Royal Academy of Engineering

THIS IS ENGINEERING

ATHLETE OR MACHINE

Which is more important in the bob skeleton event?

CONTENTS

INTRODUCTION TO THE RESOURCE

This is a teaching and learning resource for Key Stage 3 students that combines *design & technology*, *mathematics* and *science* activities to investigate the 'big question':

Athlete or machine?
Which is more important in the bob skeleton event?

Bob skeleton is an extreme winter sport in which athletes slide head first down an ice covered track on a sled that holds them just centimetres from the surface. The aim of the sport is to get to the bottom of the track in the quickest time.

It is a winter sport in which British athletes, such as, Amy Williams, Shelly Rudman and Kristan Bromley, have achieved a number of Olympic and World Championship medals.

It is also a sport that applies engineering, mathematical and scientific skills and knowledge to create the sleds and equipment needed to win these medals.

This resource has been developed with support from BAE Systems, who engineered the sled used by Olympic gold medallist Amy Williams, and is intended to be a truly inclusive STEM resource. It has been designed to be used by teachers of design & technology, mathematics and science to show students how these STEM subjects are central to the study and practice of engineering. It is also hoped that it will encourage STEM teachers to work together to create a STEM learning experience for their students.

The decision to structure the resource around the big question '*Athlete or Machine?*' was taken to encourage STEM learning based on student led investigation and problem solving.

In order to answer the big question, students must identify the factors that influence the bob skeleton and then investigate each one of these factors through practical, mathematical and scientific activities.

Through these activities students will gradually develop an understanding of the sport of bob skeleton and the factors that are key to success in the sport. When all the activities have been completed, students should be able to provide a sophisticated and justified answer to the big question.

The following pages have been written to be used by students with support from their STEM teachers depending on the students' abilities.

AMY WILLIAMS COMPETING AT THE 2010 WINTER OLYMPICS
Jon Wick
www.flickr.com/photos/jonwick

OVERVIEW

Overview

LEARNING ACTIVITY	SUBJECT FOCUS: Design & Technology	SUBJECT FOCUS: Mathematics & science	TYPE OF ACTIVITY: Practical	TYPE OF ACTIVITY: Paper-based
Making a scale model bob skeleton	PA 1		✓	
Launching a model bob skeleton using air pressure	PA 2		✓	
Investigating mass and weight	PA 6 Page 7, investigation 1 & 2	MS 6 & MS 7	✓	✓
Investigating force and gravity	Page 7, investigation 3	MS 4 & MS 6	✓	✓
Investigating energy		MS 2 & MS 3		✓
Investigating energy transfer		MS 5		✓
Converting velocity measurements		MS 1		✓
Investigating friction	Page 7, investigations 4, 5, 6 & 7	MS 8	✓	✓
Investigating aerodynamic drag (air resistance)	Page 8, investigation 9	MS 9	✓	✓
Investigating maximum velocity (speed)		MS 10		✓
Investigating steering a bob skeleton	Page 7, investigation 8	MS 11	✓	✓
Making timing gates for measuring the speed of the model bob skeleton	PA 4a & PA 4b		✓	
Making launch pressure more consistent	PA 5		✓	

KEY TO ABBREVIATIONS

MS – Maths and science activity support sheet
PA – Practical activity support sheet

AN INTRODUCTION TO THE SPORT OF BOB SKELETON

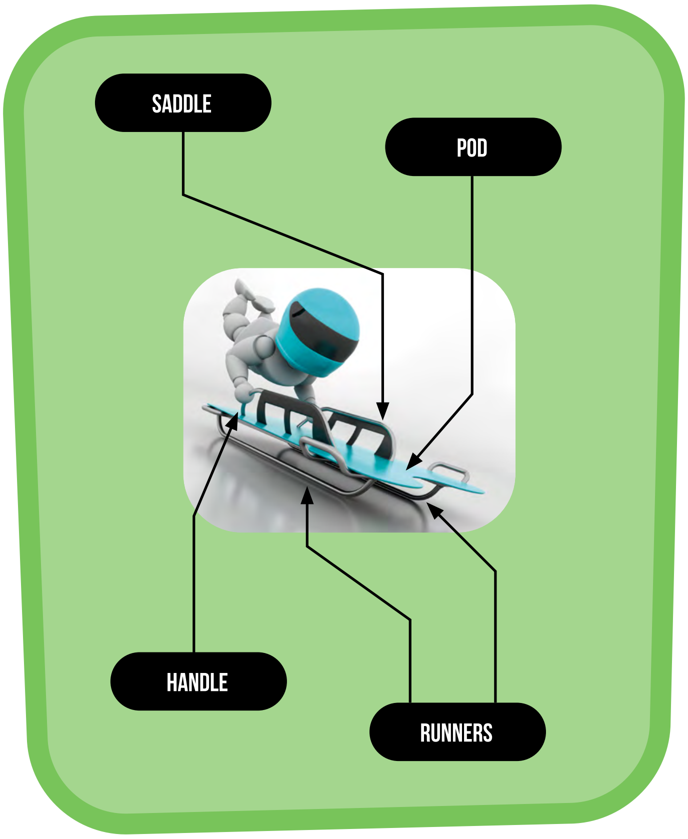
The bob skeleton event involves sliding head first on a sled down an ice covered track.

The sled has no controls and athletes travel at high speeds just a few centimetres from the icy and unforgiving surface of the track.

Bob skeleton tracks are about 1500 m long and can have a vertical drop of over 150 m.

Tracks can have up to 20 curves and athletes can experience five times the force of gravity as they hurtle towards the bottom.

Britain has one of the top international teams and has won more than its fair share of competitions and medals. For example:



Britain's Bob Skeleton Winners...

Amy Williams MBE
Olympic Gold Medallist, Vancouver 2010

Kristan Bromley
World Champion 2008
World Cup Series Champion 2008 & 2004
European Champion 2008, 2005 & 2004

Shelley Rudman
Olympic Silver Medallist, Turin 2006
World Cup Silver Medallist 2009 & 2010
European Champion 2009
2nd World Cup 2011 Series Overall

Adam Pengilly
World Championship Silver Medallist 2009

USEFUL LINKS...

www.skeletonamy.co.uk/gallery.html
Amy Williams' website

www.youtube.com/watch?v=jR1YbCMhxfI
Chris Evans is coached by Amy Williams

www.youtube.com/watch?v=IDBWe1CmUmg&feature=channel

1. Information about the track: 0:01:55
2. Athlete's view of the track: 0:02:55
3. Amy Williams' run: 0:05:02–0:07:27

http://fibt.pixabit.de/index.php?id=121&no_cache=1&L=0
Information about the bob skeleton from the sport's international governing body the FIBT.

www.bobskeleton.org.uk
The website for the British skeleton team, and a good source of information about the sport.

THE BIG QUESTION

Your challenge is to answer and justify the big question:

Athlete or machine?
Which is more important in the bob skeleton event?

The following list identifies the factors that might influence the speed an athlete and their bob skeleton sled can travel down a track:

- Weight
- The athlete's shape
- The athlete's position
- Aerodynamic lift
- Steering
- Clothing and equipment
- Starting
- Corners
- Ergonomics (how the body fits a product)
- Track incline (the slope down the length of the track)
- Friction on the ice
- Aerodynamic drag (air resistance)
- Tuning the characteristics of the skeleton
- Material choice
- Sled runners

Tasks

1. Complete ACTIVITY 1 to investigate the factors that influence the sport of bob skeleton
2. Complete ACTIVITY 2 which explains how to present your answer to the big question
3. Complete ACTIVITY 3 to see if your answer to the big question matches that of bob skeleton World Champion and engineer, Kristan Bromley

AMY WILLIAMS RECEIVING HER GOLD MEDAL AT WHISTLER ON DAY 9 OF THE 2010 WINTER OLYMPICS.

Duncan Rawlinson
Online Photography School
www.photographyicon.com

STUDENT ACTIVITIES – 1

Activity 1

1.1 Design & technology activities

Practical activities PA1–PA3 explain how to make a scale model of a bob skeleton and launcher which you can use to carry out practical investigations.

Once you have made the scale model of the bob skeleton and had fun launching it using the hand pump, you will need to complete the following tests and experiments. These will help you to identify which of the factors in the list above have the biggest influence on the speed of the bob skeleton.

Recording your tests and investigations

It is important that you make a record of your investigations. Ideally you should produce a short report (or PowerPoint presentation) that gives brief details of:

- What you were trying to find out
- How you completed the experiment
- What you discovered

Practical investigations

Mass and weight

1. Investigate the impact weight has on the speed and distance travelled by the model bob skeleton (practical activity 6)
2. Does where you put the weight make a difference to the performance of the model bob skeleton? Try adding weight to the different parts of the sled to see if it has an effect on its speed and direction of travel.

Gravity

3. Investigate the effect of launching the model bob skeleton down various inclines (slopes), for example, 5º, 10º, 15º and 20º.

Friction

4. Test the model bob skeleton on a number of different floor finishes in order to assess the type of floor that allows the model bob skeleton to achieve the fastest speeds.
5. Does the shape of the runners have an effect on the model bob skeleton? Try bending to see what impact this has on the speed and direction of travel.
6. Change or modify the runners to see if you can improve the sliding speed of the bob skeleton. You might make the runners from a different material or give them a different finish.
7. Investigate what happens when you make one runner smoother than the other?

Steering

8. Can you make the model bob skeleton hit a target that is 15 m away and to the left or right of the launch position? Try experimenting with friction and aerodynamics.

Aerodynamic drag (air resistance)

9. Add different solid shapes to the model bob skeleton to test the impact that aerodynamic drag can have on the speed of the sled. Test shapes could be made from modelling clay or expanded polystyrene and should include a cuboid, a cylinder, a rocket shape and the shape of a bob skeleton athlete. Try launching the model bob skeleton with a doll attached in different positions. For example, lying down, head first and sitting up.

The start

10. Would guiding the model bob skeleton at launch help it travel further? Develop a method of controlling the motion of the bob skeleton model at launch so that it moves off in a straight line and more of its launch energy is transferred into forward motion.
11. How fast do you think the bob skeleton athletes push their sleds at the start? Go to the playground and time each other pushing a 1000 mm x 400 mm, 34 kg rectangle for 40 metres.

How much quicker do you think the athletes can do this?

Timing

12. Construct electronic timing gates so you can record the speed of your scale model (practical activity 4).

Consistency when testing

13. Make a pressure release valve for the launch pipe to ensure your launch pressure and the run times you record are consistent (practical activity 5).

1.2 Maths and science activities

An understanding of forces and energy will help you to understand which of the factors in the list above have the biggest influence on the speed of a bob skeleton.

Develop your understanding of forces and energy involved in the bob skeleton event by investigating the topics listed below.

Recording your investigations

You will need to use the findings from your investigations in your presentation for activity 2. Each of your investigations should be written up and should include the following information:

- A description of the topic being investigated
- The mathematical equations used in the topic
- Examples of worked equations using different data
- An explanation of how this knowledge could be applied to the bob skeleton event

Investigation tasks

Energy

1. Calculate the amount of energy that is stored by the athlete and sled.
   See Mathematics and science support sheet MS 2.
2. Show how energy is transferred during the bob skeleton.
   See Mathematics and science support sheet MS 2 and MS 5.

Force

3. Explain and calculate the effect of gravitational force on the athlete and sled on flat and sloping surfaces.
   See Mathematics and science support sheet MS 6 and MS 7.

Energy and force

4. Analyse the effect of incline (slope) on force in the bob skeleton event.
   See Mathematics and science support sheet MS 7.
5. Analyse the effect of mass and weight on force in the bob skeleton event.
   See Mathematics and science support sheet MS 7.

Friction

6. Describe and calculate the effect of frictional force on the athlete and sled.
   See Mathematics and science support sheet MS 8.
7. Analyse the effect of creating a difference in frictional force on the bob skeleton's runners.
   See Mathematics and science support sheet MS 11.

Aerodynamic drag

8. Identify the three main factors that contribute aerodynamic drag (air resistance).
   See Mathematics and science support sheet MS 9a
9. Calculate the effect of aerodynamic drag on the athlete and bob skeleton.
   See Mathematics and science support sheet MS 9b.

Velocity (speed)

10. Calculate the maximum speed the athlete and sled could reach?
    See Mathematics and science support sheet MS 10.

Steering

11. Which parts of their bodies could bob skeleton athletes use to steer their sled?
    See Mathematics and science support sheet MS 11.

STUDENT ACTIVITIES – 2 & 3

Activity 2

Use your knowledge of the factors listed above to create a presentation that provides an answer to the big question:

Athlete or machine? Which is more important in the bob skeleton event?

Your presentation must describe the practical experiments and the maths and science investigations you completed when researching your answer to the big question.

Your presentation must include:

- Text
- Photographs
- Charts and graphs
- Diagrams
- Data

Activity 3

(a) Use the knowledge gained through ACTIVITY 1 to answer the 16 questions listed below.

(b) Watch the video of Kristan Bromley to see if your answers match those given by a bob skeleton World Champion and engineer.

Questions

1. Is **weight** an important factor in the bob skeleton event?
2. Is the athlete's **shape** and **position** on the skeleton important?
3. Will **lift** affect the skeleton?
4. Can the bob skeleton be **steered**?
5. Are the athlete's **clothes and equipment** important?
6. How important is the **start** of a run?
7. Why are the **corners** of the track banked?
8. What **speed** can a bob skeleton reach?
9. Do the **ergonomics** of the bob skeleton matter?
10. Is the **incline** of the track important?
11. What part does **friction** play in the bob skeleton event?
12. Can the athletes adjust or **tune** the bob skeleton to change the way it behaves?
13. How does the athlete's **line** through a corner influence their performance?
14. How important is the choice of **materials** when designing a bob skeleton?
15. What impact does the shape and profile of the **runners** have?
16. **Athlete or Machine**? Which is more important in the bob skeleton event?

Guide to making a model bob skeleton

In this activity you will make a 1:5 scale model of a skeleton bob

You will need

- A **sheet material** for the sled's pod (the prototype in the photographs and sketches uses 2mm HIP)
- **Metal rod** for the runners (the model shown uses 300mm long 1.6mm steel rod)
- A pair of **pliers** for bending the metal rod
- A sheet of **A4 acetate** for the tube that enables you to attach the sled to a launch pump
- **22mm** (diameter) **plastic pipe** (available from plumbing merchants) that you can wrap the A4 acetate around to make the acetate tube
- A **glue gun** for initially attaching the runners to the sled
- A **drill** for making holes in the sled so the runners and tube can be secured to the sled using ties
- 3 and 5mm **drill bits**
- **Adhesive tape** for making the acetate tube and blocking one end (the prototype uses duct tape)

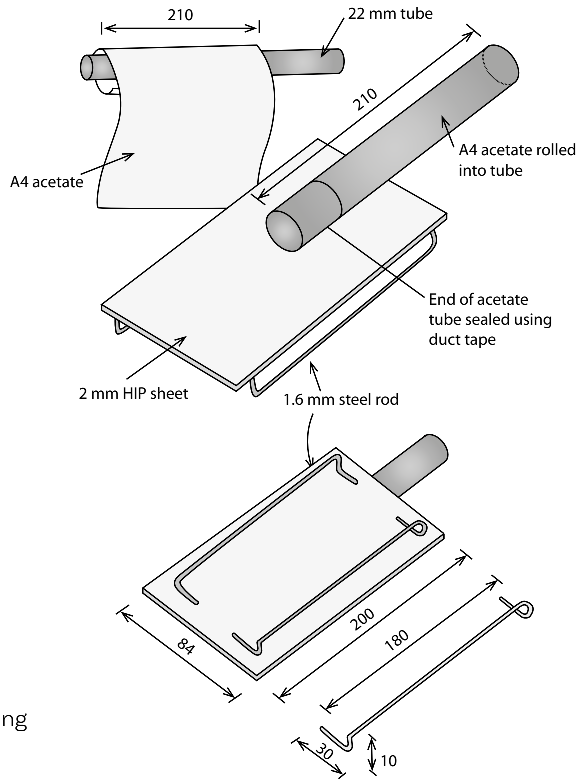


FIGURE PA 1.03
1:5 SCALE MODEL OF SKELETON

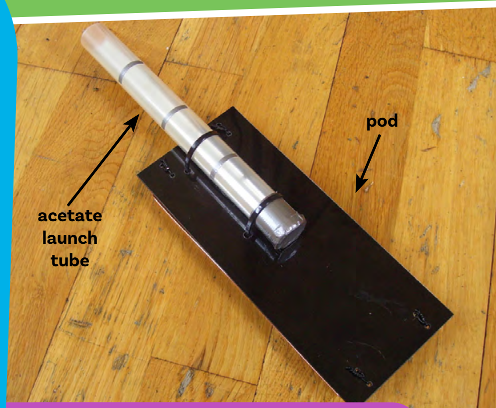


FIGURE PA 1.01

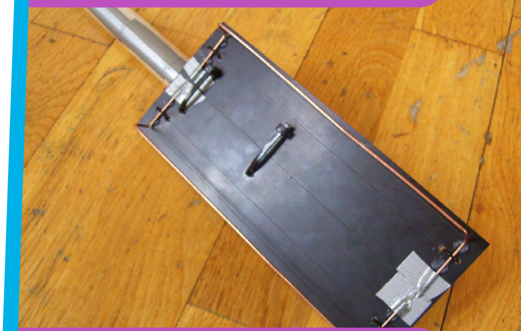


FIGURE PA 1.02

FIGURE PA 1.04

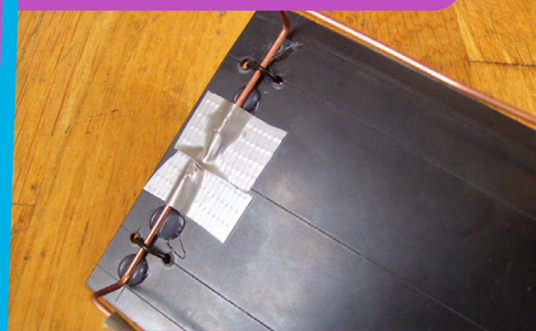


FIGURE PA 1.05

Making steps

1. Cut the sled's pod.
2. Bend the steel rod to make the runners (see figure PA 1.03 for sizes).
3. Drill holes in the sled so the runners and paper tube can be secured with ties (see drilling template on the next page).
4. Make an acetate tube by wrapping it around a the 22mm plastic pipe. Make sure you seal one end.
5. Use the glue gun to initially attach the runners and the acetate tube to the sled.
6. Use ties to secure the runners and the acetate tube (figures PA 1.04 and PA 1.05).
7. You may need to use tape to further secure the runners to the underside of the sled (figure PA 1.04).

Skeleton plan and drilling template

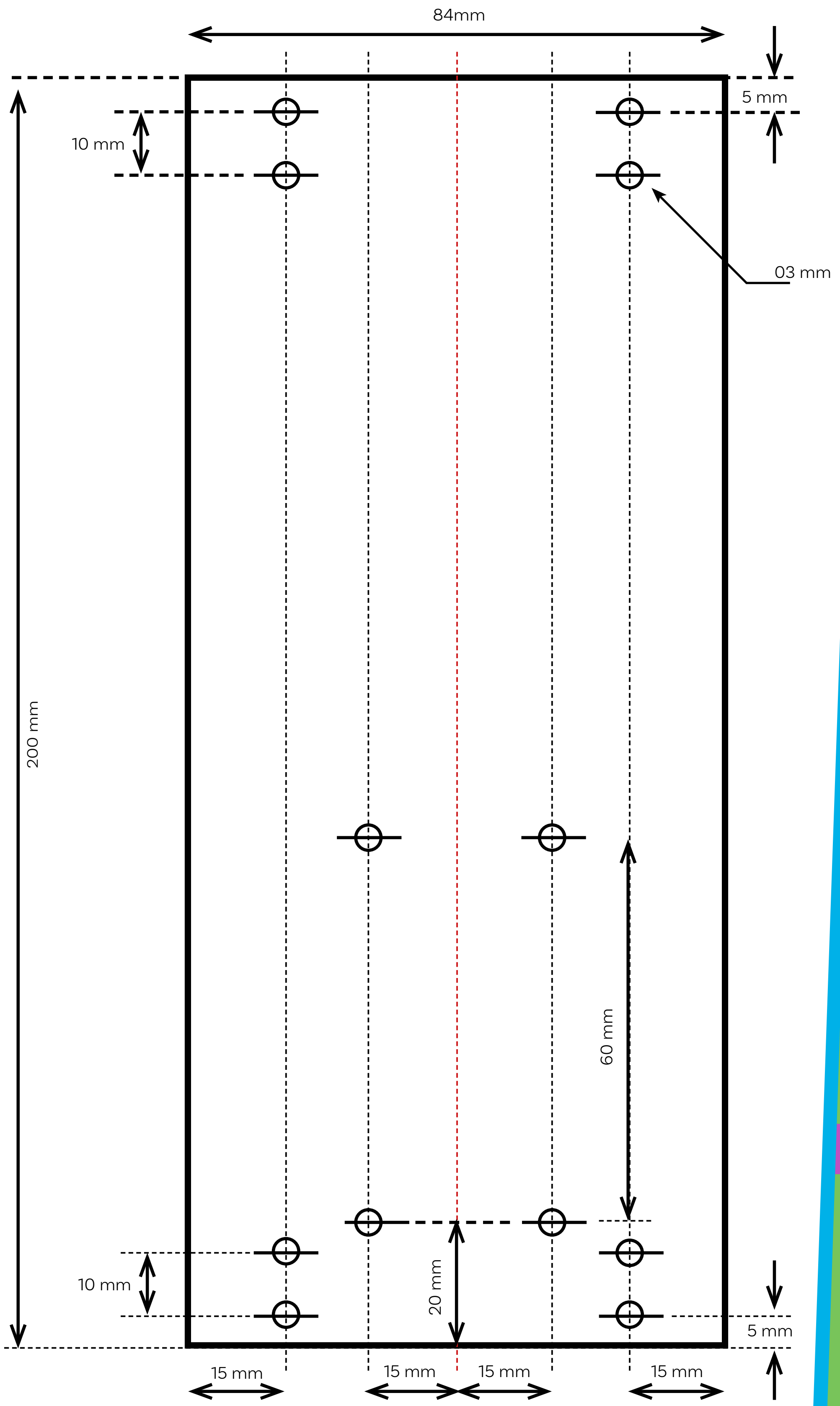


FIGURE PA 1.06

Actual size of model

Guide to making a model bob skeleton launcher

In this activity you will make a launcher for the bob skeleton scale model you have made.


FIGURE PA 2.01a


FIGURE PA 2.01b

You will need

- A **hand operated pump** like the one in the photograph (figure PA 2.01a) (these are sometimes called stirrup pumps, track pumps or hand pumps; the pump in the photograph was supplied by **www.mindsetsonline.co.uk** (code: 202-001)
- A **flexible hose** (this is usually supplied with the hand pump)
- A length of **22mm plastic pipe**
- **22mm pipe clips** (the type you hammer in)
- **Timber** or manufactured board rectangle 300 mm x 80 mm x 15 mm
- Strong **adhesive tape**

Making steps

1. Insert the 22 mm tube into the pump's flexible hose to a depth of at least 30 mm. You will probably have difficulties doing this and may need to stretch or soften the hose a little first.
2. Use a strong adhesive tape to fix the pump's hose onto the 22 mm plastic tube (figure PA 2.02).
3. To make a base (figure PA 2.03) for the launch tube cut a rectangle of wood or manufactured board that is 300 mm long, 80 mm wide and at least 15 mm thick.
4. Fix two 22 mm pipe clips to the base you have cut so that the 22 mm pipe runs down its centre (figure PA 2.04).
5. Slide the 22 mm launch pipe into the pipe clips (figure PA 2.05).


FIGURE PA 2.02


FIGURE PA 2.03

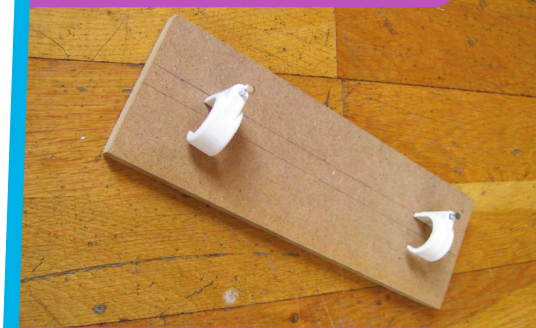


FIGURE PA 2.04


FIGURE PA 2.05

Guide to testing the model bob skeleton

FIGURE PA 3.01

FIGURE PA 3.05

In this activity you will test the model you have made of the skeleton.

You will need

- A large **space,** preferably with a wooden or polished hard floor
- A **hand operated pump** like the one in figure PA 3.01 (these are sometimes called stirrup pumps, track pumps or hand pumps; the pump in the photograph was supplied by **www.mindsetsonline.co.uk** (code: 202-001)
- **A flexible hose** (this is usually supplied with the hand pump
- A length of **22 mm plastic pipe**
- **Adhesive tape**
- **Tape measure**

Making steps

1. Start by marking the bob skeleton's tube at 50 mm intervals, as shown in figure PA 3.02. These marks enable you to insert the pump's tube into the bob skeleton's tube at the same point every time you conduct a test. This is one way of ensuring **consistency** when testing.
2. Lift the handle of the pump so that it is at the top of its stroke.
3. Insert the pump's tube into the bob skeleton's tube up to one of the marks on the tube.
4. Push down on the pump handle.
5. Use the table from the Appendix to record the distance travelled by the bob skeleton.
   Make sure you note how far you inserted the tube into the skeleton's tube for each test.
6. Continue to test the model bob skeleton making sure you record the distance travelled each time.

FIGURE PA 3.02

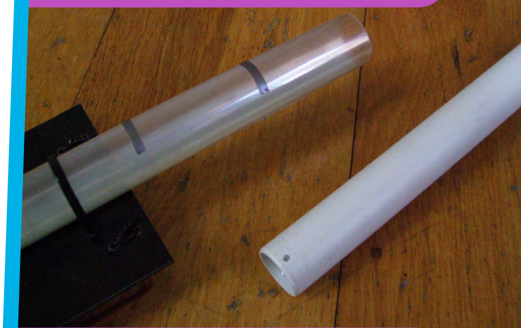


FIGURE PA 3.03

FIGURE PA 3.04

QUESTION

1. What affect does the force the bob skeleton receives at the start have on the distance it travels?

Guide to making timing gates for the model bob skeleton

In this activity you will look at a way of accurately timing the model bob skeleton over a specific distance. The time you record can then be used to calculate the speed of the bob skeleton.

The information on this sheet will help you to make two timing gates so the model bob skeleton can be timed over a specific distance.

You will need

- A4 **paper**
- **Sellotape**
- A **stapler**
- Two **microswitches**
- A **stopwatch** with sockets for external triggering (see **www.eacombs.com/Stopclocks.php** for details of their Stopclock 5500)
- **Card**
- Drinking **straws**
- Red and black plastic coated **wire**
- **Solder**
- **Soldering iron**

Making steps

1. Take 14 pieces of A4 paper and roll 14 tubes of length 300 m.
2. Tape two of the tubes together to make tube **h**.
3. Cut two of the tubes down to 240 mm. These tubes will become tube **e** and **f**. Keep one of the left over sections of tube as this can be used for tube **g**.
4. Join tubes **a**,**b** and **c** with a stapler to make a triangular frame.
5. Staple tube **d** to the top of the triangle **abc**.
6. Staple tubes **e** and **f** to the bottom corners of triangle **abc**.
7. Staple the free ends of tubes **d**, **e** and **f** together.
8. Repeat steps 3 – 7 to make another triangular frame.
9. Solder a 1500 mm long red wire to the NO (normally open) poles of the two microswitches.
10. Solder a 1500 mm long black wire to the COM (common) poles of the two microswitches.

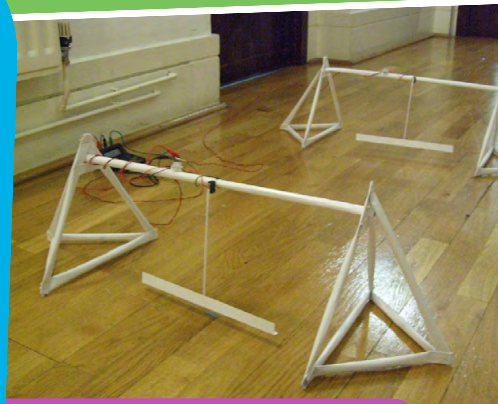


FIGURE PA 4.01

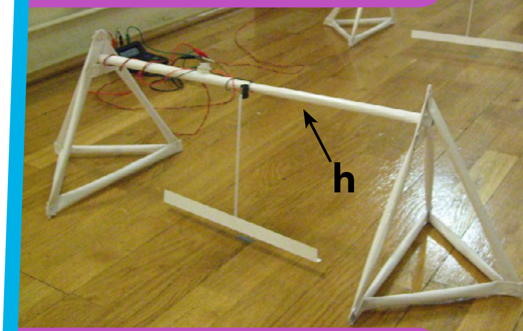


FIGURE PA 4.02

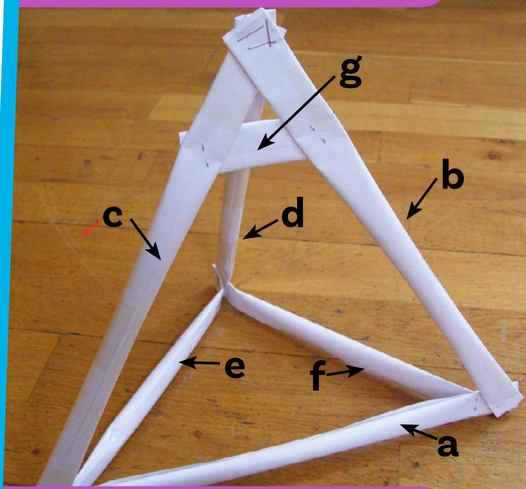


FIGURE PA 4.03

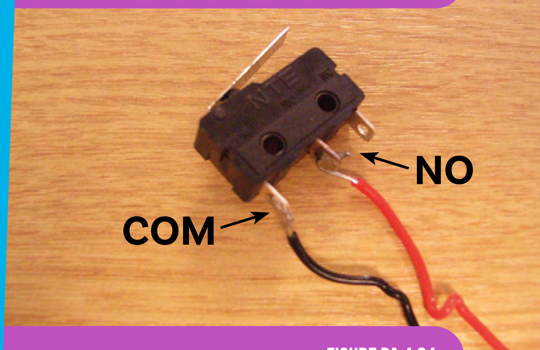


FIGURE PA 4.04

Guide to making timing gates for the model bob skeleton (continued)

Making steps (continued)

11. Fix a drinking straw to the microswitch lever and a strip of card to the end of the straw. Make the card strip rigid by folding it as in figure PA 4.05.
12. Attach the microswitch assembly to **tube h**.
13. Assemble the timing gates by inserting **tube h** into the gap above **tube g** in each of the triangular frames.
14. Position the assembled timing gates so they are one metre apart and in line as in figure PA 4.01 and figure PA 4.08.
15. Attach the black wire from each microswitch to the stopwatch's black external socket connector.
16. Attach the red wire from the front microswitch to the green external socket connector.
17. Attach the red wire from the second timing gate to the red external socket connector.

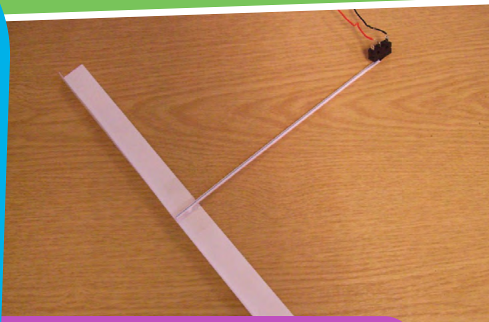


FIGURE PA 4.05

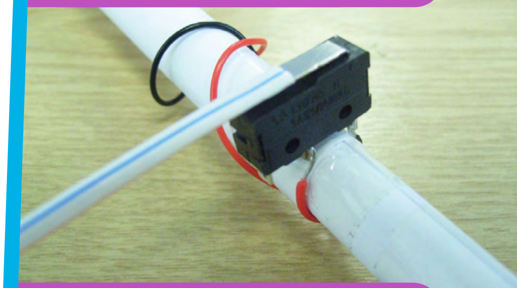


FIGURE PA 4.06

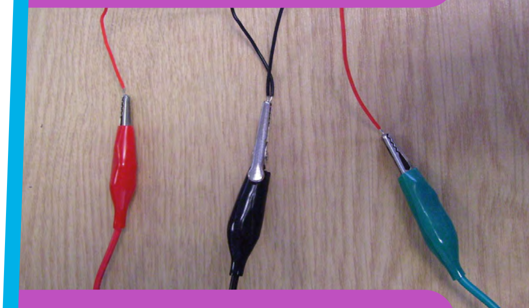


FIGURE PA 4.07

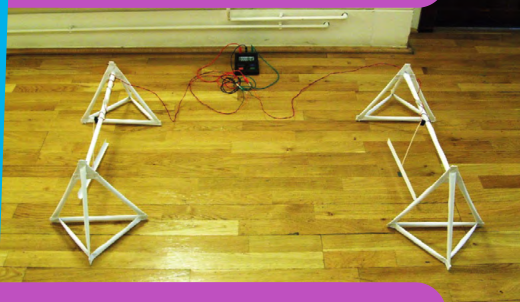


FIGURE PA 4.08

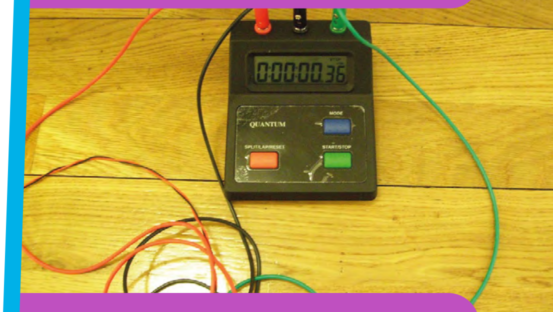


FIGURE PA 4.09

Testing the timing gates

1. Position your model bob skeleton and launcher in front of the first gate.
   Record the distance between the bob skeleton and the timing gate switch.
2. Insert the launch tube into the tube on the bob skeleton.
   Record how far you inserted the launch tube.
3. Launch your bob skeleton model.
4. Record the time on the stopwatch.
5. Repeat steps 2–4 several times.

Calculating speed using distance and time

Speed can be calculated by dividing the distance travelled by the time it took to travel the distance. The formula for calculating the speed of an object is:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

For example:

$$\text{Speed} = \frac{1\text{ metre}}{0.36\text{ seconds}}$$

Speed = 2.78 metres per second (m/s)

Mathematics and science support sheet **MS 1** provides guidance for converting this figure into kilometres and miles per hour.

Achieving consistency when testing

It is important that the times recorded during testing are achieved using the same amount of launch pressure. If each test launch uses a different amount of pressure your times will be unreliable and inconsistent.

Reliable and consistent times are important when you start to modify the model by adding weight, testing different floor surfaces or adjusting the runners. If the launch pressure is not the same for every launch, it makes it difficult to accurately judge the effect of modifications.

Pressure release valve

One way to achieve a certain level of consistency when launching the bob skeleton model is to set a maximum amount of pressure that can be used.

A home made pressure release valve, like the one in the figure PA 5.01, will burst open when the pressure from the launch pump reaches a certain level.

Using a pressure release valve ensures the maximum launch pressure will be the same regardless of the potential and kinetic energy and force of the person launching the model bob skeleton.

The opening of the pressure release valve during a launch attempt should signify the voiding of the launch and the distance and time for the attempt should not be recorded.

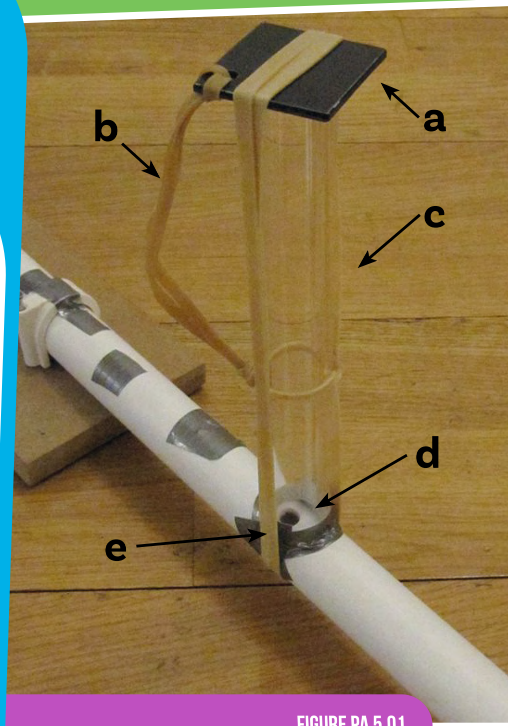


FIGURE PA 5.01

KEY FOR FIGURE 5.01

- **a.** rigid sheet material
- **b.** tie to prevent **part a** causing injury
- **c.** clear acrylic tube
- **d.** 6 mm hole drilled in launch pipe
- **e.** elastic band to hold **part a** to the top of the tube

QUESTIONS

1. How might you modify the pressure release valve in figure PA 5.01 so that more pressure could be used at launch before the valve burst open?
2. What are the problems with this method for achieving a consistent launch?
3. How many other methods can you think of for achieving a consistent launch of the model bob skeleton?

Does Barbie make a difference?

In this activity you will look at the effect of loading the model bob skeleton to investigate how the weight and shape of a load can affect the behaviour, speed and distance travelled by a bob skeleton.

You will need

- A doll that is approximately 300 mm long (figure PA 6.01)
- Tape and rubber bands for attaching the loads to the model bob skeleton
- Weights (figure PA 6.02)
- Modelling material (figure PA 6.03)

Activities

1. Attach a doll to the model bob skeleton as shown in figure PA 6.01. Launch the bob skeleton using different pressures.

   Record the distance travelled and describe the behaviour of the skeleton.
2. Attach the doll to the bob skeleton so that its feet are facing forward. Launch the bob skeleton using different pressures.

   Record the distance travelled and describe the behaviour of the skeleton.
3. Attach the doll to the bob skeleton so that it is sitting up and facing forward. Launch the bob skeleton using different pressures.

   Record the distance travelled and describe the behaviour of the skeleton.
4. Load one side of bob skeleton only using weights or modelling material. Launch the bob skeleton using different pressures.

   Record the distance travelled and describe the behaviour of the skeleton.

FIGURE PA 6.01

A Barbie doll's scale is 1:5 (just like the bob skeleton model), which means it is approximately five times smaller than the average woman.

Barbie's weight is 130g.

a) Is Barbie's weight five times smaller than a female bob skeleton athlete, which can be 52kg – 76kg?

b) Do you need to add more weight to your model bob skeleton so its load is correctly scaled?

WWW.SXC.HU FIGURE PA 6.02

WWW.SXC.HU FIGURE PA 6.03

QUESTIONS

What effect does weight have on the way the bob skeleton moves, its speed and the distance it travels?

Converting metres per second (m/s) into kilometres per hour (km/hr) and miles per hour (miles/hr)

The velocity (commonly refered to as speed) of objects studied in science are measured in metres per second (m/s). However, most people have an understanding of speed in terms of kilometres or miles per hour.

To convert metres/second into km/hr start by converting your figure into metres/minute.

For example:

If your model bob skeleton travelled at 2.78 m/s you will need to multiply this figure by 60 as there are 60 seconds in a minute.

2.78 x 60 = 166.8

This means the model is travelling at 166.8 metres per minute.

You then need to multiply 166.8 by 60 to find out how many metres the model bob skeleton travels in one hour. Why 60? Because there are 60 minutes in an hour.

166.8 x 60 = 10008

You now know the speed of the model was 10008 metres per hour or 10008 m/h.

To convert this figure into kilometres per hour or km/hr you need to divide 10008 by 1000 as there are 1000 metres in a kilometre.

10008 ÷ 1000 = 10.008 km/hr

If written to two decimal places the speed of the model bob skeleton was:

10.01 km/hr

To convert this figure into miles per hour (Mph) you need to divide it by 1.609344:

10.01 Kph ÷ 1.609344 = 6.22 miles/hr

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WWW.SXC.HU/PHOTO/542966

SCALING UP THE SPEED

The model bob skeleton is 1:5 scale, which means it is five times smaller than a full size (1:1) bob skeleton.

To scale up the speed of the model you need to multiply its speed by 5.

10.01 km/hr x 5 = **50.05 km/hr**

6.22 miles/hr x 5 = **31.1 miles/hr**

QUESTIONS

1. Convert the following speeds into miles/hour
   (a) 5m/s (b) 10 m/s
   (c) 20 m/s (d) 40 m/s
2. Convert 80 miles/hour into metres/second

Potential energy (PE)

The energy an object would release if it falls is called its potential energy. Potential Energy is measured in Joules.

The rock at the top of the cliff in figure MS 2.01 and the bob skeleton athlete and their sled in figure MS 2.02 have potential energy. We can calculate how much potential energy the rock releases by falling using the equation:

Change in potential energy (PE) of rock = m x g x h

m = Mass, which is a measure of the amount of matter there is in an object and is expressed in kilograms (kg).

g = Acceleration (the change in an object's position every second) due to the earth's gravitational pull, which is 9.81 m/s^2. This does not change much on earth.

h = The change in height of the object, measured in metres (m).

PE of the rock =

100 kg x 9.81 m/s^2 x 150 m = 147,150 **Joules**

Task

1. **Use the potential energy (PE) equation to calculate the change in potential energy of two athletes who competed in the bob skeleton event at the 2010 Winter Olympics in Vancouver, Canada.**

   Data for the track and the athletes can be found in table 1.

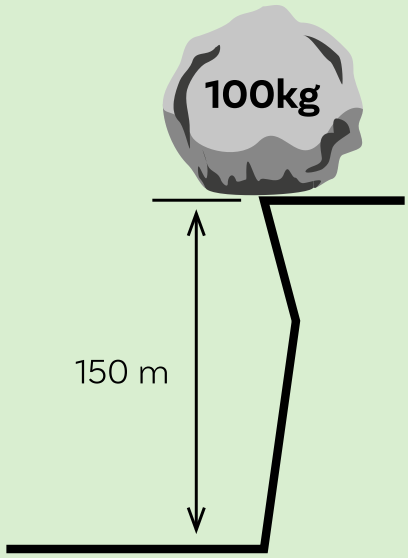


FIGURE MS 2.01

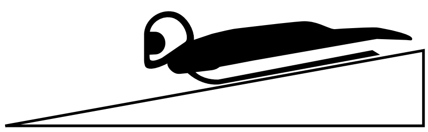


FIGURE MS 2.02

TABLE 1

Track location:	Whistler, Canada
Track length:	1,450 m
Vertical drop:	152 m
Amy Williams (GB)	
Height:	1.73 m
Athlete mass:	63 kg
Sled mass:	34 kg
Kerstin Symkowaik (Germany)	
Height:	1.64 m
Athlete mass:	70 kg
Sled mass:	33 kg

Kinetic energy (KE)

Kinetic energy is present in all moving objects. Like potential energy it is measured in Joules.

The rock and the bob skeleton athlete and their sled both have kinetic energy. The rock gains kinetic energy when it falls off the cliff, as do the bob skeleton and athlete when they slide down the track.

We can calculate the kinetic energy (KE) of an object using the equation:

$$KE = \frac{1}{2} \times m \times v^2$$

m = Mass, which is a measure of the amount of matter there is in an object and is expressed in kilograms (kg).

v = Velocity, which is the speed of the object and is measured in metres per second (m/s). For example, an object travelling at 5 m/s will cover a distance of 5 metres in one second.

The kinetic energy (KE) of the bob skeleton and athlete in figure MS 3.02 is:

$$0.5 \times (63 + 34) \times (22.5 \times 22.5)$$

$$0.5 \times 97 \times 506.25 = 24\ 553 \text{ Joules}$$

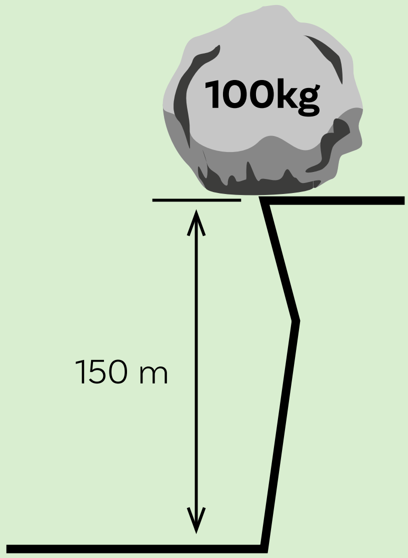


FIGURE MS 3.01

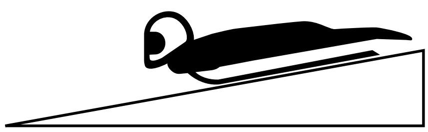


FIGURE MS 3.02

Athlete mass:	63 kg
Sled mass:	34 kg
Velocity:	22.5 m/s (50 mph)

Task

Does an increase in mass have a bigger effect on the kinetic energy (KE) of the bob skeleton than an increase in velocity?

Use the above equation to find out what happens to KE when:

(a) A 73 kg athlete slides down the track at 50mph. You will need to convert this velocity into metres/second. Support sheet MS 1 provides guidance on converting different units of velocity.

(b) A 63 kg athlete slides down the track at 27 m/s (60mph)

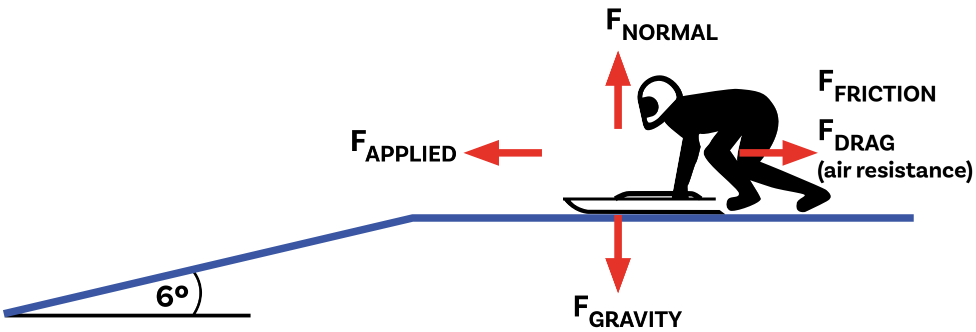
Question

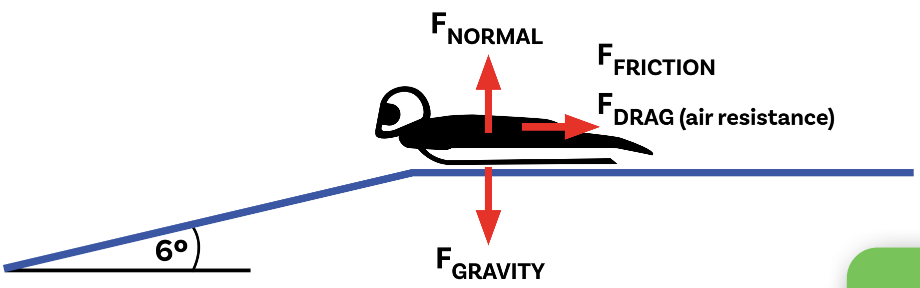
Notice that the kinetic energy is much lower than the potential energy calculated earlier. Why?

The forces acting on the bob skeleton

The net (total) force acting on the athlete and the bob skeleton is the sum of all the forces pushing them down the track minus all the forces resisting their forward movement.

Frictional force ($F_{FRICTION}$) and wind resistance (F_{DRAG}) are two forces that resist the forward movement of the athlete and the sled.





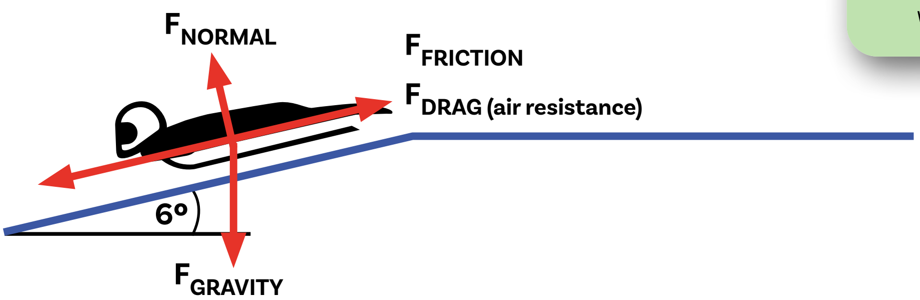


FIGURE MS 4

Athlete mass:	63 kg
Sled mass:	34 kg
Velocity:	22.5 m/s (50 mph)

Transferring energy

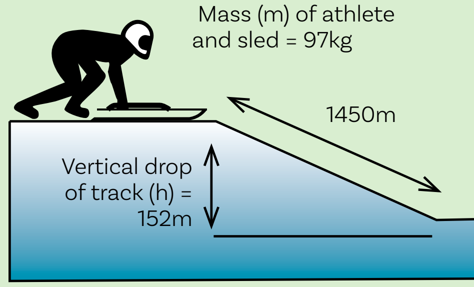


diagram not to scale

FIGURE MS 5.01

Energy can be transferred usefully, stored or dissipated, but cannot be created or destroyed. [(1)]

In the case of the bob skeleton, energy is transferred from its potential form to its kinetic form.

The more complete and efficient the transformation the faster the athlete and sled will travel.

In descending 152 m the 97 kg athlete and sled transfers 144 639 Joules (J) of potential energy. We arrive at this figure using the potential energy (PE) equation:

$$PE = m \times g \times h$$

(**h** is the change in height from the top to the bottom of the track - **see support sheet MS 2** for definitions for **m** and **g**).

The line graph above shows that if all the potential energy (PE) were to be transformed into kinetic energy (KE) then the athlete and sled would need to travel at 55 m/s (122 miles per hour) to reach a KE figure of 144 639 J. However, the 2010 bob skeleton Olympic champion, Amy Williams, is known to travel at a maximum speed of 90 mph (40.23 m/s).

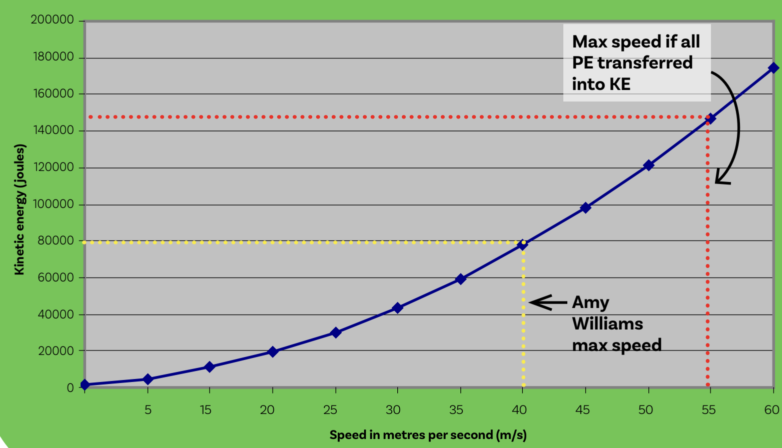
Our simple analysis of the energy transfer over estimates the maximum speed of the athlete and sled by 15 m/s or 37% because it neglects the affects of aerodynamic drag and friction.

An analysis of energy transfer during a bob skeleton run allows us to make a rough estimate of the maximum speed an athlete of a given mass can travel at. However, we could achieve a more accurate prediction if we analyse forces rather than energy.

Forces are interactions between objects and can affect their shape and motion. [(2)]

Support sheet MS 10 uses values for the gravitational force drawing the bob skeleton down the track, friction force and aerodynamic drag force to calculate the maximum speed of the bob skeleton and athlete. This method estimates Amy Williams' maximum speed to be 97 mph (43.52 m/s), which is 7 mph or 8% faster than her actual maximum speed. This is clearly an improvement in our prediction of maximum speed.

THE BOB SKELETON:
kinetic energy gained during a run



[(1)] *The National Curriculum for KS3 Science, 3.1a*

[(2)] *The National Curriculum for KS3 Science, 3.1b*

Force (F)

Force is a push or a pull, which if big enough, makes an object move or deform its shape. Gravity is a force that pulls all objects towards the centre of the earth. Gravity is also one of the forces that cause the bob skeleton to slide towards the bottom of the sloping track.

On a level track the athlete and her bob skeleton stay still (figure MS 6.01). If the athlete and her bob skeleton are on a slope they will start to move and accelerate (get faster).

Calculating the gravitational force on an object allows us to discover its weight. In science an object's weight is the gravitational force acting on it.

Force (F) is measured in newtons. The symbols for newtons is **N**.

The following equation can be used to find the gravitational force on the athlete and sled in table 2:

$$F = m \times g$$

See support sheet MS 2 for a reminder about **m** and **g**.

Gravitational force (F) on the bob skeleton athlete and sled is:

$$97 \text{ kg} \times 9.81 \text{ m/s}^2$$

$$F = 951.57 \text{ newtons (N)}$$

Task

Calculate the mass of each athlete in table 3.
You will need to rearrange the equation used to find $F_{GRAVITY}$.

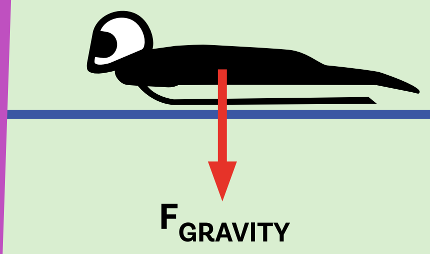


FIGURE MS 6.01

TABLE 2

Athlete mass:	63 kg
Sled mass:	34 kg
Combined mass:	97 kg

TABLE 3

Athlete 1 = $F_{GRAVITY}$	**1108.53 N**
Sled mass:	33 kg
Athlete 2 = $F_{GRAVITY}$	**1088.91 N**
Sled mass:	33 kg
Athlete 3 = $F_{GRAVITY}$	**1079.1 N**
Sled mass:	35 kg

Weight

The weight of an object is the gravitational force acting on it. Weight is measured in newtons (N) and is different to mass, which is measured in kilograms (kg) and tells us how much matter is in an object.

The weight of the bob skeleton athlete in figure MS 7.01 is **951.57 N**. We discovered this using the equation:

$$F = m \times g$$

$$F = 97\ kg \times 9.81\ m/s^2 = 951.57\ N$$

The component of the weight of the athlete and her sled acting down the 6° slope in figure MS 7.02 is calculated using the following equation:

$$F_x = m \times g \times \sin \theta^0$$

sin θ° = The sine of an angle, in our case the 6° angle of the slope. We need to use sin θ because we are **resolving** the **vertical gravitational force** through an angle of **90° - θ°**. Cos (90° - θ°) = sin θ°.

θ = Theta, the symbol for an angle

The **gravitational force (F_x)** acting on the athlete and sled in figure 8.02 is:

$$97\ kg \times 9.81\ m/s^2 \times \sin 6^0 = 99.48\ N$$

This shows that the force acting to accelerate the sled down the slope is 99.48 N which is about 10% of the combined weight of the sled and rider.

Athlete's mass	Sled's mass	Combined mass	Gravitational acceleration	Angle of track slope in degrees	Gravitational force (F_x)
63	34	97	9.81 m/s²	**6°** (10.5%)	**99.48 N**
63	34	97	9.81 m/s²	**7°** (12.3%)	**115.97 N**
63	34	97	9.81 m/s²	**8°** (14.1%)	
63	34	97	9.81 m/s²	**9°** (15.9%)	
63	34	97	9.81 m/s²	**10°** (17.6%)	
63	34	97	9.81 m/s²	**11°** (19.4%)	

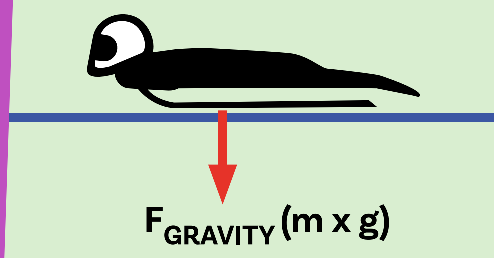


FIGURE MS 7.01

Athlete mass:	63 kg
Sled mass:	34 kg
Combined mass:	97 kg

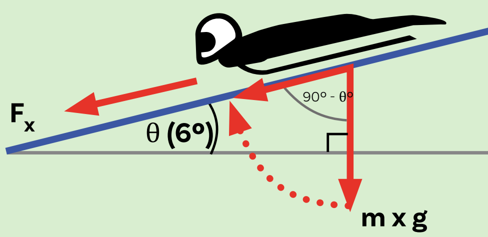


FIGURE MS 7.02

TASK

Use the equation above to investigate how increasing the mass and the angle of the slope affect the force acting on the sled to accelerate it down the hill.

You might record your investigation of the angle of slope using a table similar to the example below.

DISCUSSION

What happens to gravitational force when a heavier athlete gets on a bob skeleton sled?

Friction

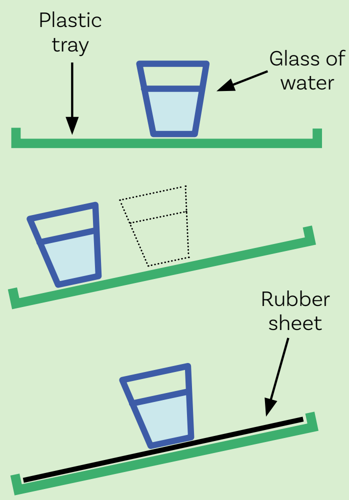


FIGURE MS 8.01

A glass of water on a plastic tray will slide to the left if the right hand side of the tray is lifted up. This is because there is little frictional force acting between the bottom of the glass and the top of the tray. Placing a sheet of rubber between the glass and the tray would stop the glass from sliding because there is a lot of frictional force between the two surfaces.

Friction is a force that resists the movement of two surfaces against each other.

In the bob skeleton event the sled slides easily over the ice. However, frictional forces are present where any two surfaces move or rub against each other.

We can investigate the affect friction has on a bob skeleton run using the following equation.

$$F_f = \mu \times m \times g \times \cos \theta^{0}$$

F_f = Frictional force

μ = Mu, the 12th letter of the Greek alphabet, is the symbol for the coefficient of friction, which is a number that represents the amount of friction between two surfaces. See table 4 for some examples of coefficients of friction and to find out the figure for the steel runners of the skeleton on the ice of the track.

m = Mass of the bob skeleton athlete and sled, which is **97 kg** in the example below.

g = The acceleration (the change in an object's position every second) due to the earths gravitational pull, which is **9.81 m/s²**

cos θ = The cosine of an angle, in our case the 6º angle of the slope. We need to use cos θ because we are **resolving** the vertical gravitational force through an angle of θ.

$$F_f = 0.03\ \mu \times 97\text{ kg} \times 9.81\text{ m/s}^2 \times \cos 6^{0} = 28.39\text{ N}$$

Compare this answer to the figure for the gravitational force **(F_x)** of the athlete and sled on a 6º slope (99.48 N). The friction force will not be enough to stop the athlete and sled from sliding down the slope (although at 28% of the gravitational force it will slow it down significantly).

TABLE 4

Coefficients of friction (μ)	
rubber - rubber	1.16
rubber - concrete	1.02
metal - wood	0.2 - 0.6
felt - wood	0.22
ice - steel	0.03

Source: http://en.wikipedia.org/wiki/Friction#Coefficient_of_friction

Questions

1. **What happens to the friction levels when the mass of the athlete increases by 10%?**
2. **How is friction force affected by an increase in the track's slope?**
3. **Does increasing the athlete's mass have a bigger impact on friction force than increasing the angle of the track's slope?**

DISCUSSION

What happens to friction force when a heavier athlete gets on a bob skeleton sled?

Aerodynamic drag – part 1

PART 1

The athlete and bob skeleton sled's forward motion down the track is resisted by:

- friction between the sled's runners and the ice
- the air

The resistance provided by the air passing over the athlete and the bob skeleton sled is a force called aerodynamic drag.

We can calculate the drag force (F_{DRAG}), or air resistance, acting on the bob skeleton sled and athlete as it travels down the track using the equation below.

$$F_{DRAG} = ½ \times \rho \times C_D \times A_f \times V^2$$

= Rho is the 17th letter of the Greek alphabet and is the symbol for density. In order to calculate air resistance we need to know the density of the air the athlete and bob skeleton are travelling through. Table 5 gives the density of a range of different fluids and solids. The density of air is 1.2 kg/m^3.

C_D = The drag coefficient is a number that is given to an object based on its shape. Different shapes have different drag coefficient numbers (table 6). The half sphere has a lower drag coefficient than the other shapes in table 6 and offers less air resistance.

The **athlete and bob skeleton** are a similar shape to a bullet (figure MS 9.01), which has a drag coefficient of approximately **0.3** but in practice the drag will be higher (**assume 0.45**)

A_f = This is the frontal area of the athlete and bob skeleton sled and is measured in m^2. The frontal area of the athlete and bob skeleton are the parts that collide with the air in front first (figure MS 9.02). See the next sheet for a more detailed explanation of frontal area.

V^2 = This is the velocity (speed) of the athlete and bob skeleton squared (multiplied by itself). V is measured in metres per second (m/s or ms^{-1})

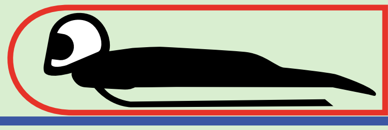


FIGURE MS 9.01

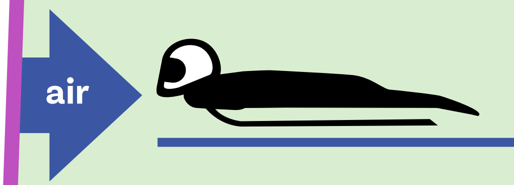


FIGURE MS 9.02

TABLE 5

Densities of different materials

Air (sea level)	1.2 kg/m^3
Water (fresh)	1000 kg/m^3
Water (salt)	1030 kg/m^3
Expanded Polystyrene	30 – 120 kg/m^3
Plastics	850 – 1400 kg/m^3
Iron	7874 kg/m^3
Gold	19300 kg/m^3

Source: http://en.wikipedia.org/wiki/Density

TABLE 6

Drag coefficient of different shapes

Sphere	0.47
Half sphere (hemisphere)	0.42
Cone	0.5
Cube	1.05

Source: http://en.wikipedia.org/wiki/Drag_coefficient

Aerodynamic drag – part 2

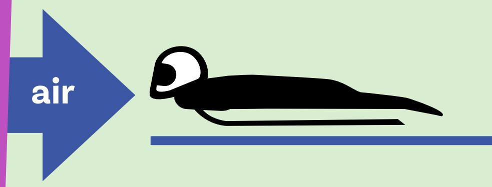


FIGURE MS 9.03

PART 2

Calculating frontal area

The frontal area of the athlete and bob skeleton are the parts of athlete that collide with the air in front first (figure MS 9.03).

The frontal area of the athlete and sled is made up of:

- the athlete's crash helmet
- The athlete's shoulders (figure MS 9.04)
- The front edge of the sled (figure MS 9.04)
- The front of the runners (figure MS 9.04)

Task

Calculate the total frontal area for the athlete and the bob skeleton

Part	Length (approx)	Width (approx)	Frontal area (m^2)	Frontal area (%)
Helmet	0.25 m	0.20 m	0.05	36 %
Shoulders	0.32 m	0.20 m	0.064	46 %
Bob skeleton	0.52 m	0.045 m	0.0234	17 %
Runners	0.10 m	0.016 m	0.0016	1 %
		Total frontal area	0.139	100 %

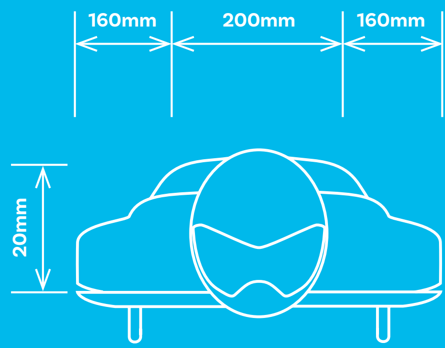


FIGURE MS 9.04

This front view of the athlete lying on the bob skeleton gives an indication of the frontal area.

The frontal area of the athlete's shoulders is approximately 0.32 m x 0.2 m. The frontal area of the bob skeleton measures approximately 0.52 m x 0.045 m. The frontal area of one runner is approximately 0.05 m x 0.016 m.

Calculating aerodynamic drag

Tasks

1. **Calculate F_{DRAG} for a bob skeleton athlete travelling at 20 mph (8.94 m/s)**

   Example

   F_{DRAG} = **½ x x C_D x A_f x V^2** (see previous sheet for definitions)

   F_{DRAG} = 0.5 x 1.2 x 0.45 x 0.139 x (8.94 m/s x 8.94 m/s)

   F_{DRAG} = 0.5 x 1.2 x 0.45 x 0.139 x 79.92

   F_{DRAG} = 3.00 N

2. Calculate F_{DRAG} for a bob skeleton athlete travelling at the following velocities:

(a) 40 mph (17.88 m/s)

(b) 80 mph (35.76 m/s)

DISCUSSION

What happens to drag force when a larger athlete gets on a bob skeleton sled?

What is the maximum theoretical speed of the bob skeleton?

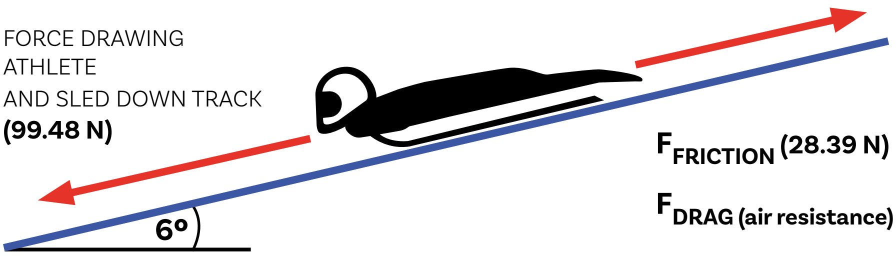
The net (total) force acting on the athlete and the bob skeleton is the sum of all the forces pushing them down the track minus all the forces resisting their forward movement.

If you ignore the effects of aerodynamic lift and regelation (which is the term given to the melting of ice under pressure), as the bob skeleton travels faster down the slope, the **drag force** (air resistance) **increases** while the **friction** force remains **constant**.

Eventually, the friction and drag force added together grow to equal the force of gravity, which is drawing the bob skeleton and athlete down the slope. At this point, no more acceleration can take place and maximum speed is reached.

The maximum speed possible can be calculated using the F_{DRAG} equation if we know:

- The force drawing the bob skeleton and athlete down the slope = **99.48 N**
- The friction force = **28.39 N**
- The difference between the force drawing the sled down the slope and the friction force = **99.48 N – 28.39 N = 71.09 N**



MPH	F_{DRAG}
0	0 N
20	3.00 N
40	12.00 N
60	27.00 N
80	47.99 N

Calculating max speed (V)

$$F_{DRAG} = ½ \times \rho \times C_D \times A_f \times V^2$$

V = the square root of the difference between the forces ÷ (0.5 x density of air x drag coefficient of athlete and sled x frontal area)

V^2 = **71.09 ÷ (½ x 1.2 x 0.45 x 0.139)**

V^2 = 71.09 / 0.03753 = 1894.22

V = √ 1894.22

V = 43.52 m/s (97 miles per hour) – **at this speed friction and drag stops the athlete and bob skeleton from accelerating (getting faster)**.

How do athletes steer the bob skeleton?

We have calculated:

The **gravitational force** accelerating the bob skeleton and athlete down the slope is **99.48 N**.

The **friction force** between the steel runners and the ice is **28.39 N**.

The **aerodynamic force** at maximum speed is **71.09 N**.

So, at high speeds the friction force is small compared to the aerodynamic force.

At high speeds, the athlete is better off trying to use aerodynamic forces to steer as these will have more effect. Moving their head has a significant effect on aerodynamic forces and can act like a rudder on an aeroplane.

At lower speeds, the aerodynamic force will be of a similar size to the friction force. By shifting their weight on the skeleton, the athlete can create different friction levels on the two runners and the skeleton can be steered.

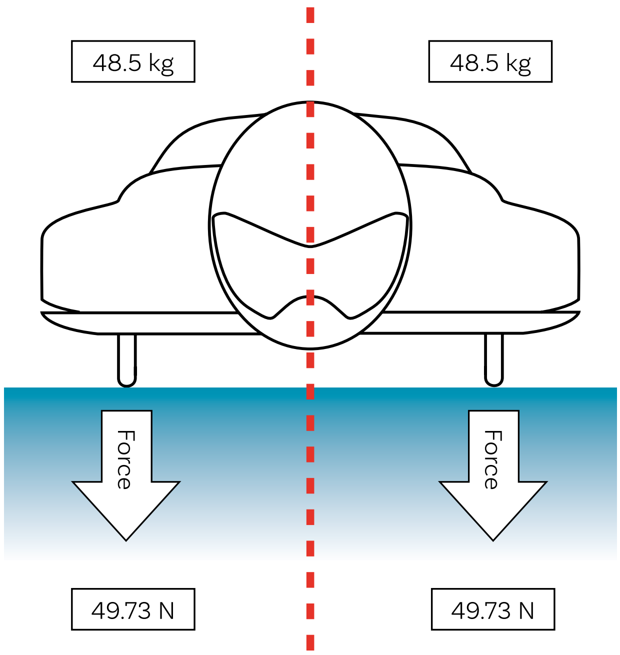
At the lowest speeds, the athlete can let their foot touch the ice. This increases friction force dramatically and suddenly and a large steering force is produced. Watch out – it can cause the athlete to crash!

So the mathematics and science of gravitational force, friction and aerodynamic drag tells us that there is no single way of steering a skeleton bob. The athlete is trained to use a combination of head position, body position and sometimes foot position to steer instinctively.

FIGURE MS 11.01

Athlete mass:	63 kg
Sled mass:	34 kg
Track gradient:	6º
Combined mass:	97 kg

But which is more important, the athlete or the machine?



APPENDIX – A TABLE FOR RECORDING MODEL BOB SKELETON TESTING

Pump tube position	Start incline (degrees °)	Launch pressure	Load (description)	Load mass (Kg)	Description of bob skeleton's behaviour during test	Total distance travelled (metres)	Time for 1 metre section	Speed
50 mm		N/A	N/A	N/A	Straight and no heave or pitch (lift). Yaws (rotates around z axis) a little at the end of the run.	1.50 m		

The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

In collaboration with our Fellows and partners, we're growing talent and developing skills for the future, driving innovation and building global partnerships, and influencing policy and engaging the public.

Together we're working to tackle the greatest challenges of our age.

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We're growing talent by training, supporting, mentoring and funding the most talented and creative researchers, innovators and leaders from across the engineering profession.

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We're influencing policy through the National Engineering Policy Centre – providing independent expert support to policymakers on issues of importance.

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Front cover image: Amy Williams competes in the Vancouver 2010 Olympic Winter Games

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