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Teachers	Grades 5-8

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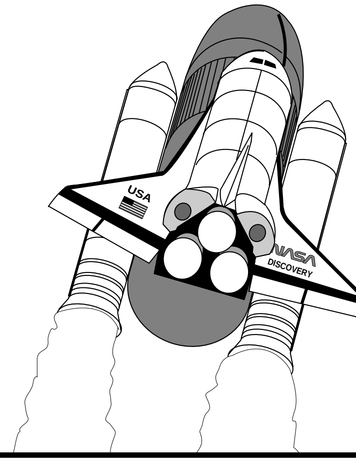


Newton In Space

Video Resource Guide

VRG-004-4/92

Application: Physical Science

Video Length: 12:35

Description

Newton In Space demonstrates the importance of Newton's Laws of Motion to space flight.

Shuttle Mission Facts

Orbital scenes were taken during the STS-39 mission.

Orbiter: *Discovery*
Mission Dates: April 28-May 6, 1991
Commander: Michael L. Coats, Capt., USN
Pilot: L. Blaine Hammond, Lt. Col., USAF
Mission Specialist: Gregory J. Harbaugh
Mission Specialist: Donald R. McMonagle, Lt. Col., USAF
Mission Specialist: Guion S. Bluford, Col., USAF
Mission Specialist: C. Lacy Veach
Mission Specialist: Richard J. Hieb
Mission Duration: 8 days, 7 hours, 22 minutes
Distance Traveled: 5,594,750 km
Orbit Inclination: 57 degrees
Orbits of Earth: 134
Orbital Altitude: 260 km
Payload Weight Up: 5,102 kg
Orbiter Landing Weight: 96,045 kg
Landed: Kennedy Space Center
Payloads and Experiments:
- AFP-675
- SPAS-II/IBSS
- Space Test Payload-1
- Multi-Purpose Experiment Canister
- Chemical Release Observation
- Critical Ionization Velocity
- Radiation Monitoring Experiment-III
- Cloud Logic to Optimize the Use of Defense Systems

Background

To understand how space travel is possible requires an understanding of the concept of mass and Isaac Newton's three laws of motion.

Mass is the quantity of matter contained in an object. It is measured by the resistance (inertia) of that quantity of matter to a change in motion. In other words, the more mass an object has, the more force is needed to move it. This principle can be easily demonstrated by pushing a stalled compact car on a level road and then by pushing a stalled full-size car on a level road. The compact car will move much more easily because it has less mass.

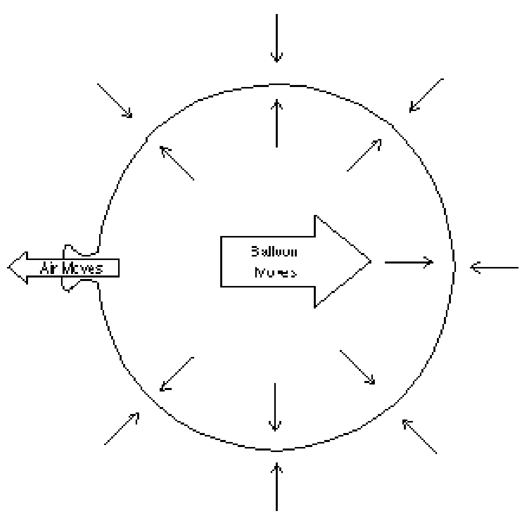
Mass doesn't change with location. The mass of an object on the surface of Earth is the same as it is in a microgravity environment. Weight, on the other hand, can change with location. *Weight* is the net gravitational force of attraction acting on the mass of an object. An astronaut walking on the Moon weighs one-sixth as much as on Earth because the net gravitational force on Earth is six times greater.

One of the misconceptions many people have about rockets is that they need an atmosphere to push against in order to work. Many years ago, Robert Goddard, the inventor of the liquid propellant rocket engine, was soundly criticized by a newspaper editorial writer because the writer shared this misconception.

> That Professor Goddard with his "chair" in Clark College and the countenancing of the Smithsonian Institution does not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react--to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools...
>
> New York Times editorial, 1921.

The author of the editorial clearly did not understand the concept of mass or Newton's laws. A rocket does have something substantial to react against---the matter it is expelling.

A rocket, in its simplest form, is a chamber enclosing a gas under pressure. A small opening at one end of the chamber allows the gas to escape, and in so doing provides a thrust that propels the rocket in



the opposite direction. A good example of this is a balloon. Air inside a balloon is compressed by the balloon's rubber walls. The air pushes back so that the inward and outward forces are balanced. When the nozzle is released, air escapes and the forces become unbalanced. The action of the escaping gas propels the balloon in a rocket flight. The balloon's flight is highly erratic because it has no structures, such as fins, to stabilize it.

When we think of rockets, we rarely think of balloons. Instead, our attention is drawn to the giant vehicles that carry satellites into orbit and spacecraft to the Moon and planets. Nevertheless, the basic principles of force, mass, and acceleration are the same. The one significant difference is the way the pressurized gas is produced. With space rockets, the gas is produced by burning propellants that can be solid or liquid in form or a combination of the two.

One of the interesting facts about the historical development of rockets is that while rockets and rocket-powered devices have been in use for more than two thousand years, it has been only in the last three hundred years that rocket experimenters have had a scientific basis for understanding how they work. The science of rocketry began with the publishing of a book in 1687 by the great English scientist Sir Isaac Newton. His book, entitled *Philosophiae Naturalis Principia Mathematica,* described physical principles in nature. Today, Newton's work is usually just called the *Principia*.

In the *Principia*, Newton stated three important scientific principles that govern the motion of all objects. Knowing these principles, now called Newton's Laws of Motion, rocketeers have been able to construct modern giant rockets such as the Saturn V and those that launch the Space Shuttle into orbit. 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 multiplied by acceleration.

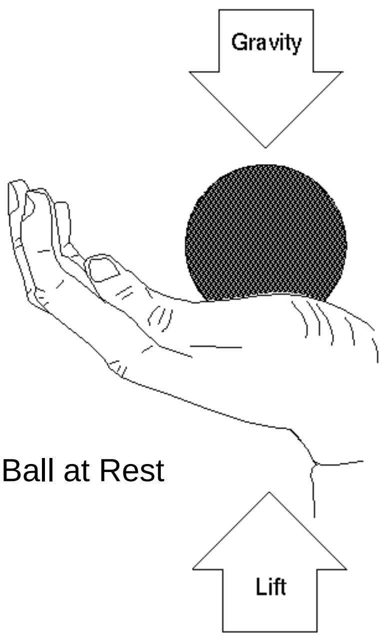
3. For every action there is always an opposite and equal reaction.

As will be explained shortly, all three laws are really simple statements of how things move. With them, we can make precise determinations of rocket performance.

Newton's First Law

This law of motion is a basic 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, and the star is moving through a rotating galaxy that is, itself, moving through the universe. While sitting "still," you are, in fact, traveling at a speed of hundreds of kilometers per second!



Ball at Rest

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

The third term important to understanding this law is *unbalanced force.* If you hold a ball in your hand and keep it still, the ball is at rest. All the time the ball is held there though, it is being acted upon by forces. The force of gravity is 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, then falls back to the Earth.

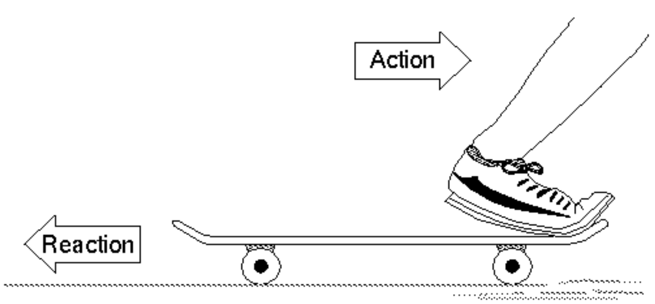
Objects in space also react to forces. A spacecraft moving through the solar system is in constant motion. The spacecraft will travel in a straight line if the forces on it are in balance. This happens only when the spacecraft is very far from any large gravity source such as Earth or the other planets 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 spacecraft is sent by a rocket on a path that is parallel to the Earth's surface. If the rocket shoots the spacecraft fast enough, the spacecraft will orbit the Earth. As long as an unbalanced force, (atmospheric friction or the firing of a rocket engine in the opposite direction from its movement) does not stop the spacecraft, it will orbit the Earth forever.

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

Newton's Third Law

For the time being, we will skip the second law and go directly to the third. This law states that every action has an equal and opposite reaction. If you have ever stepped off a small boat that has not been properly tied to a pier, you will know exactly what this law means.

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



With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the weight of the rocket. In the microgravity environment of Earth orbit, however, even tiny thrusts will cause the rocket to change direction.

One of the most commonly asked questions about rockets is how they can work in space where there is no air 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.

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.

Force is the "action and reaction" in Newton's

Third Law of Motion. We will use a gun as an example of how the second law works. When the gun is fired, an explosion propels a bullet out of the open end of the barrel, and the person firing the gun feels a "kick." This is action and reaction at work. The force acting on the bullet and on the gun is the same. What happens to the bullet and the gun is determined by the Second Law of Motion. Look at the two equations below.

$$F = m(bullet)a(bullet)$$

$$F = m(gun)a(gun)$$

The first equation relates to the bullet and the second to the gun. In the first equation, the mass is the bullet and the acceleration is the bullet's movement. In the second equation, mass is the gun and the acceleration is the kick. Since the force is the same for the two equations, the equations can be rewritten below.

$$m(bullet)a(bullet) = m(gun)a(gun)$$

In order to keep the two sides of the equation equal, the accelerations vary with the mass. The bullet has a small mass; therefore, its acceleration is great. The gun has a larger mass; thus, its acceleration is smaller.

Let's apply this principle to a rocket. Replace the mass of the bullet with the mass of the gases being ejected out the rocket engine. Replace the mass of the gun with the mass of the rocket moving in the other direction. Force is pressure created by the controlled explosion taking place inside the rocket's engines that accelerates gas in one direction and the rocket in the other.

Something interesting happens with rockets that doesn't happen with the gun in our example. The mass of a rocket is the sum of its parts. Its parts includes rocket engines, propellant tanks, payload, control system, and propellants. By far, the largest part of the rocket's mass is its propellants. The interesting part here is that the amount of propellant changes as the engines fire. It decreases until consumed. That means that the rocket's mass is not constant. It gets smaller. In order for the left side of our equation to remain in balance with the right, acceleration has to increase. This is why a rocket starts off moving slowly, but moves faster and faster as it climbs to space.

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 movement (acceleration) of a rocket is determined by the relationship between the force produced by the rocket engine and the masses of the rocket itself and the gases being ejected by the engine (second law). The reaction, or motion, of the rocket is equal to and in an opposite direction from the action, produced by the gases ejected from the engine (third law).

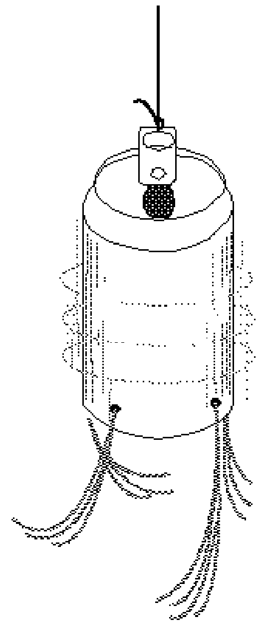
Terms

Acceleration - A change in speed.
Action/Reaction - An unbalanced force exerted in one direction accompanied by an equal force in the opposite direction.
Force - A push or a pull.
Mass - The quantity of matter in a material object. (More precisely, the amount of inertia of a material object.)
Microgravity - A gravitational force that is small compared to Earth's gravitational force.
Motion - A condition in which an object is moving in relation to its surroundings.
Rest - A condition in which an object is not moving in relation to its surroundings.
Unbalanced Force - A net push or pull in one direction.
Weight - The force of gravity upon the mass of an object.

Classroom Activities

The following hands-on activities demonstrate some of the concepts presented in this videotape.

Soda Pop Can Engine

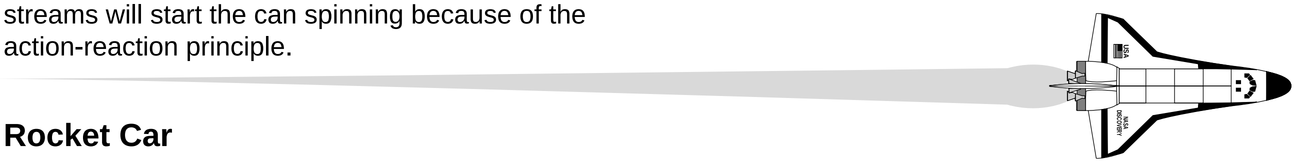


Materials:

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

Instructions:

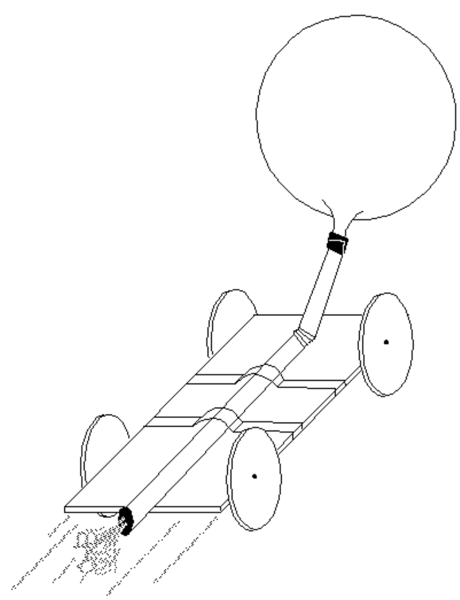
Demonstrate Newton's third law of motion by constructing a falling-water version of a Hero engine. Lay the can on its side and using the nail or ice pick carefully punch four equally spaced small holes just above and around the bottom rim. Then, before removing the punching tool from each hole, push the tool to the right (parallel to the rim) so that the hole is slanted in that direction. Tie a short length of fishing line to the can and immerse the can in water until it is filled. Pull the can out by the fishing line. Water streams will start the can spinning because of the action-reaction principle.



Rocket Car

Materials:

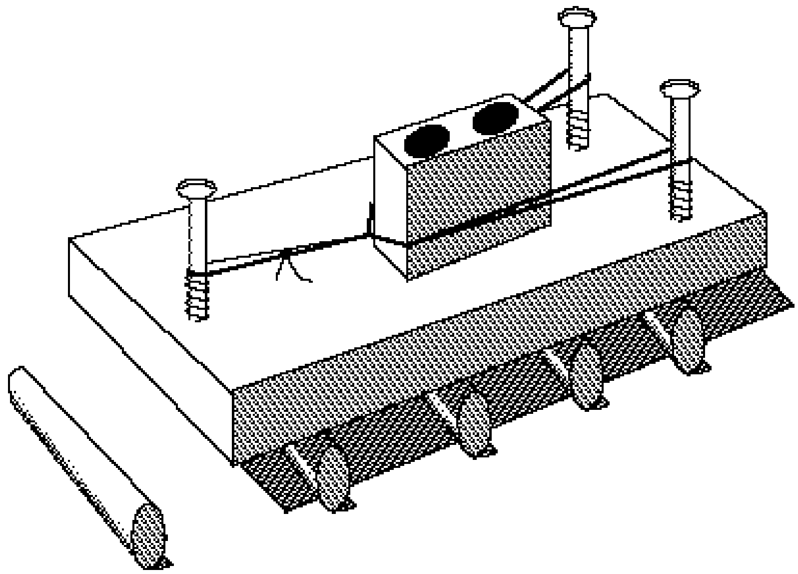
4 straight pins
Styrofoam meat tray
Cellophane tape
Flexi-straw
Scissors
Drawing compass
Marker pen
Small balloon
Ruler



Instructions:

Construct a simple balloon-powered car to demonstrate Newton's third law of motion. Cut out a rectangle 7.5 by 18 cm in size and four circles 7.5 cm in diameter from the flat surface of a styrofoam meat tray. Push one pin into the center of each circle and then into the edge of the rectangle as shown in the picture. The pins become axles for the wheels. Insert the straw into the balloon and seal the balloon's nozzle with tape to the straw. Mount the balloon to the car as shown. Inflate the balloon and release to see the car propelled along a flat surface by action/reaction.

Newton Cart



Materials:

1 Wooden block about 10x20x2.5 cm
1 Wooden block about 7.5x5x2.5 cm
3 3-inch No. 10 wood screws (round head)
12 Round pencils or short lengths of similar
dowel rods
3 Rubber bands
Cotton string (several feet)
Matches
6 Lead fishing sinkers (about 14 g or 1/2 ounce each)
Drill and bit
Vise
Screwdriver

Instructions:

Demonstrate Newton's laws of motion by propelling wood blocks with a "slingshot" launcher. Use short dowel rods as rollers. Set up the cart as in the diagram by placing a string loop over a rubber band and then place the ends of the rubber band over the two screws. Pull the rubber band back like a slingshot and slip the string over the third screw to hold the rubber band stretched. Light a match and ignite the ends of the string hanging down from the loop. When the string burns through, the rubber band will throw the block off the cart and the cart will roll in the other direction. Note how far the cart travels along the table top. Repeat the activity by using different numbers of rubber bands. As another set of variables, insert lead sinkers into the holes in the block. In this activity, the acceleration of both the block and the cart will vary with the mass of the block and with the number of rubber bands used.

References

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STS-39 Crew Biographies

Commander: Michael L. Coats (Capt., USN). Michael Coats was born in Sacramento, California but considers Riverside, California his hometown. He graduated from the U.S. Naval Academy and earned a master of science degree in aeronautical engineering from the U.S. Naval Post Graduate School. Coats was a combat pilot in Southeast Asia and a test pilot before joining NASA. He served as the pilot of the STS-41D mission and commander of STS-29.

Pilot: L. Blaine Hammond, Jr. (Lt. Col., USAF). Blaine Hammond was born in Savannah, Georgia and received a bachelor of science degree from the U.S. Air Force Academy and a master of science degree from the Georgia Institute of Technology. Before joining NASA, he was an Air Force pilot and a test pilot instructor. This was his first flight on the Space Shuttle.

Mission Specialist: Gregory J. Harbaugh. Gregory Harbaugh was born in Cleveland, Ohio but considers Willoughby, Ohio his hometown. He attended Purdue University and received a bachelor of science degree in aeronautical engineering. He also earned a master of science degree in physical sciences from the University of Houston-Clear Lake. Harbaugh served in operations and management positions at NASA before becoming an astronaut. This was his first space flight.

Mission Specialist: Donald R. McMonagle (Lt. Col., USAF). Donald McMonagle comes from Flint, Michigan and received a bachelor of science degree in aeronautical engineering from the Air Force Academy and a master of science degree in mechanical engineering from California State University-Fresno. He has been an Air Force pilot and test pilot. This was his first space flight.

Mission Specialist: Guion S. Bluford (Col., USAF). Guion Bluford was born in Philadelphia, Pennsylvania and received a bachelor of science degree in aerospace engineering from Pennsylvania State University and a master of science degree in the same subject from the Air Force Institute of Technology. He earned a doctorate in aerospace engineering from the Air Force Institute of Technology and a master of business administration degree from the University of Houston-Clear Lake. Bluford has flown on the STS-8 and STS 61-A missions.

Mission Specialist: C. Lacy Veach. Lacy Veach was born in Chicago, Illinois but considers Honolulu, Hawaii his hometown. He earned a bachelor of science degree in engineering management from the Air Force Academy. He has been a fighter pilot and a member of the Thunderbirds Air Force Demonstration Squadron. Veach joined NASA as an engineer and research pilot before becoming an astronaut. This was his first space flight.

Mission Specialist: Richard J. Hieb. Richard Hieb was born in Jamestown, North Dakota and earned a bachelor of arts degree in math and physics from Northwest Nazarene College and a master of science degree in aerospace engineering from the University of Colorado. Before becoming an astronaut, he worked for NASA in mission control and specialized in rendezvous and proximity operations. This was his first space flight.

Flight Crew Operations Directorate
NASA Johnson Space Center 3/92

Newton In Space

Videotape and Video Resource Guide Evaluation

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SA - Strongly Agree
A - Agree
D - Disagree
SD - Strongly Disagree

Please circle one

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2. *Newton In Space* is appropriate for the grade level(s) I teach. **SA A D SD**

3. *Newton In Space* is just the right length for my students. **SA A D SD**

4. The video resource guide is a useful supplement to the videotape. **SA A D SD**

5. The instructions and background information in the video resource guide are complete and easy to understand. **SA A D SD**

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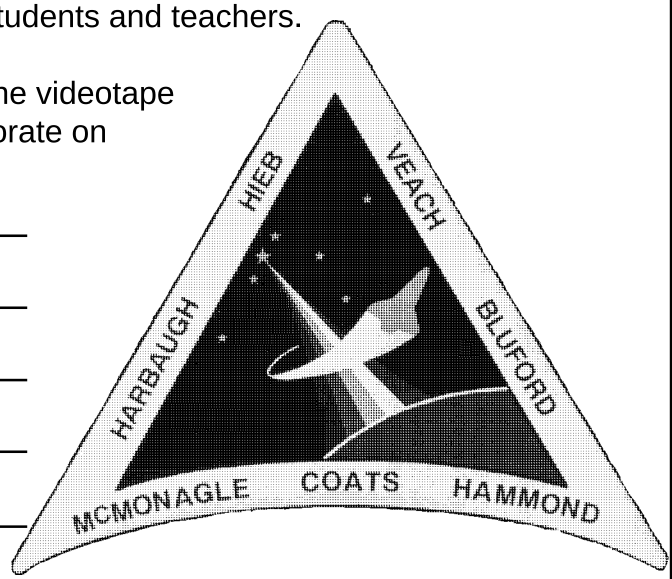

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