connected — and then the launch countdown activities begin.

On the day of launch, there are people supporting in control centers all over the country and at different NASA centers monitoring the launch vehicle and the Orion spacecraft to make sure everything is a 'go' for launch. Now, keep in mind that launch countdown begins about 24 hours before the launch vehicle actually launches. So, there are mission controllers at the mission control center at Johnson Space Center. There are engineering support personnel at the Marshall Space Flight center monitoring the propulsion elements. And then, of course, there is the launch control team in the launch control center at Kennedy Space Center. There's also the range safety personnel at the 45th Space Wing down at the Kennedy Space Center, and then there are people in the firing room, too, to make sure that everything is OK for actually launching the vehicle. All these people all over the country at the different control centers are monitoring all the vehicle systems to make sure everything is ready to launch.

And then, about 12 hours before launch, they put up balloons to make sure that the wind conditions are favorable for the launch at that point in time. Then, they upload what they call "initialization loads" that tell the vehicle, 'OK, you need to go according to this trajectory, based on what the winds are for today. And, once all of that is in place, they begin the launch countdown. They load the crew in the Orion vehicle and they make sure everything — all systems are go, all systems are operating as they should. And then, as it gets really close to launch, they poll all

the different people in the control centers and make sure every single one gives a 'thumbs up' or a 'go for launch.' And then at T minus 0, they press the button and the launch vehicle is on its way and it begins its ascent into space. What they tell me about the Ares I launch vehicle is because the first stage is the solid, with a lot of thrust, it's going to just zoom off the pad and just take off like a bolt of lightning. So, I'm looking forward to seeing one of those. Now, the Ares V launch, it's going to have two solid rocket boosters as well as a core stage with five engines on the bottom, so I imagine the rumble from that is just going to vibrate all over the place and you can just feel it in your chest.

Why Go to the Moon?— Narrated by Joel Best

(Runtime — 1:43 minutes)

Since the Moon is so much closer to the Earth than Mars, it is important for us to go to the Moon to learn how people work and live in space and learn any lessons that we need for going to these other planets; because with the Moon being relatively close-by, we can get the astronauts home if we need to. And that's why it's important for us to go to the Moon first, before we go to any of the other planets. And it's also cool to go to the Moon, not only because we did it once before, but this time we're going to set up lunar outposts, and we're going to learn about the lunar soil, the regolith as it's called, and what attributes of it might be useful for us here on Earth. And, we're also going to learn how to grow things in space, and have astronauts be able to survive and take care of themselves long-term in space. And that is going to benefit us tremendously for all of our long-term Constellation goals.

The thing I like most about working on the Ares I launch vehicle is that we are working at the very beginning development phase of the rocket that will replace the Space Shuttle. And we have this amazing opportunity to plan, develop, and carry out the ground operations and flight operations that are going to enable this Ares I launch vehicle to successfully carry the astronauts into orbit — so they can go on to the International Space Station, and then later go on to the Moon.

Launch Period vs. Launch Window — Kris Walsh

(Runtime — 1:41 minutes audio)

One is the launch period, which is how many days we can launch a mission to the proper orbit. For low-Earth orbit, basically there's no concern. That launch period is 365 days a year. To go to Mars, or to an asteroid, you're severely limited because you need a certain energy to be imparted to that satellite. They might use another planet, or the Moon to get into the proper orbit. So, we work with the satellite provider. We work with the NASA (National Aeronautics and Space Administration) organization that give(s) us targets -- we get the satellite to that target with a certain energy and then the mission designers take over from there. We also have a launch window on a day-to-day basis. And that can range from one second to over an hour. All our Mars missions were one-second windows and we got those all off in the first or second day. When we do have 12 minutes or more, if we have a problem with the launch countdown, we can safe the vehicle, recycle, and attempt again on the same day. If we have a one-second window, if we have any problems in the last four minutes of the countdown, we are down for 24 hours.

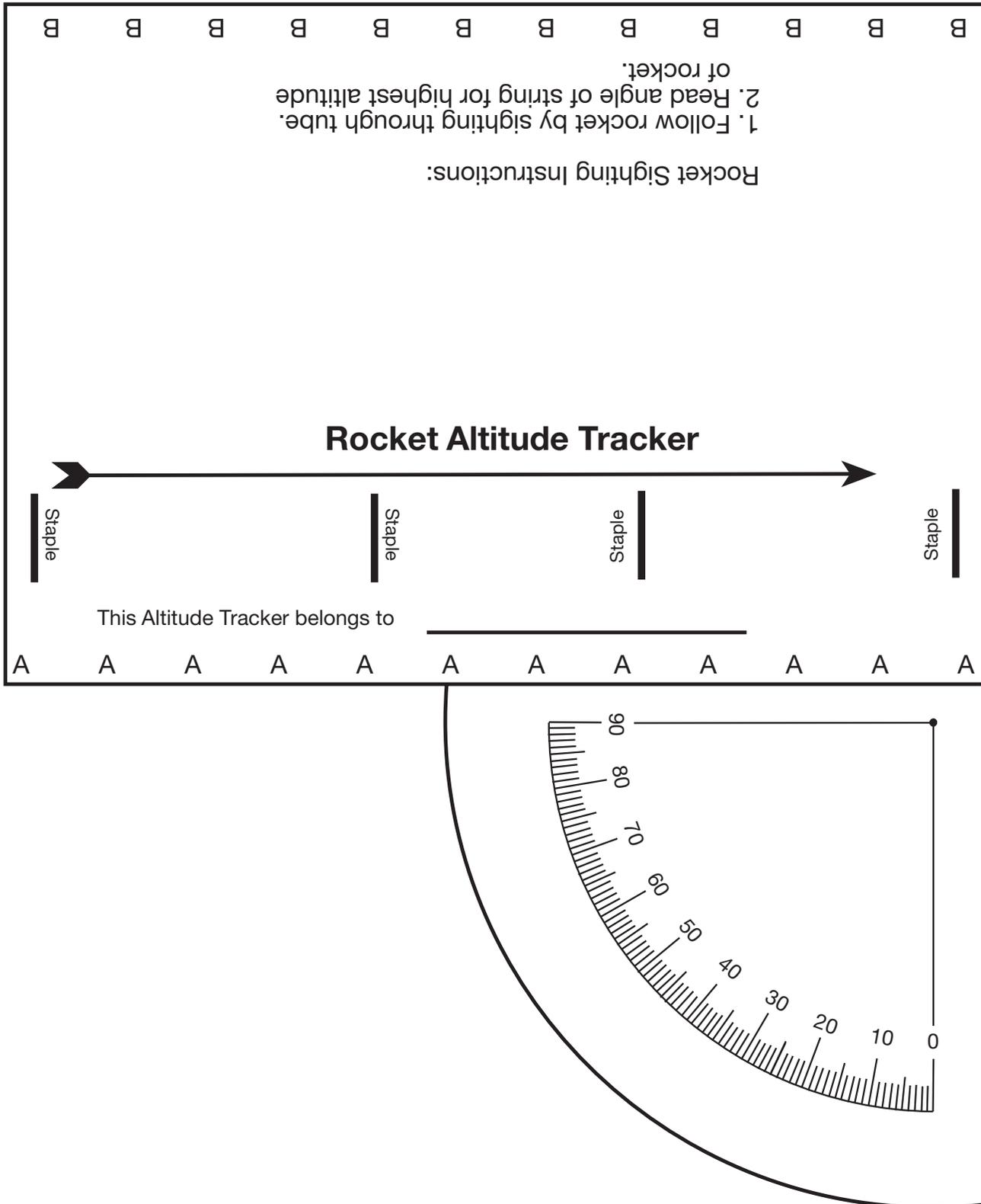
Mission Integration Manager — Kris Walsh

(Runtime — :42 seconds audio)

Every mission has a mission integration manager, or sometimes called 'missile mother.' They work all the specifications to make sure that this rocket is what's required to do the mission. They work with engineering. They work with integrative product teams. They work with suppliers. They work with quality. And they work very closely with the launch sites. And they are our primary interface with NASA (National Aeronautics and Space Administration), KSC (Kennedy Space Center), and the spacecraft manufacturer, Lockheed Martin. It's a lot of work, but it's a lot of fun, and there's not much you can do in this world that is as exciting as a launch countdown.

Appendix I

NASA Altitude Tracker



Appendix J

Safety Rules

Safety begins now. As in any project requiring a group of students to work together to use tools to construct, test, and redesign products, there are certain safety precautions. It is necessary for both the teacher and students to understand these rules and follow them exactly.

General Lab Safety

1. During the use of tools for any construction or launches, students and adults should wear safety goggles.
2. Before any tool is used, discuss the safety issues surrounding the proper use of the equipment.

Building the Rocket

1. Use only plastic drink bottles. New bottles should be used whenever possible. Bottles that have been exposed to sunlight for long periods of time should not be used. Bottles should be retired from use after 10–15 launches.
2. Use only the materials approved by the classroom teacher to construct the rocket.
3. No metal pieces or sharp objects may be used in the construction.
4. Take precautions when cutting bottles. The first incision can be made with a sharp carpet knife and the other cuts can be completed with scissors.
5. Do not use hot glue when attaching fins to the rocket body. The heat from the glue can weaken the plastic to the extent that the rocket may not be able to withstand the launch pressures. The use of cold-melt hot glues is acceptable. No cyanoacrylates (e.g., Super Glue™) should be used.
6. The supervisor must approve each design before the launch.

The Launch Area

1. Check your launch area for any potential concerns. Choose a large clearing such as an athletic practice field or vacant lot. When launching in smaller areas, use reduced pressures and adjust the launch angle to compensate for the wind.
2. The launch area and range should be large enough for the rocket pressure and should be clear before launching any rocket.
3. Do not attempt to catch a spent (falling) rocket or payload. Vertically, a rocket will typically reach nearly 500 feet (152 meters). A very aerodynamic rocket will impact the ground with speeds approaching 120 miles per hour (54 meters/second). When adding weight to the rocket with nose cones and payload, additional safety margins must be established.

The Launch

1. Launch your water rocket only under the guidance of a trained, professional adult.
2. Assign a student supervisor to be responsible for completing the “Safety Checklist” before launching (see Appendix B).
3. Always anchor the launch pad. When working on a solid concrete area, you may be able to weigh the pad down, tie it down to something solid, or attach the cord to a tree or a building in the opposite direction to counter the pull.
4. Safety goggles must be worn when within 33 feet (10 meters) of a pressurized rocket.
5. All persons not directly involved in the launch should be at least 16 feet (approximately 5 meters) away from the rocket when it is being pressurized and during the launch process.

6. If you are filling rockets with a garden hose, make sure the hose has a shutoff valve and that water is kept some distance from the launch area. Keep the water turned off when not in use.
7. To pressurize the rocket, use only bicycle pumps, air compressors, or scuba tanks with air pressure gauges. Never charge a rocket without air pressure measurements.
8. Rockets can be pressurized with various air pressures, but never above 50 psi under any circumstances. Bottle designs vary and bottles can burst at lower pressures due to bottle type, fatigue from overuse, poor construction techniques, or exposure to sunlight. Never attempt to perform a bottle burst test.
9. Keep electrical cords away from all water sources. If using a compressor, use long air hoses rather than long electrical cords.
10. Assign the following personnel to be responsible for the launch:
 - Safety Officer: Checks for safe practices and can stop a launch whenever unsafe practices are observed.
 - Loading Officer: Responsible for securing the rocket to the pad and charging the rocket with the appropriate air pressure.
 - Principal Investigator/Launch Officer: Makes final decisions about rocket design. Commences the count-down and launches the vehicle.
 - Downrange Officer: Spots the rocket and assures the safe landing of the rocket and payload. Observes the launch and records data.
11. As the bottle is being pressurized, all except the loading officer should stay away from the area. Never lean over a pressurized bottle.
12. All persons should face the rocket during launch. Kneel down and participate in the countdown. Keep the sun at your back or over your shoulder. Do not face the sun.
13. If a leak is observed during pressurization, stop adding air and release the rocket using the standard launch techniques based on the launcher you are using. Then, repair the leak or replace the bottle.
14. Bottles that are modified with fins, nose cones, and extra mass should be carefully tracked by all personnel and avoided as the rocket returns to Earth. Never attempt to catch a spent (falling) rocket or any payload that the rocket has launched.
15. If the rocket fails to release after the pin is pulled, immediately clear the area and inform the adult supervisor. The supervisor will jiggle the rocket with a long stick and cause it to release.

Signatures

I have read the Safety Rules and will observe them during the construction and launch of water bottle rockets.

Signature of student/supervisor _____

National Association of Rocketry

<http://www.nar.org>

Appendix K

Safety Checklist

In the lab or on the construction site: Signature of Group Safety Officer _____

<input type="checkbox"/>	All participants are wearing safety goggles.
<input type="checkbox"/>	All participants know the proper use of equipment and the safety issues involved with using that equipment.

While building the rocket: Signature of Group Safety Officer _____

<input type="checkbox"/>	Bottles are new or have been used for fewer than 10 launches.
<input type="checkbox"/>	Only classroom materials are being used in the rocket construction.
<input type="checkbox"/>	No metal or sharp objects are being used on the rocket.
<input type="checkbox"/>	Cuts are being made with safe cutting tools.
<input type="checkbox"/>	No hot-glue guns or cyanoacrylate (e.g., Super Glue™) were used to attach parts to the rocket.
Supervisor approval of final rocket. Signature _____	

The launch site: Signature of Launch Safety Officer _____

<input type="checkbox"/>	The pad is inspected and appears to be functional.
<input type="checkbox"/>	The pad is firmly anchored.
<input type="checkbox"/>	The size of the launch area is adequate for the experiment undertaken.
<input type="checkbox"/>	Water is not freely running near the launch pad.
<input type="checkbox"/>	All electrical cords are well away from the launch area and the water source.
<input type="checkbox"/>	The launch pin is properly placed over the lip of the bottle.
<input type="checkbox"/>	All personnel in the area are wearing safety goggles before the bottle is pressurized.
<input type="checkbox"/>	When pressurizing, air line is extended as far from pad as possible. Established pressures are not exceeded.
<input type="checkbox"/>	All personnel are paying attention to the launch, have their backs to the sun, and are looking at the rocket.

The launch: Signature of Launch Safety Officer _____

<input type="checkbox"/>	A trained adult is present.
<input type="checkbox"/>	The safety officer, loading officer, launch officer, and downrange officer are present and have been trained.
<input type="checkbox"/>	The launch area is clear, both in range and downrange.
<input type="checkbox"/>	All participants participate in the launch countdown led by the launch officer.
<input type="checkbox"/>	The safety officer can abort the launch at any time for any reason.

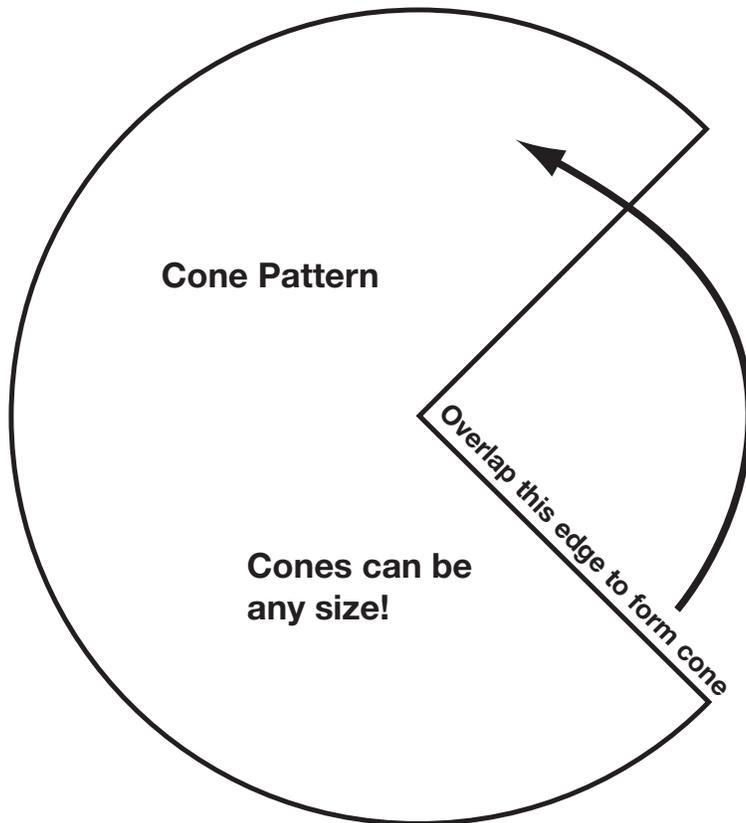
Following the launch: Signature of Launch Safety Officer _____

<input type="checkbox"/>	All electricity is turned off.
<input type="checkbox"/>	All water is turned off at the source.
<input type="checkbox"/>	Launch area is cleared of all materials and related debris.

Appendix L

Nose Cone Pattern

1. Cut out cone pattern.
2. Overlap edge to form a cone and tape down.
3. Attach nose cone to paper towel tube with tape.



Appendix M

Materials List

Pop Rocket Variables

For each group of three to four students:

Student activity, “Pop Rocket Variables,” page 6.

- Student text, “Variables and Operational Definitions,” page 12.
- Plastic 35 mm film canister with an internal-sealing lid.
- Effervescent antacid tablet.
- Paper towels.
- Water.
- Eye protection.
- Computer with Internet access connected to a video projector.
- (Optional) *October Sky* VHS or DVD with television or video projection.

Pop Goes Newton

For each group of three to four students:

- Student activity, “Pop Goes Newton,” page 17.
- Student text, “Newton’s Laws of Motion,” page 21.
- Completed student activity, “Pop Rocket Variables” from previous lesson (Briefing).
- (Optional) Video, *Newton in Space*.

The History of Rocketry

- Student text, “From Earth to the Moon and Beyond,” page 34.
- Printed copies or online access to “Brief History of Rockets:”
http://exploration.grc.nasa.gov/education/rocket/TRCRocket/history_of_rockets.html
- Construction paper, yardsticks, and markers (Optional).

Launching Ares

- Return to the Moon: The Journey Begins Now, available in the video archives at the following URL:
http://www.nasa.gov/mission_pages/constellation/main/index.html
- Mission Integration Managers: Audio with Kris Walsh.
- Getting Ready for Launch: Video with Joel Best.

Copies of the following for each student or group of students:

- Student activity, “Ground Challenge,” page 43.
- Student text, “From Earth to the Moon and Beyond,” page 34.
- Student activity, “Moon Challenge,” page 47.
- Pieces of colored construction paper labeled with the names of different types of equipment and supplies to be transported. The labels include their masses and dimensions and the stage numbers in which they are needed. (See Appendix D and E for label templates.)

Optional materials: Especially helpful for kinesthetic learners, construct manipulative representations of the various transportation vehicles using different sized boxes, labeled with their maximum payload capacities (see label templates in Appendix D):

- Pickup truck: Personal checkbook boxes approximately 3 1/2 by 6 inches (9 by 15 centimeters).
- Club cab pickup: Business checkbook boxes approximately 3 1/2 by 8 inches (9 by 20 centimeters).
- SUV: Select a box that has dimensions similar to those representing the pickup truck but with more depth.
- Trailers: Flat box similar to audiotape box approximately 3 by 4 inches (8 by 10 centimeters).

- Tractor-trailer: Shoebox.
- Tape or twist-ties to hook the trailers to the pickup trucks.
- Template labels can be placed on top of the boxes to represent the materials to be carried by a specific vehicle in a specific stage.
- Masking tape to mark off a 12-foot (approximately 3.7-meter) diameter circle on the classroom floor.

Investigating Water Rockets: Abbreviated Approach

Activity 1: What Do I Need to Know Before Launch?

- “Appendix J: Safety Rules,” page 124.
- “Appendix K: Safety Checklist,” page 126.
- Student activity, “Measuring Altitude,” page 62.
- “NASA Altitude Tracker,” page 123. (This pattern can be copied or glued onto tag board.)
- Thread, lightweight string, or fishing line.
- Cellophane tape.
- Small washer or 1–2 ounce (28–57 gram) fishing sinker.
- Scissors.
- Rope or string to measure out range (33 feet or 10 meters).
- Angle-to-height Conversion chart, page 64.
- Tennis ball per pair of students.

Activity 2: Propulsion for Entire Class

- Student activity, “Altitude vs. Water Volume,” page 84.
- Several two-liter plastic soft drink bottles.
- Water.
- Graduated cylinders (one-liter).
- Tire pump or air compressor.
- Safety glasses.
- Altitude trackers.
- Conversion charts, page 64.
- Rope to measure out range (33 feet or 10 meters).
- Compass to determine north, south, east, or west.
- Launcher (see Appendix G) or search the Internet to purchase a launcher.

Activity 3: Fin Shape

- Student activity, “Investigating Fin Shape or Size,” page 72.
- Paper towel tubes.
- Tag board (for fins).
- Ruler.
- Cellophane tape and/or glue.
- Scissors.
- Safety glasses.
- Launching mechanism (vacuum with blower or leaf blower).
- Yard (or meter) stick for measuring distances.
- Arrows: some with and some without feathers.

Investigating Water Rockets: Comprehensive Approach

Activity 1: What Do I Need to Know Before Launch?

- “Appendix J: Safety Rules,” page 124.
- “Appendix K: Safety Checklist,” page 126.
- Student activity, “Measuring Altitude,” page 62.
- “NASA Altitude Tracker,” page 123. (This pattern can be copied or glued onto tag board.)
- Thread, lightweight string, or fishing line.
- Cellophane tape.

- Small washer or 1–2 ounce (28–57 gram) fishing sinker.
- Scissors.
- Rope or string to measure out range (33 feet or 10 meters).
- Angle-to-height conversion chart, page 64.
- Tennis ball per pair of students.

Activity 2: Nose Cone Experts

- Student activity, “What a Drag” page 65.
- Paper towel tube.
- “Appendix Nose Cone Patterns,” page 127.
- Yard (or meter) stick.
- Several two-liter plastic soft drink bottles.
- Modeling clay.
- Card stock.
- Leaf blower or vacuum set to blow.
- Books to make a path.
- Long hall or open area.

Activity 3: Fin Experts (two groups)

- Student activity, “Flying Straight,” page 68, for students in both groups.
- Student activity, “Investigating Fin Shape or Size,” page 72, for one group. (Optional for students needing more structure.) Student activity, “Investigating Fin Number and Placement,” page 78 for the second group. (Optional for students needing more structure.)
- Paper towel tubes.
- Tag board (for fins).
- Ruler.
- Cellophane tape and/or glue.
- Scissors.
- Safety glasses.
- Launching mechanism (vacuum with blower or leaf blower).
- Yard (or meter) stick for measuring distances.
- Arrows: both with and without feathers.

Activity 4: Propulsion Experts

- Student activity, “Fly Like an Eagle,” page 81.
- Student activity, “Altitude vs. Water Volume,” page 84. (Optional for students needing more structure.)
- Student activity, “Altitude vs. Water Pressure,” page 87. (Optional for students needing more structure.)
- Several two-liter plastic soft drink bottles.
- Water.
- Graduated cylinders (one-liter).
- Tire pump or air compressor.
- Safety glasses.
- “NASA Altitude Tracker,” page 123.
- Conversion charts, page 64.
- Rope to measure out range (33 feet or 10 meters).
- Compass to determine north, south, east, or west.
- Launcher (see Appendix G) or search Internet to purchase a launcher.

Activity 5: Weather or Not

- Copy of the student activity, “Weather or Not,” page 90.
- Access to a computer with the Internet.
- Weather instruments for measuring wind speed, direction, visibility, and temperature.

Measuring Altitude

- “NASA Altitude Tracker Pattern,” page 123.
- Scissors.
- Pin or small nail.
- Thread, lightweight string, or fishing line.
- Cellophane tape.
- Small washer or 1–2 ounce (28–57 gram) fishing sinker.

Fly Me High

- One or more two-liter plastic soft drink bottles.
- String.
- Safety goggles.
- Glue or tape.
- Cardboard or thick paper.
- Modeling clay.
- Scissors.
- Pens and decorating supplies.
- Scale.
- Measuring devices: rulers, yard or meter sticks, and measuring tape.
- Balance.
- Launch pad with secure pin and washers.
- Water.
- Safety goggles.
- Air pump or tank.
- Altitude tracker.
- Decorative decals.
- “Appendix J: Safety Rules,” page 124.
- “Appendix K: Safety Checklist,” page 126.
- Student activity, “Fly Me High,” page 97.

You Get What You Pay For

- Spreadsheet or balance sheet.
- Calculator.
- Student activity, “You Get What You Pay For,” page 105.

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A higher resolution version of *Newton in Space* is available for a nominal fee at:

<http://quest.nasa.gov/space/teachers/liftoff/>

Return to the Moon: The Journey Begins Now, NASA video:

http://www.nasa.gov/mission_pages/constellation/main/index.html

Online Resources

Brief History of Rockets:

http://exploration.grc.nasa.gov/education/rocket/TRCRocket/history_of_rockets.html

Camping on the Moon:

http://www.nasa.gov/mission_pages/exploration/mmb/inflatable-lunar-hab.html

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Timeline of Rocket History. Marshall Space Flight Center:

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Weight Estimator. Joint Personal Property Shipping Office.

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Multimedia Resources Available with this Module

The video files are available online at:

http://www.nasa.gov/mission_pages/constellation/ares/ares_education.html

NASA Ares I Crew Launch Vehicle: Video with Bob Armstrong.

NASA Ares V Cargo Launch Vehicle: Video with Bob Armstrong.

Why Two Rockets? Video with Bob Armstrong.

Getting Ready for Launch: Video with Joel Best.

Why Go to the Moon? Video with Joel Best.

Launch Period vs. Launch Window: Audio with Kris Walsh.

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