Which is more important in the bob skeleton event?

A STEM teaching and learning resource from The Royal Academy of Engineering
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The importance of STEM learning is recognised by school teachers and leaders alike. However, giving students the opportunity to take part in a true STEM learning activity is a considerable challenge for most schools.

Timetabling and location sometimes provide barriers that make it difficult for STEM teachers to work together to deliver STEM learning, but teaching and learning resources which contextualise STEM help to address both these barriers and demonstrate to students just how relevant science and engineering can be to our daily lives.

Our team of engineers from BAE Systems worked along side Southampton University, Sheffield Hallam University and UK Sport to help Amy Williams’ achieve her gold medal dreams by designing and constructing her sled ‘Arthur’.

With engineers and technicians in short supply I truly hope that teaching resources like this inspire young people to become the next generation of engineers by helping them to understand the role of engineering in our society and how their ideas and expertise shape our world and improve our lives.

Kelvin Davies
Group Leader, Human Factors & BAE SYSTEMS UK Sport Technology Partnership Project Lead
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.
Overview

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**KEY TO ABBREVIATIONS**

MS – Maths and science activity support sheet
PA – Practical activity support sheet
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](http://www.skeletonamy.co.uk/gallery.html)
  Amy Williams’ website
- [www.youtube.com/watch?v=jR1YbCMhxfl](http://www.youtube.com/watch?v=jR1YbCMhxfl)
  Chris Evans is coached by Amy Williams
- [www.youtube.com/watch?v=1DBWe1CmUmg](http://www.youtube.com/watch?v=1DBWe1CmUmg)&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&nocache=1&L=0](http://fibt.pixabit.de/index.php?id=121&nocache=1&L=0)
  Information about the bob skeleton from the sport’s international governing body the FIBT.
- [www.bobskeleton.org.uk](http://www.bobskeleton.org.uk)
  The website for the British skeleton team, and a good source of information about the sport.
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
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, 5°, 10°, 15° and 20°.

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.
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 at www.raeng.org.uk/kristanbromleyvideo 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?
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)

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

Actual size of model

Athlete or machine? Which is more important in the bob skeleton event?
In this activity you will make a launcher for the bob skeleton scale model you have made.

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).
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.

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.
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.

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:

\[
\text{Speed} = \frac{1 \text{ metre}}{0.36 \text{ seconds}}
\]

\[\text{Speed} = 2.78 \text{ metres per second (m/s)}\]

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

**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?

**KEY FOR FIGURE 5.01**

1. rigid sheet material
2. tie to prevent part a causing injury
3. clear acrylic tube
4. 6 mm hole drilled in launch pipe
5. elastic band to hold part a to the top of the tube
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.**

**Questions**

What effect does weight have on the way the bob skeleton moves, its speed and the distance it travels?
The velocity (commonly referred 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.

\[
2.78 \times 60 = 166.8
\]

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.

\[
166.8 \times 60 = 10008
\]

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.

\[
10008 \div 1000 = 10.008 \text{ km/hr}
\]

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

\[
10.01 \text{ km/hr}
\]

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

\[
10.01 \text{ Kph} \div 1.609344 = 6.22 \text{ miles/hr}
\]

**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.

\[
10.01 \text{ km/hr} \times 5 = 50.05 \text{ km/hr}
\]

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
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:

\[
\text{Change in potential energy (PE) of rock} = m \times g \times h
\]

\( m = \) 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** = 

\[
100 \text{ kg} \times 9.81 \text{ m/s}^2 \times 150 \text{ m} = 147,150 \text{ Joules}
\]

**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.

**Table 1**

<table>
<thead>
<tr>
<th>Track location:</th>
<th>Whistler, Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track length:</td>
<td>1,450 m</td>
</tr>
<tr>
<td>Vertical drop:</td>
<td>152 m</td>
</tr>
<tr>
<td>Amy Williams (GB)</td>
<td></td>
</tr>
<tr>
<td>Height:</td>
<td>1.73 m</td>
</tr>
<tr>
<td>Athlete mass:</td>
<td>63 kg</td>
</tr>
<tr>
<td>Sled mass:</td>
<td>34 kg</td>
</tr>
<tr>
<td>Kerstin Symkowaik (Germany)</td>
<td></td>
</tr>
<tr>
<td>Height:</td>
<td>1.64 m</td>
</tr>
<tr>
<td>Athlete mass:</td>
<td>70 kg</td>
</tr>
<tr>
<td>Sled mass:</td>
<td>33 kg</td>
</tr>
</tbody>
</table>
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:

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

\[ m = \text{Mass, which is a measure of the amount of matter there is in an object and is expressed in kilograms (kg).} \]

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

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

\[ 0.5 \times (63 + 34) \times (22.5 \times 22.5) = 24553 \text{ Joules} \]

**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 ($F_{\text{friction}}$) and wind resistance ($F_{\text{drag}}$) 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

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.

(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:

\[
97 \text{ kg} \times 9.81 \text{ m/s}^2 = 951.57 \text{ newtons (N)}
\]

Task

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

<table>
<thead>
<tr>
<th>TABLE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athlete mass: 63 kg</td>
</tr>
<tr>
<td>Sled mass: 34 kg</td>
</tr>
<tr>
<td>Combined mass: 97 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athlete 1 = ( F_{\text{GRAVITY}} ) 1108.53 N</td>
</tr>
<tr>
<td>Sled mass: 33 kg</td>
</tr>
<tr>
<td>Athlete 2 = ( F_{\text{GRAVITY}} ) 1088.91 N</td>
</tr>
<tr>
<td>Sled mass: 33 kg</td>
</tr>
<tr>
<td>Athlete 3 = ( F_{\text{GRAVITY}} ) 1079.1 N</td>
</tr>
<tr>
<td>Sled mass: 35 kg</td>
</tr>
</tbody>
</table>
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:

\[ F = m \times g \]

\[ F = 97 \text{ kg} \times 9.81 \text{ m/s}^2 = 951.57 \text{ N} \]

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:

\[ F_x = m \times g \times \sin \theta^\circ \]

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

\( \theta = \) Theta, the symbol for an angle

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

\[ 97 \text{ kg} \times 9.81 \text{ m/s}^2 \times \sin 6^\circ = 99.48 \text{ N} \]

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.
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 effect friction has on a bob skeleton run using the following equation.

\[ F_f = \mu \times m \times g \times \cos \theta \]

- \( F_f \) = Frictional force
- \( \mu \) = 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 Earth’s gravitational pull, which is 9.81 m/s².
- \( \cos \theta \) = The cosine of an angle, in our case the 6° angle of the slope. We need to use \( \cos \theta \) because we are resolving the vertical gravitational force through an angle of \( \theta \).

\[ F_f = 0.03 \times 97 \times 9.81 \times \cos 6^\circ = 28.39 \text{ N} \]

Compare this answer to the figure for the gravitational force (\( F_g \)) of the athlete and sled on a 6° 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).

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 \( F_{\text{DRAG}} \), or air resistance, acting on the bob skeleton sled and athlete as it travels down the track using the equation below.

\[
F_{\text{DRAG}} = \frac{1}{2} \times \rho \times C_D \times A_f \times V^2
\]

\( \rho = \) 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/m³.

\( C_D = \) 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 m². 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).

---

**TABLE 5**

<table>
<thead>
<tr>
<th>Densities of different materials</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air (sea level)</td>
<td>1.2 kg/m³</td>
</tr>
<tr>
<td>Water (fresh)</td>
<td>1000 kg/m³</td>
</tr>
<tr>
<td>Water (salt)</td>
<td>1030 kg/m³</td>
</tr>
<tr>
<td>Expanded Polystyrene</td>
<td>30 – 120 kg/m³</td>
</tr>
<tr>
<td>Plastics</td>
<td>850 – 1400 kg/m³</td>
</tr>
<tr>
<td>Iron</td>
<td>7874 kg/m³</td>
</tr>
<tr>
<td>Gold</td>
<td>19300 kg/m³</td>
</tr>
</tbody>
</table>

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

**TABLE 6**

<table>
<thead>
<tr>
<th>Drag coefficient of different shapes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>0.47</td>
</tr>
<tr>
<td>Half sphere (hemisphere)</td>
<td>0.42</td>
</tr>
<tr>
<td>Cone</td>
<td>0.5</td>
</tr>
<tr>
<td>Cube</td>
<td>1.05</td>
</tr>
</tbody>
</table>

*Source: http://en.wikipedia.org/wiki/Drag_coefficient*
Aerodynamic drag – part 2

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

<table>
<thead>
<tr>
<th>Part</th>
<th>Length (approx)</th>
<th>Width (approx)</th>
<th>Frontal area (m²)</th>
<th>Frontal area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helmet</td>
<td>0.25 m</td>
<td>0.20 m</td>
<td>0.05</td>
<td>36 %</td>
</tr>
<tr>
<td>Shoulders</td>
<td>0.32 m</td>
<td>0.20 m</td>
<td>0.064</td>
<td>46 %</td>
</tr>
<tr>
<td>Bob skeleton</td>
<td>0.52 m</td>
<td>0.045 m</td>
<td>0.0234</td>
<td>17 %</td>
</tr>
<tr>
<td>Runners</td>
<td>0.10 m</td>
<td>0.016 m</td>
<td>0.0016</td>
<td>1 %</td>
</tr>
<tr>
<td>Total frontal area</td>
<td></td>
<td></td>
<td>0.139</td>
<td>100 %</td>
</tr>
</tbody>
</table>

Calculating aerodynamic drag

Tasks

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

   Example
   
   $$F_{\text{DRAG}} = \frac{1}{2} \rho A_t x V^2$$
   (see previous sheet for definitions)
   
   $$F_{\text{DRAG}} = 0.5 \times 1.2 \times 0.45 \times 0.139 \times (8.94 \text{ m/s} \times 8.94 \text{ m/s})$$
   
   $$F_{\text{DRAG}} = 0.5 \times 1.2 \times 0.45 \times 0.139 \times 79.92$$
   
   $$F_{\text{DRAG}} = 3.00 \text{ N}$$

2. Calculate $F_{\text{DRAG}}$ 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 \( F_{\text{DRAG}} \) 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

### Calculating max speed (V)

\[
F_{\text{DRAG}} = \frac{1}{2} \times \rho \times C_D \times A_f \times V^2
\]

\[
V = \text{the square root of the difference between the forces ÷ (0.5 x density of air x drag coefficient of athlete and sled x frontal area)}
\]

\[
V^2 = 71.09 \div (\frac{1}{2} \times 1.2 \times 0.45 \times 0.139)
\]

\[
V^2 = 71.09 / 0.03753 = 1894.22
\]

\[
V = \sqrt{1894.22}
\]

\[
V = 43.52 \text{ m/s (97 miles per hour)} - \text{at this speed friction and drag stops the athlete and bob skeleton from accelerating (getting faster).}
\]
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.

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

**Figure MS 11.01**

- **Athlete mass**: 63 kg
- **Sled mass**: 34 kg
- **Track gradient**: 6°
- **Combined mass**: 97 kg
## Appendix – A Table for Recording Model Bob Skeleton Testing

<table>
<thead>
<tr>
<th>Pump Tube Position</th>
<th>Start Incline (Degrees °)</th>
<th>Launch Pressure</th>
<th>Load (Description)</th>
<th>Load Mass (Kg)</th>
<th>Description of Bob Skeleton’s Behaviour During Test</th>
<th>Total Distance Traveled (Metres)</th>
<th>Time for 1 Metre Section</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Straight and no heave or pitch (lift). Yaws (rotates around z axis) a little at the end of the run.</td>
<td>1.50 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Athlete or Machine? Which is more important in the Bob Skeleton event?**
Preparation

The lead teacher will need to complete the following tasks prior to the STEM Day:

- Organise students into groups of three. The group should ideally be made up of one student who is suited to D&T, one who is suited to mathematics and one who is suited to science.
- Ensure all the materials and equipment needed are available or have been purchased well in advance of the day.
- Join the hand pump to the launch tube and base as on page 11 of The Royal Academy of Engineering’s bob skeleton STEM resource, Athlete or Machine? Which is more important in the bob skeleton event?

Make copies for the students of the Guide to making a model bob skeleton and the Skeleton plan and drilling template, which are found on pages 9 and 10 of The Royal Academy of Engineering's bob skeleton STEM resource, Athlete or Machine? Which is more important in the bob skeleton event?

Time

The times suggested for each activity mean this scheme of work could be used for an 8.30am–3.00pm STEM Day that includes a 20 minute morning break and a 40 minute lunch.

<table>
<thead>
<tr>
<th>MATERIALS AND EQUIPMENT</th>
<th>SUGGESTED SUPPLIER AND PRODUCT CODE WHERE AVAILABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand pump</td>
<td><a href="http://www.mindsetsonline.co.uk">www.mindsetsonline.co.uk</a> [202 – 001]</td>
</tr>
<tr>
<td>22 mm plastic pipe (1 m length)</td>
<td><a href="http://www.homebase.co.uk">www.homebase.co.uk</a> [217815]</td>
</tr>
<tr>
<td>Timber or board (300 x 80 x 15)</td>
<td>Homebase/B&amp;Q</td>
</tr>
<tr>
<td>22 mm Pipe clips (nail fixing)</td>
<td><a href="http://www.plumbworld.co.uk">www.plumbworld.co.uk</a> [PWH0170]</td>
</tr>
<tr>
<td>2mm High impact polystyrene</td>
<td><a href="http://www.mindsetsonline.co.uk">www.mindsetsonline.co.uk</a> [231 – 223]</td>
</tr>
<tr>
<td>1.6 mm steel rod</td>
<td><a href="http://www.mindsetsonline.co.uk">www.mindsetsonline.co.uk</a> [CW3 012]</td>
</tr>
<tr>
<td>A4 acetate sheet</td>
<td>WH Smiths/Rymans</td>
</tr>
<tr>
<td>Rocket nose cones</td>
<td><a href="http://www.mindsetsonline.co.uk">www.mindsetsonline.co.uk</a> [ROC 009]</td>
</tr>
<tr>
<td>Cable ties</td>
<td>Homebase/B&amp;Q</td>
</tr>
<tr>
<td>Strong adhesive tape</td>
<td>Homebase/B&amp;Q</td>
</tr>
<tr>
<td>TIME</td>
<td>STUDENT/TEACHER ACTIVITY</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>10 minutes</td>
<td>Teacher</td>
</tr>
<tr>
<td></td>
<td>Introduction to the sport of bob skeleton and the</td>
</tr>
<tr>
<td></td>
<td>day’s challenge.</td>
</tr>
<tr>
<td>90 minutes</td>
<td>Teacher</td>
</tr>
<tr>
<td></td>
<td>Demonstrate how to make 1:5 model of bob skeleton</td>
</tr>
<tr>
<td></td>
<td>sled.</td>
</tr>
<tr>
<td></td>
<td>Students</td>
</tr>
<tr>
<td></td>
<td>Make a 1:5 scale model of bob skeleton.</td>
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<tr>
<td>20 minutes</td>
<td>Scientific investigation of friction.</td>
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<td></td>
<td>Teacher</td>
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<tr>
<td></td>
<td>✦ A practical demonstration to explain friction.</td>
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<tr>
<td></td>
<td>✦ An explanation of the factors that affect friction:</td>
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<tr>
<td></td>
<td>mass, gravity and the coefficient of friction.</td>
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<td></td>
<td>Students</td>
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<td></td>
<td>Complete a short experiment. For example, seeing how</td>
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<td></td>
<td>far the sled they have made travels when launched on</td>
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<td>different surfaces. Or observing the effect of</td>
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<td>adding adhesive tape and other finishes to the</td>
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<td></td>
<td>model sled’s runners.</td>
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<tr>
<td>TIME</td>
<td>STUDENT/TEACHER ACTIVITY</td>
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<td>----------------------------------------------------------------------------------------</td>
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<tr>
<td>20 minutes</td>
<td>Scientific investigation of aerodynamic drag (air resistance).</td>
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<td>Teacher</td>
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<tr>
<td></td>
<td>✦ A practical demonstration to explain aerodynamic drag (air resistance).</td>
</tr>
<tr>
<td></td>
<td>✦ An explanation of the factors that affect aerodynamic drag: frontal area, the density of air, drag coefficients, velocity.</td>
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<tr>
<td></td>
<td>Students</td>
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<tr>
<td></td>
<td>✦ Complete short experiment. For example, launch the sled with shapes attached that have different sized frontal areas. Students could launch the model with a 100 x 70 x 25 block attached in a variety of positions eg stood up, lying down. Or launch the model sled with different sized parachutes attached.</td>
</tr>
<tr>
<td></td>
<td>✦ Use scientific knowledge to write a justified answer to the big question: <strong>Athlete or Machine? Which is more important in the bob skeleton event?</strong> The team with the best answer will be awarded the science prize at the end of the day.</td>
</tr>
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<td></td>
<td><strong>NB Students should be informed that it is already understood that the sled is important for the athlete to get to the bottom of the track in the fastest time.</strong></td>
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<tr>
<td>20 minutes</td>
<td>Mathematic investigation of friction.</td>
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<td>Teacher</td>
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<tr>
<td></td>
<td>Provide a worked example of the linear equation for friction.</td>
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<td></td>
<td>Students</td>
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<tr>
<td></td>
<td>Use the friction equation to find out the friction force acting on the bob skeleton when different masses are applied. Use Microsoft Excel to create a line graph that shows how friction increases with mass.</td>
</tr>
<tr>
<td>TIME</td>
<td>STUDENT/TEACHER ACTIVITY</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>20 minutes</td>
<td><strong>Mathematic investigation of aerodynamic drag.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Teacher</strong></td>
</tr>
<tr>
<td></td>
<td>Provide a worked example of the linear equation for aerodynamic drag.</td>
</tr>
<tr>
<td></td>
<td>Use the aerodynamic drag equation to find out the drag force experienced by the bob skeleton as it accelerates down the track. Use Microsoft Excel to create a line graph that shows how drag force increases with velocity.</td>
</tr>
<tr>
<td></td>
<td>The students responsible for writing the answer to the question <strong>Athlete or Machine?</strong> should use what they have learned in this maths session to enhance their answer.</td>
</tr>
<tr>
<td></td>
<td>Students submit work to mathematics teacher. The team with the best work will be awarded the mathematics prize at the end of the day.</td>
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<td></td>
<td><strong>Students</strong></td>
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<tr>
<td></td>
<td>Launch the model bob skeleton, unloaded.</td>
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<tr>
<td>90 minutes</td>
<td>Launch model sled with Barbie doll attached.</td>
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<tr>
<td></td>
<td>Record the distance travelled.</td>
</tr>
<tr>
<td></td>
<td>Launch model sled with Barbie doll attached.</td>
</tr>
<tr>
<td></td>
<td>Record the distance travelled.</td>
</tr>
<tr>
<td></td>
<td>Experiment with friction and aerodynamic drag to make the model steer left or right from launch.</td>
</tr>
<tr>
<td></td>
<td>Modify bob skeleton models to go further with Barbie on board.</td>
</tr>
<tr>
<td>60 minutes</td>
<td><strong>Grand final.</strong></td>
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<td></td>
<td><strong>Students</strong></td>
</tr>
<tr>
<td></td>
<td>Students get three attempts at launching their team’s bob skeleton the furthest.</td>
</tr>
<tr>
<td></td>
<td>Complete an evaluation of the day’s activities while teachers decide prize winners.</td>
</tr>
<tr>
<td></td>
<td><strong>Teachers</strong></td>
</tr>
<tr>
<td></td>
<td>Award the following prizes:</td>
</tr>
<tr>
<td></td>
<td>D&amp;T – Furthest distance travelled by model.</td>
</tr>
<tr>
<td></td>
<td>Mathematics – Most complete and accurate answers to maths tasks.</td>
</tr>
<tr>
<td></td>
<td>Science – Most detailed answer to the question <strong>Athlete or Machine?</strong></td>
</tr>
<tr>
<td></td>
<td>Teamwork – The team where all members have worked together to produce a sled that is competitive.</td>
</tr>
</tbody>
</table>
**Calculating friction force on a flat surface**

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, friction force is present where any two surfaces move or rub against each other.

**Friction force equation**

We can investigate the affect friction has on the model bob skeleton sled using the following equation. Force is measured in Newtons (N).

\[
F_f = \mu \times m \times g
\]

- **\(F_f\)** = Friction force.
- **\(\mu\)** = 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.
- **\(m\)** = Mass of the bob skeleton sled and any additional load (measured in kg). Mass is the amount of matter there is in an object.
- **\(g\)** = The acceleration (the change in an object’s position every second) due to the earths gravitational pull, which is **9.81 m/s**\(^2\).

**Coefficients of friction**

Different combinations of materials have different coefficients of friction. For example:

- Rubber on rubber = 1.18 \(\mu\)
- Rubber on concrete = 1.02 \(\mu\)
- Steel on wood = 0.2 – 0.6 \(\mu\)
- Steel on ice = 0.03 \(\mu\)

**Tasks**

The worked example below shows how to calculate the friction force acting on a bob skeleton sled, without an athlete, with a mass of 33 kg, moving across flat section of track (using the equation above).

\[
F_f = 0.03 \mu \times 33 \text{ kg} \times 9.81 \text{ m/s}^2
\]

\[
F_f = 9.71 \text{ N}
\]

(a) Calculate the friction force for the bob skeleton sled once you have added an athlete with a mass of 75 kg.

(b) Describe the effect increasing mass has on friction force.

(c) Is friction force proportional? For example, does it increase by the same amount for every 1 kg added to the bob skeleton sled, which can have a maximum mass of 43 kg?
The model bob skeleton’s forward motion is resisted by air. The resistance provided by air passing over the sled is a force called aerodynamic drag.

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

\[
F_{\text{DRAG}} = \frac{1}{2} \rho C_D A_f V^2
\]

\( \rho \) = Rho is a character from 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. The density of air is 1.2 \( \text{kg/m}^3 \). The density of some other liquids and solids are given below.

Water (fresh) \( 1000 \text{ kg/m}^3 \)  Iron \( 7874 \text{ kg/m}^3 \)  Gold \( 19300 \text{ kg/m}^3 \)

\( C_D \) = The drag coefficient is a number that is given to an object based on its shape. Different shapes have different drag coefficient numbers. For example, a cube has a drag coefficient of 1.05.

The athlete and bob skeleton are a similar shape to a bullet, 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.

\( V^2 \) = 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\(^{-1}\)).

Frontal area

The table and drawing below show how the frontal area of a full size sled and athlete can be calculated.

### Table 1

<table>
<thead>
<tr>
<th>Part</th>
<th>Length (approx)</th>
<th>Width (approx)</th>
<th>Frontal area (m(^2))</th>
<th>Frontal area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helmet</td>
<td>0.25m</td>
<td>0.20m</td>
<td>0.05</td>
<td>36%</td>
</tr>
<tr>
<td>Shoulders</td>
<td>0.32m</td>
<td>0.20m</td>
<td>0.064</td>
<td>46%</td>
</tr>
<tr>
<td>Bob skeleton</td>
<td>0.52m</td>
<td>0.045m</td>
<td>0.0234</td>
<td>17%</td>
</tr>
<tr>
<td>Runners</td>
<td>0.10m</td>
<td>0.016m</td>
<td>0.0016</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total frontal area</strong></td>
<td></td>
<td></td>
<td><strong>0.139</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

**FIGURE 1**
The drag force ($F_{\text{DRAG}}$) experienced by the athlete and bob skeleton sled shown in figure 1, when travelling at 20 miles/hour (8.94 m/s) is calculated below.

\[
F_{\text{DRAG}} = \frac{1}{2} \times \rho \times C_D \times A_f \times V^2
\]

\[
F_{\text{DRAG}} = 0.5 \times \text{Density of air} \times \text{Coefficient of drag} \times \text{Frontal area} \times \text{Velocity squared}
\]

\[
F_{\text{DRAG}} = 0.5 \times 1.2 \times 0.45 \times 0.139 \times 8.94 \times 8.94
\]

\[
F_{\text{DRAG}} = 0.5 \times 1.2 \times 0.45 \times 0.139 \times 79.92
\]

\[
F_{\text{DRAG}} = 3 \text{ N}
\]

Tasks

1. Calculate $F_{\text{DRAG}}$ for the athlete and bob skeleton sled in figure 1 when they are travelling at 5, 10, 15, 20, 25, 30, 35, 40, 45 m/s:

2. Is drag force proportional to velocity? For example, does it double when you double the velocity of the athlete and bob skeleton?

3. Suggest three ways of reducing the drag force acting on a bob skeleton sled.

4. Which force provides most resistance to the athlete and bob skeleton?

Extension

(a) Plot a line graph to show the increase in drag force from 0 m/s to 45 m/s. Label the x axis and y axis as below.

(b) Add a line to the graph to represent the friction acting on the sleds runners between 0 m/s and 45 m/s. Add the label Friction Force to this line.
Athlete or Machine?

How would you modify the athlete and the bob skeleton sled to reduce friction and drag?

Label the two pictures below with your ideas.
The friction force and the aerodynamic drag force, that resist the forward movement of the athlete and bob skeleton sled, can be calculated using the equations below.

**Friction force ($F_f$)**

$$F_f = \mu \times m \times g$$

$F_f$ = coefficient of friction ($\mu$) x mass ($m$) x gravity ($g$)

**Task**

Use the equation above and the information to the right to calculate the friction force for Amy Williams and her bob skeleton sled.

**Drag force ($F_{\text{DRAG}}$)**

$$F_{\text{DRAG}} = \frac{1}{2} \times \rho \times C_D \times A_f \times V^2$$

$F_{\text{DRAG}} = \frac{1}{2} \times$ density of air ($\rho$) x drag coefficient ($C_D$) x frontal area ($A_f$) x velocity$^2$

**Task**

Use the equation above and the information to the right to calculate the drag force for Amy Williams and her bob skeleton sled at the following velocities:

(a) 5 m/s  
(b) 10 m/s  
(c) 15 m/s  
(d) 20 m/s  
(e) 25 m/s  
(f) 30 m/s  
(g) 35 m/s  
(h) 40 m/s  
(i) 45 m/s

---

**Table:**

| COEFFICIENT OF FRICTION FOR STEEL ON ICE ($\mu$) | 0.03 |
| MASS ($m$) |  
| Amy Williams | 63 kg |
| Sled | 44 kg |
| GRAVITY ($g$) | 9.81 m/s$^2$ |
| DENSITY OF AIR ($\rho$) | 1.2 kg/m$^3$ |
| DRAG COEFFICIENT ($C_D$) OF ATHLETE AND SLED’S SHAPE | 0.45 |
| FRONTAL AREA ($A_f$) OF ATHLETE AND SLED | 0.139 m$^2$ |
Athlete or Machine?

Use the results from your friction force calculations to plot and draw a line graph. Does friction force increase as the bob skeleton gets faster?

Use the results from your drag force calculations to plot and draw a second line graph.

Which force, do you think, an engineer would spend most effort trying to reduce? You can use the graphs on this page to explain your answer.
The friction force and the aerodynamic drag force, that resist the forward movement of the athlete and bob skeleton sled, can be calculated using the equations below.

Friction force ($F_f$)

$$F_f = \mu \times m \times g$$

$F_f =$ coefficient of friction ($\mu$) x mass (m) x gravity (g)

**Task**

Use the equation above and the information to the right to calculate the friction force for Amy Williams and her bob skeleton sled.

**Answer:**

$$F_f = 0.03 \times 107 \times 9.81 = 31.49 \text{ N}$$

Drag force ($F_{\text{DRAG}}$)

$$F_{\text{DRAG}} = \frac{1}{2} \times \rho \times C_D \times A_f \times V^2$$

$F_{\text{DRAG}} = \frac{1}{2}$ x density of air ($\rho$) x drag coefficient ($C_D$) x frontal area ($A_f$) x velocity$^2$

**Task**

Use the equation above and the information to the right to calculate the drag force for Amy Williams and her bob skeleton sled at the following velocities:

**Answer:**

- (a) $0.03753 \times (5 \times 5) = 0.94 \text{ N}$, $5 \text{ m/s} = 11.18 \text{ mph}$
- (b) $0.03753 \times (10 \times 10) = 3.75 \text{ N}$, $10 \text{ m/s} = 22.37 \text{ mph}$
- (c) $0.03753 \times (15 \times 15) = 8.44 \text{ N}$, $15 \text{ m/s} = 33.55 \text{ mph}$
- (d) $0.03753 \times (20 \times 20) = 15.01 \text{ N}$, $20 \text{ m/s} = 44.74 \text{ mph}$
- (e) $0.03753 \times (25 \times 25) = 23.46 \text{ N}$, $25 \text{ m/s} = 55.92 \text{ mph}$
- (f) $0.03753 \times (30 \times 30) = 33.78 \text{ N}$, $30 \text{ m/s} = 67.11 \text{ mph}$
- (g) $0.03753 \times (35 \times 35) = 45.97 \text{ N}$, $35 \text{ m/s} = 78.29 \text{ mph}$
- (h) $0.03753 \times (40 \times 40) = 60.05 \text{ N}$, $40 \text{ m/s} = 89.48 \text{ mph}$
- (i) $0.03753 \times (45 \times 45) = 76.00 \text{ N}$, $45 \text{ m/s} = 100.70 \text{ mph}$

**COEFFICIENT OF FRICTION FOR STEEL ON ICE ($\mu$)**

- 0.03

**MASS (m)**

- Amy Williams: 63 kg
- Sled: 44 kg

**GRAVITY (g)**

- 9.81 m/s$^2$

**DENSITY OF AIR ($\rho$)**

- 1.2 kg/m$^3$

**DRAG COEFFICIENT ($C_D$) OF ATHLETE AND SLED’S SHAPE**

- 0.45

**FRONTAL AREA ($A_f$) OF ATHLETE AND SLED**

- 0.139 m$^2$
Athlete or Machine?

Use the results from your friction force calculations to plot and draw a line graph. Does friction force increase as the bob skeleton gets faster?

Use the results from your drag force calculations to plot and draw a second line graph.

Which force, do you think, an engineer would spend most effort trying to reduce? You can use the graphs on this page to explain your answer.
Which is more important in the bob skeleton event?

A STEM teaching and learning resource from The Royal Academy of Engineering

Athlete or Machine?

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