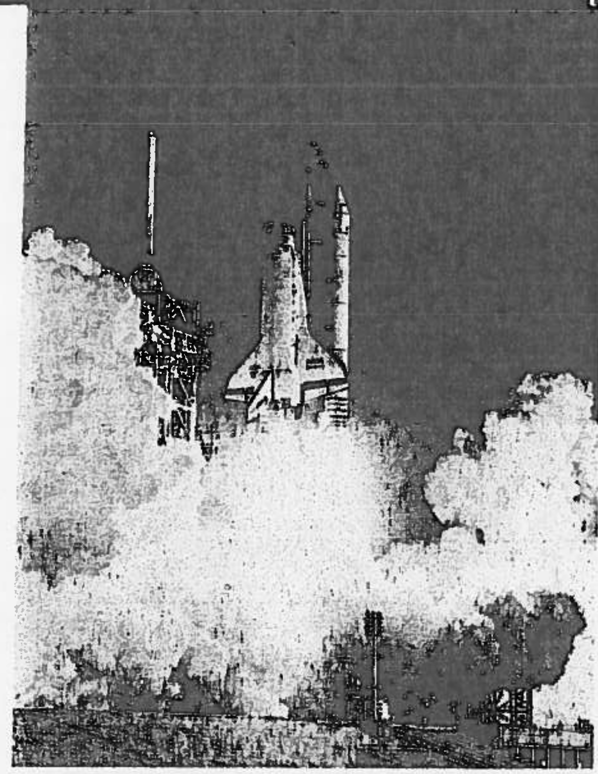
MODULE 4

Rockets



TAKE THE CHALLENGE

What happens when you blow up a balloon and then let go of it without tying the open end? It flies around wildly in all directions until the air runs out, right? Balloons and rockets work in much the same way. They both move because a gas flows from an opening. One difference is that the flight of a rocket is controlled. In this activity, you will try different techniques to control the flight of a balloon and make it travel the greatest distance you can.

Your teacher will provide the following supplies:

- balloons, all the same size
- corks, assorted sizes
- hand drill, with twist drills
- rubber bands
- straws or other plastic tubes

1. Work in teams as assigned by your teacher.

2. Blow up a balloon. Place a cork in the open end of the balloon. Wrap a rubber band around it to hold the balloon tightly against the cork. Make a small hole through the cork. In a test area assigned by your teacher, release the balloon. Compare the results of this experiment with just releasing the balloon:

____

____

3. What might be done to improve the flight of your balloon? Would a larger or smaller cork work better? What difference would a larger or smaller hole make? If a straw were inserted into the hole, would that improve performance? Does the direction in which you point the balloon when you launch it make a difference?

Working with other members of your team, experiment to find out what design works best. Try a number of different things. Be creative. On a separate sheet of paper, keep notes about the combinations you try and the results you achieve.

4. Put together your best design. Describe it in the space below. Make a sketch if you wish. Include any other information you think is important to achieving the best results.

____

____

____

____

SKETCH

5. Hold a contest with other groups to see whose balloon flies the farthest. Each group may have three flights. Record your results below:

Flight 1: _______________

Flight 2: _______________

Flight 3: _______________

6. What factors or features do you think were most important in achieving a long flight?

____

____

DID YOU KNOW

Rockets are having a profound influence on our lives today. They enable us to visit new worlds, to learn new things, and to not only envision, but explore new ways of living and of traveling that earlier people would have considered impossible. Fig. 4-1.

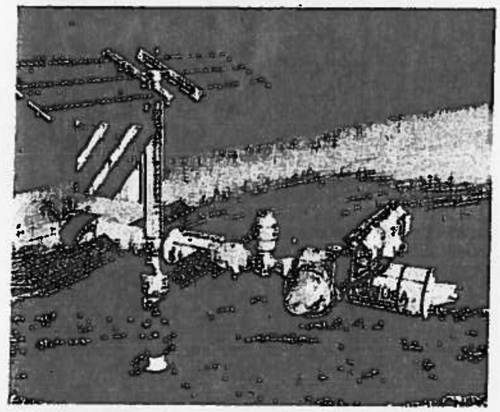


Fig. 4-1. The space station will soon allow people to live and work in space for an extended period of time.

DID YOU KNOW

According to the *World Book Encyclopedia*, rocket engines are more powerful than any other kind of engine. A rocket engine the size of an automobile engine can produce 3,000 times more power.

OUTCOMES

You've just experienced several factors involved in rocket flight. In this chapter, you'll explore the topic of rockets—how they work, factors involved in their design, and some ways in which we use them. You will learn to:

- explain the thrust force and how it is created in rockets
- identify forces that must be overcome in order for rockets to fly and tell ways in which this is achieved
- explain factors involved in rocket design
- tell some ways in which rockets are used
- build and test-fly a model rocket and calculate how high it flies

TERMS

aerodynamic drag	mass fraction	stages
apogee	orbit	telemetry
attitude	payload	Third Law of Motion
booster rockets	probes	thrust
center of gravity	propellant	vernier engines
grain	satellite	weight
gravity	sounding rockets	
mass	stability	

▶ROCKETS: WHAT A RIDE!

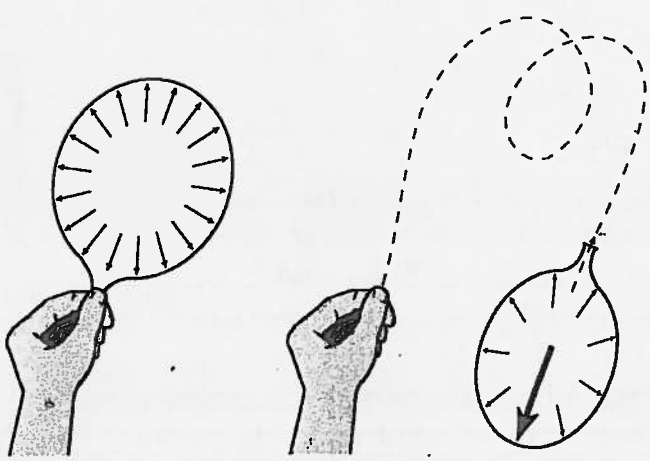
5 . . . 4 . . . 3 . . . 2 . . . 1 . . . 0 . . . We have ignition . . . Smoke and flames pour from the bottom of the giant rocket sitting on the launch pad. *We have LIFT-OFF!!!* The heavy vehicle rumbles, roars, and rises into the air—slowly at first, and then faster, *faster*, *faster*. Soon it's high in the sky. A flash! The booster rocket engines separate from the main rocket, which rapidly becomes a disappearing dot. A long smoke trail marks the rocket's path into boundless space, and then it, too, begins to disappear. We on earth finally turn away, knowing that we have witnessed only the beginning of a long journey. It's a journey in knowledge as well as in distance, and it's only possible because of rockets.

▶HOW DO ROCKETS WORK?

During the opening activity, you experimented with controlling the flight of a balloon. Since rockets work on the same principle (law of nature), let's see what was happening to propel the balloon.

You forced air into the balloon to inflate it. As long as the air could not escape, it pushed with equal force against all parts of the inside of the balloon. Fig. 4-2A. When you released the balloon, air started to escape. The force was no longer the same on all parts of the balloon. The force of the escaping air placed an equal but opposite force on the balloon itself, causing it to fly. Fig. 4-2B. When you were able to keep the escaping air moving in one direction, you caused the force to propel the balloon in the opposite direction. The force that pushed the balloon is called **thrust**.

The principle that caused the balloon to move is the *reaction* principle. In the late 1600s, Isaac Newton, an English scientist and mathematician, described this principle in his **Third Law of Motion**. It states: *To every action there is an equal and opposite reaction.* This law also applies to the way a rocket works.



A. B.

Fig. 4-2. Thrust is created when the nozzle of an inflated balloon is released. (A) When the nozzle is held closed, the air inside the balloon presses equally in all directions. (B) When the nozzle is released, pressure there is reduced. However, pressure increases on the opposite side, creating thrust.

SCIENCE

◄ Action . . . Reaction ►

Your teacher will select two students to demonstrate this activity. They will need a skateboard and a long area of clear floor. The students will do the following:

1. Position the skateboard near one end of the clear area.

2. One student should stand on the skateboard. The other should stand on the floor to one side and help him or her stay balanced. The clear floor area should be behind the person standing on the skateboard.

3. Supported by the student standing on the floor, the student on the skateboard should carefully step forward off it. (action) What happens to the skateboard? (reaction)

____

4. Was the reaction *opposite* to the action?

____

5. Was the reaction *equal* to the action?

____

Because the skateboard traveled farther than the person stepping off it, you may think the answer to this question is "no." Actually the reaction *is* equal to the action. What factor do you think makes the most difference?

____

(After you write your answer, check the footnote on this page to see if your answer is correct.*)

*Weight. The skateboard traveled farther because it weighs less than the person who stepped from it.

Highlights in the History of Rockets

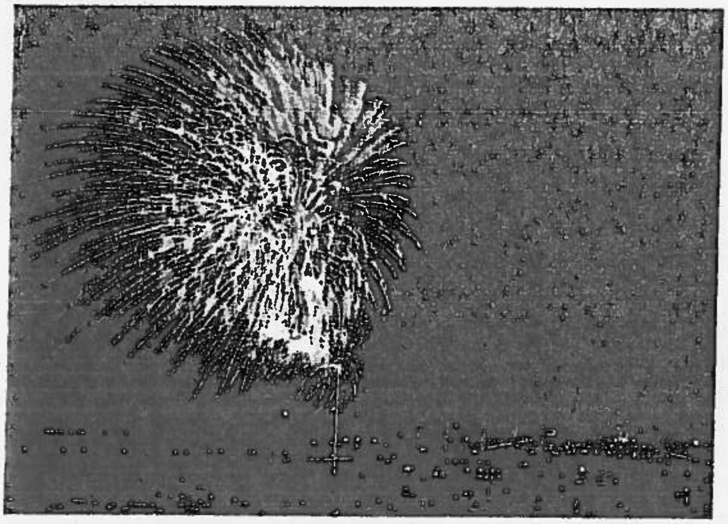


Fig. H-4-1.

- Rockets, powered by black powder, were probably invented by the Chinese in the eleventh century. They were certainly using them in war in the 1200s. The Chinese also are thought to have invented fireworks. Fig. H-4-1.

- Arab traders introduced the rocket to Europe in the 1200s. In the 1300s, Roger Bacon, an English monk, improved the formula for gunpowder. This was still the primary rocket fuel.

- Used in war, these rockets were not accurate. William Congreve, an English army officer, introduced more accurate and far-flying rockets in the early 1800s. (The mention of the "rockets' red glare" in *The Star Spangled Banner* refers to the British rocket bombardment of Fort McHenry in the War of 1812.) Fig. H-4-2.

Fig. H-4-2

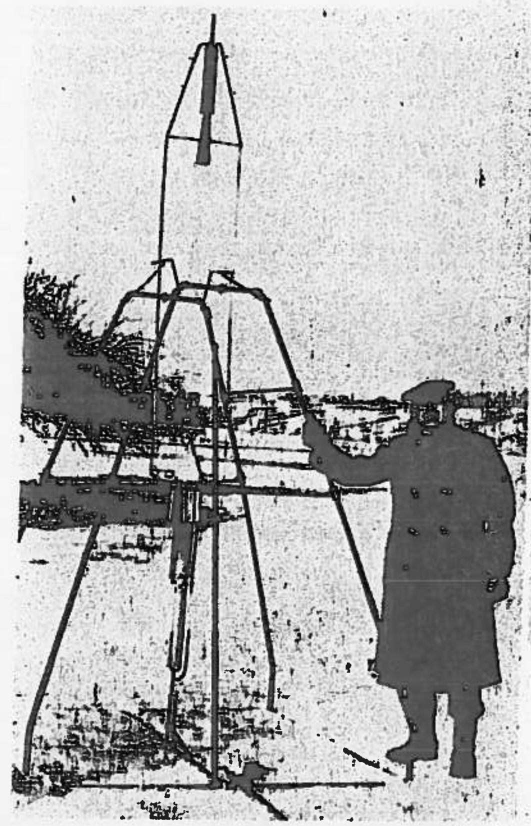


Fig. H-4-3.

- Until the twentieth century, black powder remained the major rocket fuel. In 1918, Robert Goddard invented a rocket that was powered by liquid fuel. (His early experiments, in Massachusetts, were banned by the town's fire marshal.) Goddard also suggested that rockets might eventually be sent to the moon. H-4-3.

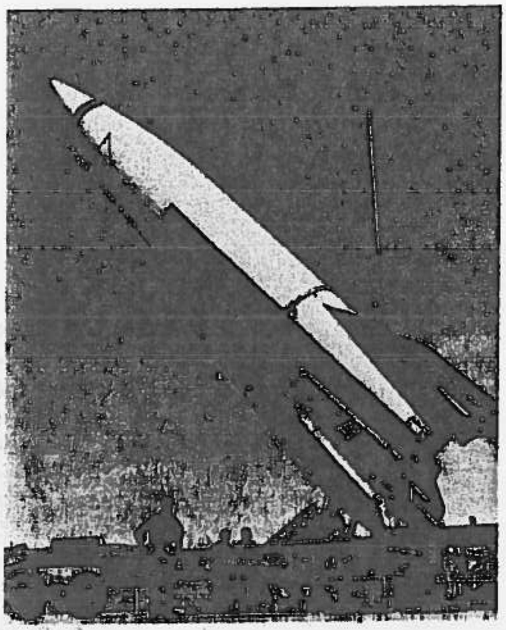


Fig. H-4-4.

- The Germans experimented with rockets throughout the 1930s. They were searching for a replacement for the long-range artillery they were forbidden to have after WW I. In 1944, their research eventually led to the development of the V-2 rocket. This was the first large rocket to exceed the speed of sound. More than 1,300 V-2s were launched against Britain in the closing months of WW II. Fig. H-4-4.

- Much of the postwar rocket research was focused on developing rockets that could be launched into space. In 1957, the Soviets launched Sputnik I, the first satellite. In 1969, a team from the United States made a manned moon landing. There were also unmanned probes of Venus, Mars, and other planets.

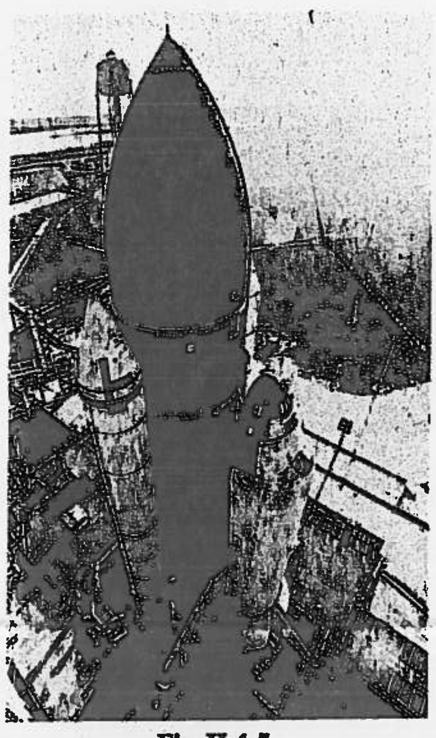


Fig. H-4-5.

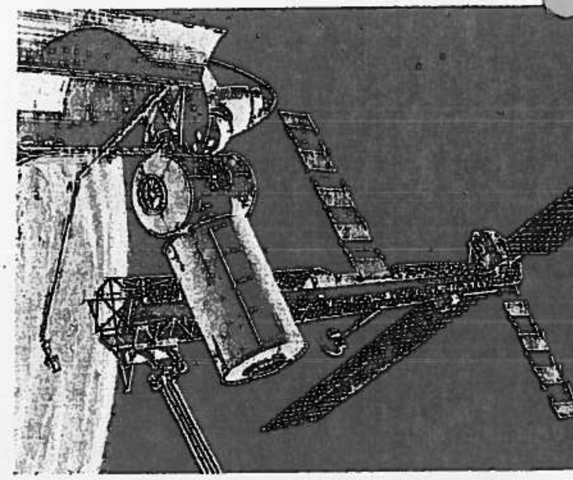


Fig. H-4-6.

- The United States is now the leader in rocket research. Such research is conducted by NASA (National Aeronautics and Space Administration). Figs. H-4-5 and H-4-6.

ACTIVITY

Prepare a bulletin board display on the history of rockets. Include photographs and drawings.

SCIENCE
Gases and Thrust

In a rocket, which of the following is the *action* and which is the *reaction*?

1. Flow of gases: ________________

2. Forward thrust: ________________

DID YOU KNOW

Solid propellant can be stored for long periods of time and remain effective. However, the burning of solid propellant cannot be started and stopped as a way to control rocket flight. Solid propellant is used mainly in military rockets and boosters (launch rockets). It's used in model rockets, too. You will use a solid-propellant engine in the rocket you build during the final activity in this chapter.

DID YOU KNOW

The percentage of propellant to use is determined by dividing the mass of propellant by the total mass of the rocket and multiplying by 100. Rocket engineers call the ratio the *mass fraction* and usually express it as a decimal. (eg., 0.91).

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

Rockets can be categorized according to the type of propellant they use. The most common types are solid-propellant rockets and liquid-propellant rockets.

Rocket Propulsion

Thrust similar to that in a balloon is created within a rocket engine. It results from combustion (burning). Besides heat, combustion requires both something to burn and oxygen. A rocket can fly in airless space because it carries both fuel and a substance that provides oxygen (an *oxidizer*). These chemicals together are called **propellant.**

Combustion takes place in a *combustion chamber*. Figs. 4-3 and 4-4. The gas created by the combustion expands rapidly, exerting pressure in all directions on the inside of the rocket. (Remember the balloon example?) When gas escapes through the *nozzle* at the rear of the rocket, an equal but opposite force is created inside the rocket, which moves it forward. The greater the speed and mass of the escaping gases through the nozzle, the greater the thrust.

Propellant

Most of the mass of a rocket is made up of propellant. For best performance, 91-93 percent of a rocket's total mass should be propellant.

SOLID-PROPELLANT ROCKETS

Solid propellant is called **grain.** It's a mixture of fuel and oxidizer. Grain is packed into an insulated combustion chamber of a rocket. Refer to Fig. 4-3. The grain burns from one end to the other or from inside out to provide expanding gases to power the rocket.

LIQUID-PROPELLANT ROCKETS

Rocket engines that use liquid propellant are much more complicated than those that use solid propellant. Refer to Fig. 4-4. Fuel and oxidizer in liquid forms are carried in separate tanks. They are moved by high-pressure gases or pumps to a combustion chamber. They must be mixed precisely and as completely as possible to give maximum power when they are burned. Liquid-propellant rockets produce more thrust per pound of fuel than solid-propellant rockets. However, because more equipment is required, liquid-propellant rockets are heavier. More thrust is required to lift them.

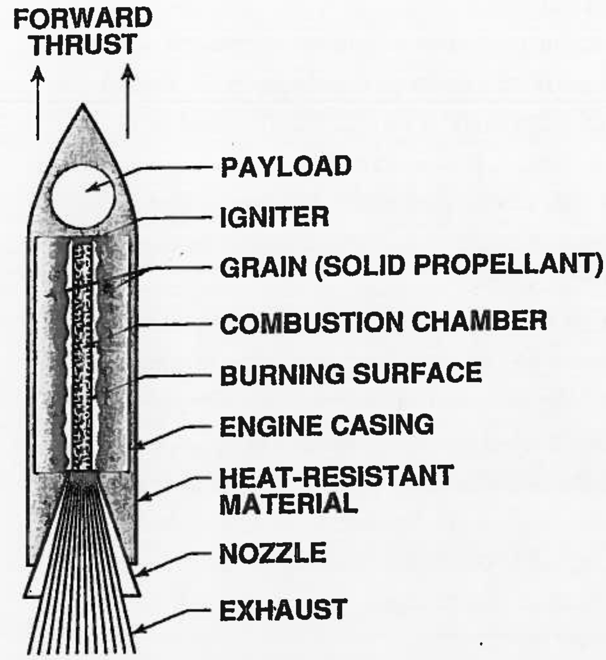


Fig. 4-3. A solid-propellant rocket.

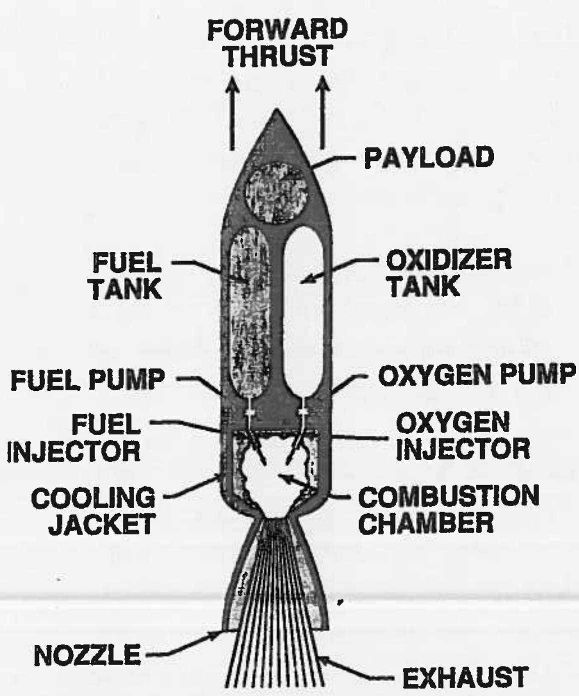


Fig. 4-4. A liquid-propellant rocket.

MATH

Figuring the Mass Fraction

If the total mass of a rocket is 6,500 pounds (3000 kilograms) and the mass of propellant is 6,000 pounds (2750 kilograms), what is the rocket's mass fraction? (Round to the nearest hundredth.)

Answer: ____________________

SCIENCE

Nozzles and Thrust

Rocket nozzles work much like hose nozzles. If you have a water hose at home, vary the size of the hose nozzle opening. Then observe the changes in the stream of water running through it. Also, feel the difference in the thrust.

SCIENCE

Burnable Surface Area

To increase thrust, the amount of burnable surface area is increased. The surface area of the hollow core is ignited, and the grain burns from the inside out. Fig. 4-5. Gases are produced at a higher rate and leave the engine at higher speeds. Sometimes cores are cut in a star shape. This increases the burnable surface area—and, therefore, the thrust.

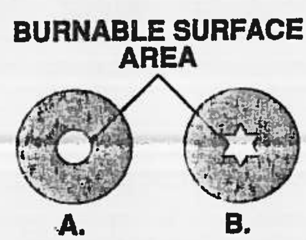


Fig. 4-5. The shape of the grain in a solid-propellant rocket.

DID YOU KNOW

The rocket system used to launch the space shuttle uses both solid- and liquid-propellant rockets. Once the fuel supply of both rockets is exhausted, they are separated from the main rocket. This reduces the weight of the vehicle. It also allows upper-stage rockets to work more efficiently and reach higher altitudes.

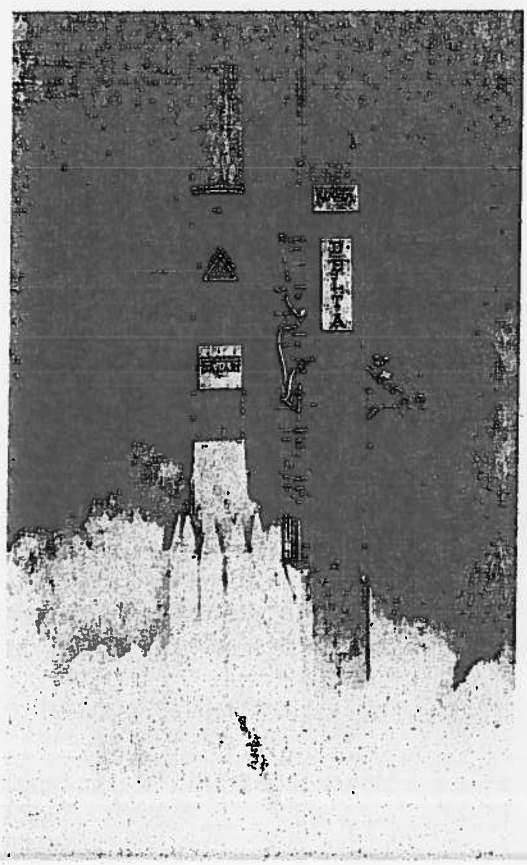


Fig. 4-6. Rockets consume a great deal of propellant. They are designed to minimize friction with the air (drag).

Liquid-propellant rocket engines can be started and stopped as needed. These engines are excellent for use in space where controlled thrusts are needed to make course changes.

Liquid propellant must be handled carefully. If mixed but not ignited, the chemicals explode easily.

ROCKETS IN MOTION

Huge amounts of propellant are consumed during lift-off. Fig. 4-6. This develops enough thrust to overcome the weight of the rocket and the drag created by friction with the air. Both become less the higher the rocket flies.

Weight

The **weight** of an object on earth is the force of its attraction to the earth—the pull of *gravity*. **Gravity** is the pull or attraction that one object exerts on other objects. The strength of the gravitational pull depends on the masses of the objects and the distance between them. **Mass** is commonly described as the amount of matter in an object. The earth has a large mass. It exerts a strong pull on a rocket sitting on its surface. A heavy rocket requires immense force to lift off.

Weight decreases as the rocket flies higher. One reason is that the distance between the rocket and the earth increases. Increasing distance reduces the pull of gravity. Another reason is that fuel is used up. It is burned and expelled as hot gases. Often **booster rockets** are used to launch the vehicle.

Aerodynamic Drag

Aerodynamic drag is the slowing force created by friction between a moving object and air. The sleek design and smooth outside surface of a rocket keep drag to a minimum. The pointed "nose" helps it move easily through the air. Also, the diameter of a rocket is kept as small as possible. The less surface area exposed to air and the smoother the airflow around the rocket, the less drag there will be. Refer again to Fig. 4-6.

SCIENCE

Aerodynamic Shapes

You will need:

- empty cereal box
- light, flexible cardboard or construction paper
- blow dryer
- cellophane tape

1. Place the cereal box on a table or desk near an electrical outlet.

2. Be sure the blow dryer is set on its lowest temperature setting. Plug the cord into the outlet.

3. Taking care with the cord, turn on the dryer and aim it at the front of the box. The force of the air stream against the flat surface should cause the box to fall over. Fig. 4-7A.

4. Bend and tape a piece of cardboard or construction paper to the front of the box to act as a deflector. Fig. 4-7B. Again, aim the air stream at the box. What were your results this time?

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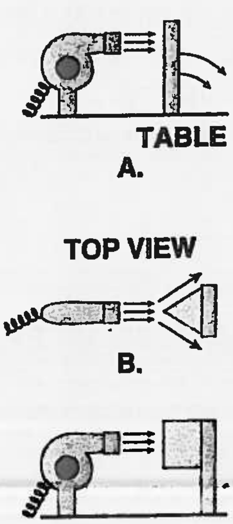

Fig. 4-7.

5. Tape the deflector in various positions on the front of the box. Fig. 4-7C. See what results you get. Does the position of the deflector make a difference?

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6. Form the cardboard or construction paper into various shapes. See which ones will divert the air around the box. For ideas, look at things around you or examine pictures of such things as airplanes, towers, etc.

7. What shapes did you find were most effective? Sketch these in the space below.

8. Examine photos of rockets. Can you find ways in which these shapes were used in their design?

SKETCH

SCIENCE

Multistaging Rockets

See for yourself how multistaging works. Activity Sheet 4-A, page 145, provides instructions for using balloons to simulate multistage rocket flight.

DID YOU KNOW

The Space Shuttle usually weighs about 4,500,000 pounds (2,041,200 kilograms) at lift-off. The rocket engines must be powerful enough to develop 7.3 million pounds (32.4 million newtons) of thrust to achieve lift-off and flight. (NASA)

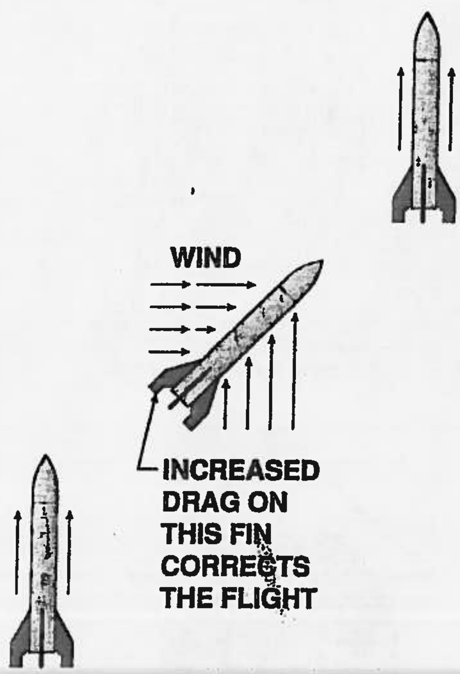


Fig. 4-9. Fins help stabilize the flight of a rocket.

▶ROCKET DESIGN

As suggested in the previous section, rockets often have more than one rocket engine. These are arranged to fire in **stages**. The first stage is the booster that launches the rocket. Then the second stage is used. This process continues one stage after another for as many stages as the rocket has. Most have only two or three.

Stability

The flight of a rocket needs to be *stable*. The rocket needs to fly smoothly without tumbling and wildly changing direction. A rocket's **stability** depends on its *center of gravity (CG)*, also called *center of mass (CM)*.

The **center of gravity** of an object is its balance point. It is the center of all its mass. If a rocket is unstable, it will tumble or spin around this point. Fig. 4-8. Control systems or features are designed to prevent unstable motions or keep them to a minimum.

Fins on the base of the rocket help it fly straight. They make it more stable. Their large surface area counteracts forces such as wind that work against straight-ahead flight. Fig. 4-9. A rocket's center of gravity should be located ahead of its fins. Refer again to Fig. 4-8.

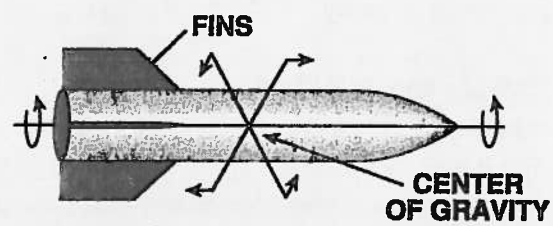


Fig. 4-8. Rockets must be designed for stable flight.

Controls

Fins that do not move are *passive controls*. They make the rocket more stable simply by being there. *Active controls* can be moved during flight to stabilize and steer the rocket.

On some rockets, fins are active controls. They can be tilted to redirect the flow of air, causing the rocket to fly in a different direction. Vanes and special nozzles are active control devices that redirect the exhaust to change the direction of flight. Fig. 4-10.

Vernier engines are small rocket engines or gas nozzles mounted on a rocket. These are fired to make fine adjustments in speed or direction. Attitude-control rockets are small engines mounted on a space vehicle. These are used to change the position, or **attitude**, of the vehicle in relation to an object such as the earth or sun.

▶PURPOSE AND KINDS OF ROCKETS

The main purpose of all rockets is to carry a *payload*. A **payload** consists of things—sometimes people—that relate to the *purpose* of the flight. They are not part of the rocket's operation. There are many kinds of rockets.

Military rockets come in various sizes. Many military rockets have sophisticated guidance systems that enable them to hit targets very accurately.

Sounding rockets collect information about the earth's atmosphere. These carry cameras and scientific instruments. Using a process called **telemetry**, data is collected and sent by radio to receiving stations on earth. Scientists use the information to study weather and climate.

Space Rockets and Satellites

Space rockets may be used to launch research equipment, sending it far into space to explore the solar system. These are called **probes**. More commonly, space rockets carry artificial *satellites* into *orbit* around the earth.

A **satellite** is an object or body in space that travels around another, larger body. Its motion is controlled by the gravitational pull of the larger body. The path a satellite follows around the earth is called its **orbit**. A satellite might be a spacecraft containing people. Other satellites are used in communication. Fig. 4-11. Still others gather data for scientific research.

SCIENCE
Locating Center of Gravity

Try locating the center of gravity of various objects.

1. Try balancing a pencil on your finger. Is the center of gravity towards the sharpened end or the eraser end? Why?

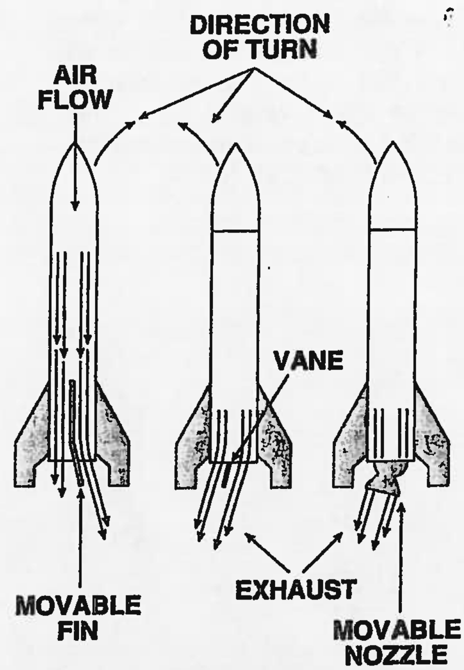


Fig. 4-10. Active rocket controls.

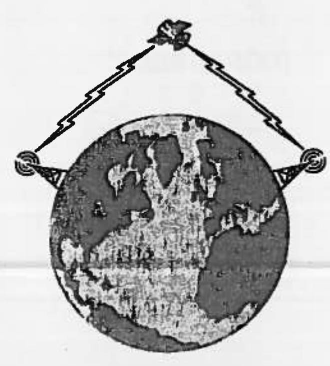


Fig. 4-11. Communication satellites relay telephone and television signals.

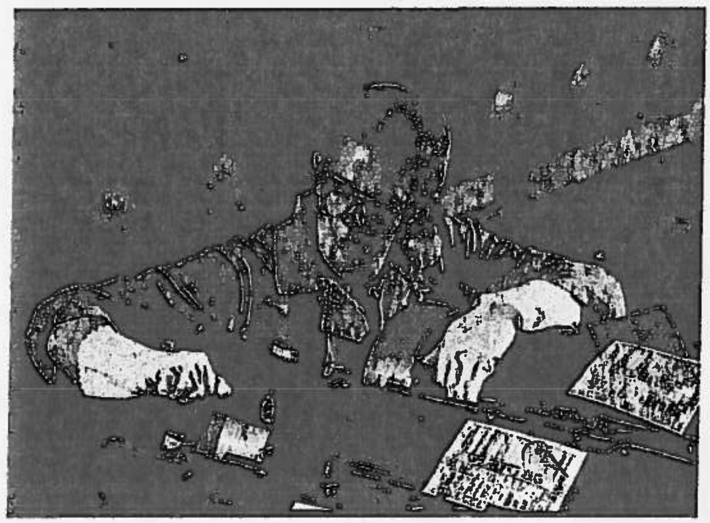
Careers

Following are descriptions of some careers that include work in the field of rockets. You'll find more detailed career information in the *Dictionary of Occupational Titles*, published by the U.S. Department of Labor.

Rocket Assembly Operator

Performs a combination of duties to produce rocket fuel and rocket motor cases.

- **Job duties: blends fuel ingredients, using a remote control panel and viewing operation on a television monitor; prepares motor case by cleaning and painting it and applying the proper insulation; fills case with propellant; adds other components to motor case; prepares assembly for stationary testing; records test instrument readings; disassembles faulty units for inspection.**
- **Education and abilities: ability to carry out instructions provided in written form and in the form of diagrams; ability to figure ratios and proportions; ability to calculate volumes; ability to use algebra and geometry to solve problems; ability to write simple reports. This career requires from 3 to 6 months of preparation.**



Rocket-Control Technician

Sets up and operates the electronic instruments used for the testing of rocket controls.

- Job duties: installs and checks testing equipment; sketches and modifies jigs, fixtures, and instruments; keeps testing equipment in good repair; directs personnel as they place the unit in the test chamber; operates the testing apparatus during the test cycle; records the results of the test; analyzes the test data, using mathematical formulas; prepares graphs and written reports; may plan the test program; may use computers and computer software to produce graphs and reports.
- Education and abilities: ability to think clearly to define problems and draw accurate conclusions; ability to use algebra, calculus, and statistics to solve complicated problems; ability to read technical and scientific journals; ability to write technical reports; this career requires from 2 to 4 years of preparation.

ACTIVITY

If you had a job in rocketry, where might you work? Find out which companies build rockets and where they are located. Mark these locations on a map. Also mark the location of major NASA sites, such as Cape Canaveral and the Marshall Space Flight Center.

Rocket-Motor Mechanic

Assembles and tests experimental solid-fuel rocket motor parts.

- Job duties: reads blueprints to determine correct sequence for parts assembly; operates metal-working machines for parts production; measures parts to check for accuracy; assembles parts into complete units; tests assembled units; confers with engineers and technical personnel to exchange information.
- Education and abilities: ability to solve practical problems; ability to interpret instructions in written form and in the form of diagrams; ability to use algebra and geometry to solve problems; ability to work with fractions, percentages, ratios, and proportions; ability to prepare written reports. This career requires from 2 to 4 years of preparation.