7.3 Gravity—a non-contact force

On the Giant Drop on the Gold Coast, passengers fall 120 metres (39 storeys) in 5 seconds, reaching speeds up to 135 km/h! A magnetic braking system stops them just before they hit the ground. In everyday life, you don't experience gravity quite as dramatically as these passengers, but you do feel its effects every minute.

Figure 7.3.1 A force of attraction called gravity pulls the skydiver towards Earth.

What is gravity?

All objects attract each other. There is a force of attraction between you and your schoolbag, as there is between you and everything around you. **Gravity** is this force of attraction. The more mass a pair of objects have, the stronger the pulling force of gravity between them. As a result, you are pulled strongly towards the Earth (just like the skydiver in Figure 7.3.1) and the Earth is pulled strongly towards you. The Earth has much more mass than you, so the pull you exert on it is barely noticeable, but you can feel its pull. In comparison, you and your schoolbag have a much smaller mass, so the force between you and your bag is very small.

Gravitational fields

If you throw a ball into the air, you know it will fall back to Earth. If an object lies within a region called the Earth's **gravitational field**, then a gravitational force will act upon it. This region is called a **force field**. Gravity acts through a force field, without direct contact. It can be described as a **non-contact force**. Figure 7.3.2 on page 264 shows the direction of the Earth's gravitational field.

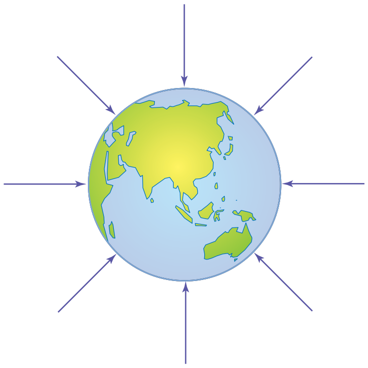


Figure 7.3.2 These field lines show the direction of a gravitational field. An object inside this field will experience gravitational force acting in this direction. The strength of the gravitational force field reduces as distance from the Earth increases.

Planets of our solar system lie within the Sun's gravitational field. As a result, these planets, including Earth, are pulled towards the Sun by a gravitational force. This force is not strong enough to pull Earth or another planet onto the Sun, but it is strong enough to keep it from escaping into deep space. Planets orbit the Sun in elliptical paths as shown in Figure 7.3.3. Similarly, our Moon and various artificial satellites are pulled into an orbit of the Earth because they lie within the Earth's gravitational field.

Comparing mass and weight

In everyday language, mass and weight mean the same. However, to scientists they are very different quantities.

What is mass?

Mass is the amount of matter in an object. Your mass would remain the same if you travelled to other planets, because the matter you are made from remains the same. Mass is measured in kilograms (kg). Smaller masses, such as the ingredients of a cake, are measured in grams (g). The mass of a large object, such as a car or truck, is measured in tonnes (t).

What is weight?

Weight is the name given to the pulling force of gravity on an object. Because it is a force, weight is measured in newtons (N). Your weight depends not only on your mass, but also on the strength of the gravitational field of the planet or moon that you are on. For this reason your weight on the Moon (Figure 7.3.4) is only one-sixth that on Earth.

7.5

Figure 7.3.4 This photo of astronaut Eugene Cernan, the last person to stand on the Moon, was taken in 1972. The Moon has less mass than the Earth, and so it has a weaker gravitational field. Although an astronaut's mass is unchanged, their weight is less on the Moon than on Earth.

Figure 7.3.3 Gravitational attraction keeps moons in orbit around massive planets, and planets in orbit around more massive stars like our Sun.

INQUIRY
science 4 fun

Centre of mass

Yes

The centre of mass or centre of gravity is a point where you can imagine all of an object's weight is concentrated. This point can be inside or, surprisingly, outside the object. Where is your centre of mass when you sit and when you bend down?

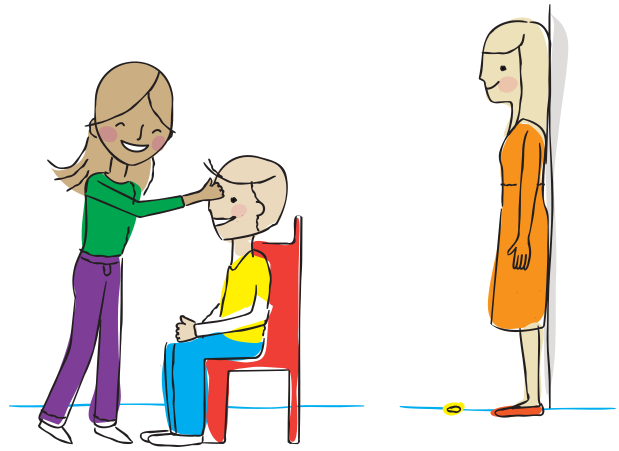
Collect this …

- chair
- wall
- coin

Do this …

Part A

1. Place the back of the chair against a wall.
2. Your partner is to sit on the chair, with their feet flat on the floor in front of the chair.
3. Put your thumb on their forehead.
4. Ask your partner to stand up.



Part B

1. Stand with your back to a wall.
2. Your partner is to put a coin on the floor, near your feet.
3. Try to pick up the coin.

Record this …

Describe what happened.
Explain why you think this happened.

Stability

When you drive over a bridge, you can usually see heavy columns, stretched cables, arches or other supports designed to give it strength (Figure 7.3.5). All structures must be designed so that they can withstand the many types of forces that can act upon them. People and equipment in an office building push down on its supports. Cars and trucks travelling across a bridge push down on its foundations. Materials expand when temperatures rise, and contract when temperatures fall. These changes can squash, stretch or twist structures, as can strong winds, rain and hail. In addition, large structures need to be able to support the force of their own weight pushing downwards, and the force of the ground below that pushes upwards with an equal force.

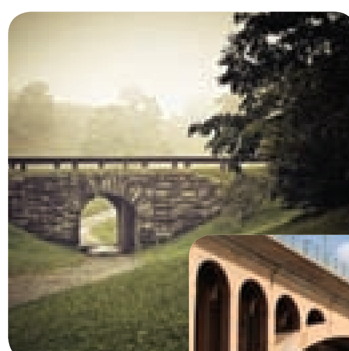


Figure 7.3.5 Compare the design structures that support each of these bridges.

Falling

If you drop an autumn leaf and a stone from the same height, you'd be fairly sure that the stone would hit the ground first. For many centuries, this caused people to believe that heavier things fell faster than lighter ones. Galilei Galileo (1564–1642) performed experiments with falling objects. He realised that the reason some things fell faster was not because they weighed more, but because they had a smaller surface area than other things. Air is pushed out of the way as an object falls. A leaf has a greater surface area than a stone of the same mass. It experiences a greater force of friction (air resistance), slowing its motion and causing it to flutter as it falls (Figure 7.3.6).

1 p271

2 p272

Figure 7.3.6 A leaf flutters as it falls, because it has a relatively large surface area and experiences more air resistance than other more compact objects.

Light as a feather?

SciFile

In 1971, Apollo astronaut David Scott dropped a feather and a hammer from the same height at the same time while on the Moon's surface. They hit the ground at exactly the same time. Go to Pearson Reader to see a video of his demonstration.

Terminal velocity

As an object's speed increases, its air resistance also increases. This means that the air resistance on a falling object increases as it falls. Eventually, the air resistance acting on the object equals its weight force. When this happens, the forces acting on the object are balanced and the object then falls at a constant speed. This speed is called **terminal velocity**. This situation is shown in Figure 7.3.7.

The terminal velocity of a skydiver without a parachute is far too great to survive a landing on Earth. Opening a parachute provides a much larger surface area, which greatly increases the force of air resistance. This slows the skydiver down and soon after a safe terminal velocity is reached.

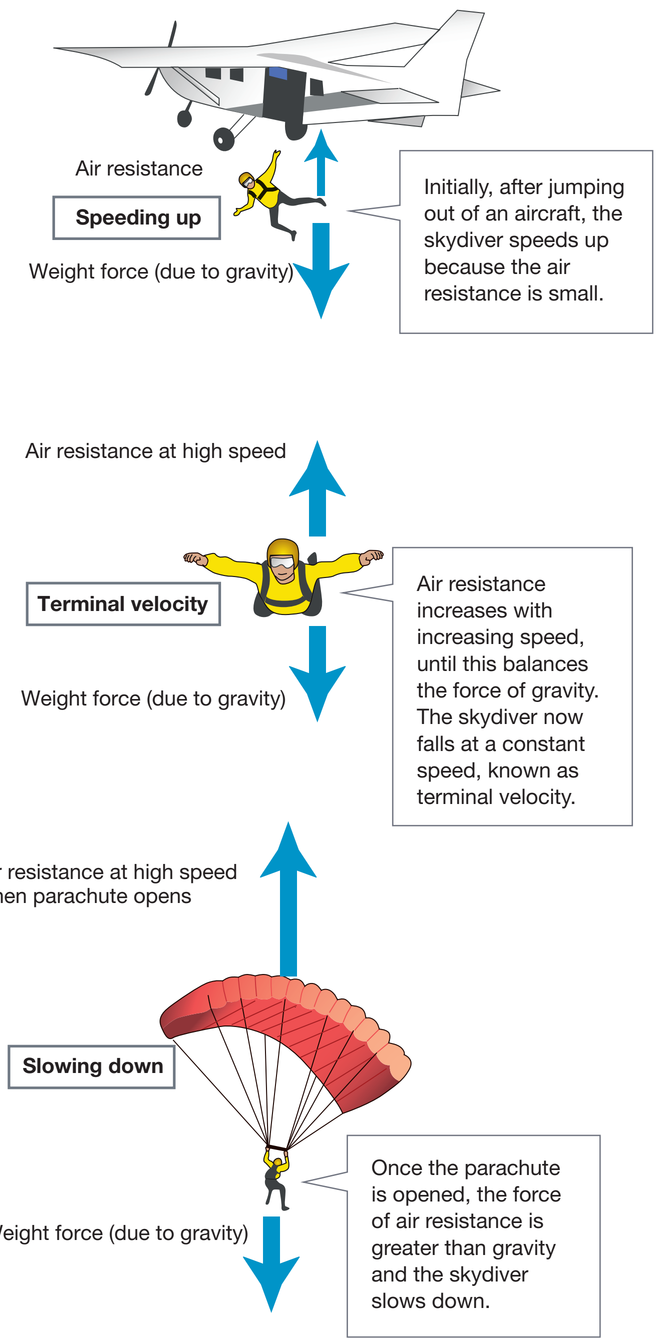


Figure 7.3.7 The motion of a skydiver depends upon the relative sizes of the forces of air resistance and weight.

7.6

INQUIRY

science 4 fun

Flying paper

Yes

An aircraft is able to fly because of the shape of its wings. How can these produce lift?

Collect this …

- sheet of paper
- scissors

Do this …

1. Cut a strip of paper, 5 cm wide and about 20 cm long
2. Hold the narrow end just below your lips.
3. Blow over the strip.

Record this …

Describe whether the paper moved up or down.
Explain why you think this happened.

Flight

People have always wanted to fly. With modern aircraft, you can. There are four key forces at work on any aircraft (Figure 7.3.8). Thrust is the force pushing the aircraft forwards. This is needed to overcome the friction, or drag force, that is produced as the aircraft moves through the air. A large lift force is produced when air streams over the wings of the aircraft. These wings have a shape called an aerofoil to create this force, as shown in Figure 7.3.9. The wing is shaped so that it is longer over the top than it is from below. As a result, air flows more quickly over the wing than it flows beneath it. This produces higher air pressure below the wing than above, which pushes the wing upwards with the lift force. The lift force of course must overcome the massive weight of the aircraft, or else it's not leaving the ground!

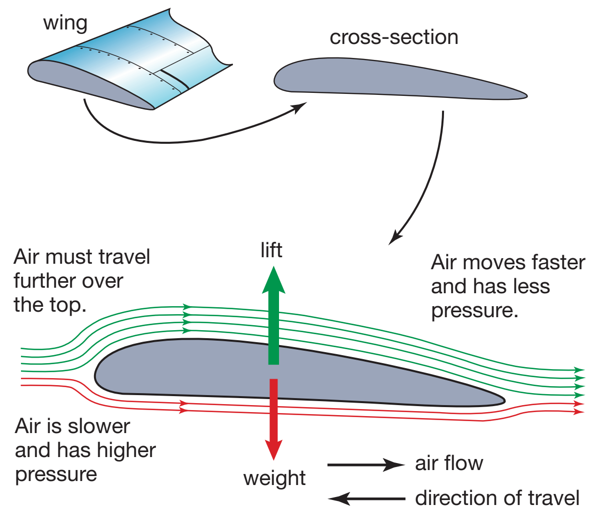


Figure 7.3.9 The way in which a wing creates lift is called the Bernoulli effect, and was discovered by Dutch–Swiss mathematician Daniel Bernoulli in 1738.

SciFile

Price of fame

Daniel Bernoulli (1700–82) became famous for applying mathematics to mechanical situations. His father, Johann, was head of mathematics at Gronigen University in the Netherlands. However, after Daniel and his father both entered and tied for first place in a scientific contest at the University of Paris, Johann banned Daniel from entering his house, because he did not want to be compared to his son.

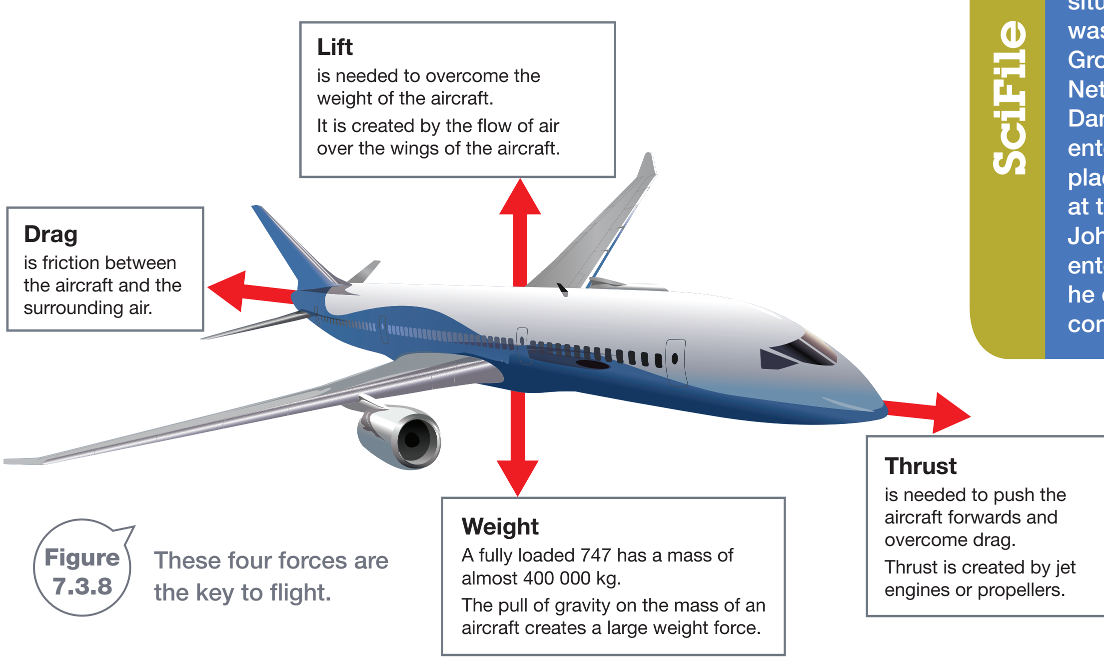


Figure 7.3.8 These four forces are the key to flight.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Science and sport

Figure 7.3.10 Wearing a streamlined helmet and using disc wheels rather than wheels with spokes reduces friction while cycling.

In any sporting competition, a slight advantage of one athlete over another can mean the difference between winning and losing. Sports scientists apply scientific ideas and techniques to improve an athlete's performance.

To prepare an athlete for an event, a sports scientist may use heart monitors and GPS (global positioning) devices to track the intensity of their training. The diet of the athlete is carefully planned and the athlete follows a tailored exercise program.

Technology can be used that may give an athlete an advantage. For example, when competing in a race, your body pushes forwards against the drag force of the friction of the air or water that surrounds you. If you can reduce this friction, you will travel slightly faster. That's why helmets like the one in Figure 7.3.10 are streamlined.

Using a pole vault made from a glass-fibre composite (as shown in Figure 7.3.11) benefits the performance of a pole vaulter. Other ways in which technology can make a difference to performance include:

- using running shoes that absorb force
- using swimwear that reduces drag
- using or football boots that provide sufficient friction
- having dimples on a golf ball to reduce drag
- using bicycles of light weight and streamlined design.

Understanding how forces affect motion can help a sportsperson to:

- throw baseballs or cricket balls with the curve or spin desired
- control their use of the wind while sailing
- keep their centre of gravity as low as possible to keep their balance when performing gymnastics, pole vaulting or high jumping
- dive into a pool without splashing
- swim with an efficient stroke in the water
- adjust the strings on a tennis racquet.

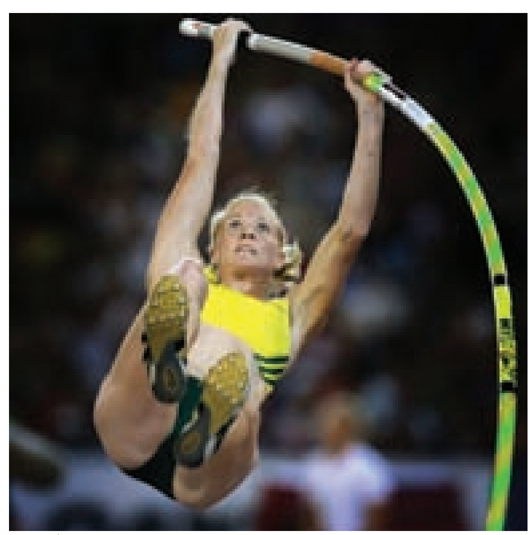


Figure 7.3.11 Replacing bamboo with a glass-fibre composite has resulted in huge increases in the record height for pole vaulting.

7.3 Unit review

Remembering

1 **Recall** gravity by selecting the correct term to complete the following sentences.
  a Gravity is a contact/non-contact force.
  b Gravity pulls/pushes objects towards the Earth.
  c All objects naturally attract/repel each other.
  d Objects fall at different speeds due to their weight/surface area.

2 **State** the unit used to measure mass.

3 **State** the unit used to measure weight.

4 **Name** the force that slows an object down as it falls.

5 a **State** whether air flows more quickly over the top or bottom surface of an aircraft wing.
  b **Name** the force that is created by this flow of air.

Understanding

6 The lines in Figure 7.3.12 represent the Earth's gravitational field.

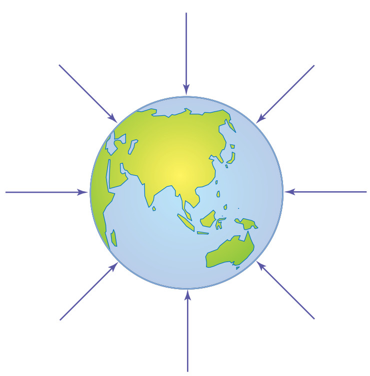


Figure 7.3.12

  a **Describe** what happens to an object that is located in the region of this field.
  b **Describe** what happens to the strength of this gravitational field as an object moves further away from Earth.
  c **Explain** why gravity is called a non-contact force.

7 **Describe** the effect of the force of gravity in three sporting events.

8 **Describe** three ways that knowledge of forces can be used to improve an athlete's performance.

9 **Describe** the role of a sports scientist.

10 Two forces act on a skydiver falling towards Earth.
  a **Name** these two forces.
  b Using a force diagram to help, **explain** at what stage of the fall the skydiver is accelerating, or speeding up, as they travel towards Earth.
  c Eventually the two forces are balanced. **Explain** how this affects the skydiver and **state** what this motion is called.

Applying

11 **Identify** whether the forces of thrust and drag on an aircraft are balanced in the following cases. If they are not balanced, **state** which is greater.
  a The aircraft speeds up.
  b The aircraft slows down.
  c The aircraft cruises at constant speed.

Analysing

12 **Compare** mass and weight by listing their similarities and differences.

13 A tennis ball, a cricket ball and a shot put are dropped at the same time. The path of the tennis ball as it falls is shown in Figure 7.3.13.

Analyse where the other two balls would be at the same time as the tennis ball (ignore air resistance).

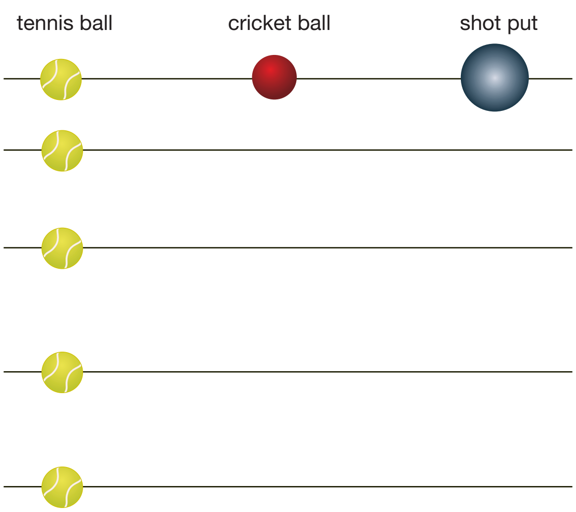


Figure 7.3.13

Evaluating

14 Is there gravity on the Moon? **Justify** your answer.

15 a **Propose** three different ways that a person's mass could change throughout their life.

b **Propose** how a person's mass could remain the same, but their weight changes.

16 Min-Jee drops a leaf and a small rock from the top of a playground slide.

a **Predict** which will hit the ground first.

b **Assess** whether gravity acts differently on objects because of their different mass.

c **Predict** what Min-Jee would observe if her experiment was repeated on the Moon.

17 a **Predict** what would happen as an aircraft tried to take off, if its wings had been attached upside down.

b **Justify** your response.

Creating

18 According to the ancient Greek philosopher Aristotle, heavy objects contain more gravity than light objects, so they fall faster. **Construct** a response to Aristotle in which you disagree with his viewpoint.

19 Imagine what would happen if instead of being an attractive force, gravity was a repulsive force that pushed objects away.

Construct three diagrams showing what could happen to things around you if this was the case.

Inquiring

1 Search the internet to gather and view:

a video footage of some extreme gravity situations, such as a vertical drop theme-park ride, bungee jumping or skydiving

b video footage of astronauts in motion on the Moon

c images showing the streamlined shape of different models of aircraft.

2 Use the internet to investigate how the strength of the Earth's gravitational field decreases the further an object gets from Earth. Construct a labelled illustration or create a multimedia display to present your findings.

3 a Explain what is meant by the term 'zero gravity'.

b Investigate how astronauts train to be able to tolerate zero gravity conditions.

4 Research different types of parachute design. Discuss key features involved in the design and explain how these assist the parachutist.

5 Can you build a strong bridge? Design at least three different types of bridges that span a length of 30 cm. Construct your bridges from the same material (for example wood, cardboard or straws). Investigate the load that each can support and write a report about your conclusions.

6 Design and build a capsule capable of protecting a precious egg as it falls from a height at your school. The capsule needs to be constructed using a sheet of newspaper, 80 cm of sticky tape, and 80 cm of string.

SAFETY

Mark off the drop zone to ensure that no one is below the capsule when it is dropped.

Investigate how well your capsule protected the egg.

Compare the designs of your classmates and describe the design features that helped to protect the egg on impact. If you could repeat the task using an unlimited supply of newspaper, sticky tape and string, outline what you would do and explain why.

7.3 Practical activities

1 Look out below!

Purpose

To investigate if heavier objects fall faster than lighter ones.

Materials

- metre ruler
- Blu Tack
- foam or rubber
- a number of unbreakable objects of different size
- sheet of butcher's paper
- 50 g mass
- electronic balance

SAFETY

Be careful not to drop objects where they could fall on someone.

Note: If possible, use a motion sensor or light gates to complete this experiment more accurately.

Procedure

1. Measure the mass of each object and record the masses in your results table (shown below).
2. Predict what will happen when each object falls. Record your predictions in the table.
3. Mark a height of 2 metres on a wall with a piece of Blu Tack. Place some foam or rubber at its base. This is your 'drop zone' to test how fast each object falls.
4. Drop the 50 g mass and another item from the marked height on the wall as shown in Figure 7.3.14.
5. Record whether the object landed at about the same time, slower or faster than the 50 g mass. Repeat the test if you are unsure.
6. Repeat, using the 50 g mass and every object to be tested, and record your results.
7. Drop the 50 g mass and the sheet of A4 paper (held horizontally) and record your result.
8. Crumple the sheet of paper into a loose ball and repeat the test.
9. Finally, scrunch the loose ball into the tightest ball you can and do the test again.

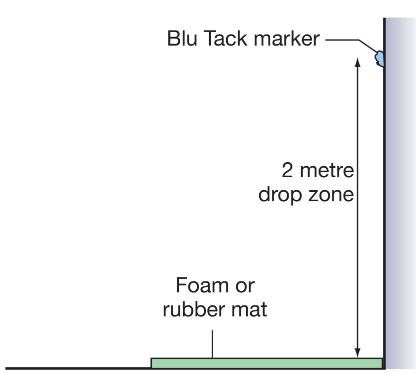


Figure 7.3.14

Results

Copy the table below into your workbook and record all your masses, predictions and measurements in it.

Falling object	Mass (g)	My predictions	Landed		
		Will fall the same/faster/ slower than the 50 g mass	about the same time as 50 g mass	before the 50 g mass	after the 50 g mass

Discussion

1. **Assess** how accurate your predictions were.
2. **State** whether most objects fell at the same rate as the 50 g mass, or faster, or slower.
3. a **State** which object fell the slowest.
   b **Propose** a reason why this was the slowest.
4. a **Name** the objects that fell faster than the 50 g mass.
   b **Propose** reasons why.
5. **Propose** a reason why the 50 g mass was used in every experiment.
6. a **Summarise** how the shape of the sheet of paper changes how it fell.
   b **Explain** why.
7. **Draw** a conclusion for this activity.

2 Robocopter investigation

A robocopter is a paper construction that spins as it falls when it is dropped from a height. Your task is to make a robocopter and then **investigate** how changing one variable or factor affects the time that it takes to fall. The design of a robocopter is shown in Figure 7.3.15. To build your robocopter, cut a copy of the template shown in Figure 7.3.16 onto a piece of paper or cardboard. Cut along solid lines and fold along dotted lines, as shown by the arrow. Place a paper clip at the base as shown in Figure 7.3.15 and you are ready for a spin!

You could test:

- changing the length of its blades
- adding more paper clips to its base
- making different-sized robocopters
- making robocopters from different thicknesses of paper or cardboard.

Write a purpose for your investigation, list the materials needed and the procedure you follow. State the variable (factor) you are testing and which variables (factors) you will keep constant. Record your results in a table and show these in a graph. Make sure you write about what you observed in your experiment and any problems that you found, and add a conclusion that summarises your findings.

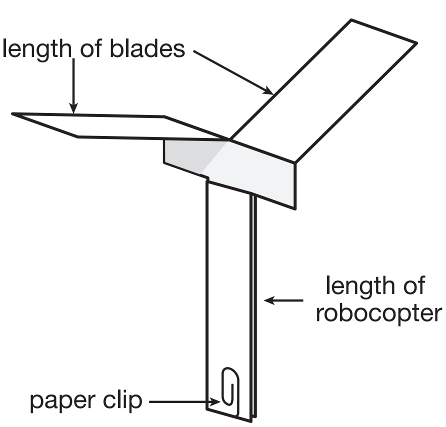


Figure 7.3.15 A completed robocopter

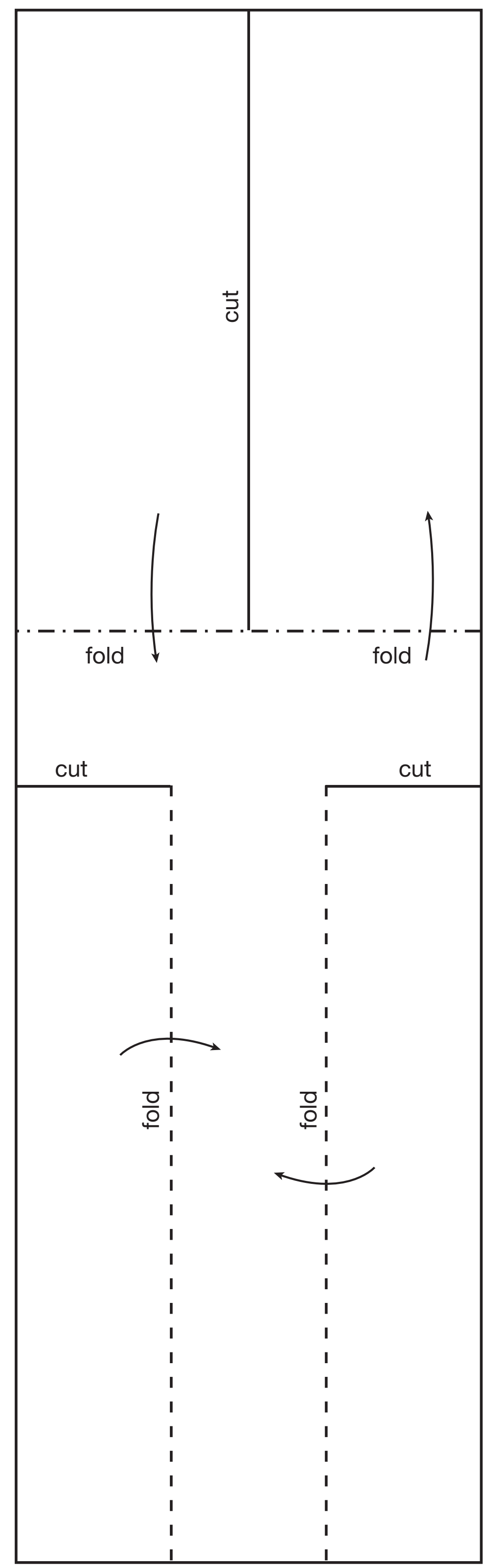


Figure 7.3.16