ELASTICALLY EJECTED

An ejection seat fairground ride catapults the riders into the air. Often it's small enough to be transported by lorry.

Passengers sit in a small capsule attached by elastic ropes to two uprights. The capsule is pulled down to stretch the elastic, then released.

Apparently it's really exciting!

photograph © Andrew Dunn, 26 June 2005

WHAT YOU HAVE TO DO

You are going to build a model ejection seat ride – to give passengers as fast a ride as possible up into the air, then back down in free fall.

EQUIPMENT

- 2 x metre rulers, each with holes drilled at 10 cm intervals.
- clamps (top and bottom for each metre ruler)
- hollow ball to make model capsule
- elastic
- scissors
- 4 x short pieces of dowel
- light gate

SAFETY NOTES

Wear eye protection in case elastic snaps. Make sure the model capsule is firmly fastened to the elastic 'ropes' so that it cannot become detached when the capsule is fired. If the capsule is weighted, ensure masses cannot fall out of the capsule, even when it moves at speed. Follow any other safety instructions your teacher gives you.

METHOD

Setting up

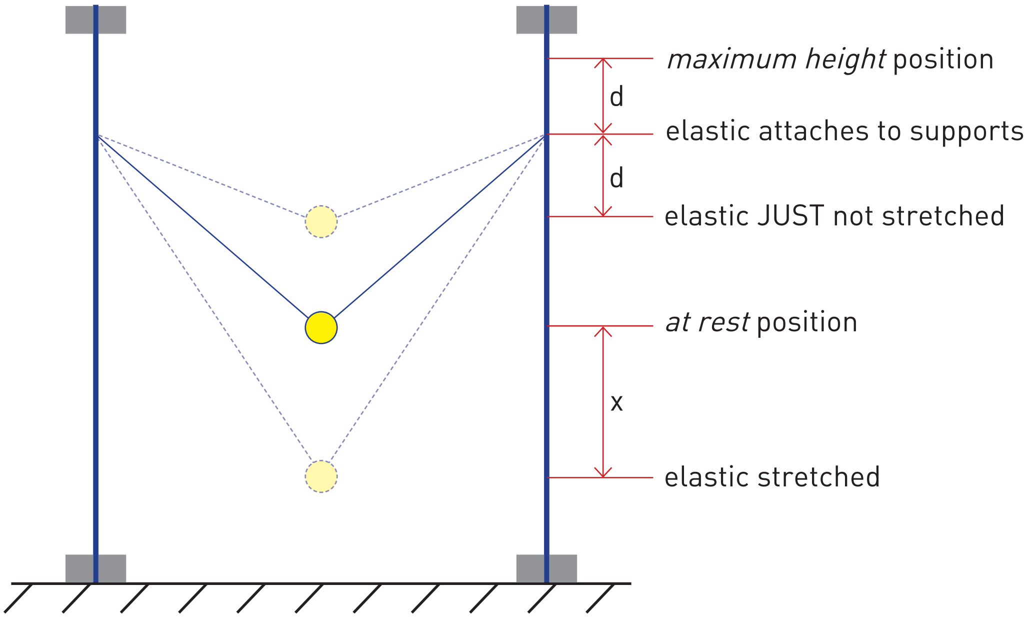
1. Tie a small loop – so that a piece of dowel will be a tight fit – in each end of a piece of elastic. Repeat for a second piece of elastic, making sure that both pieces finish with exactly the same length.
2. Fasten the elastic on each side of the model capsule:
   - Pass the elastic loop through the hole in the ball.
   - Put a piece of dowel through the loop.
   - Pull on the elastic so that the dowel wedges tightly against the inside of the ball.
   - Repeat for the other piece of elastic.
3. Clamp the two metre rules firmly top and bottom (with 0 cm at the top), so that they are vertical and about 20-30 cm apart.
4. Fasten the model capsule to the supports:
   - Pass the free end of one piece of elastic through the 50 cm hole on one metre ruler.
   - Put a piece of dowel through the loop.
   - Pull on the elastic so that the dowel wedges tightly against the metre rule.
   - Repeat for the other piece of elastic.
5. Test fire your capsule: pull it straight downwards to stretch the elastic, then release it.

   ! Check all four places where the elastic is fastened. If any show any signs of being loose, fasten them more firmly by making the loop smaller.

   ! Check the capsule does not bump against either upright. If it does, test fire again checking you really do pull the capsule straight down. If it still bumps, then move the supports slightly further apart and repeat your test fire.

Getting the ride right

You are going to model a ride where the capsule goes as fast as possible but gives a free fall drop back from its highest point. (The **THEORY OF HOW IT WORKS** section explains how this ride works. Your teacher may go through this with you to help you understand.)



6. Find the maximum height your capsule can go to for a 'free fall' return:
   - Let the capsule hang in its *at rest* position between the supports.
   - Lift the capsule gently until it is where the *elastic is JUST not stretched.*
   - Measure the vertical distance between this position and the position where the elastic is attached to the supports [d on the diagram].
   - The capsule can go this distance above the height where the elastic attaches to the support [up to *maximum height* on the diagram]. If it goes any higher, it will be pulled down by the stretched elastic rather than being a 'free fall' return.
7. Set up a light gate to record the maximum speed of your capsule. It will be travelling at its maximum speed when it passes through *at rest*, so set the light gate at this height.
   - Your teacher will show you how to set up the light gate and computer for this.
8. Pull the capsule down 10 cm from *at rest* [extension, x = 10 cm on the diagram]. Release it. Record its maximum speed, measured by the light gate, in a table.
9. Repeat twice more to get a total of three values for maximum speed.
10. Pull the capsule down a further 10 cm below its *at rest* position [extension, x = 20 cm]. Take three readings for maximum speed.
11. Repeat step 10, increasing the extension in steps of 10 cm each time, until the capsule rises above the maximum height you worked out in Step 6.
12. You may need to change the position where the elastic is attached to the vertical supports, to get the extension you need. If you have to do this:
    - Check the elastic is securely fastened (Step 5).
    - Remember the *maximum height* position will change – if the elastic is attached 20 cm higher than before, the position of *maximum height* will be 20 cm higher than before.
    - Remember the position of the light gate will have to change as well – if the elastic is attached 20 cm higher than before, the light gate will need to be 20 cm higher than before.
13. Once you have completed readings for this length of elastic, take another set using a different length. You will need to repeat all the steps, including **setting up**.

RESULTS

original, un-stretched, length of elastic	cm			
distance apart of vertical supports	cm			
extension, *x* / cm	maximum speed of capsule / cm/s			average value for maximum speed / cm/s
	1st reading	2nd reading	3rd reading	

1. You will have a different results table for each un-stretched length of elastic. For each table, fill in the column giving the average value for maximum speed, for each extension.
2. If you used a range of different un-stretched lengths of elastic, combine the results for these into one table (see next page).
   - If different groups used different lengths of elastic, you will need to combine your results with the results from other groups.

extension, *x* (cm)	average value for maximum speed (cm/s)			
	un-stretched length = cm	un-stretched length = cm	un-stretched length = cm	un-stretched length = cm
10				
20				
30				

3. Describe the relationship between the extension and the maximum speed, for any particular length of elastic.
4. Is there any connection between the un-stretched length of the elastic and the maximum speed of the capsule, while still having a free fall return?

EXPLANATIONS

1. Your calculation of the maximum height the capsule could reach, for a free fall return, involved lifting the capsule up to the point where the elastic was JUST not stretched. How accurately were you able to determine this position?
2. When you calculated the average values of maximum speed, you had to decide how many decimal places to use. Why did you choose the accuracy you did?
3. If you changed the position where the elastic attached to the vertical supports, you also changed the position of the light gate and maximum height. How would this have affected the accuracy of your results?
4. You only used tables for your results. What graphs or charts would have been helpful for your results? How would they have helped you?

SOME MORE QUESTIONS

- If you used a capsule painted in contrasting colours you will have been able to observe how the capsule moved during flight. What, if anything, did you notice? How could you increase this movement, to make the ride more exciting?
- For a real ejection seat ride, what factors will affect the choice of type, length and extension of the elastic?

SOME MORE THINGS TO TRY

- How much will different types of elastic stretch when masses are suspended from them? Predict, then test, the effect on the ride of using a stronger piece of elastic (use the same length).
- Use your ejection seat ride to calculate the acceleration due to gravity.
  - Record the time taken for your capsule to fall back down to its *at rest* position, from the height at which it stops.
  - Record its downwards speed when it reaches this *at rest* position.
  - Calculate the acceleration.

    acceleration = change in speed ÷ time taken

THE THEORY OF HOW IT WORKS

What forces act on the capsule?

- If there were no capsule on the elastic, the elastic would just hang in a loop, below the suspension points [down to elastic *JUST not stretched* on the diagram]. How far down the loop hangs just depends on how long the elastic is.
- When the capsule is on the elastic, the weight of the capsule (plus any passengers) makes the elastic stretch [so it hangs at *at rest* in the diagram].
- The vertical forces on the capsule are the downward force due to gravity (weight) and the upward force due to the stretched elastic.

  There will be two vertical forces upward on the capsule, one from the elastic on each side. Each vertical force is the vertical component of the tension in the elastic. The total upward force is the sum of the two vertical forces, one from each piece of elastic.
- The capsule is *at rest* when the vertical forces are balanced – when the weight of the capsule (and passengers) is exactly the same size as the upward force due to the stretched elastic.
- When the capsule is pulled down, just before releasing it [to the position *elastic stretched* on the diagram], there is an increased upward force on it due to the increased tension - because the elastic is stretched more. The vertical forces are not balanced: there is a resultant force in an upwards direction because the upward force is greater than the downward force. This resultant upward force makes the capsule accelerate upwards when it's released. The more the elastic is stretched, the greater the resultant upward force and so the greater the acceleration upwards.

What happens to the speed?

- The speed of the capsule changes whenever there is a resultant force – and therefore an acceleration – on it.
- When it's first released, upwards acceleration is large, so the capsule speeds up rapidly.
- As the capsule moves upwards, the elastic stretches less, so the tension in the elastic decreases and the resultant upward force decreases. The upward acceleration decreases, so the capsule increases speed less rapidly.
- When the capsule reaches the height at which it rests naturally (the position it was in before it was pulled downwards), the upward force and the downward force are equal. It has no acceleration. The capsule is travelling at its maximum speed at this point. Above this point, what happens to the capsule depends on whether or not the elastic is stretched.
- All the time the elastic is not stretched [between the positions elastic *JUST not stretched* and *maximum height* on the diagram] the only force on the capsule is the downward force due to gravity, which gives the capsule a downward acceleration. If the capsule is travelling upwards, it continues to travel upwards but its speed gets slower and slower until it stops.
- If the capsule travels high enough, it will again stretch the elastic. There will then be two downward forces acting on the capsule: the force due to gravity and the force due to the tension in the elastic. These two forces cause a downward acceleration, which slows the capsule more quickly than gravity alone (if the capsule is travelling upwards) or speeds it up more quickly than gravity alone (if the capsule is travelling downwards).

When will the capsule be in free fall?

- An object is in free fall if it falls downwards under the influence of just gravity.
- Your capsule will fall in free fall for a while, if it starts falling downwards before it is 'pulled' downwards by tension in the elastic. In other words, it must stop travelling upwards and begin falling down again before it travels high enough to make the elastic stretch [that is before it rises above the *maximum height* position on the diagram].
- Your task becomes one of firing the capsule so that it travels as close as possible to, but not above, this point.

HEALTH AND SAFETY

A risk assessment must be made before starting any practical work.

Ensure students use elastic responsibly. Wear eye protection to protect eyes from possible injury should elastic snap. Ensure elastic is securely attached to both capsule and supports, so that the capsule cannot become detached during flight. If the capsule is weighted, great care must be taken to ensure the mass cannot become detached from the capsule when it is fired.

THE INVESTIGATION

An ejection seat fairground or theme park ride catapults the riders into the air. Often it's small enough to be transported by lorry. Passengers sit in a small capsule attached by elastic ropes to two uprights. The capsule is pulled down to stretch the elastic, then released.

Technically it is a reverse bungee. Further information can be found by entering ejection seat bungee into an Internet search engine. (Failure to include bungee will produce sites about aircraft ejection seats.)

Students build a model ejection seat, adjusting the tension in the elastic so that the capsule is fired as fast as possible but so that the return downwards is in free fall.

Students may be able to model the electromagnet that is commonly used in real ejection seat rides to hold the capsule in position before release - but it is unlikely they will be able to make an electromagnet strong enough to hold the capsule against the tension needed to get it to perform well when released.

SUGGESTED SEQUENCE

This activity is best carried out in a minimum group size of three: this makes it possible for one student to release the capsule and record results, another to check the capsule doesn't go above the 'maximum height' allowed and another to record the flight on video camera or video phone (to assess the 'thrill factor' of the ride).

As an additional activity, students investigate how different types of elastic stretch. They predict and assess the performance of an ejection seat ride made using different types of elastic. An alternative approach is for different groups to use different types of elastic: each group investigates the performance of their elastic then the groups contribute their findings to a class plenary.

As with most practical activities, students often gain more from the evaluations and follow up questions if these are tackled as a class, allowing students to benefit from a wider range of knowledge and ideas.

Time required

There should be no difficulty completing this activity in the time you normally allow for practical investigations. You may wish to allow additional time before and after the practical session to allow for discussion, explanation of the theory involved and to complete the evaluation.

NOTES

The metre rulers need to be firmly clamped top and bottom so that they remain rigid even when the capsule, on its elastic, is pulled down.

The capsule can be made from any hollow ball such as a plastic 'ball pit' ball or a tennis ball, with holes cut in opposite sides to allow the elastic to be fastened (and a further hole to allow the elastic to be fastened securely on the inside of the ball). This extra hole can also be used for adding weight to the ball if desired – but great care must be taken to ensure the weight cannot become detached from the capsule when it is fired.

The simplest way to fasten the elastic to the ball and to the upright supports is to make a small loop in each end of the elastic, thread this loop through the hole in ball or support. Secure the loop in position using a small piece of dowel through the loop. Ensure the loop is small enough that the dowel will not slip out.

If one hemisphere of the capsule is painted in a contrasting colour, students will be able to use a video camera to record any spin during the ride – to help assess the 'thrill' factor.

Using light gates

The light gate and data-logging software will need to be configured so that the light gate measures the time taken for the capsule to pass through, then calculates the speed from this (you will need to know the diameter of the capsule for this). Students do not need to know how to configure the light gate and software, but it may be helpful for them to understand what the light gates and computer are doing, as this gives a practical example of the relationship between speed, distance and time.

If students attempt to calculate the acceleration due to gravity, using the method suggested in **SOME MORE THINGS TO TRY**, they will need to use two light gates, one configured to calculate the speed (it doesn't matter whether it is on the way up or on the way down, as both will be the same), the other configured to measure the time taken between the capsule passing through the first time (on the way up) and passing through the second time (on the way down). The time taken to fall from the maximum height to the position of maximum speed is half this time. This investigation might be best as a teacher led demonstration.

Understanding the theory

The theory of how this ride works is given in a separate section at the end of the student information. Students should be able to carry out this activity without reading or understanding the theory section, but of course their learning from the activity will be greatly enhanced if they do read and understand the theory. However, much of the theory about maximum speed and free fall is complicated, so you may wish to work though the theory with students either as a whole class or in groups.

THE THEORY

What forces act on the capsule?

- When there is no capsule on the elastic, the weight of the elastic itself will actually cause the elastic to stretch slightly – this is ignored here.
- The capsule at rest on the elastic will also have sideways forces on it, being the horizontal components of the tension in the elastic. The capsule will move sideways until these two forces balance each other. These forces are again ignored here. They would become noticeable if different types or lengths of elastic were used on each side of the capsule - then the capsule would be unlikely to come to rest centrally between the vertical uprights.

What happens to the speed?

- Students frequently find the relationship between speed and acceleration confusing. In order to understand the theory behind the ejection seat, it is essential that they grasp the idea that an object still travels upwards while being acted on by a downwards acceleration – and can describe the effect that this will have on the speed of the object.

When will the capsule be in free fall?

- Technically, the capsule will always be in free fall in the region where the elastic is not stretched [see diagram]. Whether or not it goes into the region where the elastic accelerates it downwards initially is irrelevant; that only affects the speed of the capsule at the point at which it starts travelling in free fall.
- Fairground and theme park rides that allow passengers to experience 'free fall' (such as 'Apocalypse' at Drayton Manor) generally seem to hold their passengers stationary for a few moments above the drop before letting them fall – to enhance the terror, no doubt! – so this is the model of 'free fall' that the students are copying. You may wish to discuss with them that this is only one possible scenario in which the capsule is in 'free fall'.

TECHNICIAN EQUIPMENT LIST

per group

- 2 x metre rulers, each with holes drilled at 10 cm intervals
- 4 x clamps (top and bottom for each metre ruler)
- hollow ball to make model capsule e.g. plastic 'ball pit' ball or a tennis ball, with holes cut in opposite sides to allow the elastic to be fastened and a further hole to allow the elastic to be fastened on the inside
- 1 m elastic
- scissors
- 4 x short pieces of dowel
- light gate