Royal Academy of Engineering

Student guide

THIS IS ENGINEERING

WINNING MEDALS

Does engineering design make a difference?

This resource aims to give students the opportunity to investigate the impact of science, technology, engineering and mathematics (STEM) on wheelchair sport.

CONTENTS

INTRODUCTORY STUDENT ACTIVITY

Time to OBSERVE

What does wheelchair sport look like?

Use the internet to search for a video of wheelchair athletes competing against each other. Typing *'wheelchair basketball'* into the YouTube search box might be your starting point or you could go to **www.youtube.com/paralympicsporttv**.

Time to THINK

Try to identify the athletic skills that are important for wheelchair sport while you watch video footage of wheelchair athletes in action.

Time to THINK

What might life be like for a wheelchair athlete? What might be the challenges they have to face? What does it take to become a Paralympian?

Changes in the design of wheelchairs for sport

The first official Paralympic Games where wheelchair athletes competed against each other took place in Rome in 1960. The wheelchairs used by the Paralympians then looked very different to those used by wheelchair athletes today.

Time to THINK

Make a list of how the wheelchairs in Figure 1 and Figure 2 differ.
Why do you think there are differences between the two designs?

Figure 1: 1960s-style wheelchair

Figure 2: Modern basketball wheelchair

TECHNOLOGY AND ENGINEERING STUDENT ACTIVITY

Time to MAKE

Guide to making a model wheelchair

The photographs in this section explain how to make a 1:10 scale (approximately) model of a track wheelchair, which are the wheelchairs used by athletes competing in racing events such as the 400 m, the 800 m and the marathon.

This guide allows a standardised model of a track wheelchair to be made and used in the two practical STEM challenges. However, if the time and skills available are sufficient, it would be more of a challenge to design and build the model wheelchair from scratch.

Practical STEM challenge

Once made, the model can be used in the following practical STEM challenges.

1. How far can you launch a model wheelchair?
2. How straight can you make a model wheelchair travel? (Lane discipline is very important in wheelchair track events)

Materials required

- 3 mm corrugated plastic sheet
- 3.2 mm aluminium rod
- 3 mm steel rod
- 75 mm diameter polythene wheels x 2
- 39 mm diameter polythene wheel
- Drinking straw
- Blu-Tack

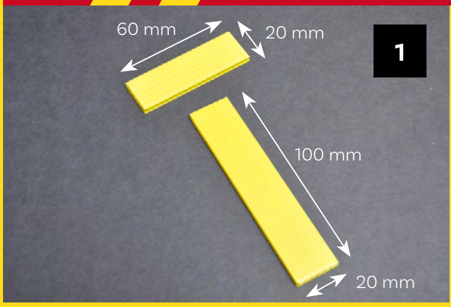
Tools required

- Scissors
- Hot glue gun or double-sided sticky pads
- Pliers
- Hand drill or cordless drill
- 4 mm drill bit

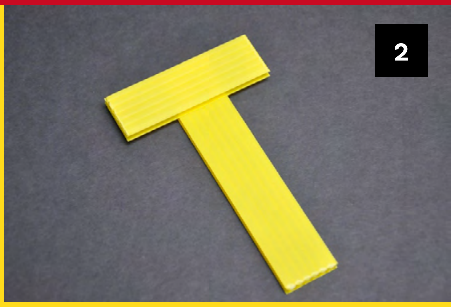
Optional

- Tyres for 39 mm and 75 mm wheels

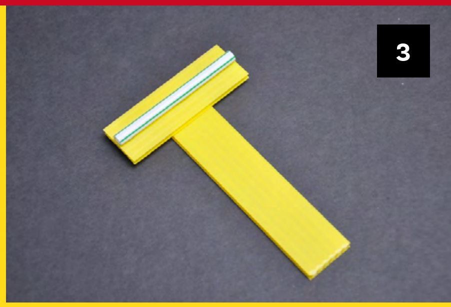
Making instructions



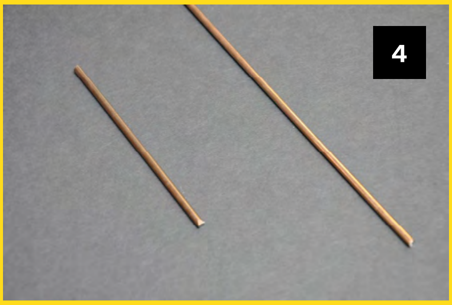
Cut two lengths of corrugated plastic for the wheelchair's chassis.



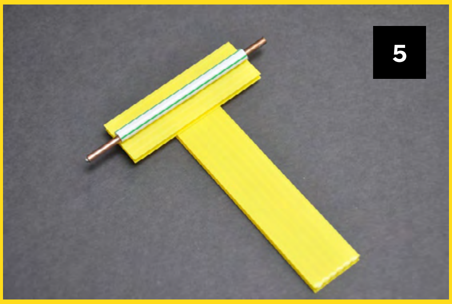
Join the corrugated plastic with hot glue or double-sided sticky pads.



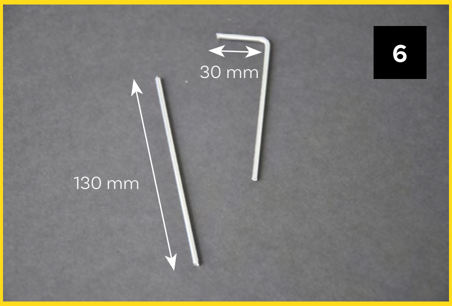
Fix a 60 mm length of drinking straw to the chassis with hot glue.



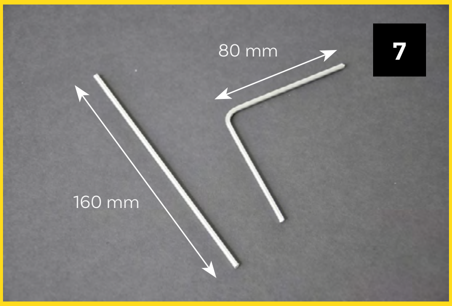
Make a rear axle by cutting an 85 mm length of the 3 mm steel rod.



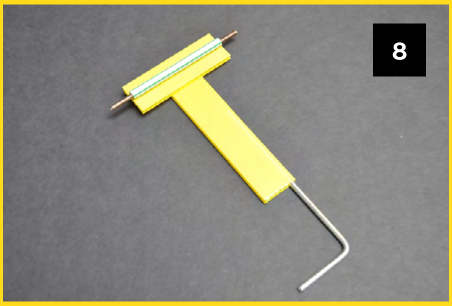
Insert the steel rod axle into the drinking straw on the underside of the chassis.



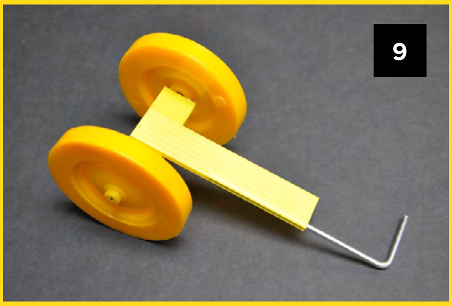
Cut one 130 mm length of the 3.2 mm aluminium rod. Make a 90° bend 30 mm from one end of the rod.



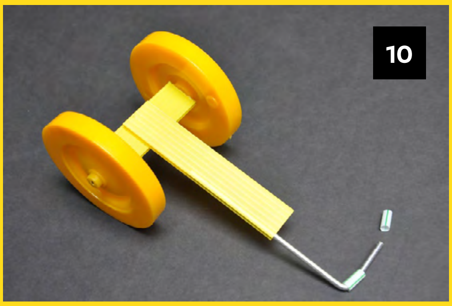
Cut one 160 mm length of the 3.2 mm aluminium rod. Make a 90° bend at its midpoint.



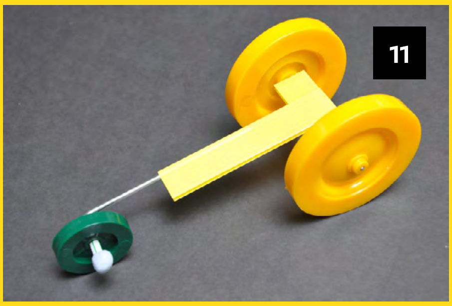
Insert the 130 mm bent aluminium rod into the corrugated plastic chassis. This will become the front wheel's axle.



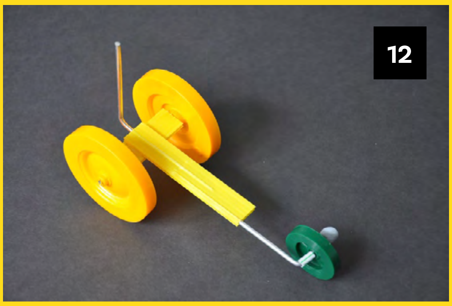
Slide the 75 mm diameter wheels onto the steel axle.



Slide a 10 mm length of drinking straw onto the front wheel's axle.



Add the 39 mm diameter wheel to the front axle. If the wheel does not easily slide on and spin freely you will need to use a 4 mm drill to increase the size of wheel's hole.



Insert the 160 mm bent aluminium rod into the rear of the model wheelchair's chassis. This part will help you to launch the model.

SCIENCE AND MATHEMATICS STUDENT ACTIVITIES

The science and mathematics of sports wheelchair design

Science and mathematics can help to explain the design features of sports wheelchairs. The following sections use science and mathematics to investigate the design of wheelchairs used for sport.

Acceleration

Acceleration is key to the success of any athlete and must be considered when designing a sports wheelchair. This is either because they are competing with others for straight-line speed from a start at rest or because they want to change direction quickly in response to the motion of a ball or other athletes.

In either case, the athlete needs to generate enough upper-body muscle force and apply it at the correct instant to get the whole-body acceleration they require.

Visit **www.youtube.com/paralympicsporttv** and observe how different wheelchair athletes accelerate their wheelchairs. For example, compare wheelchair track athletes, eg, 100 m sprinters, with basketball and tennis wheelchair athletes.

Torque

In order to accelerate, the athlete needs the help of torque, which is a 'moment' (a particular application of force in a rotational or 'twisting' fashion) used to rotate an object about an axis or pivot point (fulcrum).

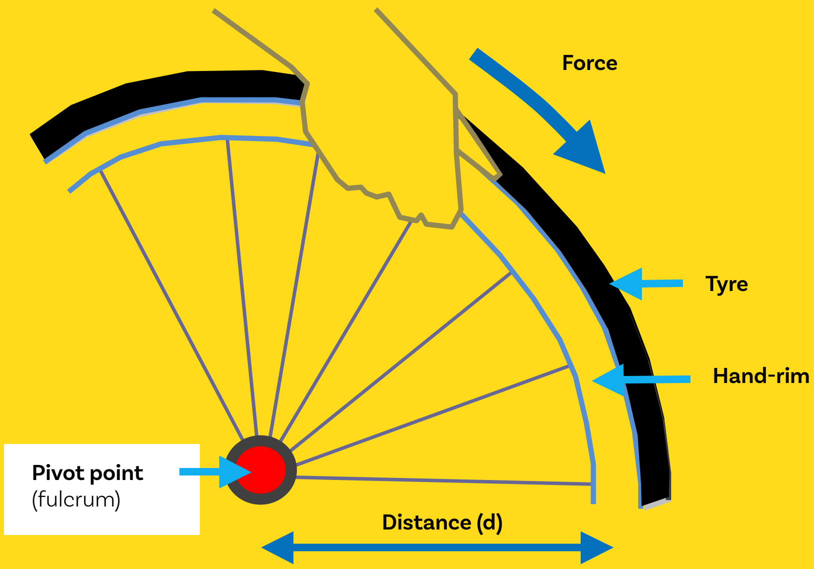
The torque applied to a wheelchair to make it accelerate in a straight line or change direction (also a form of acceleration) is the upper-body muscle force of the athlete applied to the hand-rims of the wheels on the wheelchair. This is a real world example of torque.

Torque (Nm)= **force** (N) **x distance** (m)

Force is measured in Newtons (N)
Distance is measured in metres (m)
Torque is measured in Newton metres (Nm)

Where the distance (d) is the measurement between the point at which the force acts and the pivot point (the fulcrum).

Figure 3



Athletes who can apply or remove the most torque the fastest, and control it best, will be able to accelerate their wheelchairs best. This will make them both faster (linear acceleration) and more agile (rotational acceleration).

The International Wheelchair Basketball Federation (IWBF) regulations stipulate that the wheels of a wheelchair used for basketball must have a diameter no bigger than 69cm.

Time to THINK

Why are larger diameter wheels helpful when it comes to wheelchair basketball?

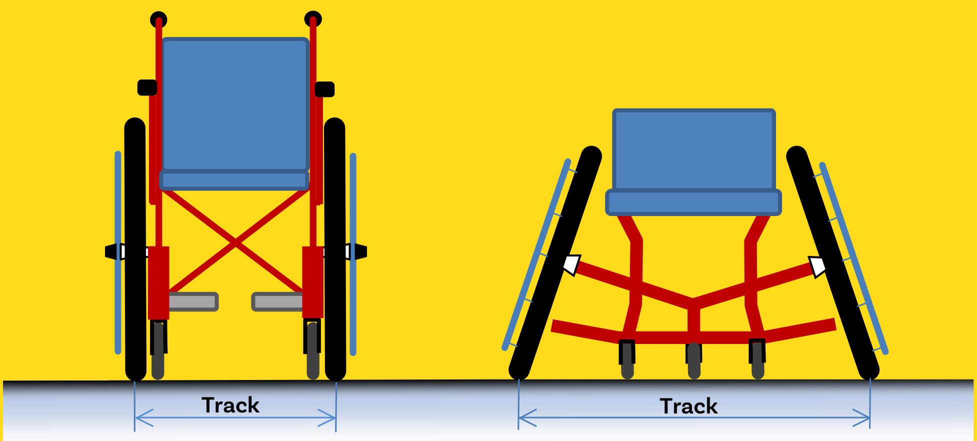
Stretch and challenge

If there was no maximum diameter for the wheels used for basketball wheelchairs, how big do you think the wheels could get before they became too difficult to use?

Track

The distance between the points at which a wheelchair's two tyres touch the ground is called the track. The two drawings below show the difference between the track of an ordinary wheelchair and one used for basketball.

Figure 4



Everyday wheelchair

Wheelchair for playing basketball

Time to THINK

How much bigger is the basketball wheelchair's track?

There are a number of significant differences between wheelchairs that are for everyday use and those that are used for sport. One obvious difference is the way the wheels of a sports wheelchair are angled or 'cambered'. Cambering the wheels of a wheelchair increases its track. Increasing the track of a wheelchair brings a number of advantages to the athlete. But how much bigger is the track of a sports wheelchair? It is possible to work it out using the information we know about the sizes of a standard wheelchair and some basic trigonometry.

The distance between the wheels of a standard wheelchair is about 60 cm. If we take this as our starting point for the sports wheelchair and assume from observing wheelchair basketball that the camber of the wheels is about 20° we can calculate how much greater its track is using the following equation.

$$\sin(20) = \frac{\chi}{34.5}$$

$\chi = \sin(20) \times 34.5 = 11.7$ cm = 12 cm (if we round up to the next whole number).

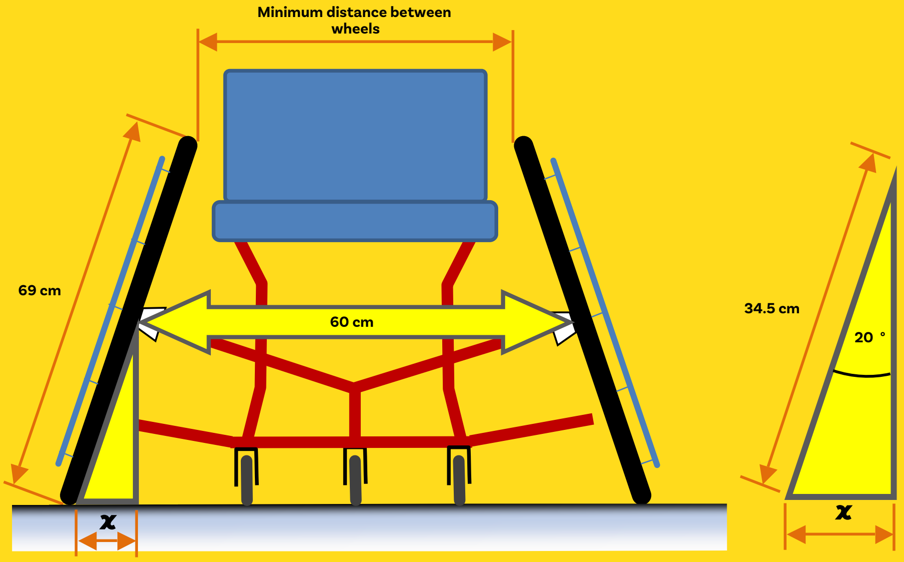
So the track of the wheelchair in Figure 5 = 12 + 60 + 12 = 84 cm.

And the minimum width between the wheels, which determines the seat width, is:

60 -12 - 12 = 36 cm,

which is ideal because the athlete needs to be able to sit between the wheels (the width of a sports wheelchair's seat is usually 34 cm – 54 cm).

Figure 5



Moments

The cambering of the wheels makes the wheelchair more manoeuvrable because it creates a *turning moment advantage* compared to a wheelchair with vertical wheels.

The turning moment is a form of torque acting about the centre of rotation of a mass. This can be calculated using the torque equation we met earlier.

Turning moment (Nm) = **force** (N) x **distance** (m)

Where force is the effort made by the athlete to turn the wheelchair's wheel and this time the distance is the measurement between the centre of rotation of the wheelchair and the point at which the wheel touches the ground.

The centre of rotation of the wheelchair in a turn is the centreline of the wheelchair.

Time to THINK

How much of an advantage do cambered wheels provide a wheelchair athlete?

Time to THINK

What are the other advantages of cambering the wheels of a wheelchair used for basketball?

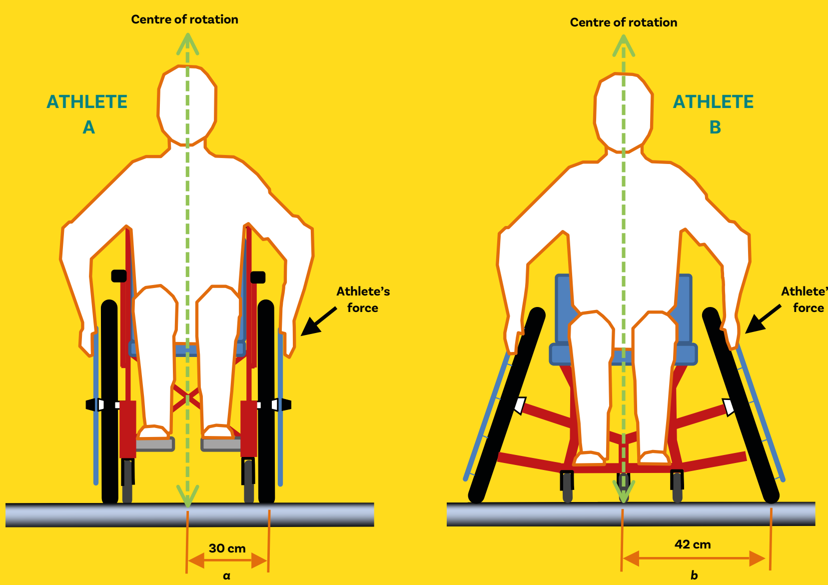


Figure 6

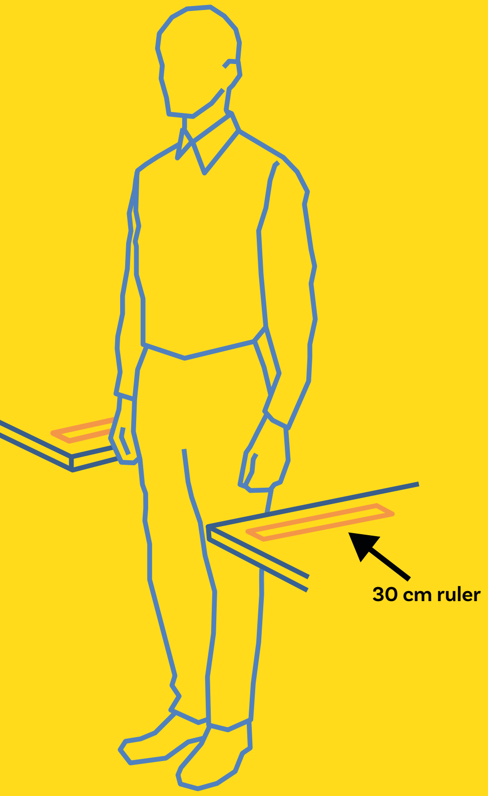


Figure 7

Velocity

Time to THINK

How fast can a wheelchair athlete go?

One way to answer this is to look at the world records for wheelchair athletes. The International Paralympic Committee (IPC) publishes world record data for all of the sports it oversees [1]. The current world records for a selection of track events for T54 classification [2] wheelchair athletes are given below in Table 1.

Table 1

Men (T54)		Women (T54)	
Distance	Time (seconds)	Distance	Time (seconds)
100 m	13.63	100 m	15.82
200 m	24.18 *	200 m	27.52
400 m	45.07 *	400 m	51.91
800 m	91.12	800 m	105.19
1500 m	174.51	1500 m	201.22

* The same athlete

We can discover the average velocity of world class wheelchair athletes using the equation below.

$$\text{velocity (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$

Time to COMPETE

What is the maximum hand velocity possible when powering a wheelchair? Do a controlled test!

- Take two tables and position them with a 50 cm gap between them.
- Lay a 30 cm ruler on the edge of each table as shown in Figure 7.
- Stand between the tables with your hands comfortably by your sides and your palms stretched out.
- See how fast you can move your hands backwards and forwards over the 30cm distance as if you were powering a wheelchair. A friend should count the number of times your hands can make a 30 cm 'trip' down the length of the ruler and back again in 20 seconds.
- Work out an average velocity, in terms of metres travelled per second, for your hands using the equation below.

$$\text{velocity (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$

- At what point do you think your hands have maximum velocity?

[1] Paralympic world record data can be downloaded in various file formats from **http://www.paralympic.org/Results/world-records/Athletics**

[2] Track athletes competing in the T51 – T54 classifications have activity limitations in both lower and upper limbs. The athletes with a T54 classification have fewer activity limitations than those with lower classification numbers. *The Layman's Guide to Paralympic Classification* can be downloaded from **http://tinyurl.com/cuqb8yd**

Figure 8

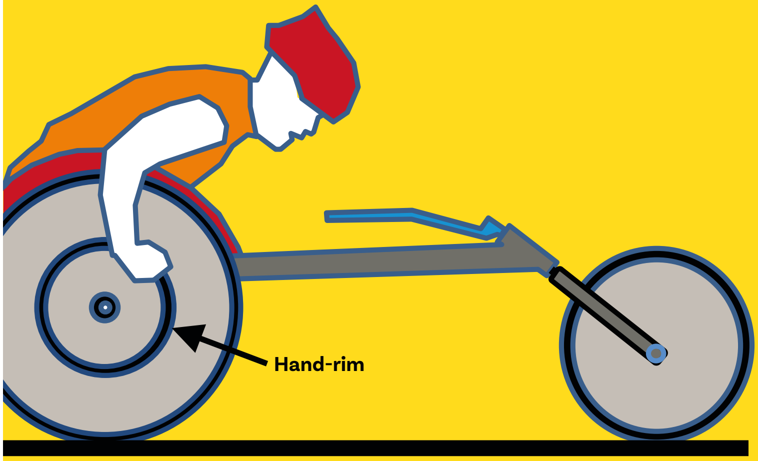
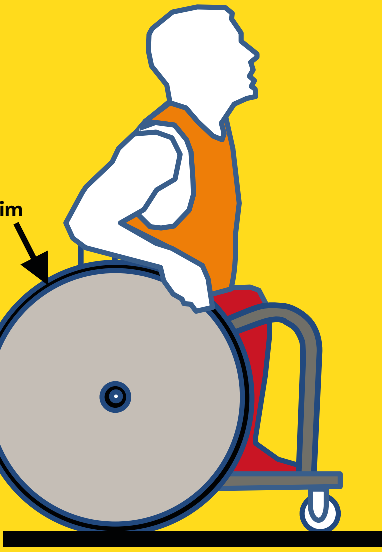


Figure 9



Time to THINK

A Paralympic track athlete can move her hands at a maximum velocity of approximately 4 m/s. How is it that she can make her wheelchair travel faster at an average velocity of 8 m/s?

Compare the drawing of the track wheelchair in Figure 8 with the drawing of the basketball wheelchair in Figure 9. Why do you think the hand-rims are different diameters?

PRESENTATION ACTIVITY

Use the practical, scientific and mathematical knowledge you have developed during your investigation of wheelchair sport to present your group's answer to the big question, *does engineering design make a difference to a wheelchair athlete's performance?*

Presentation specification

The presentation must:

- include a justified answer to the big question, *does engineering design make a difference to a wheelchair athlete's performance?*

The presentation could:

- refer to more than one wheelchair sport
- highlight both the athlete's and the engineer's responsibilities in the build-up to competition
- identify some of the challenges faced by wheelchair athletes in their preparations for competitions
- describe the skills wheelchair athlete's need to master in order to compete at the highest level
- suggest how the engineer enhances the skills of the athlete
- explain some of the technical problems faced by the engineer when designing and making wheelchairs for sport
- suggest how engineers solve the technical problems they encounter
- include other relevant information about wheelchair sport.

The presentation could take a number of forms and can include:

- text
- photographs
- diagrams
- charts
- graphs
- data.

Wheelchair athlete Shelley Woods

Picture courtesy of BAE Systems plc

Royal Academy of Engineering

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We're engaging the public by opening their eyes to the wonders of engineering and inspiring young people to become the next generation of engineers.

Front cover image: Wheelchair athlete Shelley Woods
Picture courtesy of BAE Systems plc

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