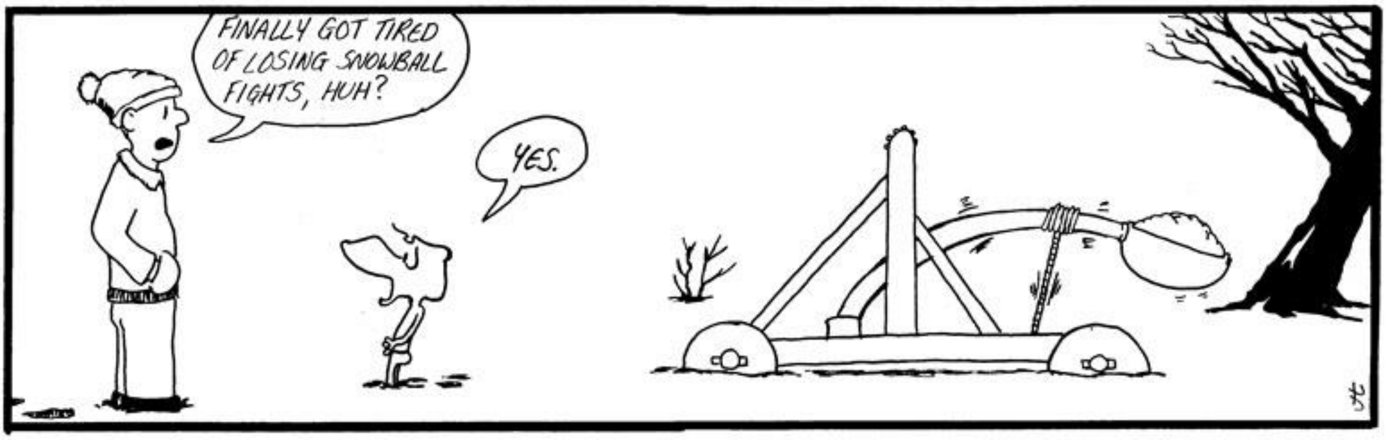

With support from Oxfordshire County Council, Science Oxford is pleased to present;

Catapult Engineering

The Physics of Siege Weapons

STEM Club Resource Pack

OXFORDSHIRE COUNTY COUNCIL

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Introduction:

Catapult engineering involves using stored energy to hurl a projectile without using any explosives. The stored energy comes from building mechanisms that use tension, torque and gravity.

The main types of catapult are the trebuchet and the Mangonel.

In this project you will be building and test different siege weapons, discovering the mechanisms that make them work and how to improve them, before building your own, ultimate siege weapon.

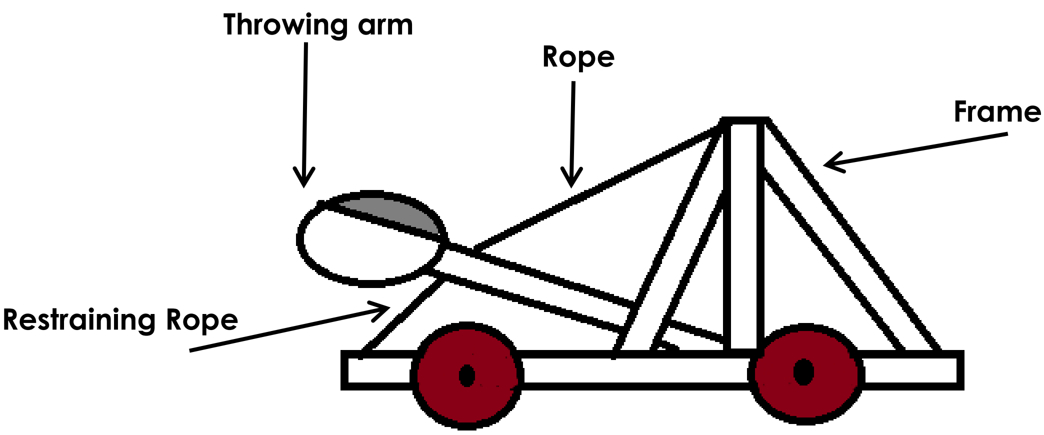
A Trebuchet*

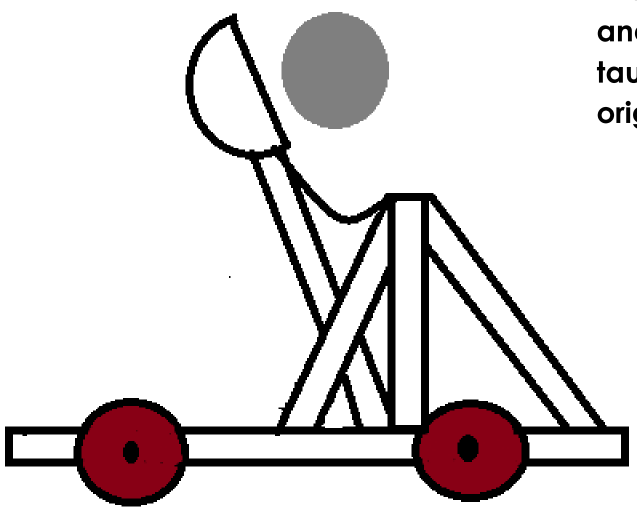
A Mangonel*

The Mangonel:

The Mangonel is probably the most familiar looking type of catapult. It involves stretching or winding up a long piece of rope attached directly (or indirectly) to a throwing arm, therefore putting it under tension. When released, the rope will want to return to its relaxed length and will therefore create a pulling force in the opposite direction, pulling on whatever object it is attached to. Tension is effectively the opposite of compression.

The angle at which the throwing arm is pulled back to will affect both the distance the projectile will travel and also the height that it reaches when in the air.



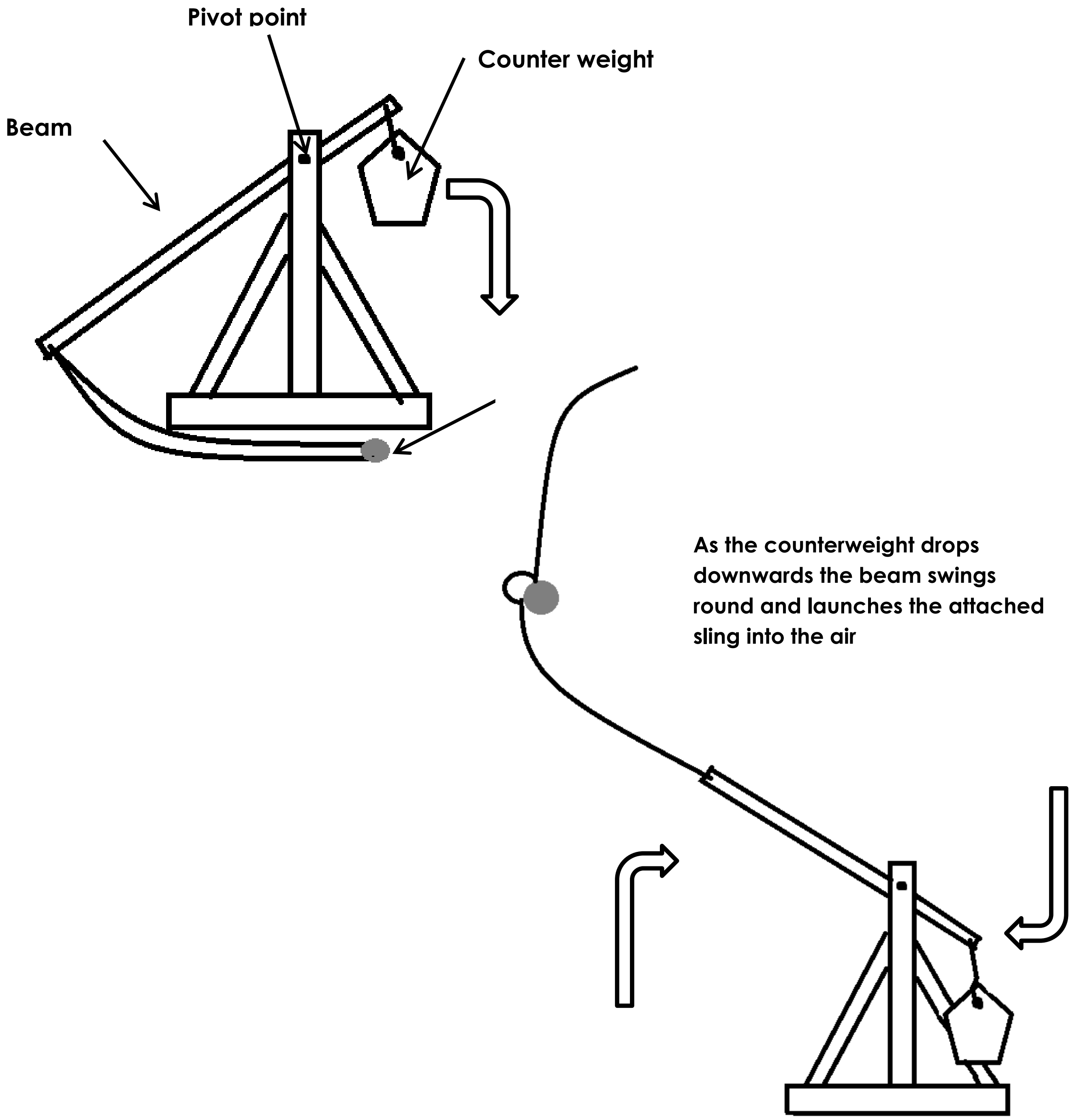


The restraining rope is released and the previously strained and taught rope pulls back to its original position

The Trebuchet:

The Trebuchet was one of the more accurate and efficient types of catapult used in ancient times.

It worked by using the energy of a falling counterweight to rotate a beam around a pivot resulting in the release of whatever projectile was loaded into the sling at the other end of the beam.



Suggested Timetable:

Stage 1: Introduction to Catapult Engineering

Introduction to Siege Weapons and the engineering behind them

Stage 2: Initial Investigations (resource sheets)

Investigate the components that make the best catapult

Stage 3: Planning and Design (resource sheets)

Start to plan and design your own Weapon

Stage 4: Construction

Start Building!

Stage 5: Testing

Test your design to see what works

Stage 6: Modification

Make changes to your design to make it even better!

Stage 7: Demonstration and Competition

Show off your catapult and put it to the test!

Stage 2: Initial Investigations

Investigating Launch Angles

In this investigation you will be exploring the effect the launch angle has on the distance a projectile (ball) travels. To do this you will be using the 'Xpult' catapult shown below. The 'Xpult' catapult operates similarly to a modern day mangonel; a rubber band stores elastic potential energy as it is stretched, which is released as kinetic energy when it is released.

Equipment needed:

'Xpult' Catapult	Tape measure
Pen	Target (optional)
Paper	

What to do:

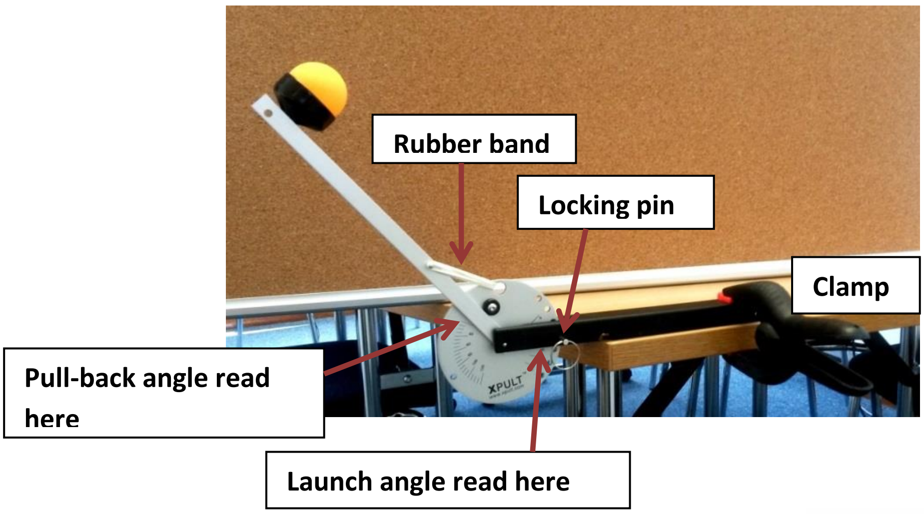
'Xpult' Catapult kit:

- Catapult itself including a locking pin
- Three rubber bands
- A table tennis ball and a small white plastic perforated ball.
- A clamp for attaching the catapult to the table

Set up the catapult as show below:

- Unfold the catapult by removing the locking pin and swinging the aluminium launch lever all the way round to the other side of the black plastic base.
- Clamp the black base to the edge of a table.
- Thread a rubber band through the large hole in the aluminium disc, and hook it onto the designated hooks each side of the aluminium lever.
- Re-insert the pin into one of the holes, for now anywhere between $30-60^0$
- Set up a tape measure from the base of your catapult all the way across the room, covering at least 3 metres.

If your tables don't stretch 3 metres, you can always place the tape measure on the floor



Allocate roles within your group (although you can swap around so that everybody gets a turn and everything):

- A spotter- this person is in charge of determining the exact landing location of the ball
- A shooter- this person operates the catapult
- An Analyst- this person is in charge of entering the data into the table correctly

Initial tests- to understand the relationship between the launch angle and the pull-back angle

- Set the launch angle to 45º (note that you read the launch angle at the bottom edge of the black plastic base). You can experiment with different launch angles later, but for now start with 45º
- Start with a pull-back angle of 20º, the white perforated ball and just one rubber band.
- Launch the ball three times, and record each distance.
- Calculate the median of the distances, this is just the middle distance (not the smallest or the largest, the one in between)
- Calculate the range of the distances- this is the difference between the furthest shot and the nearest shot (biggest number-smallest number)
- Now move the pull-back angle by 10º, so you go to 30º and repeat the experiment three times.
- Continue to increase the pull-back angle in increments of 10º until you have reached a pull-back angle of 90^0 or higher. The ball has a tendency to fall out of the cup if you pull the catapult arm too far back.
- Continue to calculate the median and range for each different pull-back angle and fill in the table below.

Experiment 1 Launch angle = 45º Number of rubber bands = 1

Pull-back angle (º)	**Shot 1 (cm)**	**Shot 2 (cm)**	**Shot 3 (cm)**	**Median (cm)**	**Range (cm)**
Example	*28*	*25*	*32*	*28*	*32-25=7*
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					
110					
120					

Analysing your data

One of the quickest ways to analyse data is to draw a graph. Put the pull-back angle on the y-axis (vertical column) and the distance of the median shot (grey column) on the x-axis (horizontal axis). Create your own or fill in the one below.

Experiment 1 Launch angle = 45º Number of rubber bands = 1

Pull-back angle (º)

120																	
110																	
100																	
90																	
80																	
70																	
60																	
50																	
40																	
30																	
20																	
10																	
0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340

Median distance ball travelled (cm)

Another way to analyse your data is to look at the range column of your table. The smaller your range, the more consistent your catapult was for that pull –back angle. So the 'best' pull back- angle will be the angle at which the ball travelled the furthest the most consistently, which can be determined by the row with the highest median and the lowest range.

Further tests

From here you can experiment further to find the 'best' setting for your 'Xpult' catapult. You might decide that the best setting is the one that makes the ball go the furthest distance, or you might decide that the best setting is the one that makes the ball travel the highest up and over an object (you could set up a make shift wall) or you might decide that the best setting is the one that makes the ball travel and hit a target the most consistently.

Things to change:

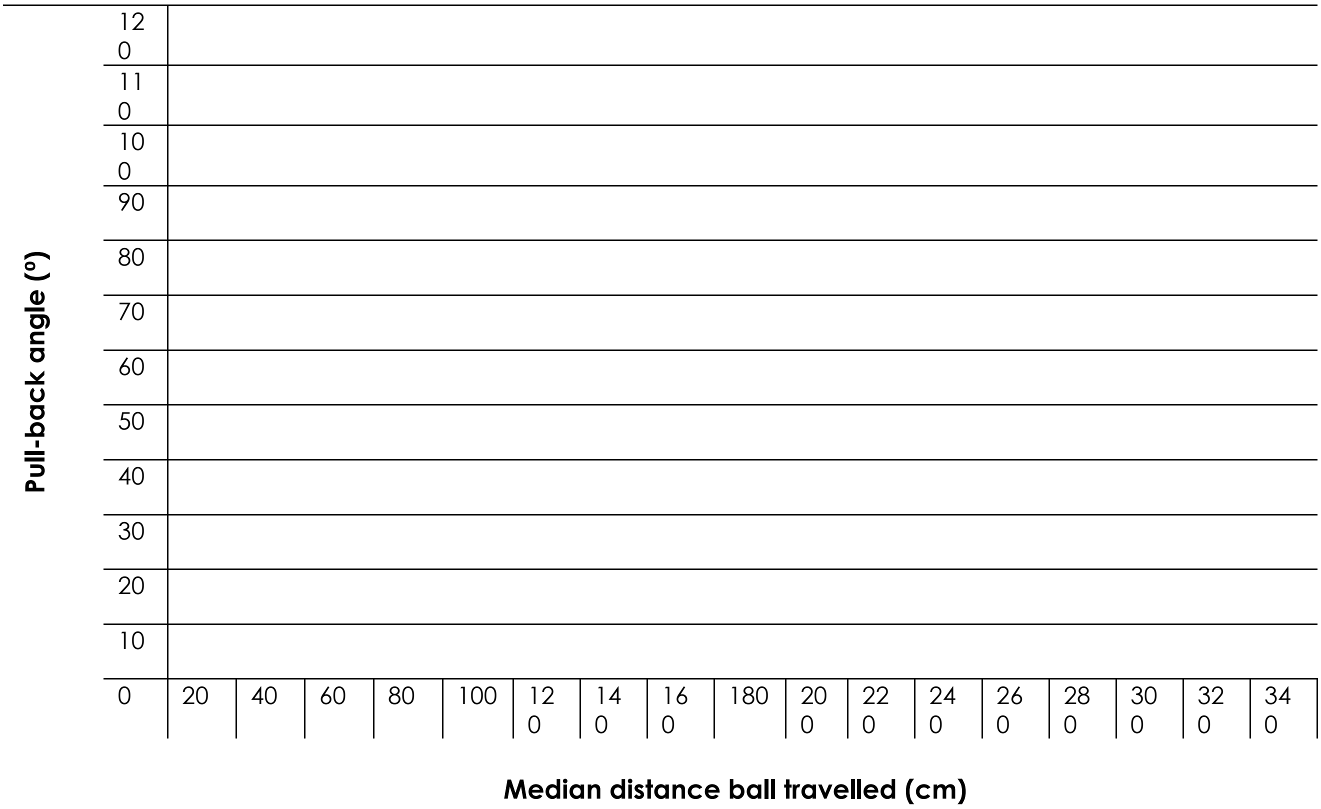
- The Launch angle
- The number or rubber bands

Use the blank tables below or create your own.

Experiment 2 Launch angle = Number of rubber bands =

Pull-back angle (º)	**Shot 1 (cm)**	**Shot 2 (cm)**	**Shot 3 (cm)**	**Median (cm)**	**Range (cm)**
Example	*28*	*25*	*32*	*28*	*32-25=7*
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					
110					
120					

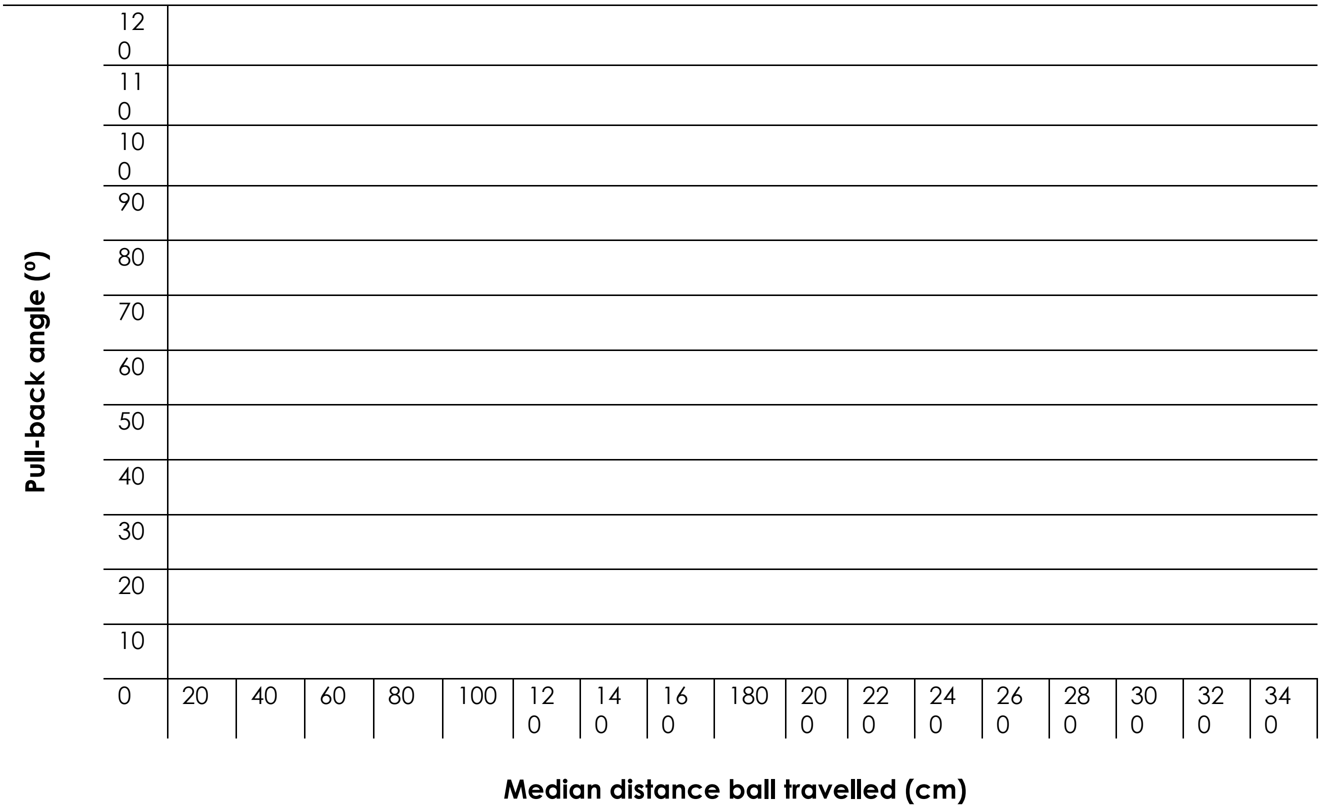
Experiment 2 Launch angle = Number of rubber bands =



Experiment 3 Launch angle = Number of rubber bands =

Pull-back angle (°)	**Shot 1 (cm)**	**Shot 2 (cm)**	**Shot 3 (cm)**	**Median (cm)**	**Range (cm)**
Example	*28*	*25*	*32*	*28*	*32-25=7*
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					
110					
120					

Experiment 3 Launch angle = Number of rubber bands =



Investigating counterweights and arm length

In this investigation you will be exploring the effect the arm length and the mass of the counter weight has on the distance a projectile travels. To do this you will be using K'nex to construct a trebuchet.

A trebuchet operates by using the energy of a falling counterweight to rotate a throwing arm around a pivot point, resulting the in the release of a projectile attached to the upper end of the throwing arm.

Equipment needed (per group):

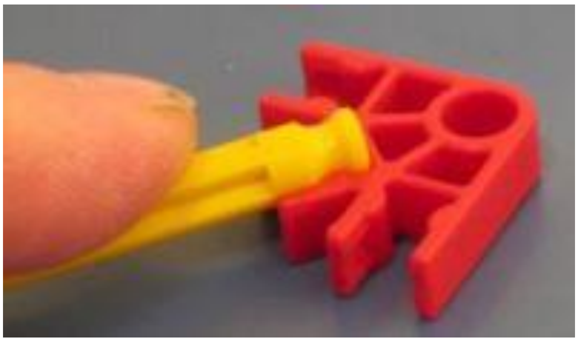
Box of K'nex	Tape measure
Pen	Target (optional)
Paper	String
Scissors	Weights

Using K'nex

K'nex comes in two types – rods and connectors. Rods come in lots of different sizes, with the colour of the rod corresponding to size (so all the yellow rods are the same size, all the grey rods are the same size, etc.). Connectors come in different shapes, with colour corresponding to shape.

Rods and connectors connect together in one of three different ways:

1) The top of a rod will click directly into the 'teeth' of a connector, as below.
2) The teeth of the connector will bite into the body of a rod
3) A rod can be threaded through the hole in the centre of a connector



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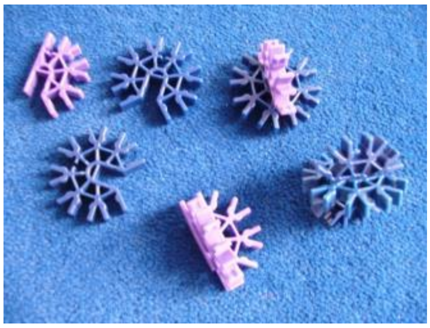
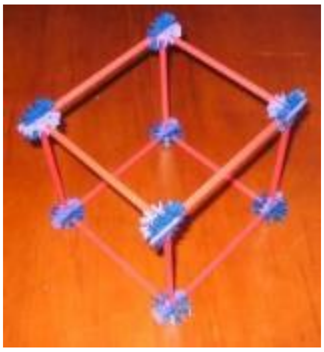
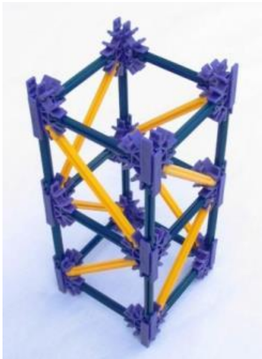
3D Structures

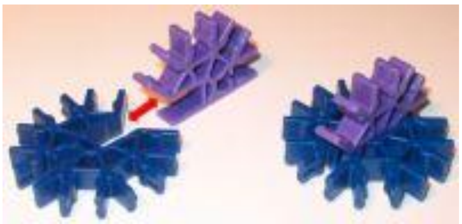


To make 3D shapes, the blue and purple connectors need to be used. These connectors can be slotted together – blue connector can connect to blue; or purple to purple; or blue to purple, as below

These pieces can then be used to make strong 3D shapes, for example the cube pictured below





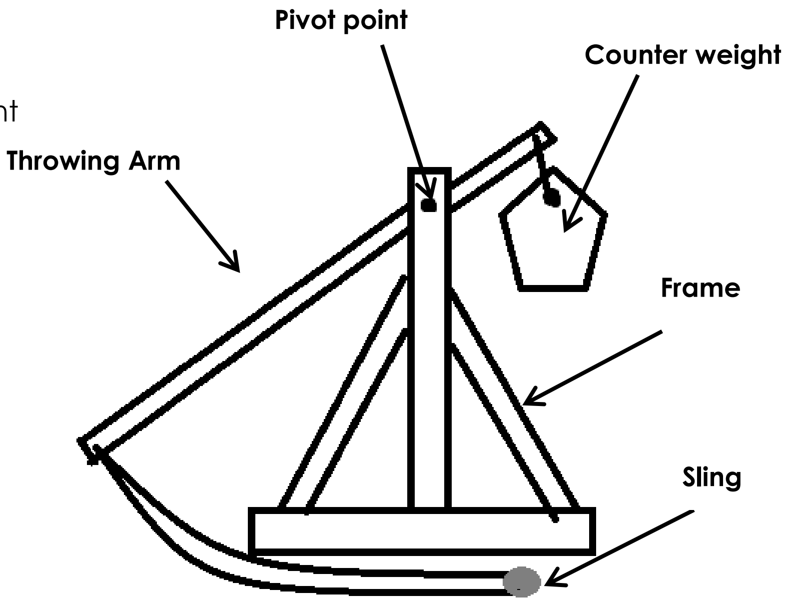


However, from an engineering point of view, square and rectangular sides aren't very strong. By putting cross-braces in the sides, and turning the squares to two triangles, it greatly increases the strength of the shape

Construct your Trebuchet

You can construct your trebuchet using a design of your own choice; however it will need to have some basic principles

- A Frame
- A pivot point
- A throwing arm
- A counter weight
- A sling attachment



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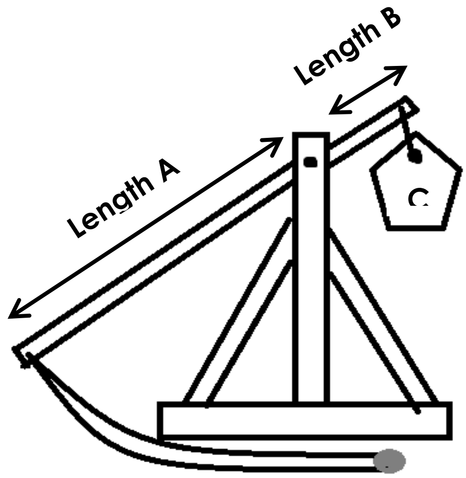
Testing your trebuchet

The aim of this investigation is to look at the effect different arm lengths and counter weights have on the distance your projectile travels.

Things to bear in mind



- To start with you will need to test ***either*** different arm lengths ***or*** different counterweights- you will need to keep one constant to start with!
- If your counterweight is too heavy, the K'nex will just break.
- If Length A is longer than the height of the frame, your throwing arm will not rotate properly and will get stuck
- If the length of string for your catapult is too long, you will not get enough lift in your throw

Allocate roles within your group (although you can swap around so that everybody gets a turn and everything):

- A spotter- this person is in charge of determining the exact landing location of the projectile.
- A shooter- this person operates the trebuchet.
- An Analyst- this person is in charge of entering the data into the table correctly

Get Testing

- Set up a tape measure from the base of your trebuchet all the way across the room, covering at least 3 metres.
- Start off with a constant counter weight and alter the arm length.
- Launch your projectile three times, and record each distance
- Calculate the median of the distances, this is just the middle distance (not the smallest or the largest, the one in between)
- Calculate the range of the distances- this is the difference between the furthest shot and the nearest shot (biggest number-smallest number).
- Now alter the arm length, you could make length A smaller than length B, the same size as length B or bigger than length B.
- Test again, when you have tried different combinations of arm lengths, you can start changing the counter weight.

Experiment 1

Counter weight mass =

Length A = __________ Length B = ___________

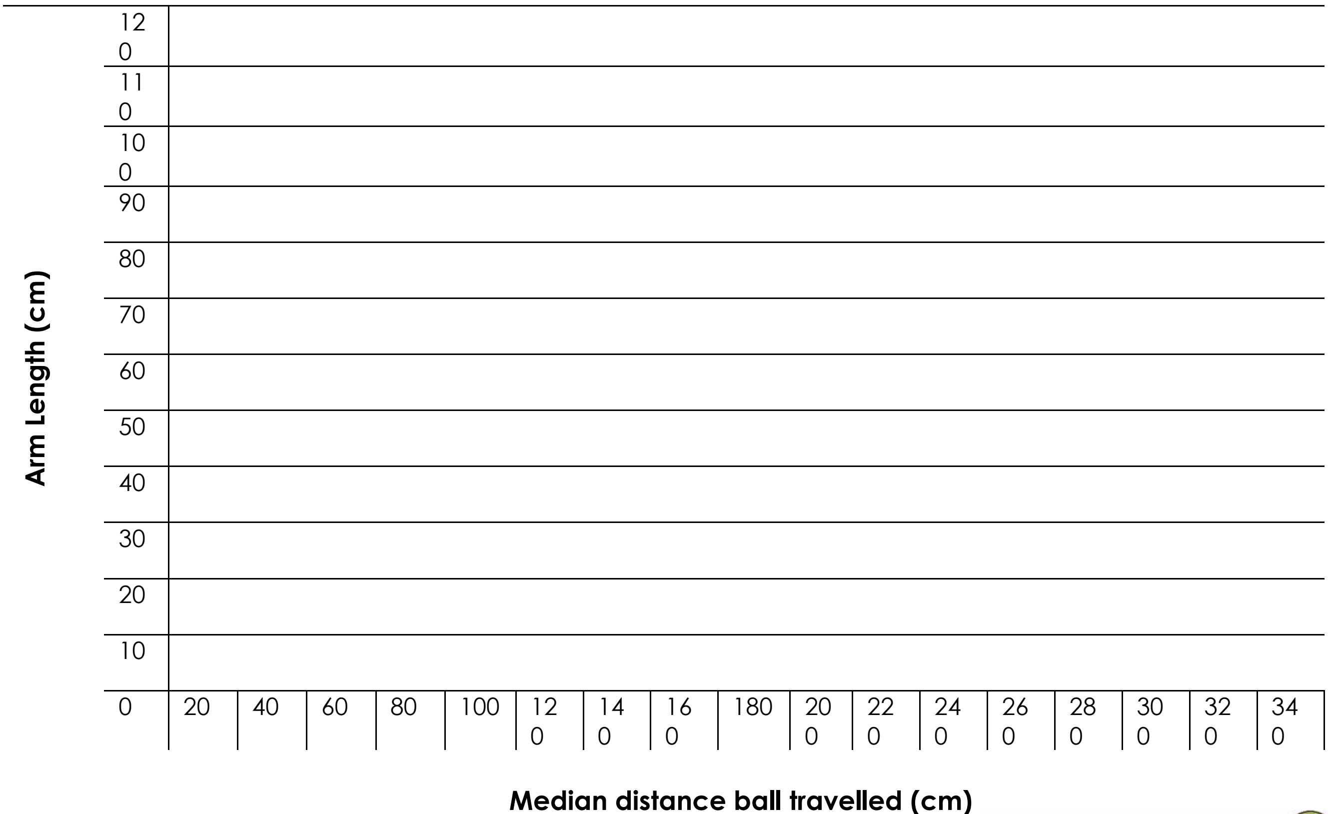
Length A (cm)	Length B (cm)	Shot 1 (cm)	Shot 2 (cm)	Shot 3 (cm)	Median (cm)	Range (cm)
50cm ***Example***	*50cm* ***Example***	*28*	*25*	*32*	*28*	*32-25=7*

Analysing your data

One of the quickest ways to analyse data is to draw a graph. Put the arm length on the y-axis (vertical axis) and the distance of the median shot (grey column) on the x-axis (horizontal column). Create your own or fill in the one below. You can create two separate lines for Length A and length B

Experiment 1

Counter weight mass =



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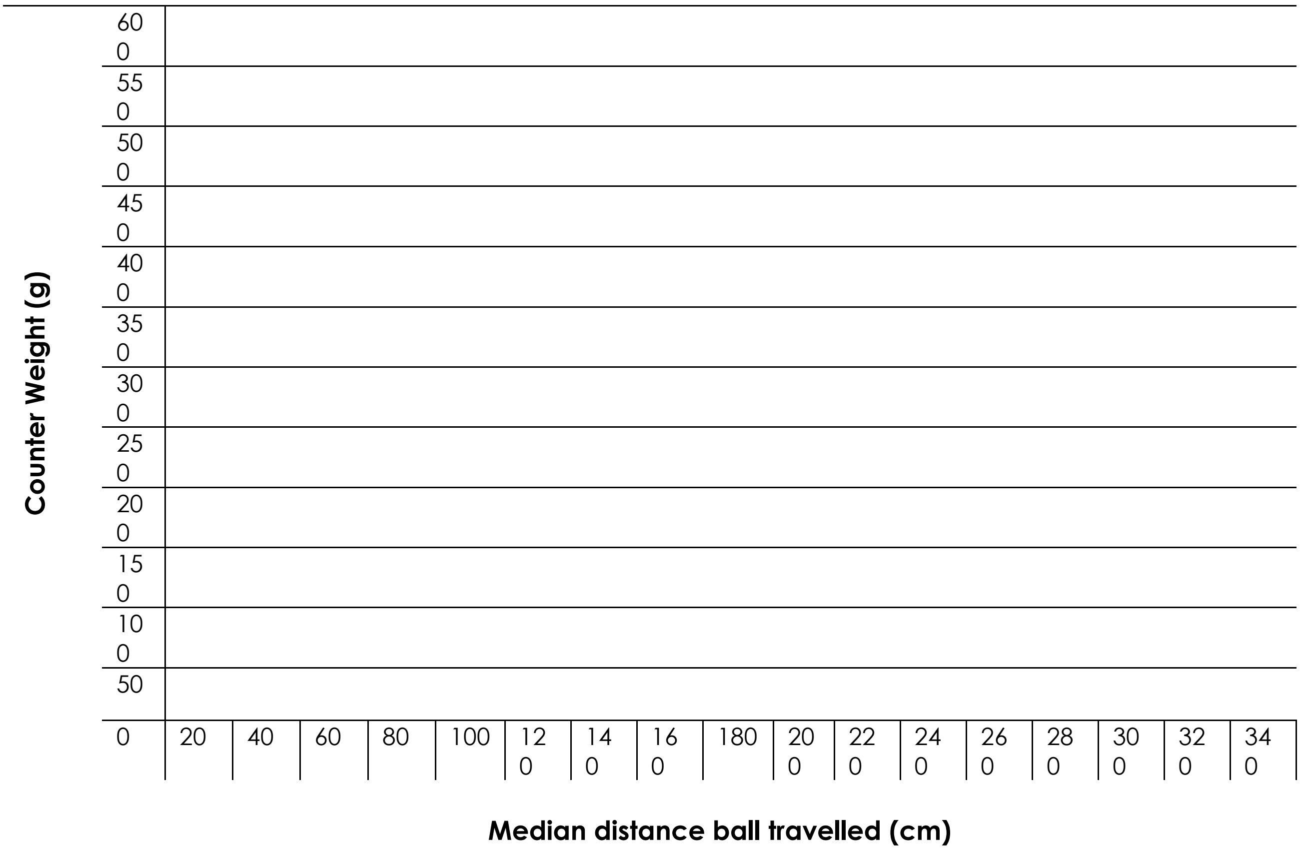
Experiment 2 Length A = __________ Length B = ___________

Counter Weight (g)	**Shot 1 (cm)**	**Shot 2 (cm)**	**Shot 3 (cm)**	**Median (cm)**	**Range (cm)**
100 ***Example***	*28*	*25*	*32*	*28*	*32-25=7*

Experiment 2 Length A = ________ Length B = _____________



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Stage 3: Planning

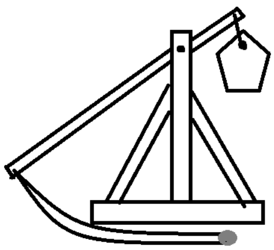
Introduction to building your own catapult

It is time to decide which siege weapon you want to build: a Trebuchet or a Mangonel

You will have the following equipment available:

Wooden dowel rounded assorted thicknesses	Hammer
Wooden dowel square assorted thicknesses	Hack saws
Wooden wheels	Cutting Vice
Plywood sheeting	Tape measure
Glue guns	Awls
Wood glue	Pliers
Carpet tacks	Sandpaper
String	Screw hooks
Screw eyes	Material
Hand drill	Wooden cogs

Trebuchet- initial planning

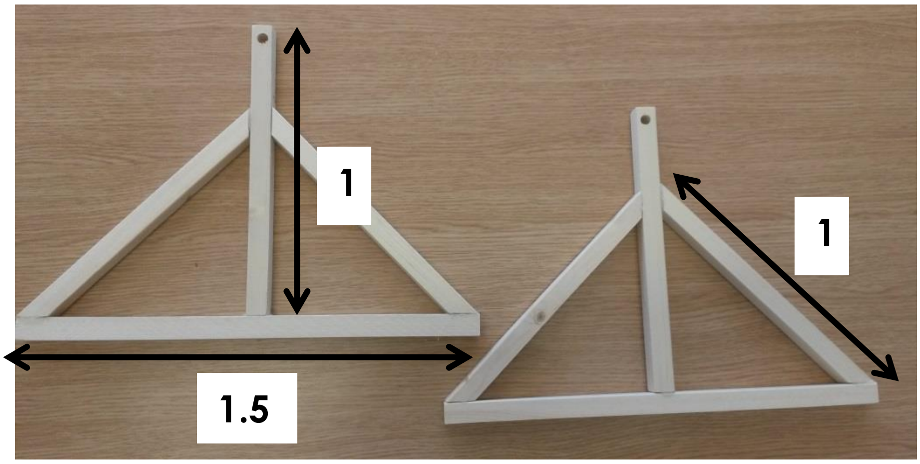


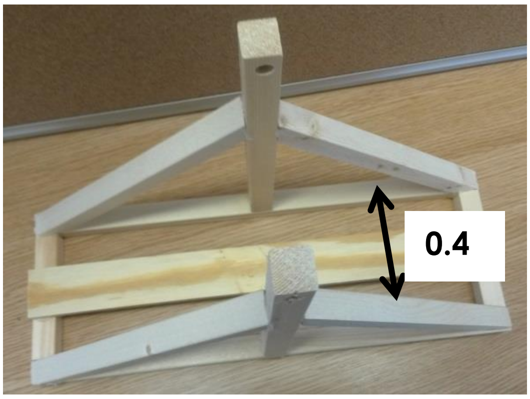
There are three main parts to a trebuchet:

- A stable frame
- A counterweight
- The arm and sling mechanism

Stable frame

One of the simplest and strongest ways to make a stable frame is using an 'A frame' where you have two beams connecting at a 45º angle.
The A- frames show below use a ratio of 1:1:1.5 for the lengths of wood.

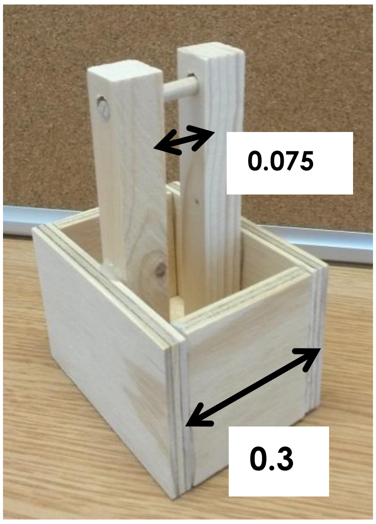




Attach you A-frames together at the base; the one pictured uses a piece of wood that is a ratio of 0.4 compared to the first lengths of wood. You can also decide to add a length of wood down the middle to run your projectiles along.

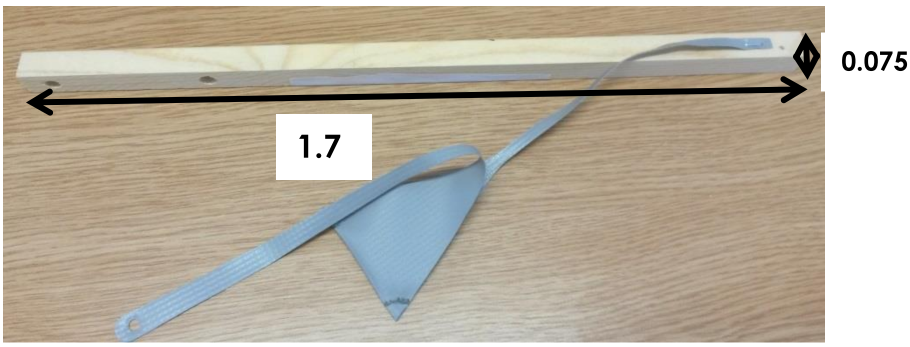
Counter Weight

It is important to build a counterweight which will fit inside your frame, with a gap either side; otherwise it will get stuck when the arm swings. The counterweight does not have to hinge or take on the form of a box, but it does allow you to alter the weight.

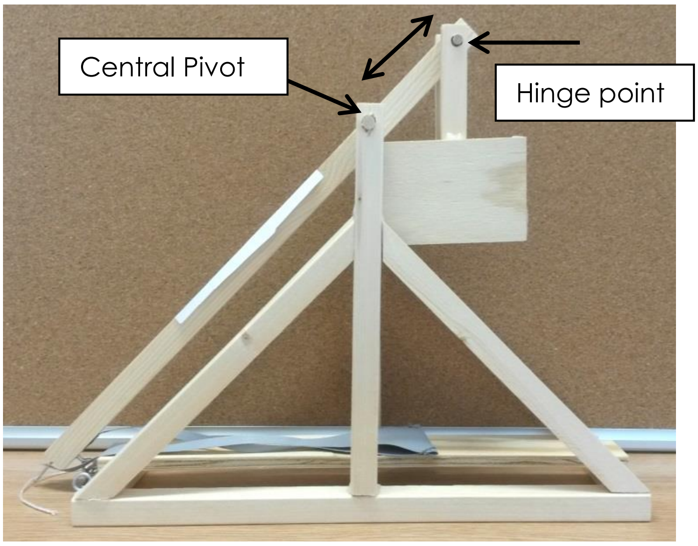


Arm and Sling Mechanism

The arm should normally be the longest piece of wood in your trebuchet, make a sling pouch and attach one end of it to the end of your throwing arm.

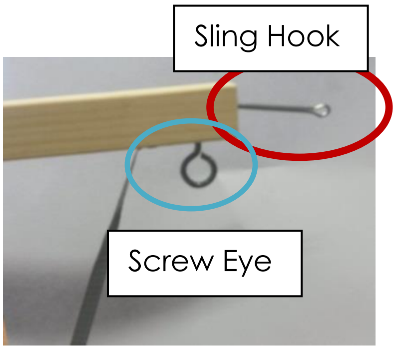


Put your trebuchet together. The positioning of the hinge points and the distance you place the counterweight from the central pivot are up to you, and should be decided as an outcome from investigation 2.

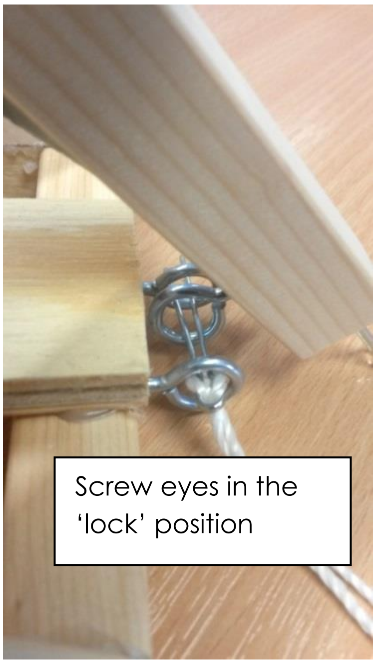


Optional additional mechanisms

Sling Hook
A hook to attach the additional end of your sling pouch to. This can simply take the form of a long pin at the end of your throwing arm.



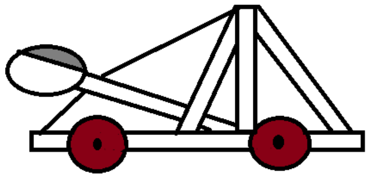
Firing pin
The Firing pin is comprised of three screw eyes, one attached to the bottom of the throwing arm and two on the base of trebuchet frame. When the throwing arm is pulled all the way back, the screw eyes should all line up and a long pin can be inserted all the way through which will lock the arm in place until you decide to release the pin and fire the trebuchet.



Mangonel- initial planning

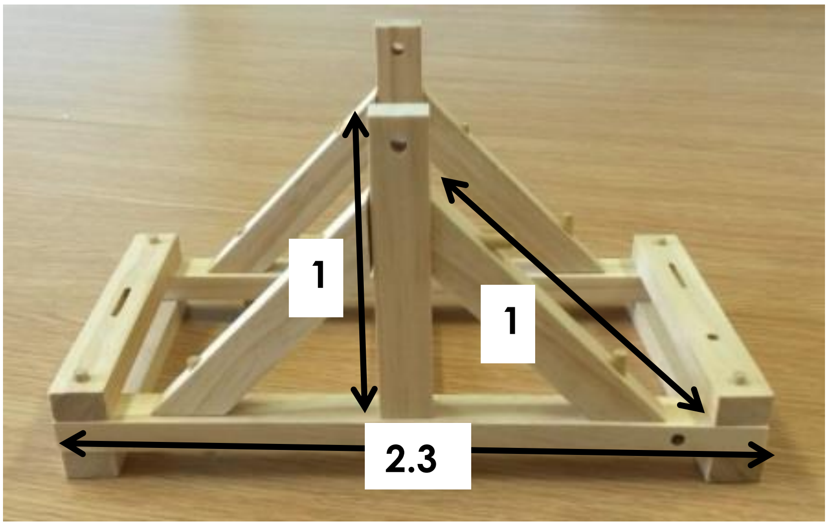
There are 2 main parts to a mangonel:

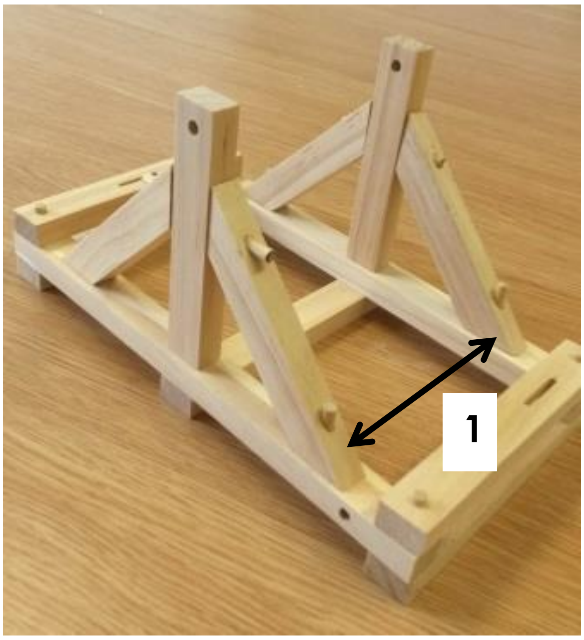
- A stable frame
- A throwing arm and tension mechanism



Stable frame

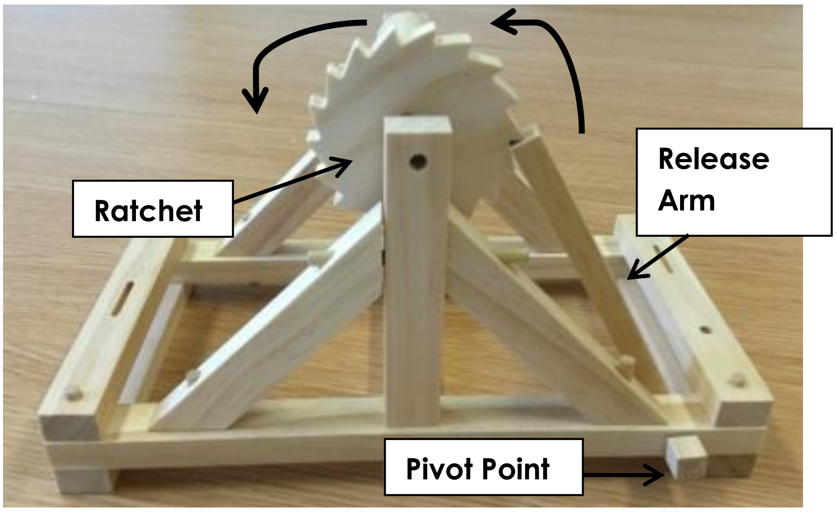
One of the simplest and strongest ways to make a stable frame is using an 'A frame' where you have two beams connecting at a 45º angle.
The A- frames show below use a ratio of 1:1:2.3 for the lengths of wood. The design below also uses doweling in all the joints as well as glue for added strength and stability. The overall height of the frame is a lot lower than that of a trebuchet- as there is no counterweight mechanism to rotate through the frame.

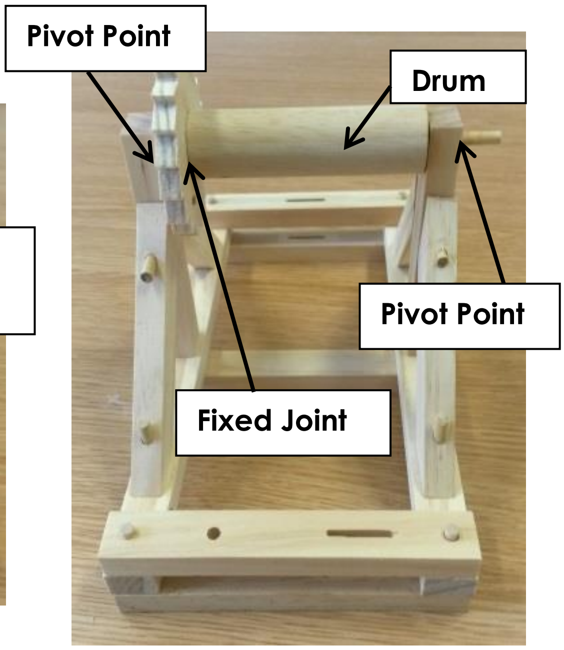




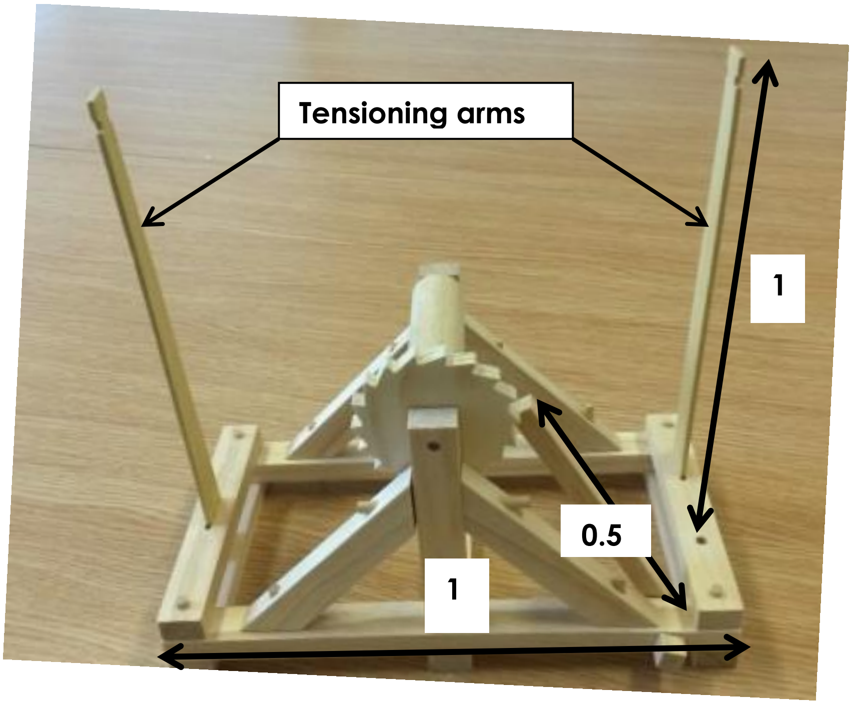
Throwing arm and Tension mechanism

The mechanism for throwing a projectile is a bit more complicated than that of a trebuchet. The following is adapted from a design created by Leonardo da Vinci. It uses two ‘tensioning arms’ along with a ratchet (a gear that allows continuous motion in one direction whilst preventing motion in the other direction) and a winding mechanism.





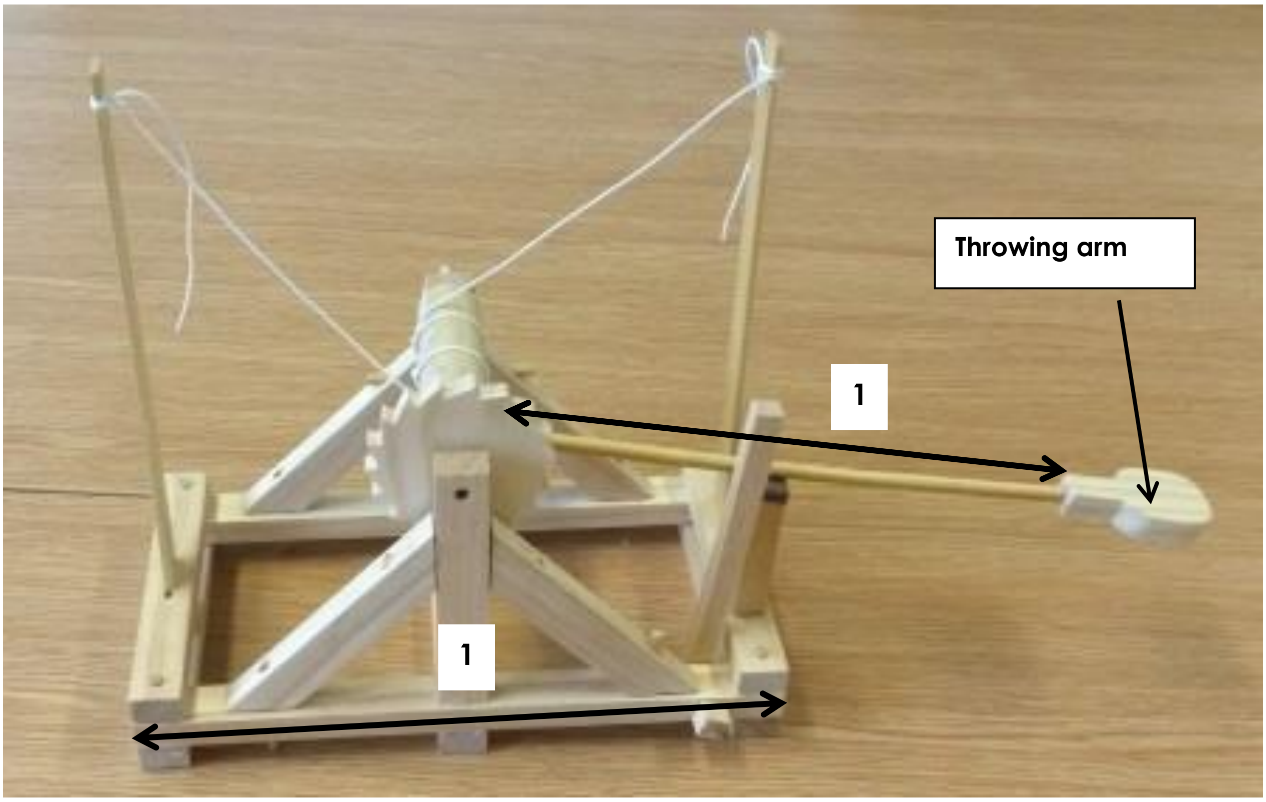
A Ratchet is attached to a drum, which is free to rotate within the frame. By adding a release arm one side of the frame, you create a mechanism that can be wound up in one direction and locked in place until you are ready to release the tension.



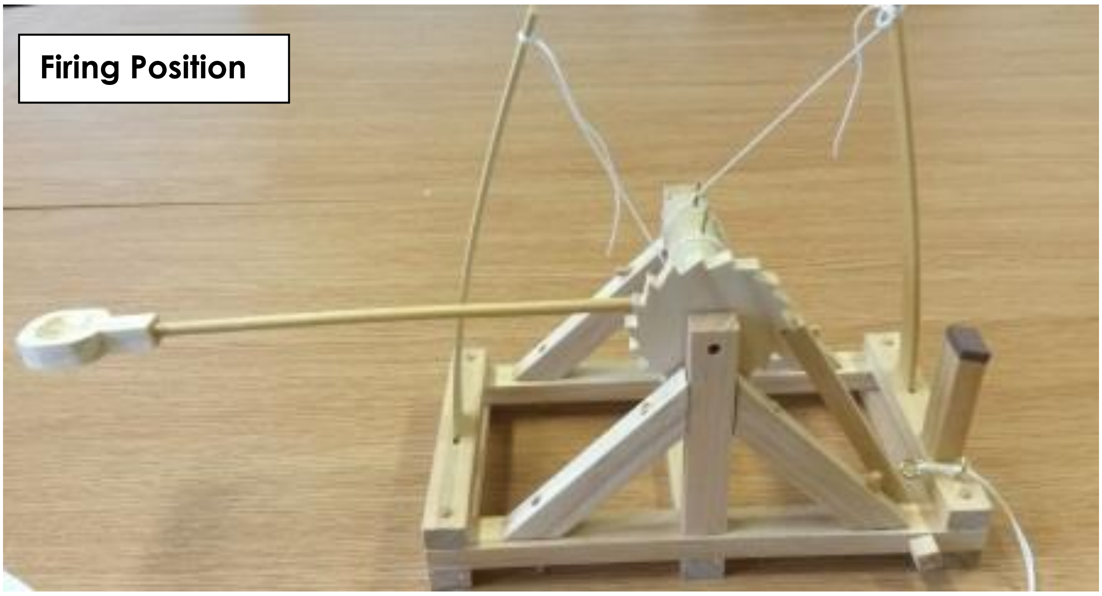
The tensioning arms shown here are embedded into the frame, in pre-cut slots in the base. They are also in a 1:1 ratio with the length of the frame.

The release arm is in a 0.5:1 ratio with the length of the base.

One of the tensioning arms in centrally placed the other one is off centre- this allows room for the throwing arm to move through.



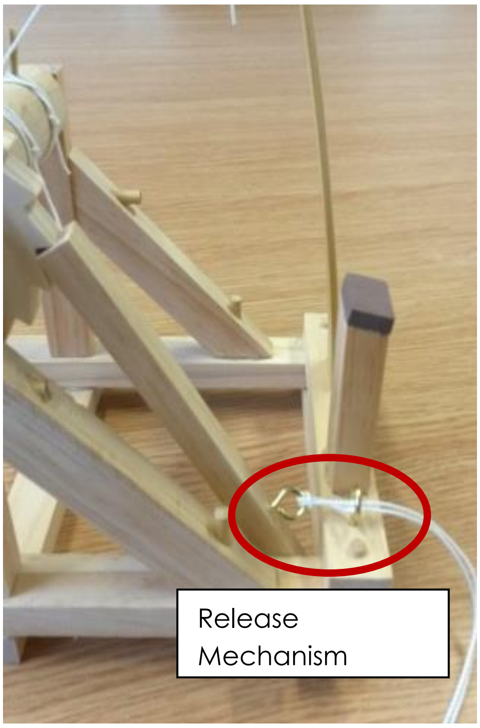
The throwing arm shown here is made from a long piece of doweling with a carved wooden spoon on the end (pictured facing downwards). It is in a 1:1 ratio with the length of the base. A swing arm stop has also been added. This prevents the throwing arm from hitting the ground after launching and potentially breaking. String has also been added to attach the tension arms to the drum mechanism. When the drum is wound to the left, the throwing arm is pulled backwards into the launch position and the tension arms are pulled tight and curved inwards (shown below.)

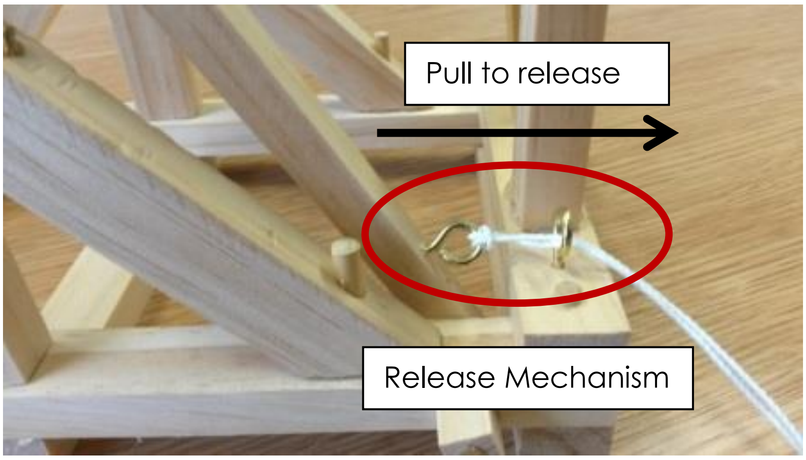


Optional additional mechanisms

Firing mechanism

The Firing pin is comprised of two screw eyes and a piece of string, one screw eye is attached to the bottom of the release arm and one is attached to the base of the mangonel frame. Tie a piece of string around the first loop eye and then thread it through the second screw eye. To release the throwing arm, pull sharply on the string, which will dislodge the release arm from the ratchet and release the drum to roll forwards releasing all the tension and firing the throwing arm forwards.





Risk Assessment

	2.
	3.
	4.
	5.

What might be dangerous?	Who might it be dangerous for?	How we will make it safer.
1.		
2.		
3.		
4.		
5.		
6.		

Please Note: this sheet **must** be filled out **before** you start building

OXFORDSHIRE COUNTY COUNCIL

SCIENCEOXFORD