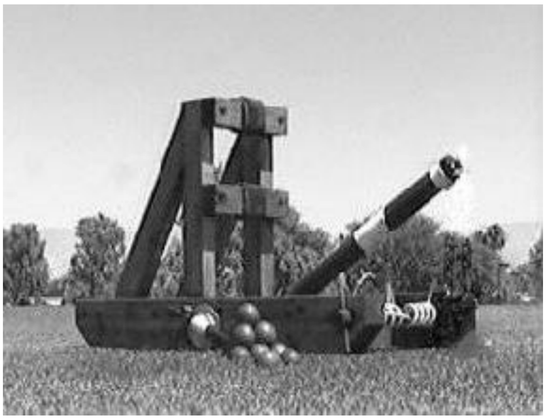
The Mighty Roman Mangonel



Dear Student,

This exercise gives you a fun opportunity to explore some of the important aspects of engineering:- design, structures, materials, dynamics, scientific programming and sensors, to name but a few. The value you derive from it will depend on the quality of teamwork involved and on how deeply you think about these topics.

As you read this document, you will note that the size of most of the component parts of the machine have been predetermined. Initially, you are free to make choices on the length of the 'throwing arm', the number of loops in the "skein" and to what angle the throwing arm is winched (the meaning of the terms in quotes will become clear as you read on). After you have assembled the Mangonel and tested it as is, you will have the opportunity to replace the throwing arm and "Missile" holder with one of your own design. Decisions on these values should be made at team level and be based on scientific considerations.

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What you should find in your kit:

Name	Spec.	Quantity Per Mangonel	Part No.
Base Beam	Hardwood (as per drawing)	2	1
Front Brace	Hardwood (as per drawing)	1	2
Square Brace	Hardwood (as per drawing)	2	3
Feet	Hardwood (as per drawing)	4	4
Angle Struts	Hardwood (as per drawing)	2	5
Vertical Beam	Hardwood (as per drawing)	2	6
Strike Bar	Hardwood (as per drawing)	2	7
Anchor Block	Hardwood (as per drawing)	2	8
Throwing Bar	28mm diameter dowel	1	9
Winch Dowel	20.5mm diameter dowel	1	10
Wooden Dowel	9mm diameter dowel	5	11
Steel Bar	6mm diameter silver steel	2	12
Wooden Dowel	6mm diameter dowel	2	13
Trigger Hook	Mild steel (as per drawing)	1	NA
Wooden Spoon	As provided	1	NA
Large Washers	1 inch diameter	2	NA
D-shaped metal ring	As provided	1	NA
Split rings	As provided (copper plated)	2	NA
Yellow Twine	Polypropylene	10m	NA

Nylon Cord	4mm white nylon cord	4.5m	NA
Leather	As provided	As provided	NA
Nails (Tacks)	10mm	8	NA
Wood Screws	5X50mm Black Jappaned	24	NA

Tools you will need: (to be provided by each team)

Name	Purpose	Comment
A flat head screwdriver	Assembly	To be provided by team. 1 per team.
A light hammer	For fixing leather to strike bars with tacks	To be provided by team. 1 per team.
Matches/Lighter	For fusing rope ends	To be provided by team. 1 per team.
90 Degree set-square	For locating vertical beams	To be provided by team. 1 per team.
A length of wire to make a hook (coathanger?)	To help feed white nylon cord (skein)	To be provided by team. 1 per team.
Fine/Medium sandpaper	Modification of dowels and other wooden parts	To be provided by team. 1 per team.
Craftknife	Cutting twine etc.	To be provided by team. 1 per team.

Miscellaneous: (will be provided by the demonstrators)

Name	Purpose	Comment
Wood glue	For attaching feet to base beams ***only***	Will be provided by demonstrator
Superglue	For attaching D-ring to throwiong arm	Will be provided by demonstrator

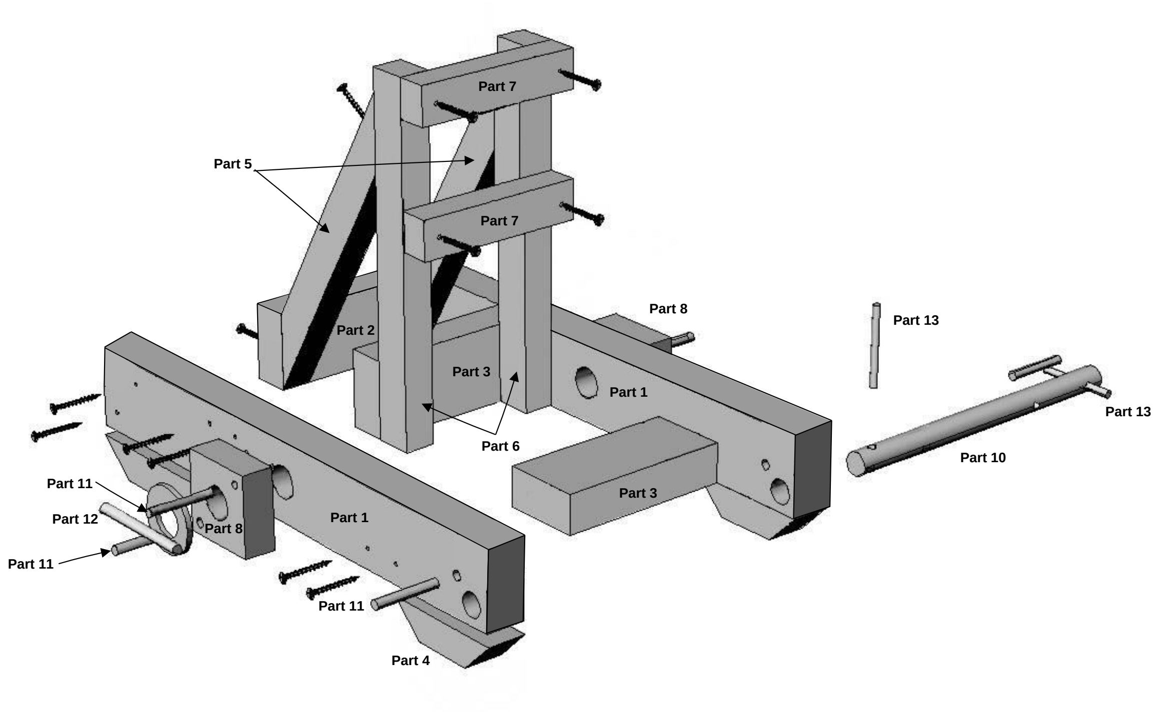
NOTES ON SAFETY AND WORKING WITH WOOD:

Wood is a funny material. It’s a product of nature, and as such, it can be a little bit unpredictable. Experienced carpenters say you never know how strong a piece of wood is until it breaks. Be sure to look for any defects in the wood, such as: knots, checks, cracks and water damage, etc. DON’T USE any pieces that have any defects, ESPECIALLY THE ARM! Ask for new piece instead. Also, it’s important to be aware that a piece of wood can look perfectly fine and apparently free from defects, but can still have faults such as internal stresses, voids and fractures that cannot be seen on its surface.

Ultimately, you are building this model AT YOUR OWN RISK. If you feel very unsure about using the tools required or in selecting appropriate pieces of wood to use, seek the help of your supervisor.

Every reasonable precaution has been taken to make this exercise a safe one, but remember that safety is a personal responsibility – even for students.

Assembly Instructions:



Assembly Diagram

Building the frame: **Note: Figures 1-3 and figure 6 show 45^0 angled fillets on some corners. These are not present on your machines**

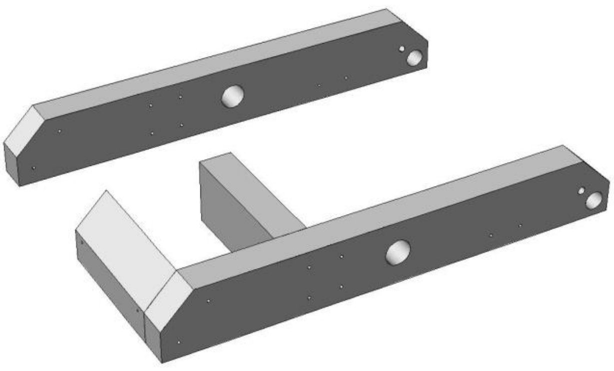


Figure 1.

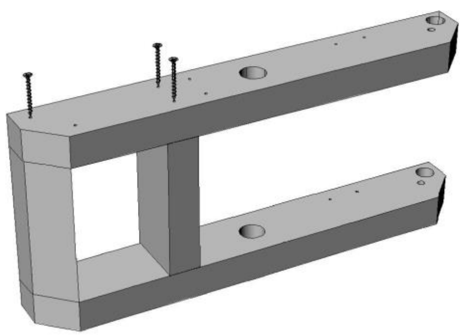


Figure 2.

The braces must be screwed carefully onto the side members, this is important as there is a lot of pressure and impact on these pieces when you fire the machine! – make sure you get things in the correct position and that they are square!

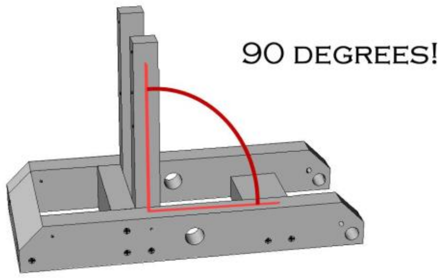
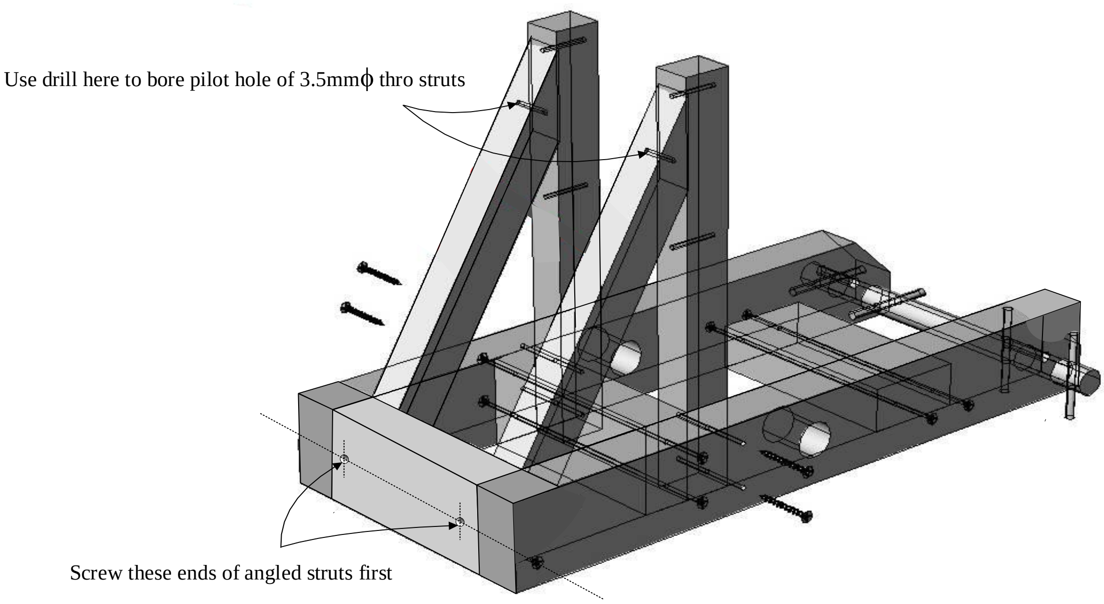


Figure 3.

The Vertical beams: The two vertical beams are screwed to the inside of the frame.

Figure 4.



The Struts: The angled struts go on next.

It is not always possible to be certain if location holes will line up. To accommodate inaccuracies it is sometimes necessary to drill a hole once an assembly is partially assembled. We will carry this out here drilling a pilot hole into the uprights once the diagonal struts have been located with reference to the front brace.

The feet:

Use the wood glue to attach the four feet in position (shown in Assembly Diagram). This is the only part that we will use the wood glue on. It is important to note that ideally the wood glue would be used, in addition to the screws, to fix the vertical and diagonal members to each other and to the frame. However, as we wish to disassemble the Mangonel at the end of the project we will not glue here.

The arm strike beams, will go on later after the skein has been tensioned. Don't put them on now or you'll have a hard time tensioning your skein!

The Winch: Slide the dowel into the holes at the back of the frame. If it is humid the dowels can swell and may seem very tight. You may need to file the holes a little bigger in this case. If the winch dowel is hard to turn, scrape a pencil lead all over the surfaces that make contact. Pencil lead is made from graphite, and it's a great way to lubricate things that need to stay dry. Graphite has been used for lubrication for centuries!

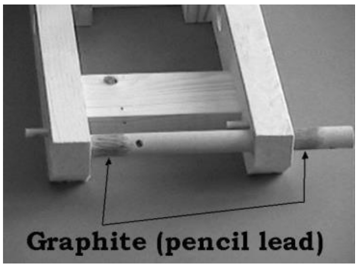
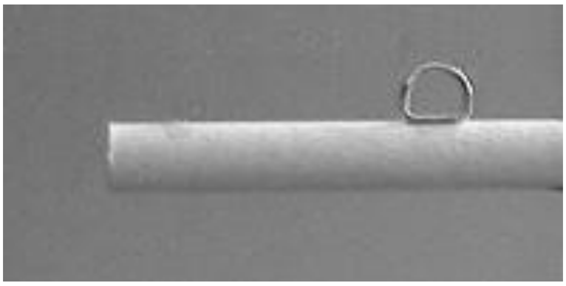


Figure 5

Figure 6

Slide the 6 ϕ pegs through the holes on the winch dowel outside the frame (Figure 5). The holes on the inside will be used to hold the rope later. Put one of the 9 ϕ pegs into the holes in the frame next to the winch. This latter dowel should be able to slide in and out of the frame, so don't glue it! (Use the graphite to take it slide easier)

The Throwing Arm: The arm is probably the most important part of the machine. If it's not assembled properly, it may break after repeated use. The arm has a round cross section with some minor cutouts to



help to keep it in the right orientation in the rope skein.

Super glue the D-ring onto the line on the side of the arm so that the top of the D-ring is 100mm from the top of the arm and is longitudinally aligned with the line. (Figure 7). The glue is not actually going to hold this in place, so don't use a lot of it. Gluing the D-ring in place is only done to make the next step a lot easier.

Figure 7

Wrapping the arm: What follows is a technique for making wood stronger by wrapping cord around it and so, hopefully, keeping it from breaking under stress. It's how we will secure the winch hook (D-ring) to the arm and also the throwing cup. Here's the basic technique for wrapping-

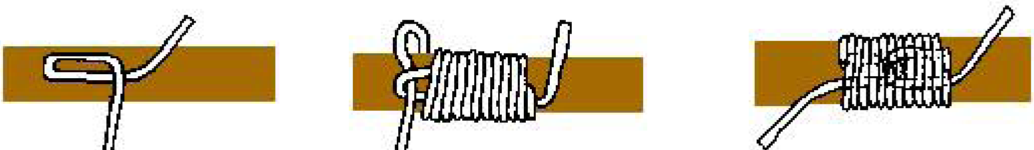
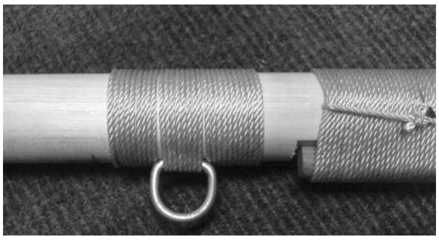


Figure 8 **Figure 9** **Figure 10**

1. Make a loop against your beam (Figure 8).

2. Wrap the cord around the beam and over the loop. Be sure to keep the cord as tight as you can during this process (Figure 9).

3. Insert the loose end of the cord through the open loop (make it a tight wrap) then pull the loose end under the wrapping using the other loose end (Figure 10). On some types of cord you can just cut the



ends and leave it at that, but nylon tends to slip, so bring the loose ends together over the wrapping and tie them together. You may want to practice the wrapping a couple of times before you make it permanent.

Start about 12mm below the D-ring, and wrap the arm all the way up to at least 12mm above the D-ring. Pass the cord through the

Figure 11

ring as you wind it up (Figure 11). The most important thing is to keep the windings as tight as possible. Now you are ready to fit the 'missile holder'. Position the spoon on the arm in the correct orientation with respect to the D ring. Correct orientation of the missile holder is most important to ensure that missiles are thrown along a line perpendicular to the axis of the skein. Proceed by wrapping the combination along its length in a manner similar to that shown in Figure 12

Figure 12.

The skein: This is the source of power for your machine. For easy construction and a machine that can throw balls about 15-20 metres, use approx. 7 loops on the skein (7 strands on top of the arm, and 7 on bottom). The more wraps you use, the harder it will be to tension the skein, and the harder it will be to cock the machine when firing. Using too much tension will damage the machine, so don't go crazy!

Tap into place two $\phi\, 9$ pegs into the skein anchor blocks (if they are a loose fit, due to manufacturers variations in diameter) , Figure 13 then place the metal washers over the large holes in them and put these assemblies on the outside of the frame. Now lay the capstans (the 6ϕ metal rods) over these plates centered over the holes. Tie one end of the nylon rope to something (a vertical beam will work), and pass it through the skein hole from outside the frame. Thread it the same on both capstans- bottom-to-bottom, then top-to-top, etc (Figures 14, 15). After you get one or two wraps in, put the arm in the bundle so that it keeps the bottom wraps separate from the top wraps of each loop. When you're done it should look like Figure 16. This is all a rather 'fiddly' task – if you play about for a bit you'll get the hang of it.

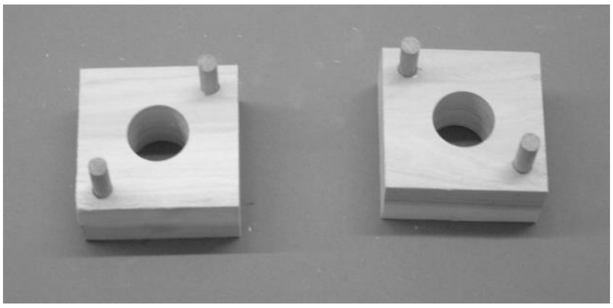


Figure 13

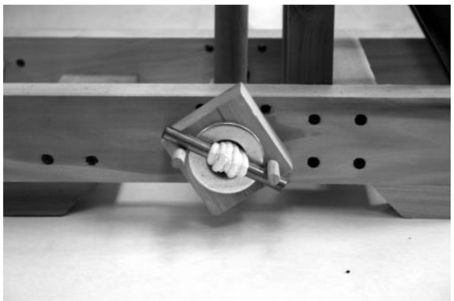


Figure 14

If you're having trouble getting the rope past the other loops and through the holes you can make a loop from a clothes hanger wire or any bit of stiff wire to help pull through the rope ends.

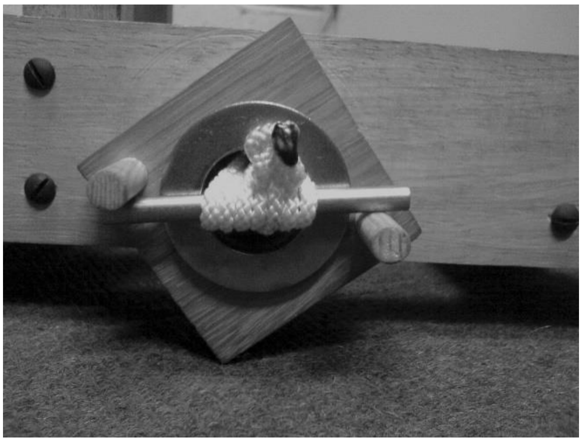


Figure 15

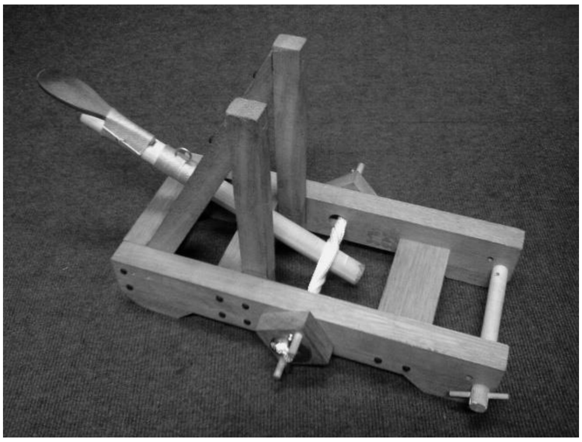


Figure 16

Once you've got all your loops in place, untie the rope from the vertical beam and tie the ends of the rope together in a secure square knot over the capstan (Figure 15). Fuse the ends so the knot won't slip. Slide the throwing arm relative to the skein so that it is at your selected arm length. Your model should look something like Figure 16.

Your skein should already be pre-tensioned. Don't worry if you didn't get it very tight. Just wind it up more during this phase. The base of the arm will stick out a bit from the skein bundle but don't let it touch the ground. Make sure it is facing the right way (D-ring to the back, cup of the spoon facing to the front) before you tension the skein.

To tension the skein, turn the two anchor blocks at the same time towards the vertical beams (Figure 17). Make only a quarter turn at a time. You may need an assistant to hold the throwing arm upright until there is enough holding torque. The anchor blocks should stay in place from friction alone. The completed skein should look like Figure 17.

Figure 17.

How many turns to use will depend on how much torque you require, how many loops you have and how much tension (if any) is already in the skein. At least one full turn is usually enough, but use two or more full turns if you have to. It should be hard to turn. The harder it is to turn, the more force you are storing in the twist. But don't over-tighten it or you'll start to deform the frame. If the capstans start to bend or the steel ring-plates begin to buckle, you're turning too hard!

The strike pads and beams: Nail the leather(ette) strips to both strike bars using the tacks. Don't put any nails in the face of the pad, or it will probably cause the throwing arm to crack. You may need to use a number of layers of leather. The purpose of the strike pads is to absorb some of the impact from the throwing arm and so to preserve the assembly for repeated use.

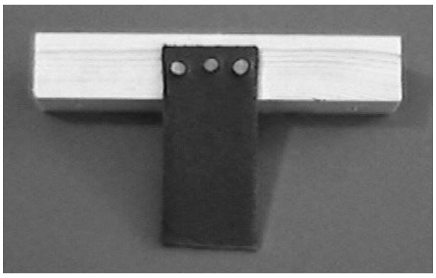
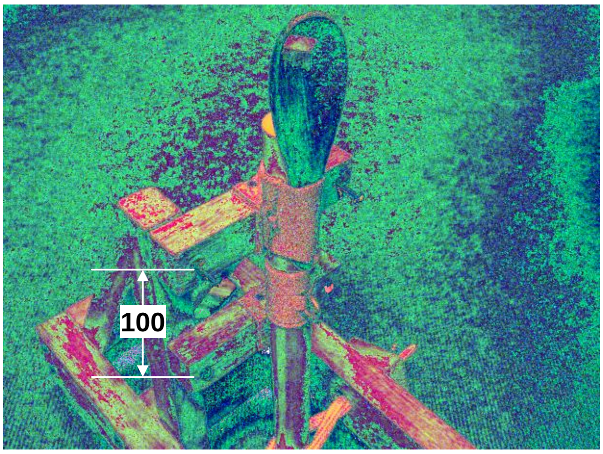


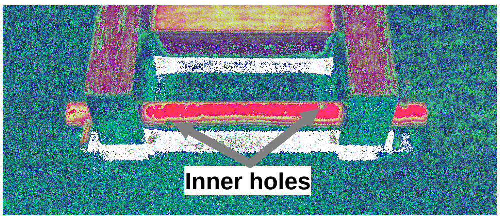
Figure 18

Now pull the throwing arm back (you might need someone to hold the base steady while you do this) and place one of the strike beams between the arm and the vertical beams so that the holes in the strike beam are flush with the 'screw guide' holes at the top of the vertical beams (Figure 19). The arm will hold it in place while you attach it with the screws. Then attach the second strike beam so that it is 100mm below the first strike beam, from top to top.

Figure 19



The Winch: Use some of the yellow cord for the winch (you decide on a sensible length). Make a



double loop of it and thread this through one of the 'inner' holes in the 'winch dowel'(see Figure 20). Feed the ends of the cord back through the loop and pull it tight to make the cord secure. Now install the two split rings onto the cord and tie-off the cords free ends through the other 'inner' hole in the dowel. Be sure to use both split rings for extra strength. Then hook the trigger onto the split rings as in Figure 21.

Tie a yellow string at least 1.75metres feet long to the top loop of the trigger (Figure 21) and you'll be ready to go!

Figure 20.

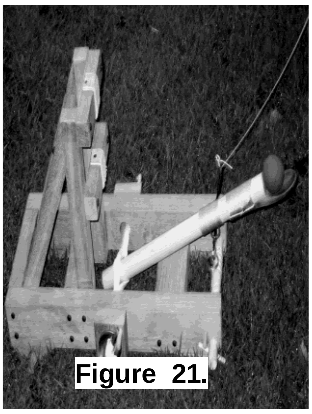


Figure 21.

Cocking and firing: Carefully wind the arm down with the winch. Be sure to stay low and well behind the machine when winding the winch! <u>NEVER stand with your head or any part of your body over the arm!</u> When the trigger's rings are almost touching the winch rod, it is fully cocked. Slide one of the ϕ 9 pegs into the closest hole to the winch handles to hold it in place (Figure 22).

<u>You now have a live machine, **be careful!**</u>

<u>**NEVER put your fingers or anything else between the arm and the strike beams!**</u>

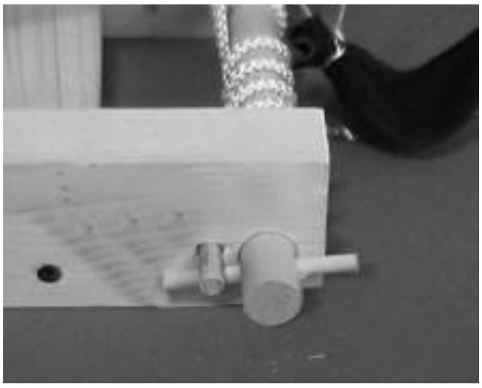


Figure 22.

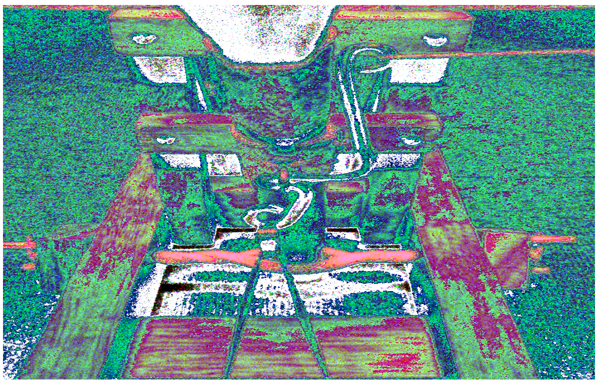


Figure 23.

To fire the machine, place your projectile into missile holder (Figure 23). You should never "dry fire" the machine without any projectile in the spoon. This can damage your machine and may even break the arm.

Secure the mangonel to the ground by whatever method you are instructed to use. Then make sure there is nothing, **and especially no people** in front of the machine or behind it for at least 20 metres. Let everyone in the area know what's about to happen, stand off to the side and pull the cord!

Tuning:

One way to tune the machine is to adjust the skein. You can either use lots and lots of turns of thinner nylon rope (nylon is the best thing to use, unless you can get a rope made from horse hair!), or add spacer blocks between the sides of the frame and the capstans, effectively making the skein longer. Either of these can improve the power of the machine.

You can also adjust the arm. A lighter weight arm will swing faster, but it will probably also break. A longer arm will have more leverage, but it will also be heavier. Maybe you could use a flexible arm. You will have to think about this, can you explore it mathematically?

Safety: Please remember that **THIS MANGONEL MODEL IS NOT A TOY**! It is a representative model of a real ancient military weapon and is intended to be educational. Only fire it under supervision, and be aware that the end of the arm moves fast enough to rip your skin open, and it hits the strike pads hard enough to break bones. **NEVER put your fingers or anything else between the arm and the strike beams!**

If any part of your machine is damaged or defective, do not fire the machine. Contact your supervisor for replacement parts.

This machine can hurl a projectile with enough force to knock someone unconscious, break teeth and bones and rupture eyeballs. You are responsible for your own safety and the safety of others when you demonstrate this machine. PLEASE BE CAREFUL!

NOTES ON SCALING:

A lot of people make bad mistakes when trying to scale a model to different sizes.

1. Length: This is the easy one. If you have a measurement four metres long, and you want to double

it's size (increase its scale a factor of two) then it will be eight metres long. And so on…

But what a lot of people forget is that they have to scale it in all three dimensions. So, if you have a board that is 50mm by 100mm by 2.5metres long, and you want it half scale, then you have to cut it to 25mm by 50mm by 1.25metres.

2. Mass / weight: This one loses a lot of people, so try to keep up- First of all, mass and weight are not the same thing. But they scale similarly, so don't worry about it. Mass and weight DO NOT scale the same as length though! Too many people make the mistake that if they double the length, then all the weights double too. No so. Think about a cube that is 1metre by 1 metre by 1 metre in length on each side. Its total volume is 1 cubic metre. Now let's double its scale to 2 m x 2m x 2m. Now its volume is 2 x 2 x 2, or 8 m^3. So, what's obvious here is that the length doubled, but the volume increased by a factor of eight!

If we tripled it, to 3m x 3m x 3m, then it's volume would be 3 x 3 x 3 = 27 m^3! Now the volume is 27 times as much even though the length only went up three times! Volume is how we figure weight. What's the weight per m^3 of something, times the number of cubic metres you have = the weight of the whole thing. Mass (or weight) scales as the cube of the length. So, if you want to quadruple (four times) the size of a machine, then its weight needs to increase by (4 x 4 x 4 = 64!!!) 4^3 = 64 times as much weight for a machine only 4x as big. Scale it up five times, and the weight goes up 125 times. Obviously, your machine is going to have to be a lot stronger!

3. Strength: Here's where people get into real and serious trouble. When you scale a machine up, say 4 times, the weight of each member will go up sixty-four times!! The properties of the material (shear strength, bending resistance, etc.) haven't changed, and the beam has to support its own weight in addition to the increased weight of any other members and stresses that it supports. The result is that the total strength of the machine gets proportionally weaker as the scale goes up. Strength scales as a smaller-than-one fraction of the length.

Things like compression, tension, flexion, shear, and tear can all scale very differently even in the same material. What does this mean? Basically, when you scale things up, they become relatively weaker. They have more trouble supporting their own weight, and the weight of everything else it supports is also increasing cubically, so at some point you have to change the design, or use materials that are inherently stronger to begin with, and keep their limits in mind too.

4. Non-scalable properties: There are things that you can't scale, like gravity. Unless you're wiling to go to the Moon or Mars, etc. Friction is a product of the frictional coefficient (non-scaleable), times surface area (scales as the square of the length), times pressure (uh…). Too complicated for this document. Density doesn't scale. So, air resistance (a product of air density and cross sectional area and velocity) isn't easy to scale either. All these things can affect performance, so if you have a catapult that hurls 60metres, and you double the scale, don't expect it to hurl 120metres (unless your projectile is considerably less than 8x the weight).

Try to figure out more scaling problems on your own. This is a great project for experimentation!

Web links for more information:

This site is mainly about the Trebuchet, but includes this wonderful article and full-scale reproduction of the Roman Mangonel- http://members.iinet.net.au/~rmine/middel.html

More information-

http://www.codesmiths.com/siege/mangonel.htm http://www.castles.me.uk/mangonel.htm

More catapult technology-

http://members.iinet.net.au/~rmine/middel.html http://perso.wanadoo.fr/bbcp/english/engins/engins.html

Fun with catapults-

http://www.onager.net/ http://www.ultranet.com/~zappo/siege/babyonager.shtml

A computer simulator for the Mangonel/Onager-

http://www.xs4all.nl/~mdgsoft/catapult/sim/

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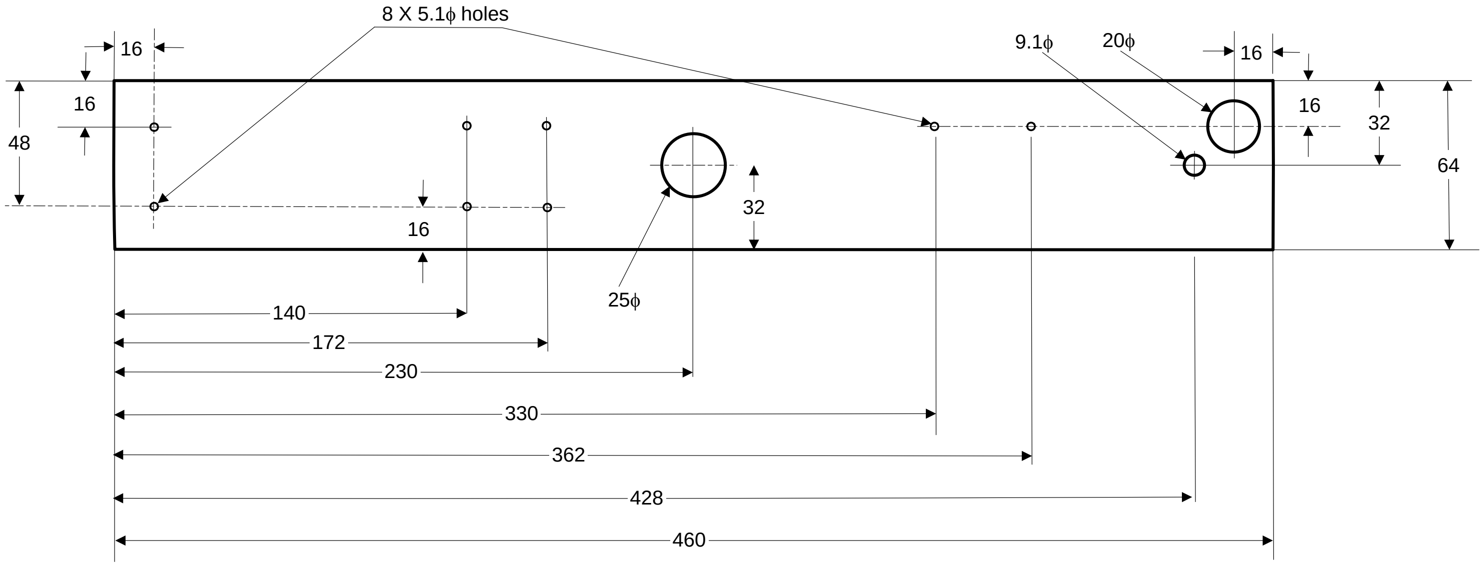
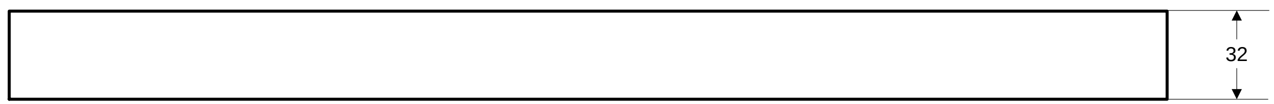
Part Drawings:

Part 1: BASE BEAMS

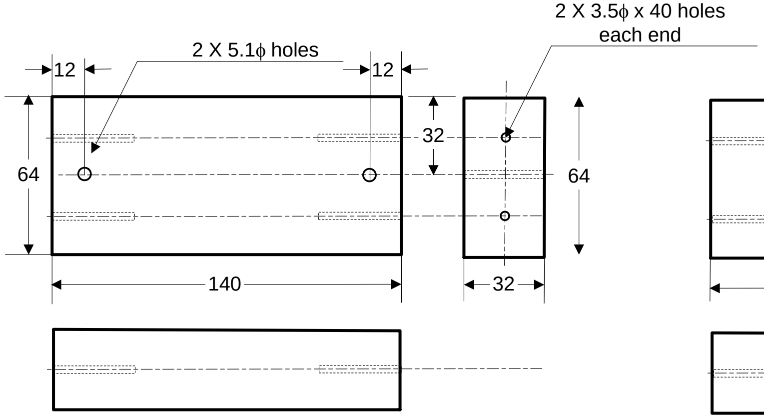
Part 1: Quantity 2off per Unit: Material Wood





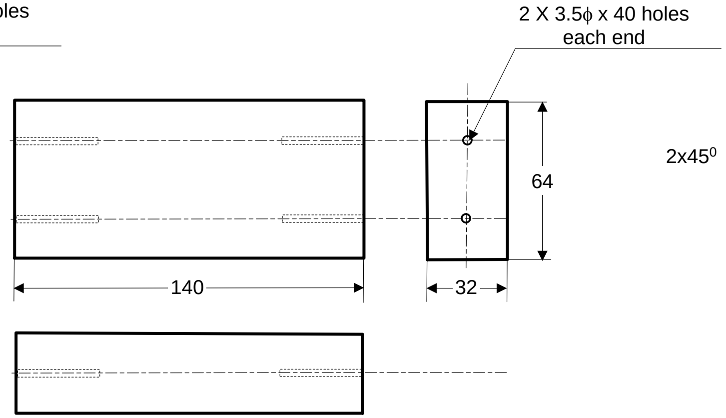
Part 2: FRONT BRACE

Part 2: Quantity 1off per Unit: Material Wood



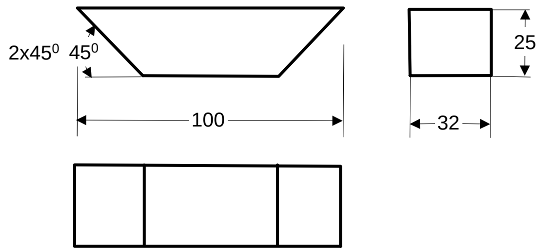
Part 3: SQUARE BRACE

Part 3: Quantity 2 off per Unit: Material Wood



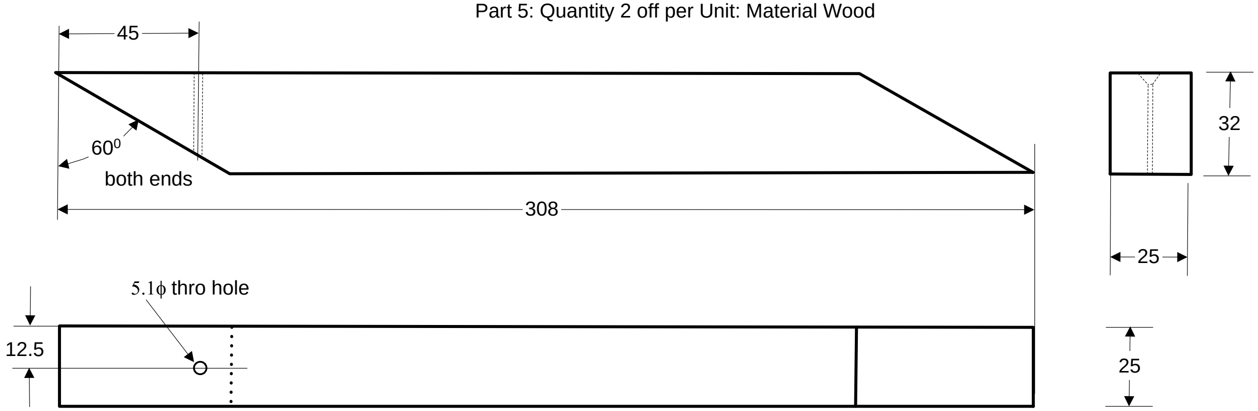
Part 4: FEET

Part 4: Quantity 4 off per Unit: Material Wood



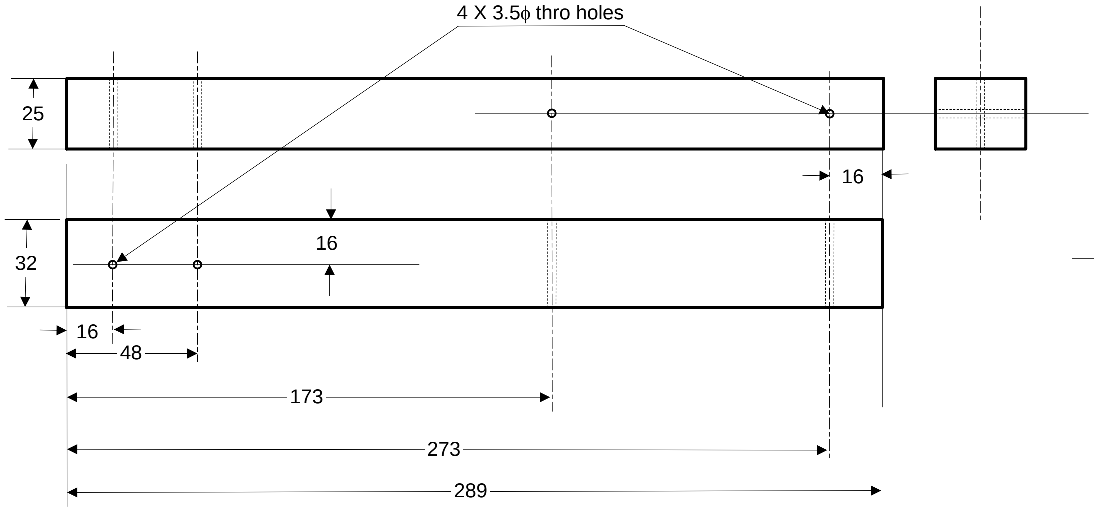
Part 5: ANGLED STRUTS

Part 5: Quantity 2 off per Unit: Material Wood



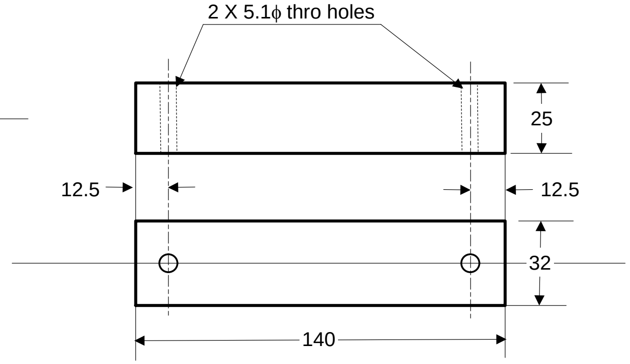
Part 6: VERTICAL BEAMS

Part 6: Quantity 2 off per Unit: Material Wood



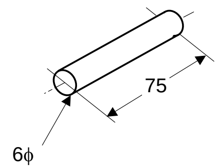
Part 7: STRIKE BARS

Part 7: Quantity 2 off per Unit: Material Wood



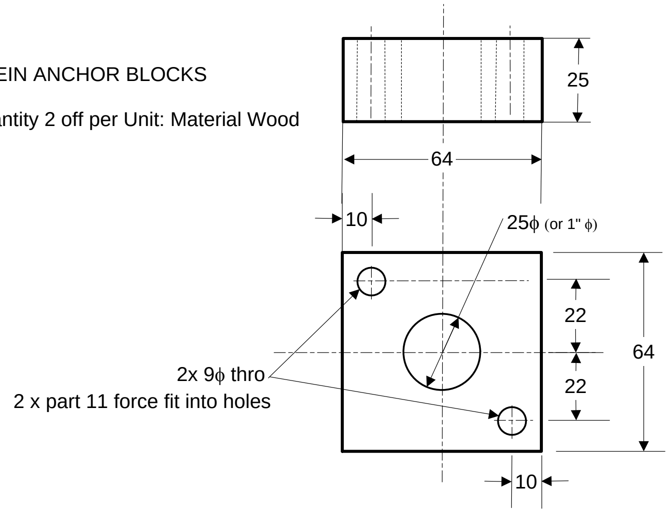
Part 12: Steel rods

Part 12: Quantity 2 off per Unit: Material Steel see BOM)



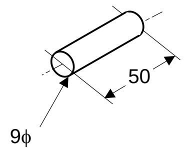
Part 8: SKEIN ANCHOR BLOCKS

Part 8: Quantity 2 off per Unit: Material Wood



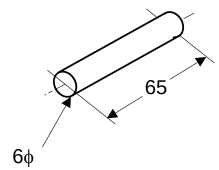
Part 11: DOWELS

Part 11: Quantity 5 off per Unit: Material Wood (standard dowel see BOM)



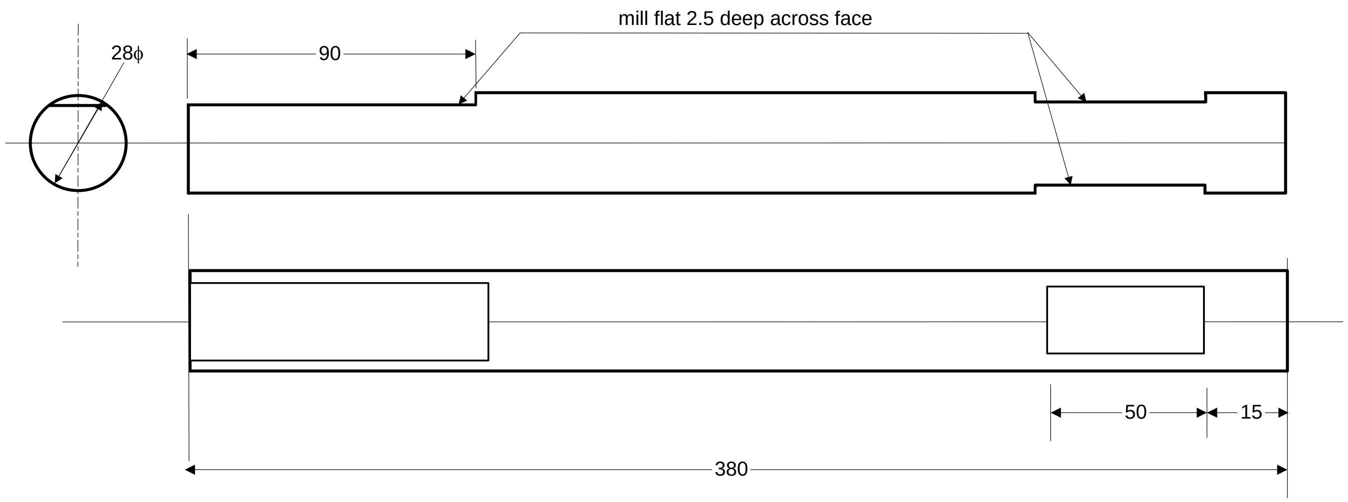
Part 13: DOWELS

Part 13: Quantity 2 off per Unit: Material Wood (standard dowel see BOM)



Part 9: THROWING BAR

Part 9: Quantity 1 off per Unit; Material Wooden Dowel



Part 10: WINCH DOWEL

Part 10: Quantity 1 off per Unit; Material Wooden Dowel