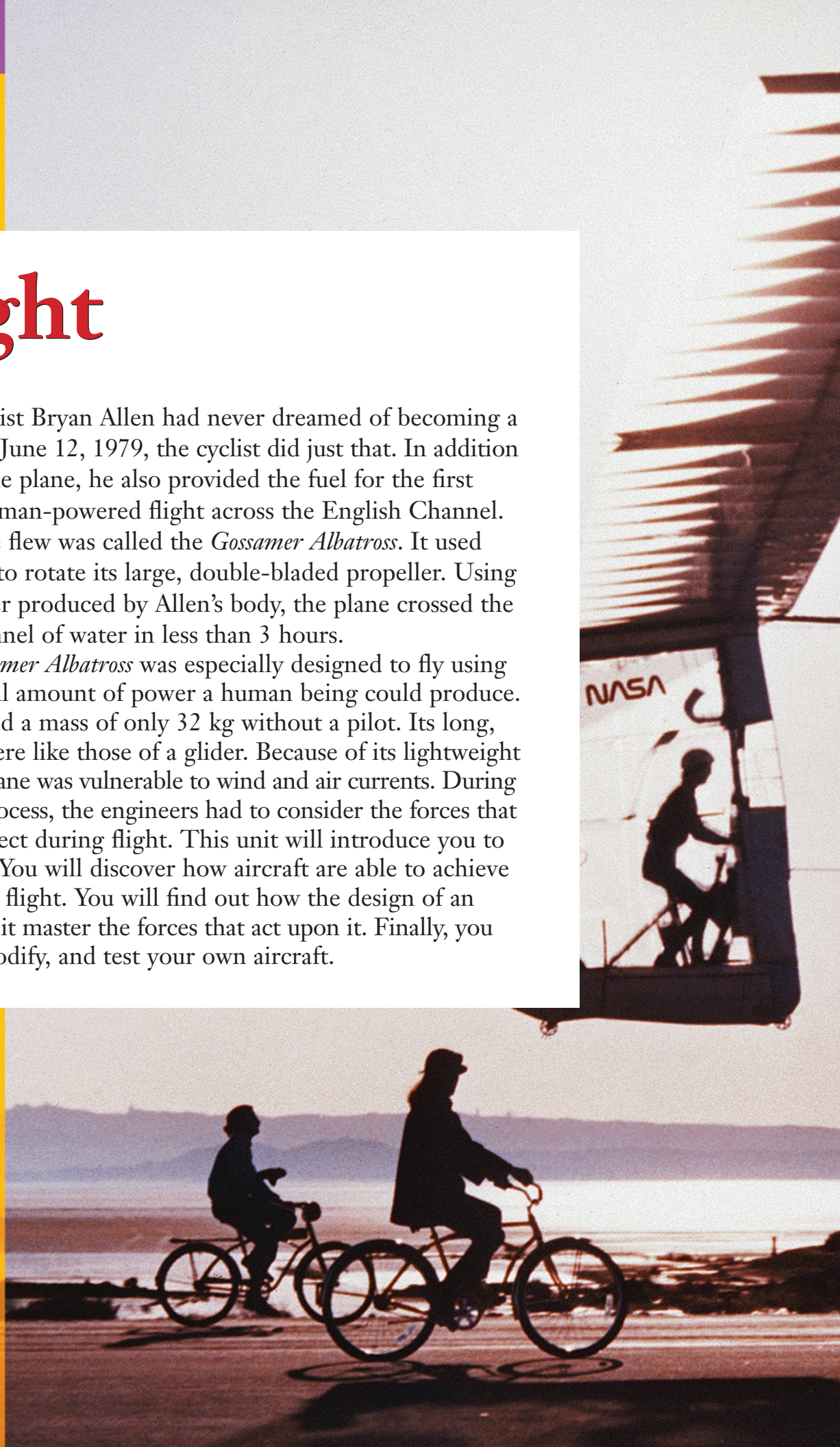
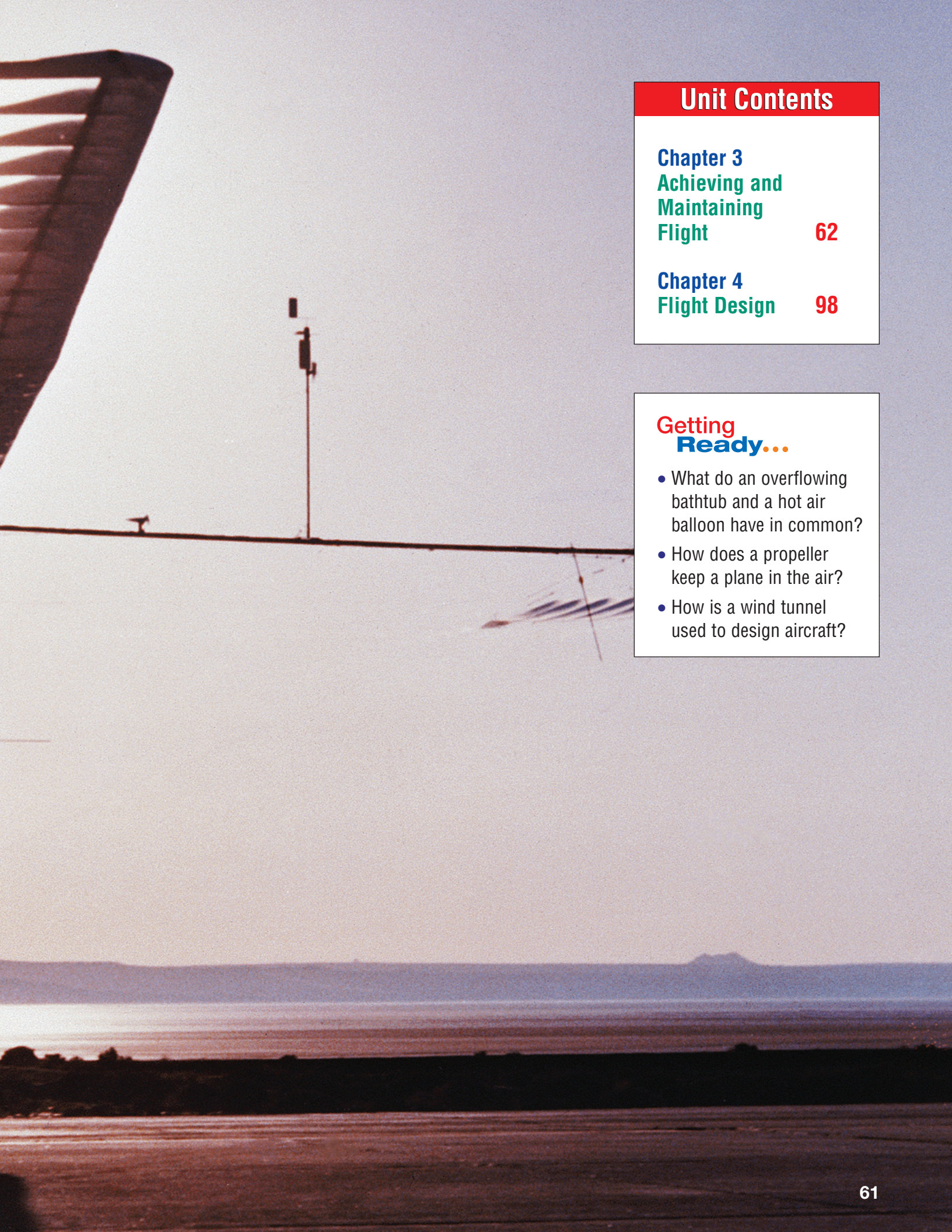
UNIT 2

Flight

Amateur cyclist Bryan Allen had never dreamed of becoming a pilot. But on June 12, 1979, the cyclist did just that. In addition to piloting the plane, he also provided the fuel for the first successful human-powered flight across the English Channel. The plane he flew was called the *Gossamer Albatross*. It used pedal power to rotate its large, double-bladed propeller. Using just the power produced by Allen's body, the plane crossed the 35.8 km channel of water in less than 3 hours.

The *Gossamer Albatross* was especially designed to fly using only the small amount of power a human being could produce. The plane had a mass of only 32 kg without a pilot. Its long, thin wings were like those of a glider. Because of its lightweight design, the plane was vulnerable to wind and air currents. During the design process, the engineers had to consider the forces that act on an object during flight. This unit will introduce you to these forces. You will discover how aircraft are able to achieve and maintain flight. You will find out how the design of an aircraft helps it master the forces that act upon it. Finally, you will build, modify, and test your own aircraft.





Unit Contents

Getting Ready...

- What do an overflowing bathtub and a hot air balloon have in common?
- How does a propeller keep a plane in the air?
- How is a wind tunnel used to design aircraft?

CHAPTER 3

Achieving and

Getting Ready...

- How does a 100 000 kg plane stay in the air?
- Why do you think a wing is curved?
- What is the difference between a jet engine and a rocket engine?

The *Bumblebee II* is the world's smallest piloted aircraft. The plane is approximately 2.7 m long and 1.7 m wide. Despite its small size, the *Bumblebee II* can achieve a top speed of over 300 km/h. It carries a single pilot.

The *Bumblebee II* is dwarfed by the *An–225 Cossack*, the world's largest plane. The *An–225 Cossack* carries only cargo and a flight crew. It is 84 m long and has a wingspan of 88 m. The plane has a mass of about 250 000 kg when it is empty and has a maximum takeoff mass of over 600 000 kg (mass of plane, cargo, and crew). It was originally built to transport the *Buran*, a space shuttle built in the former Soviet Union.

The *Bumblebee II* and the *An–225 Cossack* are two very different aircraft. They are opposites in size, yet the exact same forces act on these planes during flight. The two planes move forward by different means. The *Bumblebee II* has a propeller, while the *An–225 Cossack* uses jet engines. In this chapter, you will discover more about the forces that act on aircraft during flight. These forces are the keys to achieving liftoff and maintaining flight. You will also learn about propellers, jet engines, and rocket engines, which are three different means of propelling aircraft and spacecraft.

Maintaining Flight

What You Will Learn

In this chapter, you will learn

- which forces act on an object in flight
- how an aircraft achieves liftoff and stays airborne
- different ways aircraft are propelled through the air

Why It Is Important

- Every day, humans rely on flight for transportation, trade, defence, emergency services, and more.
- Understanding how different forces affect an object during flight can help us improve aircraft performance and efficiency.
- Many Canadians are involved in the flight industry.

Skills You Will Use

In this chapter, you will

- design a glider and modify it so it will fly further
- build a hot air balloon and a parachute
- model a principle that explains how aircraft fly
- determine how wing shape and angle influence flight

How does this propeller help a plane stay in the air?

Starting Point ACTIVITY 3–A

Paper Toss

The shape of an object can affect how it interacts with its surroundings. Complete this activity to find out if the shape of a piece of paper changes the path it follows through the air.

What to Do

1. Take an ordinary piece of paper. Hold it out in front of you and drop it. Describe how the paper moves as it falls. Pick up the paper and throw it away from you. Describe its motion.
2. Roll the paper into a cylinder. The cylinder should be tight and not reopen. Drop the cylinder and describe how it moves as it falls. Pick up the cylinder and throw it away from you. Describe its motion.
3. Crumple the paper into a small ball. Drop the ball and describe its motion as it falls. Pick up the ball and throw it away from you. Describe its motion.

What Did You Find Out?

1. How does the shape of the paper affect the way it moves through the air as it falls?
2. How does the shape of the paper affect the way it moves through the air when you throw it away from you?
3. How could you explain the differences you observed in this activity?

Section 3.1

Forces That Act During Flight: Gravity and Lift

Key Terms

buoyancy
lift
Bernoulli's principle

Have you ever wondered how a plane stays in the air? What about a hot air balloon or a dragonfly? All aircraft are subject to forces that act on an object in flight. These forces work in four directions: downward, upward, backward, and forward. They act upon all things that fly, from the smallest insect to the largest jumbo jet. In the next few pages, you will learn more about these forces and how they affect an object during flight. How do you think these forces will affect a paper glider as it flies through the air?

Figure 3.1 The same forces that act on a large passenger jet act on all objects during flight, including this dragonfly.

Find Out ACTIVITY 3–B

My Flying Machine

Build a paper glider of your own design in this activity.

What You Will Need

paper, various types and sizes
books about paper gliders

What to Do

1. Design and construct a paper glider. You can use the design books provided for inspiration. Your glider can be any shape or size. Your teacher will provide different types of paper for you to choose from.
2. As a class, brainstorm a list of ways you could compare how each glider flies. With your classmates, choose two of these factors to compare when you fly your gliders. Determine how you will measure these factors.
3. Fly your glider. Measure or observe one of the factors you chose as a class in step 2. Record your findings in your notebook.
4. Repeat step 3 for the other factor.
5. Compare your measurements or observations with your classmates.

What Did You Find Out?

1. Explain how your measurements or observations compared with those of your classmates for the two factors. How might your design have affected your glider's performance in each case?
2. Suggest two design changes you could make to your glider (such as smaller wings). How do you think the glider's performance would change if you made each design change?
3. Describe a change you could make that might make your glider fly further.

Gravity

When you flew your glider in the last activity, no matter what design you used or how hard you threw it, it still fell to the ground eventually. The force of gravity, which pulled your glider to the ground, acts on all objects. Gravitational attraction pulls all objects with mass toward each other. However, only very large objects, such as a planet or star, have a noticeable gravitational pull. This is because the force of gravity is very small.

The force of gravity acts in a downward direction. If an object is released above the ground, it will always fall downward due to Earth's gravitational pull. Gravity acts on all objects during flight. However, other forces also act on these objects. Some of these forces keep aircraft from falling. In the next activity, you will build several hot air balloons. How do they overcome the force of gravity to rise into the air? What factors might affect how high a balloon rises?

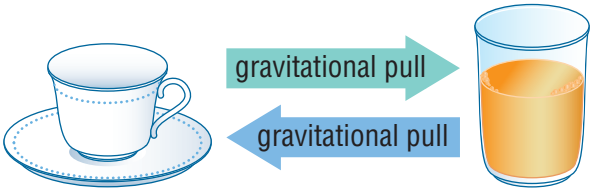


Figure 3.2 All objects that have mass are influenced by gravity. Any two objects will always attract each other with gravitational force.

Figure 3.3 Because the force of gravity is very small, only very large objects, such as our planet, have a noticeable gravitational pull.

Type of Force

- Gravity

Direction of Force

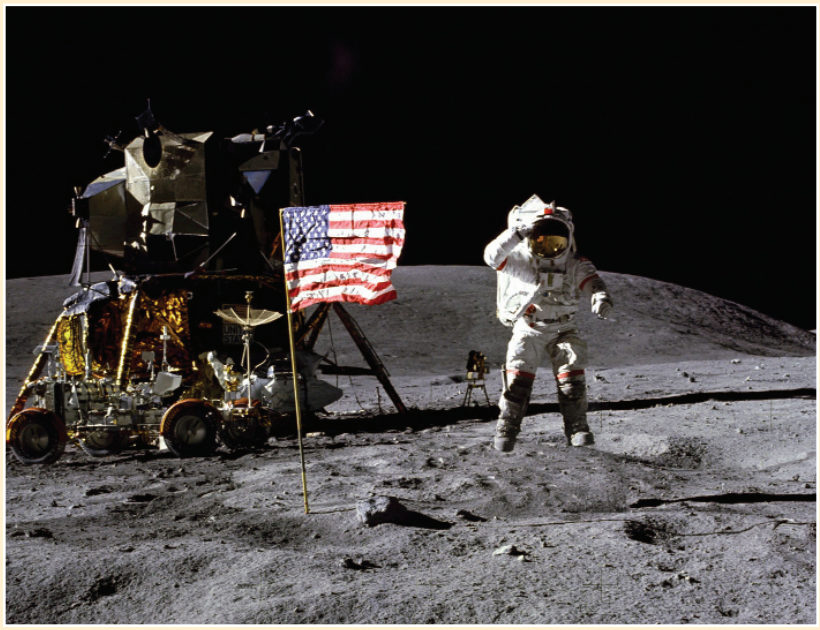
- Downward

How does it work?

- Gravitational attraction pulls all objects with mass toward each other. However, the force of gravity is small. This means that only very large objects, such as Earth, have a noticeable gravitational pull. Earth pulls all objects toward it.

Examples:

- If you toss an object in the air, it will always fall downward eventually.
- You can jump much higher on the Moon than you can on Earth. This is because the Moon has less mass than Earth. Its gravitational pull is much smaller.



Off the Wall

Have you ever let go of a helium balloon and watched it float away? Like hot air balloons, helium balloons can overcome the force of gravity and rise into the air. When you hold onto a helium balloon, your mass keeps it from floating up into the atmosphere. If enough are used, helium balloons can lift you off the ground. In 1982, a man filled 45 large weather balloons with helium. He tied them to his lawn chair and quickly became airborne. He had risen over 4800 m when passing jet planes spotted him and alerted air traffic controllers to the flight hazard. The man landed safely after deflating some of the balloons with shots from a pellet gun. He was fined $4000 for his unauthorized flight.

CONDUCT AN

INVESTIGATION 3-C

SKILLCHECK

- Observing
- Problem Solving
- Modelling
- Compare and Contrast

Build a Balloon

Humans have been sailing the skies in hot air balloons for centuries. In this investigation, you will make several hot air balloons out of different materials.

Question

What causes a hot air balloon to float in the air?

Safety Precautions

Materials

1 small plastic garbage bag
1 large plastic garbage bag
scissors
ruler
hairdryer
pencils
tissue paper
wire
glue
construction paper
balance

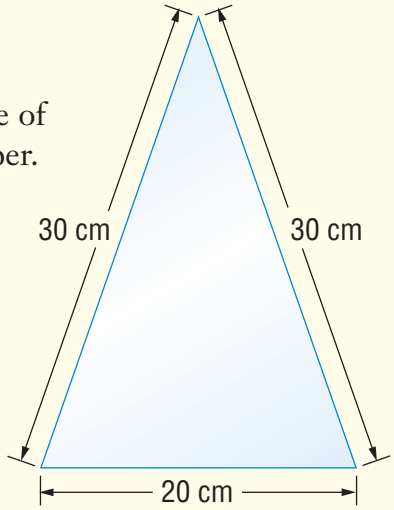
Procedure

Part 1

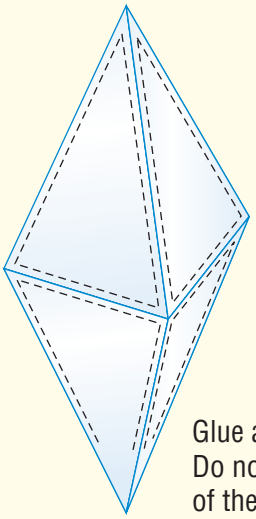
1. As a class, brainstorm a list of factors that might affect how high a balloon rises. Record this list in your notebook or science journal.
2. Working with a partner, weigh both garbage bags. Record the mass of each bag.
3. In your notebook, record the number of litres that each garbage bag can hold. You will find this value written on the packages the bags came in or your teacher may provide it.
4. Fill the small garbage bag with hot air from the hairdryer. Let go of the bag once it is of full of hot air. Estimate how high the balloon rises. Record your observations in your notebook.
5. Repeat step 4 for the large garbage bag.

Part 2

1. Draw the shape shown on a piece of construction paper.



2. Place a sheet of tissue paper over the outline. Trace the outline onto the tissue paper and cut it out.
3. Repeat step 2 seven more times. You will need to make eight sections for your balloon.
4. Glue the sections together as shown below. Leave the ends of the bottom sections unglued. Use glue sparingly, as it can increase the mass of your balloon, but make sure the seams are sealed.



Glue along dotted lines. Do not glue the bottom of the balloon closed.

5. Cut a piece of wire so that it is long enough to go around the hole at the bottom of the balloon. Form a square with the wire. Fold the paper around the wire and glue it together so that the wire stays in place.

6. Once the glue has dried, set the hair dryer to high. Place the balloon over the hairdryer nozzle and fill it with hot air.

7. Release the balloon when it is filled with hot air. Estimate how high the balloon rises. Record your observations.

8. Try flying your tissue paper balloon outside. Pick a cool day with very little wind.

Analyze

1. Compare results with other students in your class. Were they the same or different? If they were different, explain why this might be the case.

2. With your partner, review the list of factors you brainstormed with your class in Part 1, step 1. These are factors that might have affected how high each balloon rose in the air. Which of these factors do you think played the biggest role in this investigation? Explain your reasoning.

3. Draw or describe two possible design changes to your tissue paper balloon. Explain how you think each of these changes would affect the height to which the balloon could rise.

Conclude and Apply

4. Hot air balloons fly best in cold weather. Explain this statement.

5. Once a hot air balloon is up in the air, in which direction will it fly? If you took a balloon ride and wanted to go over your house, where should your launch site be?

6. Full-size hot air balloons carry heavy weights called ballast. What do you think is the purpose of ballast?

7. Commercial balloons are enormous in size. Provide a reason why bigger may be better when it comes to balloons.

Gravity is the force that pulls an object downward. When you constructed hot air balloons in the previous activity, they rose into the air. This means that there must be an upward force that, if strong enough, can overcome the force of gravity. In the case of a hot air balloon, this force is called buoyancy.

Buoyancy

Buoyancy is an upward force that is produced by a liquid or gas surrounding an object. Have you ever tried to swim to the bottom of a swimming pool? If you have, you know what buoyancy is. It is the force that pushes you up. When you enter the water, you *displace* (take the place of) water. The surrounding water exerts the same amount of upward force on you that it had exerted on the water that you displaced. This is the force of buoyancy. If the force of buoyancy is greater than that of gravity, you will rise toward the surface. If the force of gravity acting upon you is more than the force of buoyancy, you will sink. A hot air balloon works in a similar way.

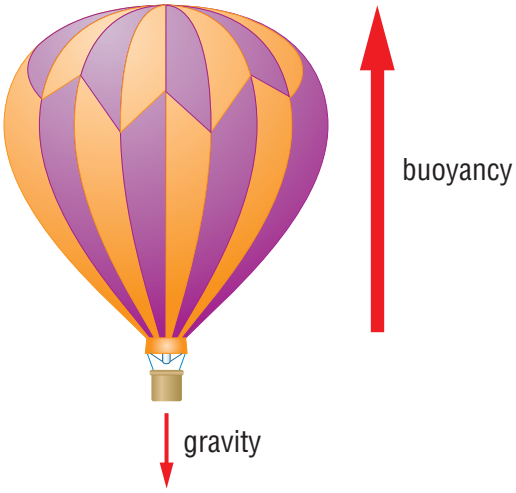


Figure 3.4 If the force of gravity acting upon a balloon is less than the force of buoyancy, the balloon will float.

Figure 3.5 You displace water when you sit down in a bathtub filled with water. If the tub is too full, the water will run over.

Both buoyancy and gravity act on a hot air balloon. Instead of being immersed in water, a balloon is surrounded by air. Both liquids and gases produce buoyancy. When the air in a hot air balloon is heated, several things happen.

- First, the air particles in the balloon gain energy when they are heated. They move around and bump into each other. As they collide, the particles move apart and the air expands, taking up more room. It displaces the air that was there before. The surrounding air exerts the same pressure on the balloon that it had exerted on the air that was displaced. Since the balloon is lighter than the air it displaced, this pressure causes the balloon to rise.
- Second, as the balloon rises, its altitude increases. As altitude increases, air pressure decreases. As a result, there is less pressure acting on the balloon. The balloon eventually stops rising.

READING Check

Use the term buoyancy to explain how a balloon rises.

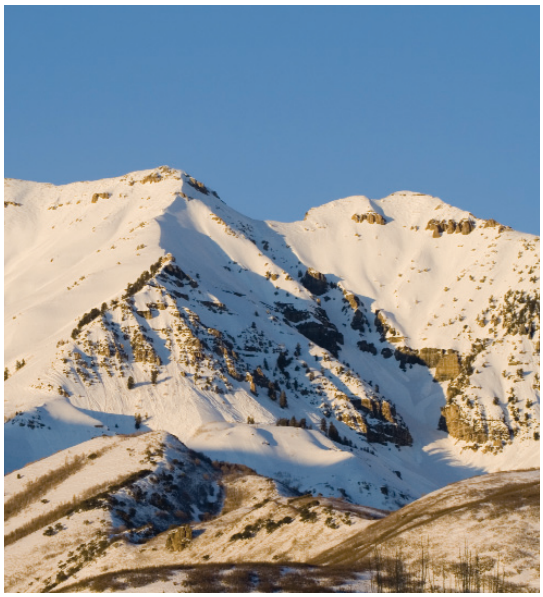


Figure 3.6 Air pressure decreases as altitude increases.

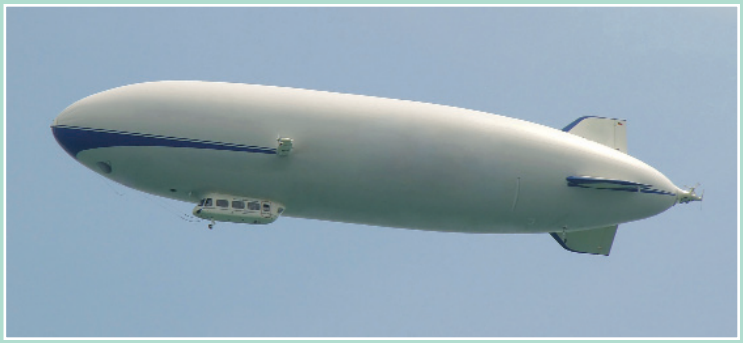
Figure 3.7 Ballooning is a balancing act. A balloon continues to rise until the forces of gravity and buoyancy acting on the balloon are equal.

Type of Force

- Buoyancy

Direction of Force

- Upward



How does it work?

- A liquid or gas is displaced by an object, such as a body in water or a hot air balloon in air. The surrounding liquid or gas exerts the same pressure on the object that it had exerted on the displaced liquid or gas. If the object is lighter than the liquid or gas that it displaced, the pressure will create an upward force. If this force (buoyancy) is greater than that of gravity, the object rises.

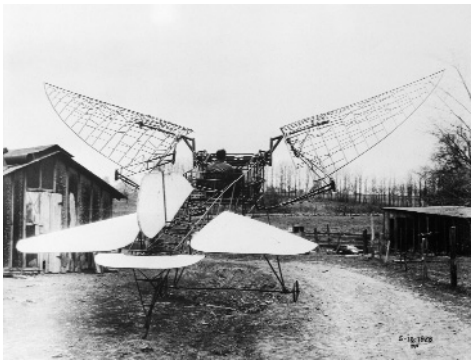
Examples:

- The hot air in a balloon displaces the cooler, heavier air around it. The surrounding air exerts the same pressure on the balloon that it had exerted on the displaced air. Because the balloon is lighter than the air it displaced, the pressure causes it to rise.
- A blimp is essentially a balloon filled with a gas that is lighter than air. The force of buoyancy is greater than the force of gravity, and the blimp rises.

The hot air in a balloon is lighter than the cooler air outside the balloon. For this reason, a balloon is called a lighter-than-air aircraft. What about aircraft that are heavier-than-air, such as gliders, planes, helicopters, rockets, and even living things? How do these aircraft take off and stay airborne? How do they overcome the force of gravity?

Off the Wall

Not all would-be aircraft are able to take off and stay airborne. Many of the earliest aircraft designers unsuccessfully tried to mimic the flight of birds. These flying machines, known as ornithopters, flapped their wings to fly. Large ornithopters, such as the one shown below, cannot stay in the air for long. However, that does not keep people from building them. In 2006, a team from the University of Toronto launched one from a jet. It made a 14-second flight before falling to the ground!



DESIGN YOUR OWN

INVESTIGATION 3-D

SKILLCHECK

- Identify the Problem
- Decide on Design Criteria
- Plan and Construct
- Evaluate and Communicate

Winged Vehicles

Challenge

Working as a group, use the materials provided to design and construct a winged vehicle that will become airborne when rolled down a ramp. Test and modify your vehicle to determine which design will propel it furthest through the air.

Safety Precautions

Materials

vinyl rain gutter
K'nex™ kit that contains wheels
ticket board
masking tape
plastic straws
stiff paper, such as manila paper or a used file folder
photocopy or printer paper
measuring tape
scissors

Design Criteria

A. You may use only the materials provided to construct your winged vehicle.

B. You may not push or propel your vehicle in any way when you release it to roll down the ramp.

C. You may modify your design up to three times to achieve the furthest flight distance.

Plan and Construct

1. With your group, plan how you will design your winged vehicle.
2. After you have determined your design, work together to construct your vehicle. Use the rain gutter to set up your ramp.
3. Create a data table to record how far your vehicle flies.
4. Test your vehicle several times by letting it roll down the ramp. Measure and record the distance it flew in each case.
5. Modify your design to try to achieve a greater flight distance. Test your design several times after each modification. Measure and record the distance travelled.

Evaluate

1. Describe some of the variables that influenced how far your vehicle flew.
2. What role did the wheels play in the movement of your vehicle?
3. What role did gravity play in the movement of your vehicle?
4. Explain why you think your vehicle became (or did not become) airborne.

Lift

In the last activity, you modified a winged vehicle to determine which design would enable it to become airborne and carry it the furthest distance. By modifying your design, you increased the upward force experienced by the aircraft. The force that acts upward on an aircraft, helping it become and remain airborne, is called **lift**.

Like gravity, lift acts on all objects during flight, even a passenger jet that has a mass of over 100 000 kg. You may wonder how a heavy airplane can fly without being pulled down by gravity. If you look at the wings of just about any airplane, you will notice that they are not flat. While wings come in a variety of shapes, most planes have wings that are somewhat curved.

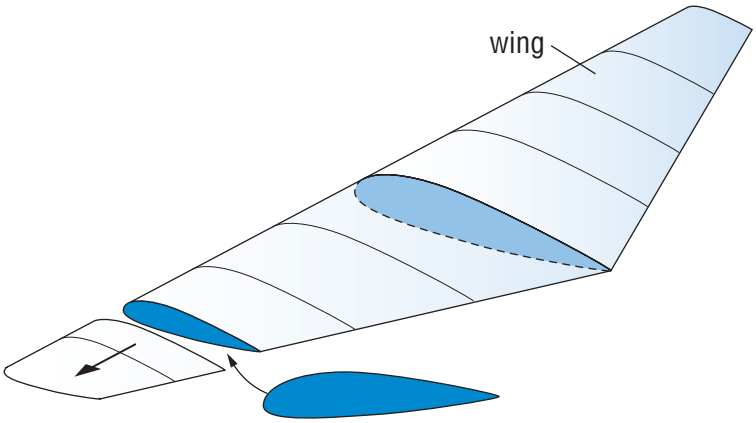


Figure 3.8 Wings come in a variety of shapes and sizes. However, most planes have curved wings like the one shown.

DidYouKnow?

A large passenger jet such as a Boeing 747 must attain a speed of 290 km/h to achieve liftoff. The commercial airliner has a mass of over 360 000 kg.

Bernoulli's Principle

As an airplane flies, air travels over and under its wings. Because the wings are curved, air that passes over the wing travels further than the air that passes under the wing. However, the air passing over the wing reaches the back of the wing at the same time as the air passing under it. This means it has to travel faster. It must cover a greater distance in the same amount of time. You can compare this to taking a detour to get to a destination. The detour means you have to travel a greater distance. To get to your destination in the same amount of time as the direct route took, you need to travel faster.

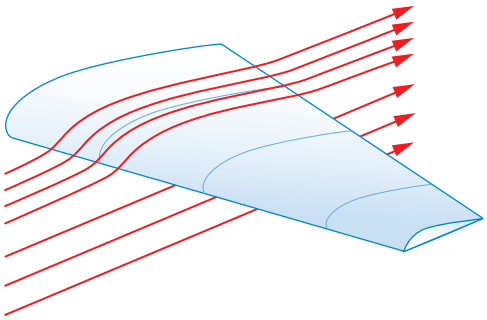


Figure 3.9 An airplane's wings are rounded. This means that the air passing over the wing travels faster than the air passing under it.

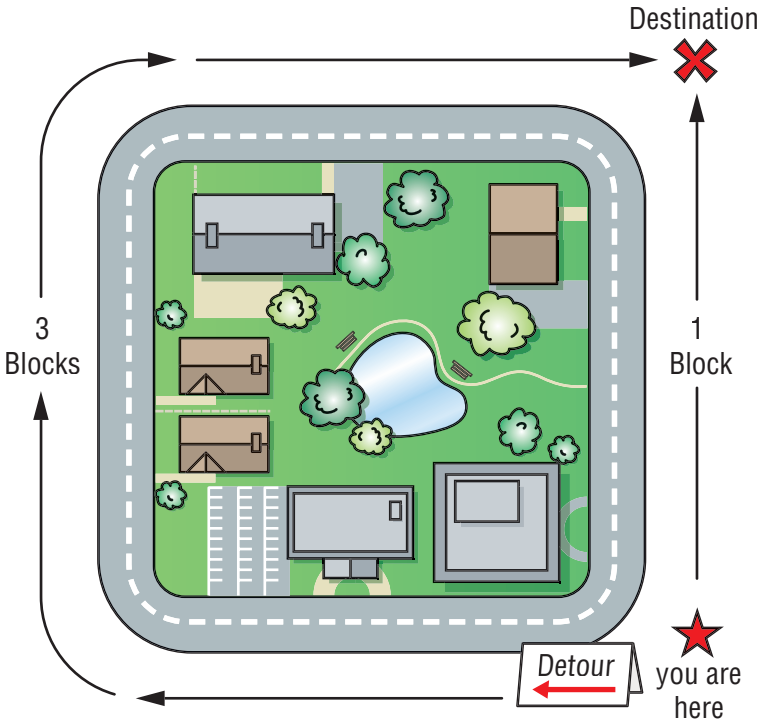


Figure 3.10 When you take a detour, you have to travel a greater distance to get to your destination. If you want to make it there in the same amount of time, you need to travel faster. When air travels around the curve of a wing, it travels further. It must therefore travel faster to reach the back of the wing at the same time as the air travelling under the wing.

Figure 3.11 Daniel Bernoulli explained lift long before the first airplane left the ground.

In the 1700s, a Swiss mathematician named Daniel Bernoulli showed that a liquid or gas creates less pressure as its speed increases. This principle is called **Bernoulli's principle**. In the case of an airplane, air moves faster as it travels over the wing. This causes the air pressure above the wing to fall. As a result, the wing is pushed upward by the higher-pressure air flowing underneath it. The end result is that the wing is lifted up. In the next activity, you will design an investigation that will demonstrate Bernoulli's principle.

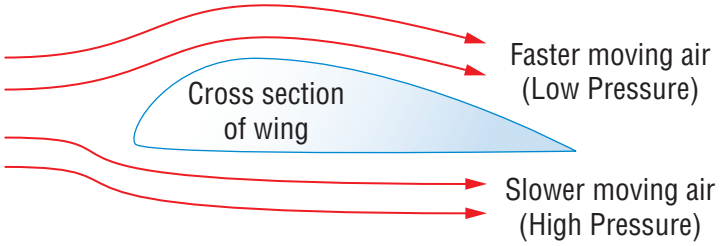


Figure 3.12 Air moves faster as it travels over a curved wing. Bernoulli's principle explains that air creates less pressure as its speed increases. The pressure above the wing falls, and the wing is pushed upward by the higher-pressure air flowing underneath it. The wing is lifted up as a result.

READING Check

How does Bernoulli's principle explain lift?

Table 3.1 Understanding Bernoulli's Principle and Lift

Part of Wing	Shape	Air Speed	Pressure	Wing Action
top	curved	faster	lower	pushed up
bottom	flat	slower	higher	

Type of Force

- Lift

Direction of Force

- Upward

Examples:

- An owl's wing has a curved shape. Air travels faster over the top of the wing, creating a pressure difference that lifts the wing.
- A Boeing 747 is hundreds of thousands of times heavier than an owl. However, it experiences the same lift as a bird does.

How does it work?

- Because wings are curved, air passes over a wing more quickly than air passes under it. A liquid or gas creates less pressure as its speed increases. The air pressure above the wing falls. The higher-pressure air flowing underneath the wing pushes it upward. As a result, the wing is lifted up.

Find Out ACTIVITY 3–E

Demonstrate Bernoulli's Principle

Bernoulli's principle explains how a wing generates lift. If you were Daniel Bernoulli, could you demonstrate your principle to other scientists?

What You Will Need

materials for your demonstration, different for each group
activity handout

What to Do

1. Review the activity handout provided by your teacher. You will be performing this activity to demonstrate Bernoulli's principle to your classmates. With your group, discuss how you will carry out your demonstration.
2. As a group, gather the materials you need to complete your demonstration. Set up your demonstration. Practise it before you present it to your class.
3. Assign one group member as recorder. As a group, determine how your activity demonstrates Bernoulli's principle. Have the recorder write down your ideas. Review the ideas to make sure all group members agree on them.
4. Present your demonstration to your class. Have the recorder explain how your activity demonstrates Bernoulli's principle.

What Did You Find Out?

1. How could you modify your demonstration to improve it? Explain your reasoning.
2. Describe the demonstrations presented by other groups. How does each demonstration illustrate Bernoulli's principle?

Section 3.1 Summary

The forces that act on an object during flight work in four directions: downward, upward, backward, and forward. These forces act on both flying organisms and machines.

- Gravitational attraction pulls all objects with mass toward each other. Only very large objects, such as a planet or star, have a noticeable gravitational pull. This is because the force of gravity is very small. Earth's gravitational pull pulls objects downward.
- Buoyancy is an upward force that is produced when an object displaces a liquid or gas. A hot air balloon or blimp floats when its buoyancy is greater than the force of gravity acting on it.
- The upward force that acts on an object in flight is called lift. Bernoulli's principle explains lift. This principle states that a moving liquid or gas creates less pressure as its speed increases.

Key Terms

buoyancy
lift
Bernoulli's principle

Check Your Understanding

1. Use the term buoyancy to explain why a hot air balloon rises.
2. A robin breaks its wing. When it heals, the wing is no longer curved. Do you think the songbird is still able to fly? Explain your reasoning.
3. The *An–225 Cossack* has a mass of about 250 000 kg when it is empty. How does such a heavy plane achieve liftoff and remain airborne?
4. Draw and label an example of a situation that demonstrates Bernoulli's principle.
5. Gravitational attraction pulls all objects with mass toward each other. The Sun has a mass that is much greater than Earth. Explain why an aircraft is pulled toward Earth and not the Sun during its flight.

Section 3.2 Forces That Act During Flight: Drag and Thrust

In Section 3.1, you learned about the forces that act upward and downward on objects during flight—gravity, buoyancy, and lift. The other forces that act on aircraft act in a forward and backward direction. The force that acts backward on an object during flight can cause it to slow down and even fall to the ground. Aeronautical engineers create aircraft designs that reduce this force as much as possible. How might this force act upon a paper glider? How could you reduce the effect this force has on a glider?

Key Terms

drag
thrust

Find Out ACTIVITY 3–F

My Flying Machine: Flying Further

How can you reduce the backward force that acts on a glider during flight? In this activity, you will create paper gliders of different materials and sizes to learn the answer to this question.

What You Will Need

paper of various thicknesses and smoothness
measuring tape
glider instructions

What to Do

1. With a partner, construct a paper glider using the instructions provided. You can choose any type of paper and make your glider any size.
2. Throw the glider. One partner will throw the glider, and the other will measure and record how far the glider flew.
3. Repeat two more trials. Calculate the average distance the glider travelled for all three trials.
4. Evaluate your glider's performance. How could you reduce the backward force experienced by the glider? Brainstorm a list of possible modifications with your partner. You may modify your design in any way or construct your glider from a different material.
5. Repeat steps 2 and 3. Make sure the same partner throws the plane.

What Did You Find Out?

1. How did you modify your glider? Were you able to decrease the backward force on the glider? Explain.
2. How did you determine whether the backward force had been reduced?
3. Explain why you completed three trials for each glider design.
4. Suggest one way you might change the design of your glider to make it more stable (meaning it wobbles less or flies for a longer period of time). Explain your reasoning.

CONDUCT AN

INVESTIGATION 3-G

SKILLCHECK

- Observing
- Modelling
- Plan and Construct
- Compare and Contrast

Design a Parachute

Sometimes we want to increase the backward force experienced by an object during flight. In this investigation, you will design your own parachute and see if you can reduce the speed at which an object falls.

Question

Do different parachutes make an object fall at different speeds?

Safety Precautions

Materials

construction paper
cloth
string
glue
masking tape
scissors
timer
tissue paper
plastic
paperclips
small weight
stapler
tape measure

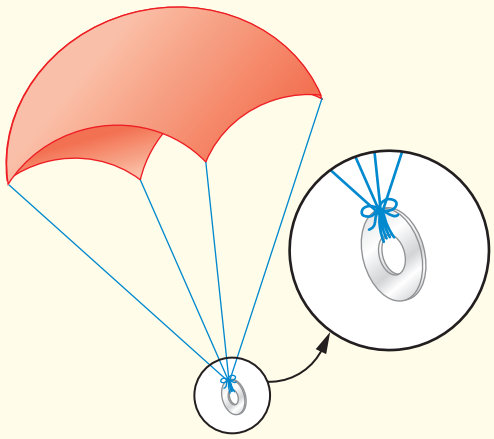
Procedure

1. As a class, brainstorm a list of factors that might increase the amount of backward force acting on a parachute. Record these ideas in your notebook.
2. Your teacher will demonstrate how long it takes a weighted object to fall to the ground from a certain height. In your notebook, record the height the object fell from and the time it took to fall. You will be dropping your parachute from the same height, using the same weight.
3. On a wall, measure the height from which you will be dropping your parachute. Mark the height with masking tape.
4. Copy the table provided below into your notebook.

Parachute Trials: Design #1

	Trial 1	Trial 2	Trial 3
Time object took to fall with parachute (seconds)			

5. Working with a partner, design a parachute on paper. Use the list you helped brainstorm in step 1 to help you create your design. What shape and size will the canopy (the part of a parachute that holds air) be? What material will you use? You will be attaching a weighted object to the bottom of your parachute with strings. How long will the strings be? How many will you use? Draw an illustration of your parachute. Record the materials you will use and the measurements of your parachute next to your drawing.
6. Make your parachute according to your design. Attach strings to the canopy of your parachute. Tie the weighted object to the ends of the strings as shown below.



7. Drop the parachute and weight from the height you marked earlier. Time how long it takes to fall to the ground. Record your results in your table.
8. Complete two more trials.
9. Design and build at least two more parachutes. Try to improve your original design to make the weight fall more slowly. Draw an illustration of each parachute. Record the materials you used and the measurements of your parachutes.
10. Draw two more tables like the one you drew in step 4 for your second and third designs.
11. Complete three trials for each new design.
12. If there is an opportunity to do so, take your best parachute and carefully roll it up so that you can throw it. Go outside and throw it as high as you can. See if you can get it to unroll and come down like a real parachute.

Analyze

1. Did the object fall at a different speed when you attached it to a parachute? Explain why you think this happened.
2. How did you try to improve on your original design for your second and third parachutes? Were you successful? Explain.
3. Which of your parachute designs took the longest to reach the ground? Explain why you think this design was the most effective.
4. Identify the controlled, independent, and dependent variables in this investigation.

Conclude and Apply

5. How do you think each of the following design changes would affect the amount of time it takes a parachute to fall to the ground?
   (a) increasing the mass of the object tied to the parachute
   (b) increasing the mass of the material used for the canopy
   (c) decreasing the size of the canopy
   (d) adding a hole to the top of the canopy

DidYouKnow?

Drag only occurs when a solid object passes through a liquid or gas. If an object moves through a vacuum, there is no drag. Would a satellite travelling through space experience drag?

INTERNET CONNECT

www.mcgrawhill.ca/links/ns+science6

Cars also experience drag. Vehicles designed from the 1930s through the 1960s were not very aerodynamic. They did not need to be. Their powerful engines overcame the effects of drag. After the 1970s, fuel became more expensive. The automobile industry responded by using technology to reduce the amount of drag that cars experienced. This meant they could go faster but still burn less fuel. Today, concern about energy use, cost, and the environment still pushes designers to make more aerodynamic cars. Go to the above web site and click on **Web Links** to find out where to go next.

Drag

The force that acts backward on an object in flight is called **drag**. Drag slows down a solid object as it moves through a liquid or gas. The liquid or gas particles must be pushed out of the way or pulled along with the object, causing it to slow down. As the speed of an object increases, so does drag. When drag occurs in the air, it is sometimes called *air resistance*. An aircraft experiencing a lot of drag will not fly as fast as an aircraft experiencing less drag. If drag is too great, the aircraft will stop moving forward and will fall to the ground.

When you tested your glider in Activity 3-F, what factors influenced the distance your aircraft travelled? You may have found that the shape and texture of an object affects drag. An object that has a smooth texture and a streamlined shape experiences less drag. Such an object is described as being *aerodynamic*. Airplanes and helicopters are designed to reduce drag. Long, thin wings experience less drag. Similarly, the surface of a plane is smooth, and its design is streamlined.

Type of Force

- Drag

Direction of Force

- Backward

How does it work?

- Liquid or gas particles must be pushed out of the way or pulled along with the object, causing it to slow down.

Examples:

- A fighter jet is streamlined so that it can fly at high speeds with minimal drag.
- A falcon like the one shown here forms a bullet-like shape as it dives after its prey. This shape reduces drag at high speeds.

Sometimes we design things to increase drag, rather than to reduce it. We do this when we want objects to fall more slowly. When you designed a parachute earlier, you were able to reduce the speed at which an object falls. The canopy of a parachute provides a large surface area. It is not streamlined, so it increases drag, slowing its fall so that the object or person it is carrying lands safely. Some parachute designs do more than increase drag. They have wing-like properties that allow skydivers to control where they land (see Figure 3.14).

Aircraft need to generate a forward force that overcomes the backward force of drag if they want to become and stay airborne. Living things such as birds, insects, and other flying and gliding organisms also need to generate this force. What force opposes the force of drag? How do living things create enough forward force to overcome drag?

Figure 3.13 A parachute is designed to increase drag. This allows things to fall slowly.

Figure 3.14 Modern parachutes have wing-like properties that allow skydivers to land on very specific targets.

THINK & LINK

INVESTIGATION 3-H

SKILLCHECK

- Observing
- Compare and Contrast
- Plan and Design
- Communicate

Two Flying Organisms

Think About It

Many different organisms are able to fly or glide through the air. This includes birds, insects, mammals, reptiles, fish, and amphibians. In this investigation, you will compare the movements of two different organisms as they fly or glide.

What to Do

1. Read the handout your teacher has provided about different organisms that fly or glide.
2. In your group, choose two organisms that fly or glide that you would like to compare. Use your own observations and the information in the handout to compare the movements of these organisms when they fly or glide.
3. Create a list of the ways the organisms move differently during flight. Create another list of the similarities in the ways they move.
4. Describe any unique structures and traits that enable your organisms to fly or glide.
5. As a group, create a poster, comic, video, poem, dance, or other creative display that compares the movement of the two organisms. Be sure to refer to the unique structures and traits that enable your organisms to fly or glide.

Analyze

1. Are your organisms' movements during flight more similar than different? Or is the reverse true? Explain.

Thrust

As you saw in the last activity, living things use different means to generate a forward force to overcome drag. This force is known as thrust. **Thrust** pushes a flying machine or organism forward during flight.

Wings get their lift when air flows around them. However, the air must be set in motion for this to happen. This means that an airplane must be moving forward in order to experience lift. It must have thrust to become airborne. In order to stay aloft, a plane must experience more thrust than drag. Without thrust, an aircraft cannot remain in the air. It will crash to the ground. Propellers, jet engines, rocket engines, wing muscles, and even gravity can generate thrust.

In the next section, you will learn more about the different ways aircraft generate thrust. You will explore how advances in technology have helped humans generate enough thrust to not only fly through the air but also into space.

Figure 3.15 How does this bat (A) generate thrust? How about this plane (B)?

Type of Force

- Thrust

Direction of Force

- Forward

How does it work?

- A force is generated by wings, propellers, or other means. This force overcomes drag and moves the object forward through the air.

Examples:

- A bee flaps its wings about 190 times per second to generate the thrust it needs to take off and fly forward.
- A rocket uses its powerful engines to create the thrust it needs to escape Earth's gravitational pull and enter orbit.

READING Check

Why must thrust be greater than drag for an aircraft to stay in the air?

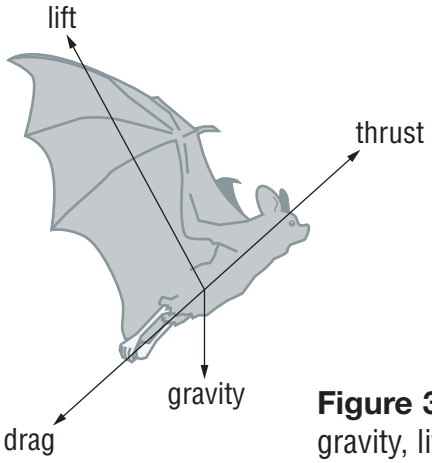


Figure 3.16 A wing experiences the forces of gravity, lift, thrust, and drag while in flight.

Table 3.2 Comparing the Forces That Act During Flight

Force	Direction	How It Works
gravity	downward	• Earth pulls all objects downward. • Only very large objects, such as Earth, have a noticeable gravitational pull.
buoyancy	upward	• An object displaces a liquid or gas (for example, a hot air balloon displaces air). • The surrounding liquid or gas exerts the same pressure on the object that it had on the liquid or gas that was displaced. If the object is lighter than the liguid or gas it displaced, the pressure will cause it to rise.
lift	upward	• Wings are curved. • Air passes over a curved wing more quickly than under it, as it must travel further. • Air pressure decreases as air speed increases. • Higher-pressure air flowing under the wing pushes it upward. • The wing is lifted up.
drag	backward	• Liquid or gas particles must be pushed out of the way or pulled along with the object, causing it to slow down. • As the speed of an object increases, so does drag.
thrust	forward	• Force is generated by wings, propellers, or other means. • If the force overcomes drag, the plane moves forward through the air.

Section 3.2 Summary

Forces also act on aircraft in a forward and backward direction during flight.

- Drag slows an organism or aircraft down during flight. A streamlined aircraft experiences reduced drag. A parachute is designed to increase drag, allowing a person or object to fall more slowly.
- Thrust pushes an aircraft forward. Thrust must be greater than drag or an aircraft will not remain in the air.

Check Your Understanding

1. Give an example of an aircraft that is designed to increase drag. How does increased drag help it perform its function?
2. Describe the difference between air resistance and drag.
3. Name three means of generating thrust.
4. Some cars and planes are designed to be very aerodynamic. Use the term "drag" to explain this statement.

Key Terms

drag

thrust

Section 3.3 Powered Flight

Key Terms

propeller
propulsion
jet engine
rocket engine

Many aircraft appear to fly without power. However, these crafts are actually gliders. Gliders, such as glider planes, hang gliders, and even paper gliders, take off or are released from a height. They "fly" until the force of gravity pulls them down to Earth. Their flight is not sustained over time. In order to generate the thrust required to maintain sustained flight, aircraft must be powered in some way. They must generate continual thrust. Organisms such as birds, bats, and insects use their wing muscles to generate thrust. However, human chest muscles are too weak to generate the type of power these creatures use to fly. Instead, we have to rely on technology. There are three ways that mechanical aircraft generate thrust. These are the propeller, the jet engine, and the rocket engine.

Propellers

Helicopters, as well as many planes, use propellers to gain and maintain lift. How does a propeller work? A **propeller** is made up of two or more twisted blades. An engine makes these blades turn like a pair of spinning wings. The tips of the propeller blades spin faster than the centre of the propeller. This creates an air pressure difference. It is very similar to the pressure difference that occurs between the top and bottom side of a wing in flight. As described by Bernoulli's principle, a force is generated. But unlike a wing in flight, where the wing lifts upward, this force pushes air backward. Air rushes toward the rear of the aircraft.

DidYouKnow?

A helicopter propeller is called a *rotor*. The blades of a rotor are long and thin. The lift they provide not only lifts the helicopter, but it also provides the thrust the helicopter needs to travel forward. To move horizontally, the pilot simply tilts the rotor slightly forward, causing the air to be pushed toward the rear of the aircraft.

Figure 3.17 A propeller is made up of two or more twisted blades.

Find Out ACTIVITY 3–I

Build a Helicopter

In this activity, you will make an aircraft that uses a propeller to generate thrust.

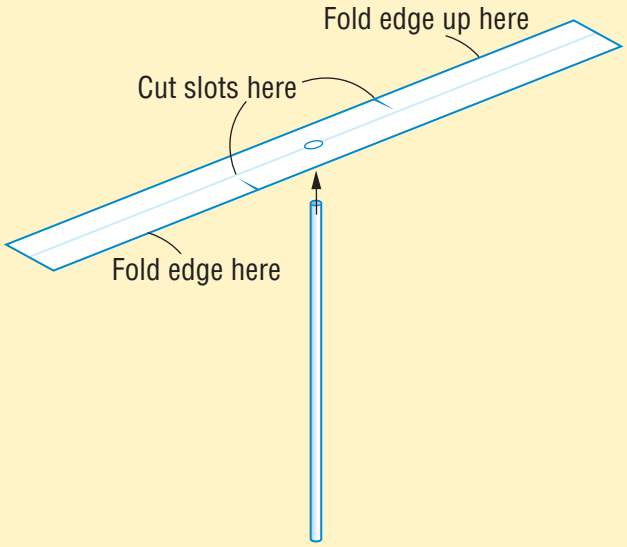
Safety Precautions

What You Will Need

straw or wooden dowel
scissors
ruler
pencil
stiff paper, such as a used file folder or manila paper

What to Do

1. Cut a 4 cm by 20 cm piece of stiff paper.
2. Draw a line that runs width-wise across the centre of the paper. This line should be 10 cm from each edge.
3. Cut slots as shown in the diagram. Each slot should be 2 cm long and 3 cm from the centre line you just created. Fold the edges of the paper upward as shown. This will become the helicopter's propeller.
4. Poke a hole in the centre of the paper. Make the hole slightly smaller than the diameter of a straw.
5. Push the straw through the paper as shown.



6. To fly the helicopter, place it between your hands and tilt the propeller slightly down and away from you. Push one hand forward at the same time as you pull the other hand backward. Be sure the folded edge is moving forward.
7. See if you can modify your propeller so that it will fly better. Describe your modifications in your notebook. Test your modified helicopter, and record your observations.

What Did You Find Out?

1. Describe how your helicopter moved when you released it.
2. Based on your observations, what is the best size and shape for the propeller in this activity?

Off the Wall

Propellers were used in ships long before they played a role in flight. The first propellers were not very efficient. Surprisingly, propellers used to be shaped a lot like screws. Then one day, the tip of a pointed propeller broke off in the water. Amazingly, the boat travelled much more quickly with the broken propeller. Since then, propellers have been designed with a flat front.

Why do you think a plane moves forward when air moves toward the rear of the plane? When a particle pushes against another particle, the second particle will react by applying the same force back. When air is forced backward, away from the propeller, it strikes other air particles. These air particles apply a force back. This force is thrust. It is exactly as strong as the force of the air that was pushed backward by the propeller. Thrust results in the **propulsion**, or forward motion, of the plane. The amount of thrust and propulsion a propeller creates depends on the angle of the blades and how quickly they spin.

Aircraft also use jet engines as a means of propulsion. How does a jet engine work? Can you create a model of a jet engine and show how it generates thrust?

Figure 3.18 Many planes, such as this Canadian-designed de Havilland Buffalo, use propellers.

Type of Propulsion

- Propeller

How does it work?

- The tips of the propeller blades spin faster than the centre of the propeller. This creates an air pressure difference. As explained by Bernoulli's principle, a force is generated and air is pushed backward. The air strikes other air particles, which apply a force back, resulting in the forward motion of the plane.

Examples:

- A propeller plane uses one or more propellers to generate thrust to move it forward.
- A helicopter uses a propeller to generate both lift and thrust.

Find Out ACTIVITY 3–J

Balloon Jets

You can observe the force that propels a jet plane by making your own jet with a balloon.

What You Will Need

balloons of different sizes
drinking straw
masking tape
5 m length of string

What to Do

1. Thread the string through the straw.
2. Tie each end of the string to a sturdy post about 2 m above the ground. Make sure the string is tight and level.
3. Blow up the balloon. Ask a partner to tape the balloon to the straw while you hold the mouth of the balloon shut.
4. Keep squeezing the balloon end while you pull your balloon rocket to one end of the string.
5. Release the balloon.
6. Blow up the balloon again. Stop when it is half filled with air. Repeat the activity.
7. Repeat the activity with different-sized balloons.

What Did You Find Out?

1. Explain why the balloon moved when you released the air.
2. What affects the speed at which the balloon travels?

Jet Engines

A **jet engine** uses expanding gases to propel a plane. A fan at the front of the engine pulls in large volumes of air. Some of this air goes into a compressor, which increases the air's temperature and pressure. The hot, high-pressure air is mixed with fuel. The mixture is then ignited. The gases expand and shoot from the back of the engine. This causes the plane to move forward.

Why do you think the plane moves forward when gas shoots out the back of the engine? The same reason the balloons shot forward when you released air from them in the previous activity. When air shoots out of the back of a jet engine, it strikes other air particles. These air particles apply a force back. This force is exactly as strong as the force released by the jet engine. It causes the plane to shoot forward. This is very similar to the way a plane moves forward when a propeller pushes air toward the rear of a plane.

READING Check

How does a jet engine work?

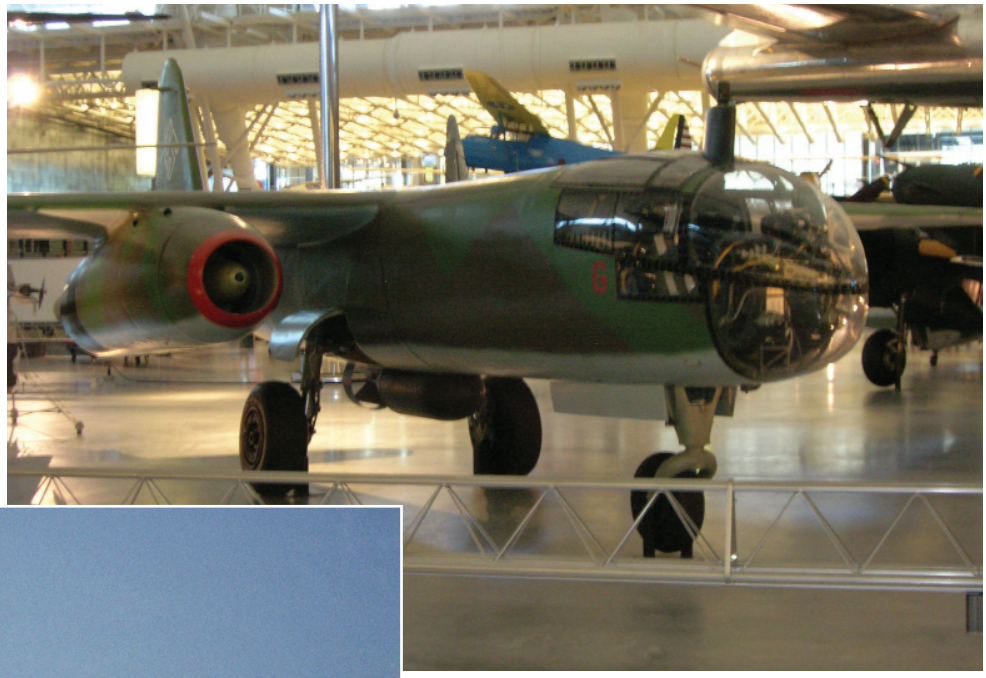


Figure 3.19 A World War II jet bomber. Notice the air intakes at the front of the jet engines.

Figure 3.20 The Concorde is a passenger jet that can fly faster than the speed of sound. However, due to high operational costs, the plane has been grounded.

Type of Propulsion

- Jet engine

How does it work?

- A fan at the front of the engine pulls in large volumes of air. Some of this air goes into a compressor, which increases the air's temperature and pressure. The hot, high-pressure air is mixed with fuel, and the mixture is ignited. The gases expand and shoot from the back of the engine, propelling the plane forward.

Examples:

- The *SR-71 Blackbird* can fly at three times the speed of sound. This jet-propelled aircraft is the fastest in the world.
- The *Airbus A380*, shown below, is the largest passenger jet in the world. It uses jet engines to transport up to 840 people per flight.

Rocket Engines

Jet engines allow humans to travel through the atmosphere at great speeds. Sometimes these speeds are even greater than the speed of sound. However, jet engines cannot travel into space. Their use is limited because they use air to generate propulsion. This is where **rocket engines** fill an important role.

Rocket propulsion is similar to jet propulsion in that expanding gases are responsible for thrust. However, rocket engines are designed differently from jet engines. Jet engines take in and compress air. The gases shoot out of the rear of the engine, and the plane moves forward. There is no air in space. This limits the height at which a jet can fly.

Rocket engines work in the atmosphere too. But unlike jet engines, they also work in space. Rocket engines are

Figure 3.21 A rocket engine creates enormous thrust that carries it into space.

able to create thrust in space because they generate their own gases. They do not take in air. Instead, rockets carry a special chemical that is mixed with fuel. The two chemicals are ignited, producing hot gases. These gases are pushed out the back of the engine, providing thrust that pushes the rocket into space.

Table 3.3 compares some different methods of propulsion. At a glance, could you identify what sort of propulsion an aircraft or organism uses?

Table 3.3 Comparing Different Means of Propulsion

Aircraft or Organism	Means of Propulsion
Wasp	Wings
Parachute	Gravity
Helicopter	Propeller
SR-71 Blackbird Jet	Jet Engine
Vostok 1 Rocket	Rocket Engine

Type of Propulsion

- Rocket engine

How does it work?

- Rockets carry a special chemical that is mixed with fuel. The two chemicals are ignited, producing hot gases. These gases are pushed out the back of the engine, propelling the rocket forward. The engine does not need air to run.

Examples:

- The *Vostok 1* was the first rocket to take a human into space. It was powered by 20 rocket engines.
- The Space Shuttle has three main rocket engines. They were the first reusable rocket engines used in space flight.

THINK & LINK

INVESTIGATION 3-K

SKILLCHECK

- Observe
- Identify
- Compare and Contrast
- Problem Solving

Propulsion

In this investigation, you will identify and describe the means of propulsion used by different aircraft and organisms.

Think About It

Can you determine by observation alone how an aircraft or organism is propelled?

What to Do

1. Look at the pictures on this page.
2. Identify and describe how each type of aircraft or organism is propelled.

Analyze

1. How did you decide how each aircraft or organism was propelled?

Section 3.3 Summary

The propeller, jet engine, and rocket engine each play an important role in flight.

- A propeller is made up of two or more twisted blades. Their motion creates an air pressure difference that moves the plane forward.
- A jet engine uses expanding gas to propel a plane. The gas shoots out of the back of the engine, causing the plane to move forward.
- A rocket engine is similar to a jet engine except that it can be used in the vacuum of space. Unlike a jet engine, it does not need air to run.

Key Terms

propeller
propulsion
jet engine
rocket engine

Check Your Understanding

1. How is a propeller similar to a wing?
2. What is the difference between thrust and propulsion?
3. Compare and contrast how a jet engine and a rocket engine work.
4. An aerospace company has designed a new jet engine. It is more powerful than any engine that has ever been built. They hope to market it to NASA (National Aeronautics and Space Administration in the United States) for use on the Space Shuttle. Do you think NASA will buy it? Explain your reasoning.

Prepare Your Own Chapter Summary

Summarize Chapter 3 by doing one of the following:

- Create a graphic organizer.
- Produce a poster.
- Write a summary to include key chapter ideas.

Here are a few ideas to use as a guide:

- Make a chart that compares the forces that act on an object during flight. Next to each force, give the direction in which it acts.
- Draw a flow chart that shows what happens when the air in a hot air balloon is heated.
- Create a poster that illustrates the three ways in which thrust is generated in aircraft and spacecraft.
- Draw a diagram to show how lift is generated using Bernoulli's principle.