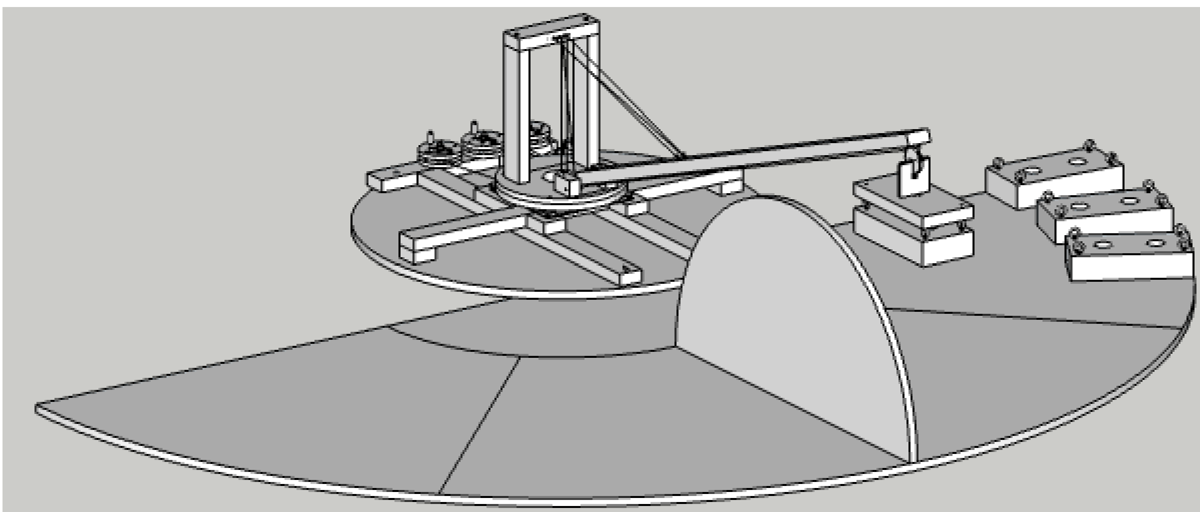
Raise the Roof

Team Advisor

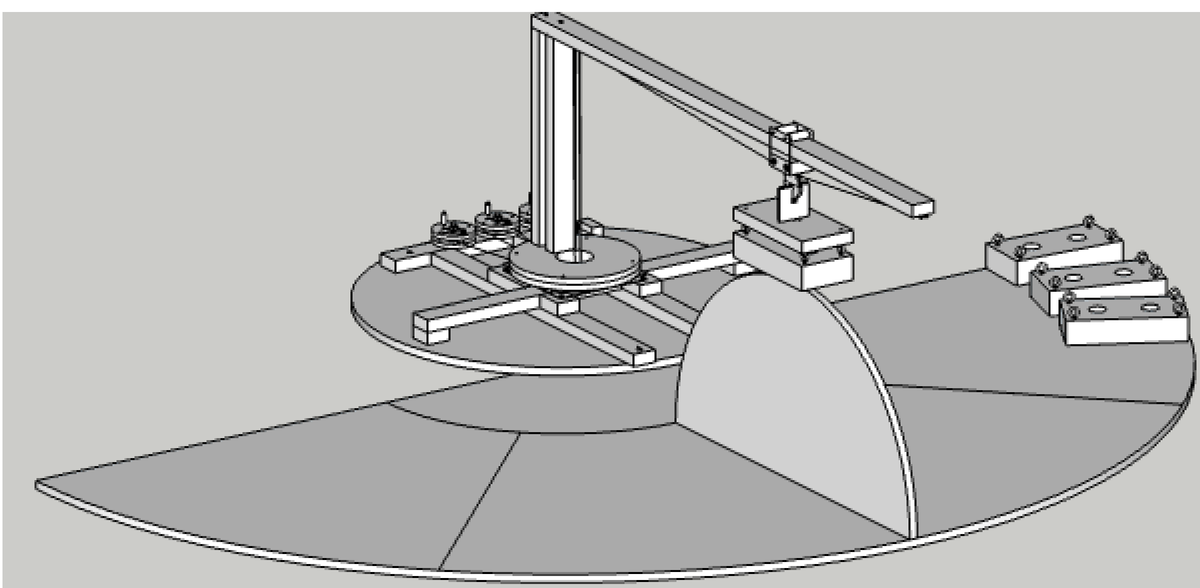
Post Graduate division

8/23/26

Ross La Fetra



Boom Crane



Tower Crane

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Summary

Our objective was to build a device to simulate moving housing modules on a work site. Since housing modules are heavy, we wanted to show a mechanism that demonstrates mechanical advantage, letting us move heavier modules than we otherwise would be able to do. We chose to make two devices, each meeting the objective on their own, but using a different crane type.

The boom crane has three degrees of freedom: the direction, the boom angle (a combination of height and distance), and the height. These degrees of freedom are controlled by three knobs (spools) connected to strings.

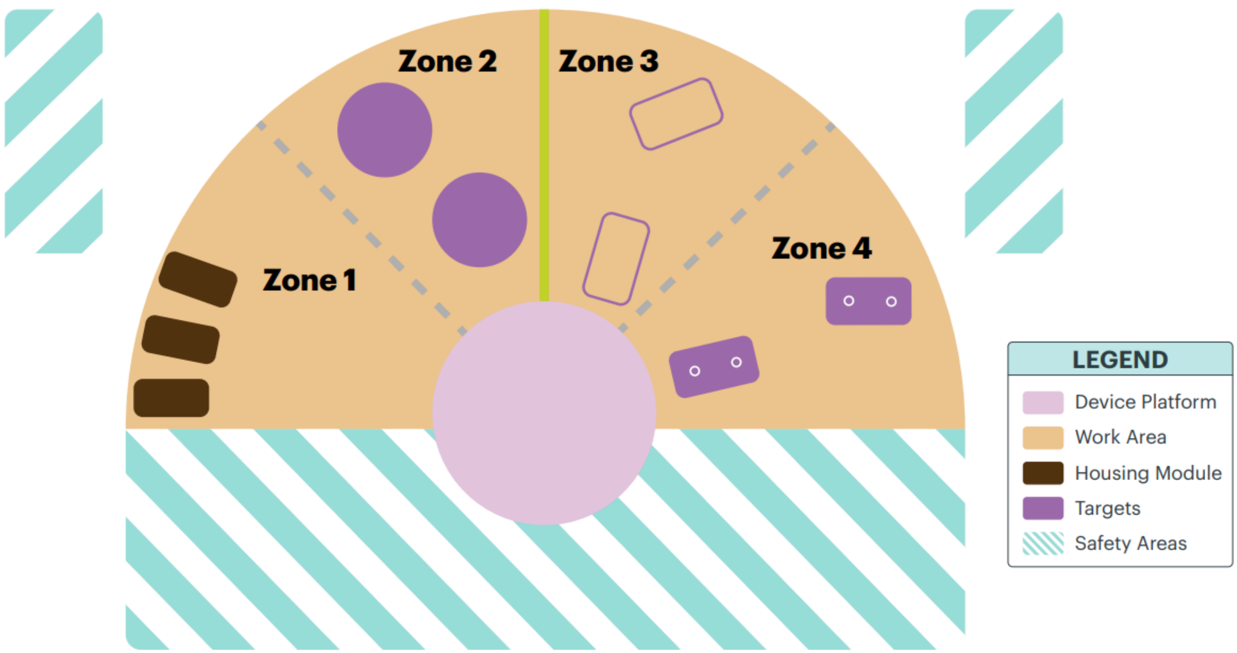
The tower crane also has three degrees of freedom: the direction, the distance, and the height. Unlike the boom crane, each of these are independent of the other. (The height of the module in the boom crane is a combination of two of the degrees of freedom.) Again, we used the same knob and string approach.

Neither approach addressed additional degrees of freedom – rotation of the module. It would have been nice to be able to rotate the module to point in any compass direction, but we didn't go there. Rotation of the module in the other axes was prohibited by the requirement the module was moved flat.

Other means of controlling the cranes could be considered. Anything that moves a string will do. One possibility is add electric motors to the spools.

Problem Statement

The Raise the Roof challenge imitates a building site where prefabricated housing modules need to be lifted into position by a device we create. The modules start at predefined locations, and need to be moved to team defined locations in specified zones of the site. The sites must be chosen before lifting any of the modules. The modules cannot be dragged, they must be lifted before being moved. There are three identical modules to be moved, and the targets and zones depend on the division. Zone 1 is the initial location of the modules. Zone 2 is adjacent, and has large circular targets. Between Zones 2 and 3 there is a barrier that the module must be lifted over. Zone 3 is adjacent to Zone 2, and has rectangular targets. Zone 4 is adjacent to Zone three, and has targets with two pegs that the module must be lowered onto. The modules may be attached and detached by hand when resting on the site's surface. The module must remain horizontal at all times.



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Housing modules are heavy, and we are not all that strong. The challenge wants us to show mechanical advantage. Mechanical advantage allows us to increase the force applied by decreasing the distance it moves, conversely, decreasing the force required by increasing the distance moved. Basically, it makes it possible for us to lift heavy objects.

Final Design

Our prototype worked well enough that we made it our final design. See the section on prototype 1.

Project Description

Theory

Degrees of Freedom

Degrees of Freedom are how many independent things we can do.

In theory, we only need one degree of freedom, which location we are at. However, it would be very difficult to build a device that does all we need it to do with only one degree of freedom. Also, this would not work very well in a real world situation, things move around, but your device cannot cope with that – the sites are prechosen.

Two degrees of freedom are more reasonable. One degree of freedom can be how high we lift the module, another degree of freedom can be which way the device is pointed. It doesn't have to be that simple. Imagine a fishing rod with a hook (but no reel). You can control how high the hook is, or how far from you the hook is, but not independently. Each choice of height also chooses the distance. So it counts as one degree of freedom. The other degree could be what direction the fishing rod is pointed. (Now fishing rods are disallowed if you hold the fishing rod, but if the device holds it, we call it a boom crane.)

Three degrees of freedom allows more choices in how the module is placed, and is a realistic choice for the real world. The three freedoms could be (but also could be combined) are direction, distance, and height. This allows you to place the module anywhere.

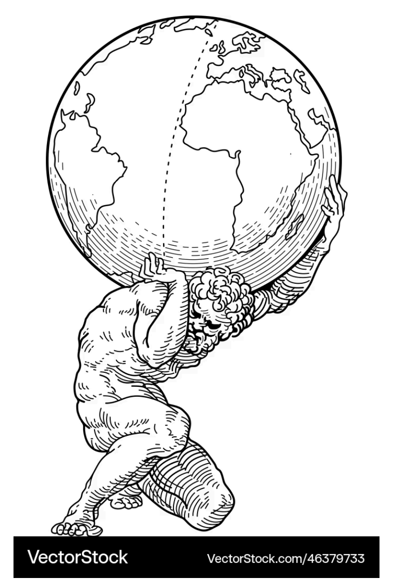
Four degrees of freedom. If three allows you to place the module anywhere, what could the fourth degree be? Which direction the module is pointing! This can get hard, and usually not done in the real world. Someone on the ground holds a rope to control the rotation of what is being carried.

Five and six degrees of freedom are when we control the other axes of rotation, but the rules say we must transport the module horizontally at all times, so these traditional degrees of freedom are not allowed.

For our project, we will use three degrees of freedom, but control all six – just not independently.

Mechanical Advantage

There are many kinds of mechanical advantage. Perhaps the ancient Greeks said it best. While Atlas, a God, had to carry the weight of the world on his shoulders (direct application of force), Archimedes (a mere mortal) is said "Give me a lever long enough and a fulcrum on which to place it, and I shall move the world" (use of mechanical advantage).



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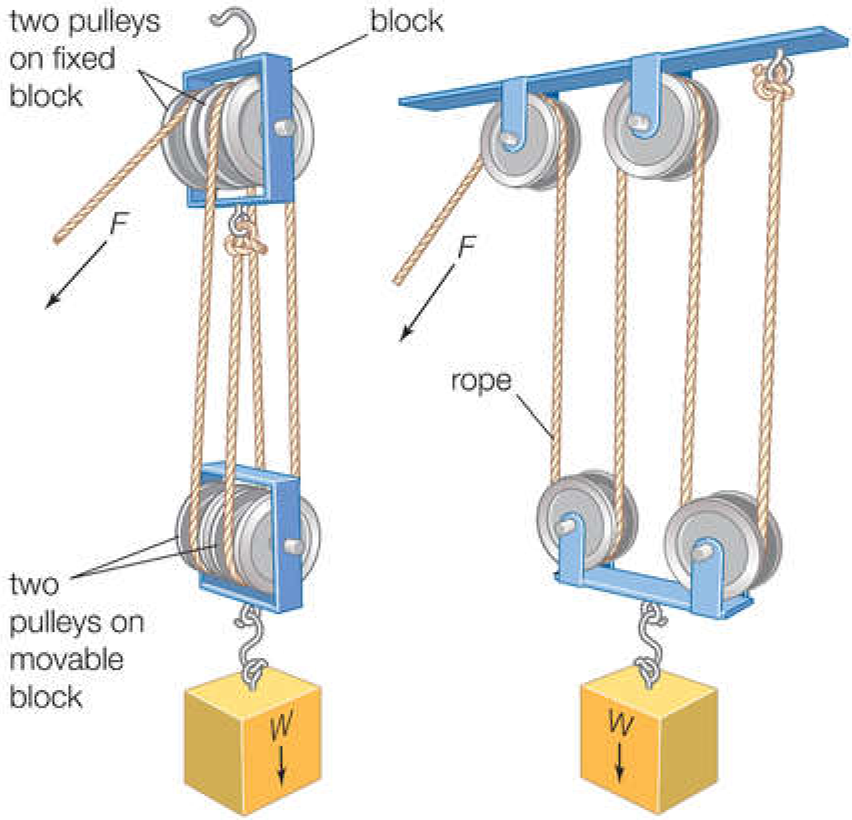
Here are some ways of implementing mechanical advantage:

- Lever: Like the Archimedes example above, the short end moves a little with a lot of force, while the long end moves a lot with little force. Not so useful for this project.
- Inclined plane: It is easier to pull something up a gentle slope than a steep slope, but you have to pull further on the gentle slope than the steep slope. Wrap this around a pole and you have a screw, another kind of mechanical advantage. We'll use lots of screws to hold things tight, but not lifting our module.
- Hydraulics: Think of two syringes of different sizes attached by a tube. If you squeeze the smaller syringe a lot, fluid (say water) will travel to the larger syringe and move it. Being larger, it will move less, but with greater force. In the real world hydraulics are used a lot (it is easy to make small tubes go where you want them to go), but they use a pump for the small syringe. It is hard to use syringes this way, small syringes typically travel only a small amount, while large syringes travel a large amount – opposite of what we need.
- Gears and pulleys: The small gear or pulley turns quickly (with little force), while the large gear or pulley turns slowly (with a lot of force). Essentially gears and pulleys are the same, gears connect directly, while pulleys use a belt. We'll use this in our project.
- Block and tackle: This is how you get mechanical advantage with a string. Since the force over the length of the string is always the same, if we can use a single piece of string to connect two things together multiple times, we can increase the force. Pulleys allow us to do that. The block is a group of pulleys, and the tackle is the string. In the picture below, there are 4 ropes between the fixed and movable blocks. If we pull the rope 1 inch, then the blocks move ¼ inch closer together, but with 4 times as much

force. Commonly used in cranes and sailing boats. We will use this in our project.



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Construction Techniques

Drilling

When drilling, you want the cutting edge of the drill bit to run at a certain speed. The cutting edge of a small drill does not move very fast, so we want the drill to run at high speed. The drill we have really does not run fast enough to get the desired speed, so make sure it is in high speed mode (2), and you pull the trigger all the way back. The drill wants to be turning clockwise both when you are drilling and when you are pulling the drill back out of the hole.

When we drill the very large hole (2⅛“), run the drill in the low speed setting (1).

Tapping

We will use the drill again to tap (cut threads into a hole). We are tapping into plastic, and the difficulty here is the plastic getting hot and melting. (Other materials have other issues, so these instructions are for plastic only.) Set the drill to low speed (1), and when tapping, run the drill slowly – not super slow, maybe half speed. Make sure the tap is clean and the drill is turning clockwise when tapping the hole. You must reverse the drill to remove the tap (unlike the drill bit).

Types of screws

We will use three types of screws, so it is best to learn the difference. (Images from amazon.com.)

- Machine screws: These are designed to fit into a threaded hole or nut. The screw is the same diameter along its length (no tapering), pitch (distance between threads, or the ridges of the screw) are tight (small distance).

- Sheet metal screws. These are designed to go through sheet metal, but they also work well in wood. For most of the length the diameter is the same, but at the very end it tapers to a point. The pitch is coarser than the machine screw, but still relatively tight.

- Deck screws: These are designed for wood. For most of the length the diameter is the same, but at the end (longer than the sheet metal screw) it tapers. The pitch is very coarse. The heads also tend to be larger.

- Wood screws: Wood screws have a thread pitch similar to sheet metal screws, but the taper runs the length of the thread (although not the same taper). They are, as the name implies, designed for wood.


I like to think that the machine screw is blunt, the sheet metal and wood screws are sharp, and the deck screw is very sharp.

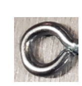
In addition to different threads, you can also have different heads. The head is the wide part of the screw that doesn't have threads and doesn't go into the hole. We will be dealing with five types of heads:

- Round head: a hemisphere

- Pan head: similar to a round head, with a flat top. Kind of looks like a frying pan

- Flat head: a cone that tapers uniformly from the threads to the top of the head. In a countersunk hole (a hole with a matching shape), the head is flat to the surface.

- Bugle head: Similar to the flat head, but the taper increases as we get to the top of the head. Frequently these do not need to have special holes (countersunk) to lay flat.

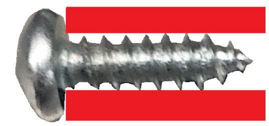
- Eye: Instead of a head that will press down, the eye extends the shaft into a loop, or eye, that you can use to pass something through, like a hook or a string.


Our machine screws will be round and flat head, our wood screws flat head, our sheet metal screws will be pan head, and our deck screws are bugle head. They don't have to be that way, but ours are.

Holes for Screws

Often we want to drill a hole for our screws, but how big?

- Body Drill: The hole is big enough to just clear the edges of the threads, so the screw can move in and out without turning it. (Pretty useless for holding the screw in, but we'll see why we want it later.) A screw in a body sized hole can turn freely.



- Tap Drill: This is used mostly for machine screws, and is a hole that matches the deepest part of the threads. (A sheet metal screw is shown here.)

- Pilot Drill: This is a bit smaller than the tap drill, and is used to guide the screw like a pilot guides an airplane. It also makes the screw easier to screw in (less material to push out of the way).

- No hole: Here the screw has to push all the material out of the way. Can cause small pieces of wood to split.

Nuts

Nuts are something that screws can screw into. Usually they are only for machine screws – other kinds of screws hold into the material directly. Really it is something with a hole that has threads to match the screw. For an ordinary nut (which we will not use), that is all there is to it. We will use two special types of nuts:

- T nut: This nut is designed to go into a hole and lay flat. They are great for using machine screws in wood where you do not want the nut to stick out on the other side. Frequently they have spikes to hold into the wood as well. Viewed from the side, they kind of look like a T.

- Lock nut: Very similar to an ordinary nut, but has something to lock the nut in place. We use these were a regular nut might twist off accidentally. We will use ones that have an unthreaded Nylon (plastic) insert that provides lots of friction to the nut turning, effectively locking it in place.

Screwing Boards Together

We are often tempted to just run a screw through two boards to hold them together. That sort of works. The problem is the threads hold onto both the top and bottom boards, so the screw cannot really press them together. If we drill a hole in the top board large enough the threads don't touch (much) – a body drill, then the head of the screw will hold the boards tightly together.

Splitting the Wood

A screw is like a round wedge. If you drive it into something, that something wants to split. If the screw is large and is being driven in near an edge, there isn't enough material to resist the split, and your wood splits (and the screw falls out). Not what we want at all. So near edges or on small pieces, use a pilot drill. Also if the wood is hard, like if there is a knot there.

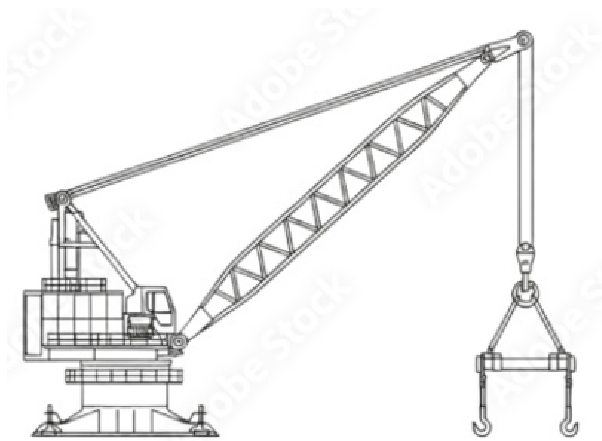
Marking the Wood

We will need to mark our wood to tell us where we want to cut and drill. Usually we need two dimensions for holes – how far from two different edges. Any easy way to do this is to measure the distance, make a small mark, then use a square to draw a line. If done correctly, that line is all the same distance from the edge. We can then easily mark the second distance. Frequently squares are also rulers, making this especially easy.

For a cut, we usually need a distance and a straight line. Mark the distance, then use the square to make the straight line.

Design

Our work site is semicircular with our device at the center. This really begs us to have our device at the center and pivot to move the modules. While there are many types of cranes, two simple cranes that work well for this type of task are the boom crane and tower crane. We will build them both.

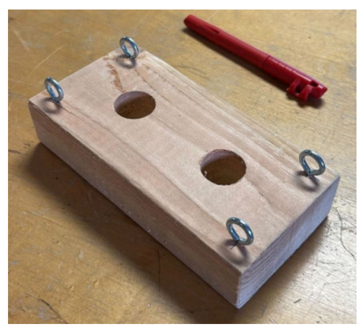


Boom Crane

Tower Crane

Module Attach

No matter what kind of crane we use, we need a way of attaching to the module to lift it up. The module has 4 steel eyes, one at each corner. We could use a hook or a clip in each eye to lift the module. How many do we need? If we use one, the module will hang vertically from that eye, but we have to move it flat, so that will not work. If we use four (and are careful), the module will move flat, which is what we want. Can we use less? How about three? The two opposite hooks seem to be tight, but the third (between the others) is loose. What if we get rid of that third hook? Does anything change? Give it a try, and you will find out that two hooks in opposite corners works just fine. And there is less stuff to attach, so it is easier.



Are hooks best? The eyes beg for a hook, but what about magnets? Are they strong enough? Does it matter how you hold the magnet? Flat, parallel, or perpendicular? You can test out the magnet on one eye. If you can lift the block part way, you are carrying half the weight of the block (the corner touching the surface is carrying the other half of the weight). So if you can pick up the corner with one magnet, you should be able to pick up the block with two magnets (at opposite corners). Testing with some small rare-earth magnets worked well, so we will use two magnets at opposite corners of a piece of wood the same size as the module. (While we pull the string to raise the attachment assembly, the weight of the attachment assembly alone has to bring it back down, overcoming any friction there may be. So there is a minimum weight needed here.

So we can adjust the orientation of the module, we will attach the board with magnets to a lift mechanism with a screw, so it can pivot about a vertical axis. We will use a pulley as part of the lift mechanism for two reasons: first, it gives us mechanical advantage (block and tackle); second, there will be two places attached to the rest of the crane (through strings). If we had only one string, the attachment assembly would likely rotate.

The Base

Both types of cranes need a base. A boom crane typically pivots near the bottom, a tower crane near the top. However, the tower crane can pivot near the bottom, and for simplicity, we will do that, and allow us to use the same design for both.

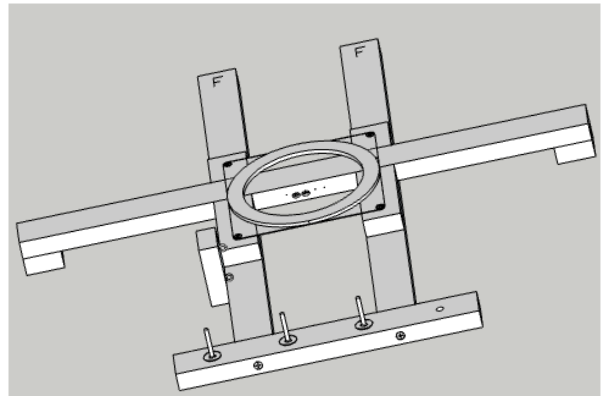
Our controls, whatever they turn out to be, want to be attached to the lower part of the base, which is fixed. We will start with dials and strings.

We need a pivot for the base, something that is fixed at the bottom, but allows the top to turn. This is one of our degrees of freedom. There are all sorts of things we could use, say a vertical axle that the top turns around on, or maybe a door hinge. Have you ever seen a plate that spins easily? They have a bearing called a lazy Susan bearing, and it will be ideal for us. It is not very high, can take a large load, does not wobble, and they are easy to buy.

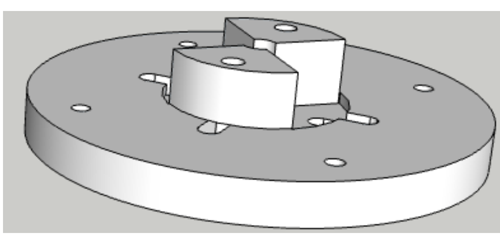
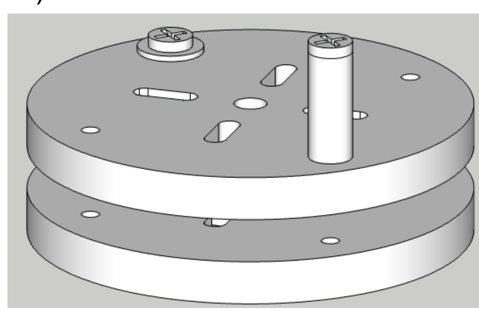
On the top side of the bearing will be a bit different for the boom crane and tower crane. For the boom crane, we need to make another pivot for the boom. For the tower crane, we will attach the tower and arm. (Usually the tower is fixed and the arm pivots, but we are making both pivot together here).

We are going to use strings to control everything. Some things we need to control are above the base. We need a way of passing a string from the bottom to the top. Ideally, that string will not change length when the base turns. How to do this? If the string runs vertically through the pivot point (center), it doesn't change length. If it runs near the center, it doesn't change length much. Fortunately, the lazy susan bearing has a hole in the center, and we will take advantage of this.

If you look at a crane, the base is usually wide, and frequently has outriggers that make it wider. Something with a narrow base tips over easily – that is not good for a crane. So in real life, they make the base wide. We will do that too. (We are even allowed to clamp our base to the work site, however we hope we will not need to do that.) Our crane will sit on the 24" (" means inch, ' means foot) diameter circle. We will put our feet (base supports) close to that. A full circle would give us the best resistance to tipping, but 4 feet (evenly spaced) does pretty well. (3 doesn't work so well – so do you ever see 3-legged chairs? 5 works better – and most office chairs have 5 legs now because of that.) We can do that with 2 boards that cross. Now generally joints are weak and boards are strong, so we want the boards to cross without a joint in them. The way to do that is to stack the boards at the crossing point, one on the bottom, one on the top. The one on the top will need something to bring it back down to the level of the bottom board, otherwise our crane will rock – extremely bad. That can be done with a short piece of board at each end. We need to mount the lazy susan bearing, which we could do with just the boards we've talked about so far, but for reasons that will become clear later, we will add a second bottom board, some small boards to fill the gap between the bearing and top board. All in all, it will look like the picture to the left.



We mentioned strings to control the crane. We could just pull on the strings, but that is not so elegant. We will make spools that we turn to wind up the string. First we need to make a spool. The spool has a center hole, walls to keep the string in, a handle to turn it, and a way to attach the string. We will 3D print this, but it can be made other ways as well. Since it is symmetrical and has overhangs (3D printing does not like overhangs), we will split it into two identical parts that fit together to form the spool (and add a handle).

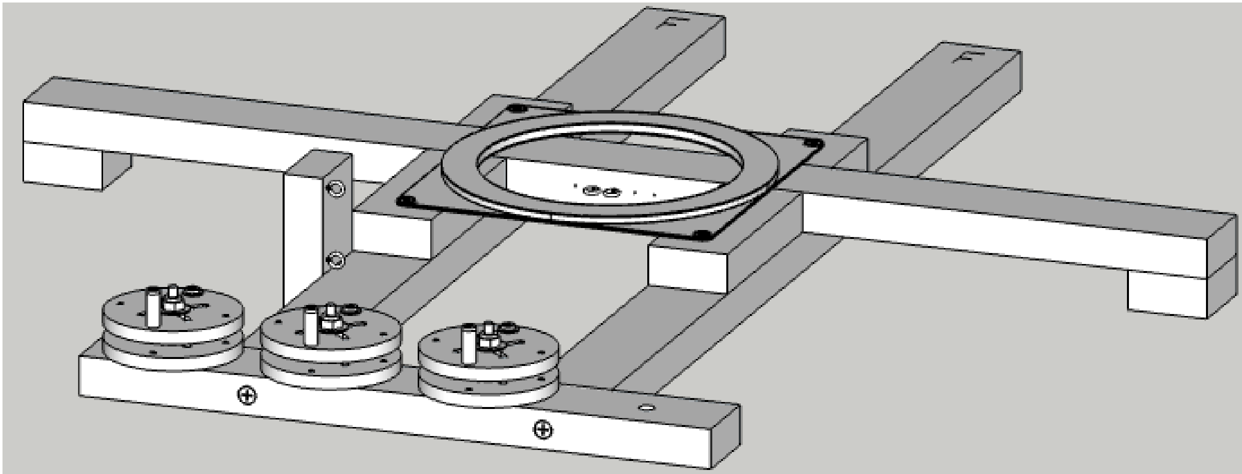



We need a place to mount the spools, so we will add a board in the rear of the crane bottom to mount the spools. We have three degrees of freedom, so we need 3 spools. We will leave space for four spools in case we want to add one more degree of freedom.

For controlling the direction of the crane, we will wrap a string around the bottom of the top part of the crane. Our spools are lower than that, so we need to guide the string to the right height. We can use a couple of screw eyes to do that, and add a small board on the side to hold the screw eyes in the right position.

For the other controls, we need to run the strings up to the top part of the crane. We don't want the direction of the crane to affect them (very much), so we want to guide the strings up near the center of the lazy susan bearing. We can add more screw eyes on the top board to do that.

This is what our completed base will look like:



The Boom Crane Top

If you are doing the tower crane, you can skip this section.

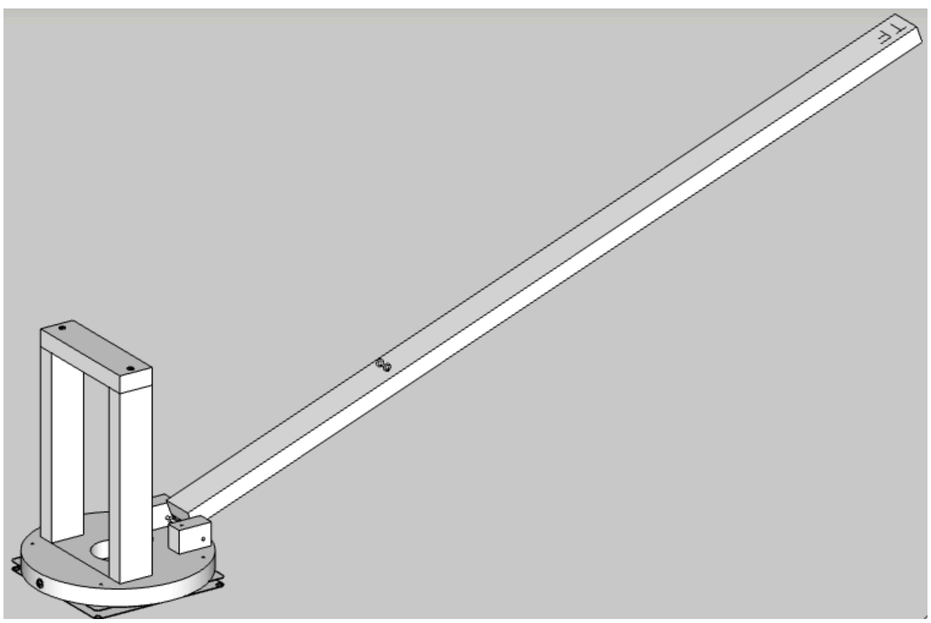
We will build the top part on a round base. The round base will also act as a giant pulley to rotate the top part of the crane.

We need to attach the boom (arm) of the crane. This can be done with a couple of small blocks of wood. We will run a small axle through the block of wood and some screw eyes in the boom. This way the boom can raise and lower.

We need a way to raise the boom. We can build a small tower, then run a string (using a block and tackle) to the arm. When we pull on the string, the arm will raise. The taller the tower, and the further out we attach it to the boom, the easier it will be to raise the boom. Of course, if it is easier, we will have to pull the string more to raise the boom.

To raise and lower the load, we can run a string out on the bottom of the boom, through an eye near the end of the boom, down through a pulley on the load and back up to an eye at the end of the boom. Another block and tackle.

Here is what the top part will look like (without module attach):



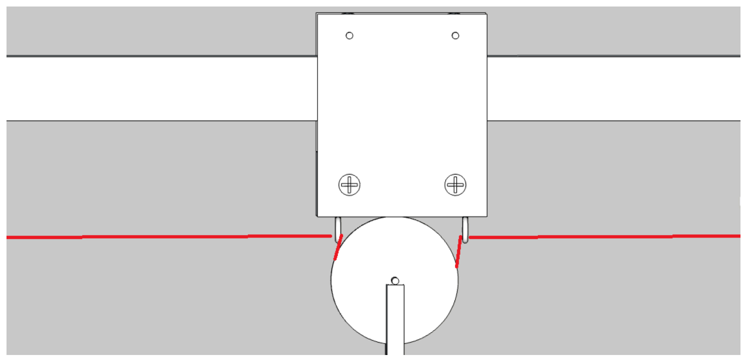
The Tower Crane Top

If you are doing the boom crane, you can skip this section.

We will build the top part on a round base. The round base will also act as a giant pulley to rotate the top part of the crane.

We need to attach the arm of the crane. This can be done with long vertical blocks of wood. A trolley will move back and forth along the arm to control how far out the load is. A string will be used to move the trolley.

To raise and lower the load, we can run a string to and along the arm to the end of the arm. Along the way, it will go through the trolley, down to the pulley on the load and back up top the trolley (a block and tackle). Note that as the trolley moves, one side of the string gets longer, the other shorter, and the load does not move up or down.



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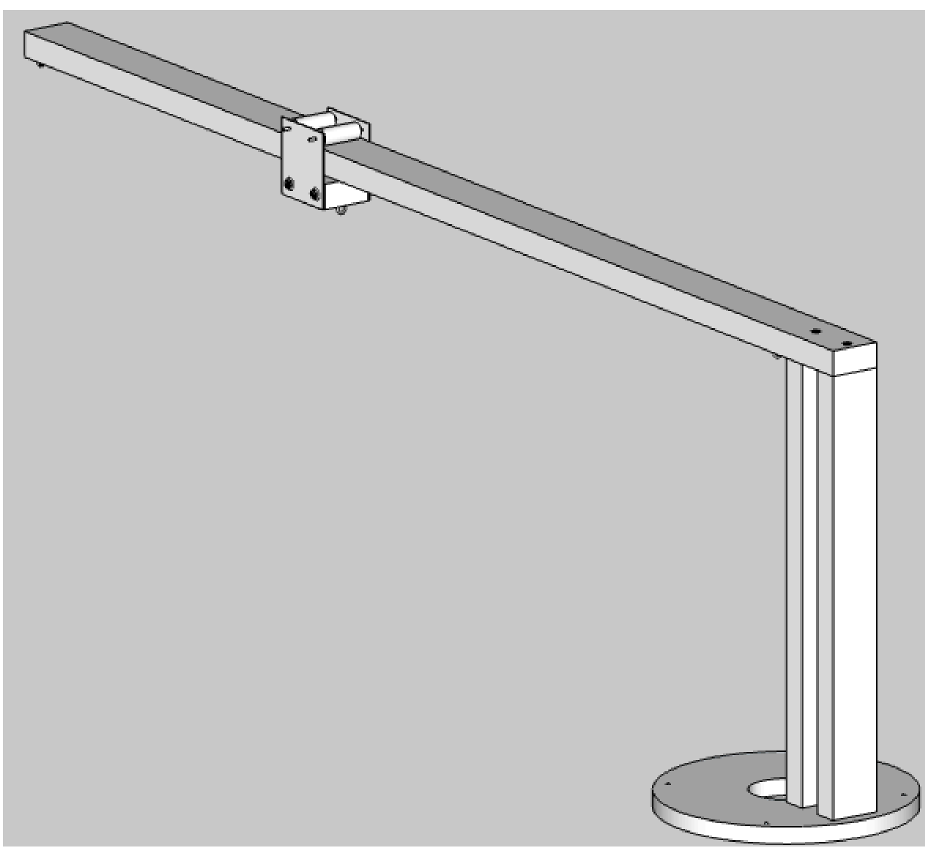


Prototype 1

Materials

Carrier	Base	Boom	Tower	description
7”				1x4 wood
	80”	62”	66”	1x2 wood
		1	1	¾x7½” wood round
1				2x2 foam core
			2	2x2⅜” sheet metal
		28’	30’	string
2				¼ “magnets
	1			Lazy susan bearing
1				pulley
	6			spool halves
			2	rollers
1			2	2x50mm axle
		1		⅛x3¼” rod
	5			#6-32x¼” screws
	3			#6-32x⅞” screws
	5	1	2	#6 washers
	3			#6x½” spacers
		5	10	#6x½” sheet metal screws
	6	2		#6x1¼” wood screws
		4	4	#6x1¾” wood screws
	4			#8x1¼” deck screws
1				#8x1½” deck screw
	2			#8x2½” wood screws
	3			#10-24x2” machine screws
	3			#10-24 T-nuts
	3			#10-24 lock nuts
	6			#10 washers
	4	8	6	#216 screw eyes

Tools

The tools we used were:

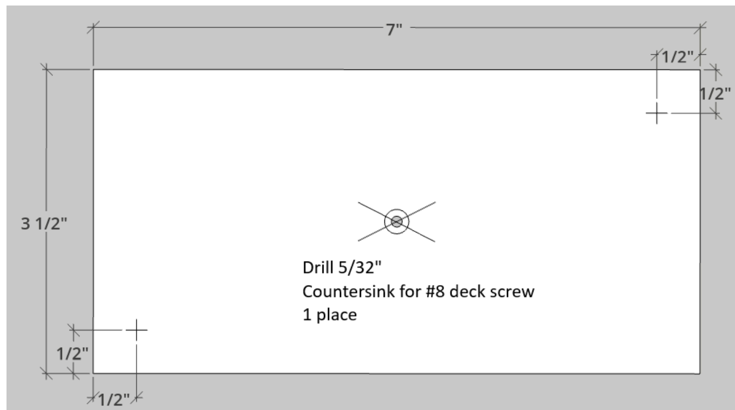
- hand saw
- drill motor
- screwdriver
- drill bits, countersink, hole saw, tap
- punch
- ruler, square
- scissors, shear
- hammer

Fabrication

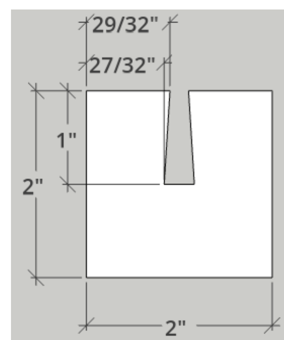
Almost all the wood we will be using is known as 1x2, referring to 1” inch by 2”. Sadly, 1x2 is not that big anymore, modern 1x2 is really ¾”x1½” or even slightly smaller. So when we talk about cutting a piece of wood, we will give only its length with the width and height predetermined by the 1x2 boards we will use.

Carrier

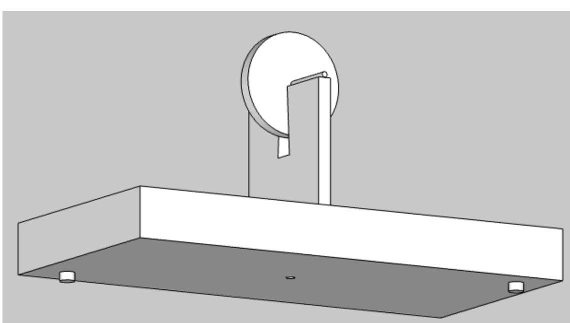
CarrierBoard: Cut a piece from a 1x4 board (measures ¾”x3-½”) that is 7 inches long. Draw two lines from opposite corners. Actually, you only need to draw the center part of the lines. Where the two lines intersect is the center of the board. Mark, drill, and countersink as shown. Glue two ¼” magnets where shown near the corners.



CarrierUpright: Cut a 2”x2” piece of foam core. Cut a slot in the center that is 3/16” wide at the top, 1” deep, and 5/16” wide at the bottom.



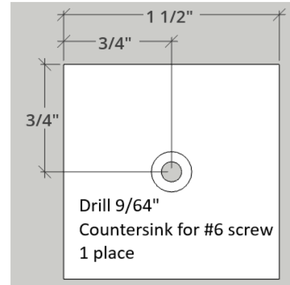
Carrier: Use a #8x1½“ deck screw to attach the riser to the side of the board without magnets. Be sure the screw goes into the center of the foam core right under the notch. Do not over tighten the screw, the foam core is not very strong, and you can easily over tighten it.



Tape a 2x50mm axle and a pulley as shown to the top of the riser. Your carrier should look like the picture on the left:

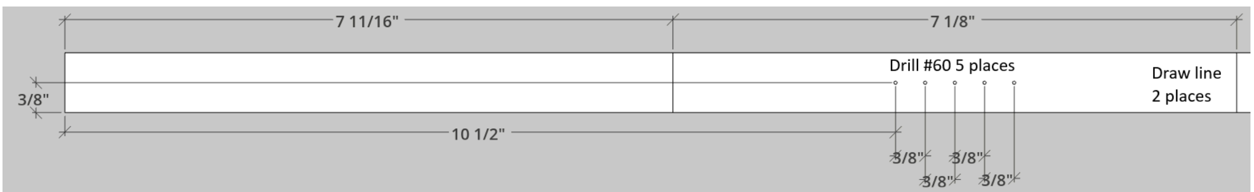
Base

Cut, mark, drill, and countersink two pieces of wood as shown.

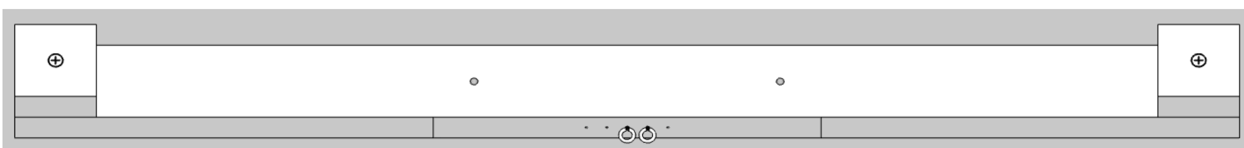


Cut, mark, drill, and countersink one piece of wood as shown.

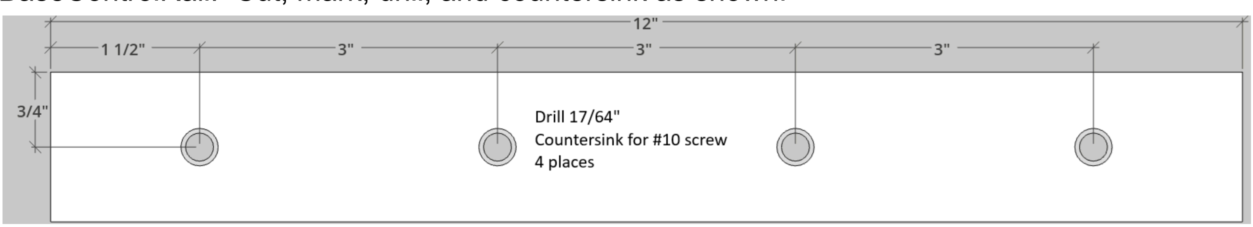
Rotate that same piece and mark and drill as shown.



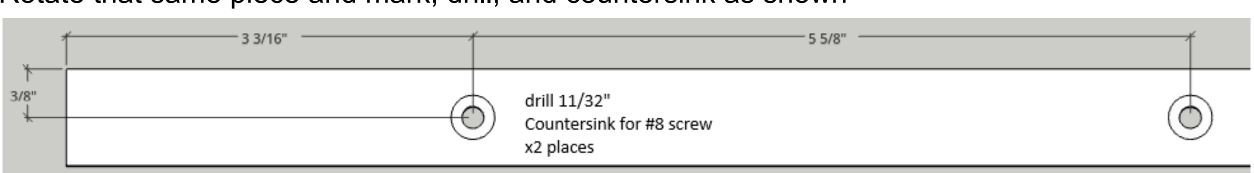
BaseTopAssembly: Now use two #6x1¼ wood screws and two #216 eye screws to make it look as shown.



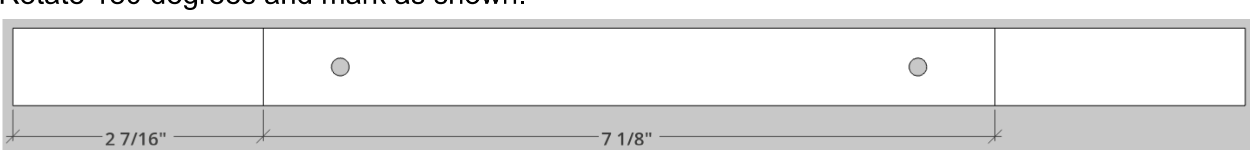
BaseControlRail: Cut, mark, drill, and countersink as shown.



Rotate that same piece and mark, drill, and countersink as shown

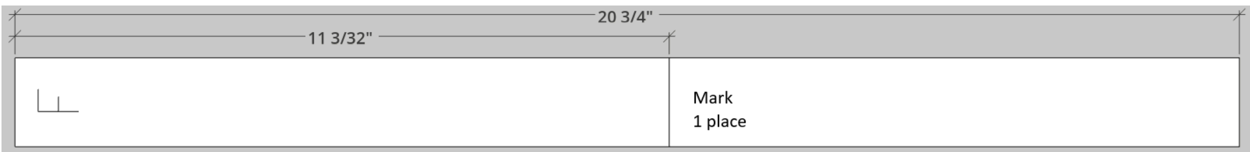


Rotate 180 degrees and mark as shown.

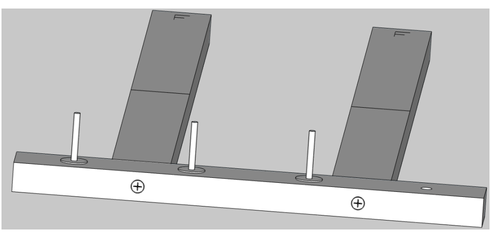
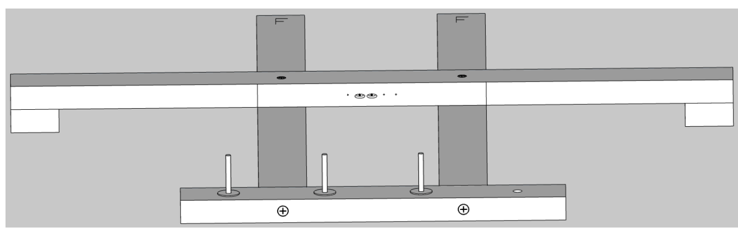


BaseControlRailAssembly: Turn over (so countersunk holes are on the bottom) and place #10-24 T-nut in hole, set (hit with hammer), and screw in #10-24x2” machine screw in three places as shown. (Note the drawn lines.)

BaseBottomBar: Cut and mark two pieces of wood as shown.



BaseBottomAssembly: Assemble as shown (left picture below), using two #8x2½“ wood screws. (Note that the baseBottomBar boards want to align with the lines drawn on the baseControlRail board.) A good way to get things to align properly is to work on a table. You can clamp (or hold) the pieces on the table as you screw them in place. This makes sure they align vertically.

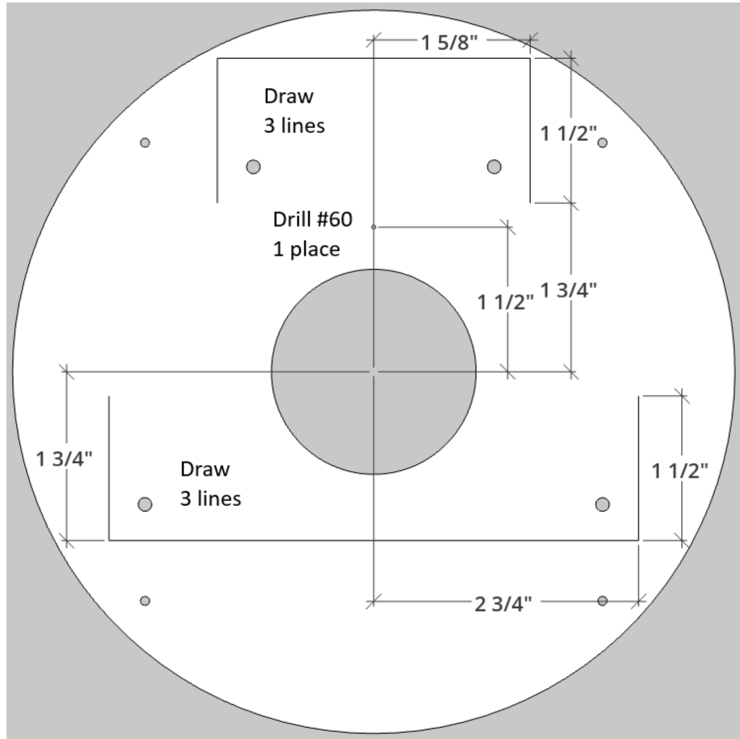
 

BaseAssembly: Assemble the baseBottomAssembly (picture above right) and the baseTopAssembly using two #6x1¼ wood screws. You want to align the boards to the marks made on the boards.

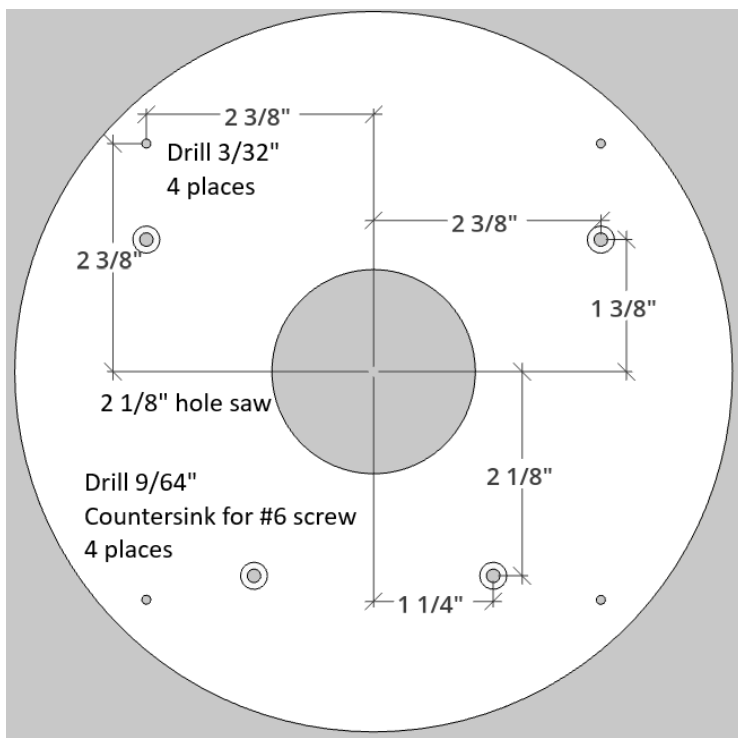
Boom Crane Top

If you are doing the Tower Crane, you can skip this section.

BoomBase: Use the precut round wood. Before cutting the center hole, there is a small hole at the center. On the top side, draw a line through the center to help with marking the wood. Mark hole location (1x#60) and draw lines (6x).

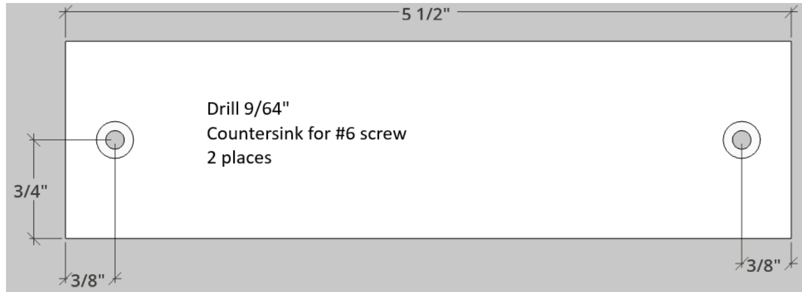


On the bottom side, draw a line through the center to help with marking the wood. It is important to align the top and bottom lines. Mark, drill, and countersink as shown. Use a hole saw to cut a 2⅛” hole at the center. Run the drill at the lower speed setting, cut half way through, pulling the saw out from time to time to clear the sawdust. Once half way through, cut from the other side to complete the hole. Drill the other holes.

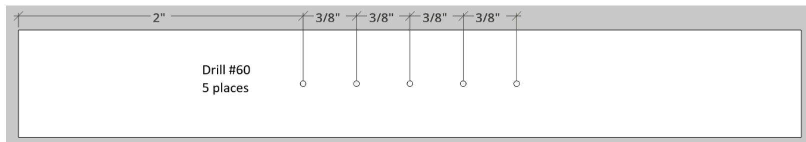


BoomTopRiser: Cut two 8” pieces of wood.

BoomTopBar: Cut, mark, drill , and countersink one piece of wood as shown.

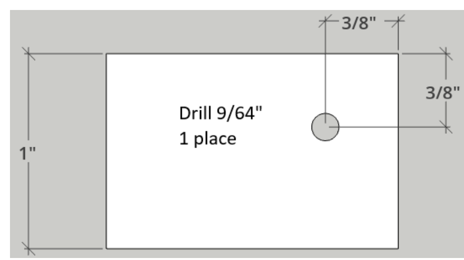


Turn the wood 90 degrees, and mark and drill as shown

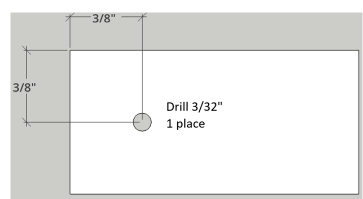


Screw in two #216 screw eyes as shown.

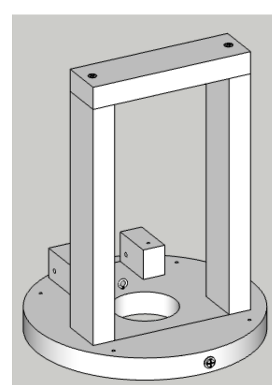
BoomSide: Cut, mark, and drill two pieces of wood as shown:



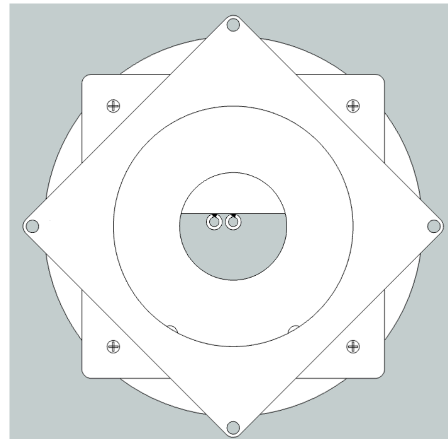
Rotate 90 degrees and mark and drill as shown:



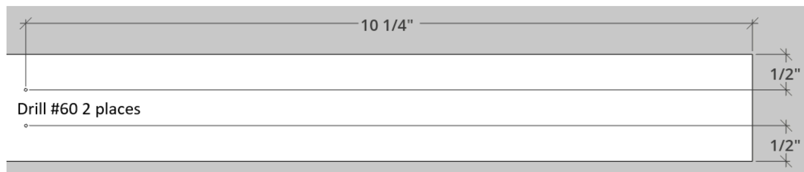
BoomTopAssembly: Attach the boomSide boards to the boomBase using #6x1¼“ wood screws aligning the boomSide boards to the lines on boomBase as shown. Attach the boomTopRiser boards to the boomBase using #6x1¾” wood screws, aligning the boomTopRiser boards to the lines on boomBase. Attach the boomTopBar to the boomTopRiser boards, aligning the edges, with #6x1¾” wood screws as shown. Screw in one #216 screw eye as shown. Screw in one #6x½“ sheet metal screw with #6 washer somewhere on the back side of the boomBase.



Turn over, and attach the lazySusan bearing to the boomBase board. Align the lazy susan bearing to the pilot holes in the boomBase, and attach with #6x½ sheet metal screws (x4 places)

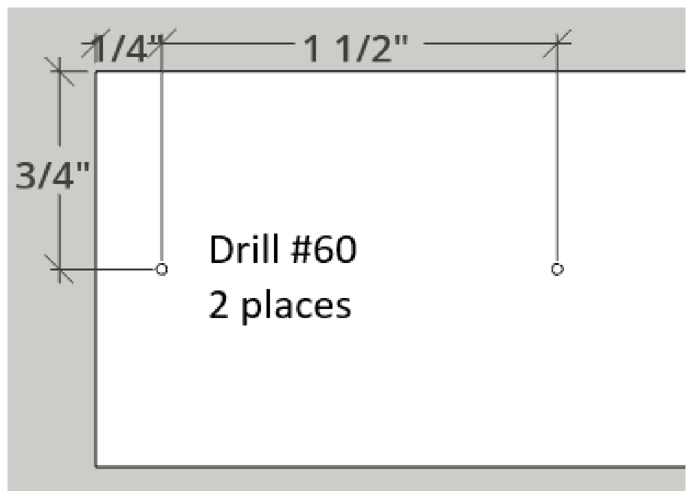


Boom: Cut a piece of wood 36" long. Mark one end of one side "TF" for Top Front.

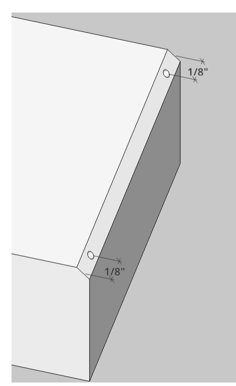


On the front side at the back, mark and drill as shown:

Turn over, and mark and drill as shown on the bottom front:

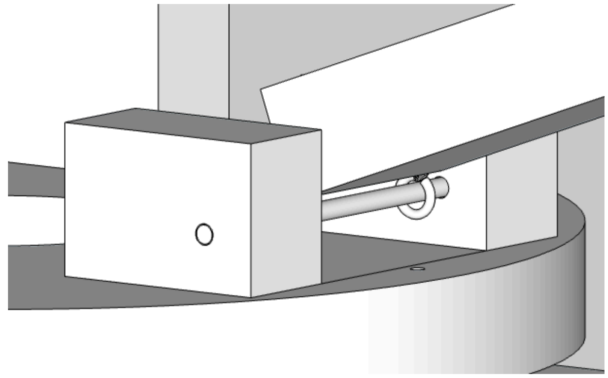


On the bottom back, we want to have screw eyes at an angle. To drill, we need a flat surface, so we need to break (flatten) a corner, as shown. Use a file to do this. Then drill as shown in two places.

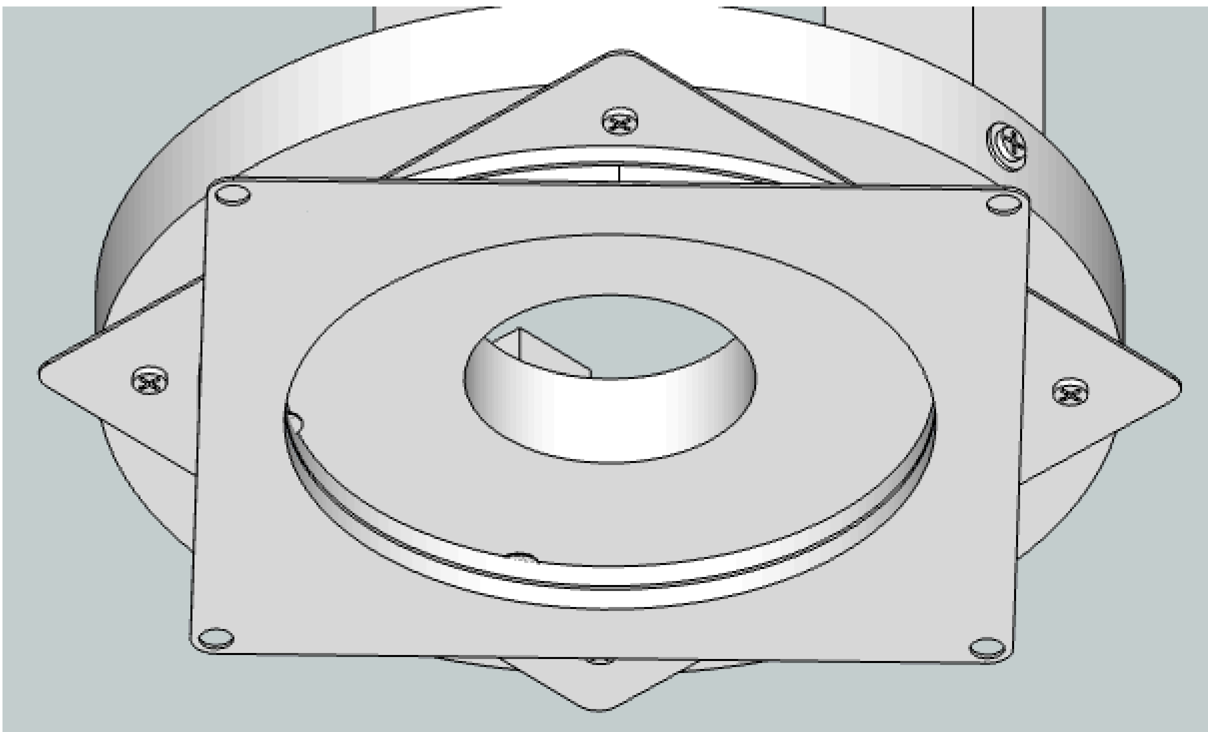


BoomAssembly: Screw in 6x #216 screw eyes as shown.

BoomAssembly: Attach the BoomAssembly to the BoomTopAssembly by lining up the holes with the screw eyes, and slipping a ⅛" x 3¼" rod through them, as shown:



Attach the lazy susan bearing with four #6x½" sheet metal screws as shown.



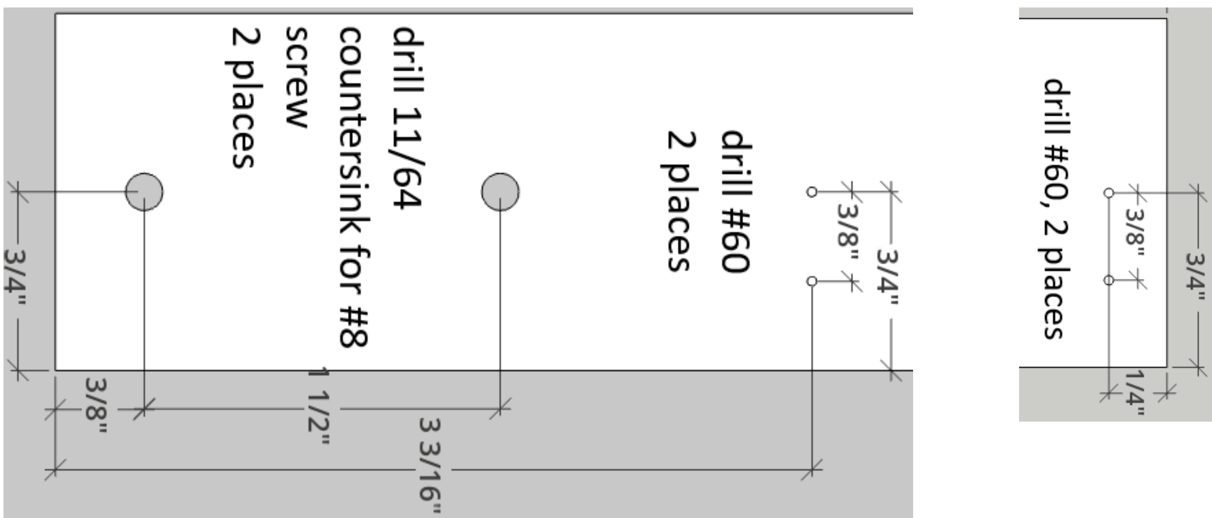
This completes the BoomAssembly.

Tower Crane Top

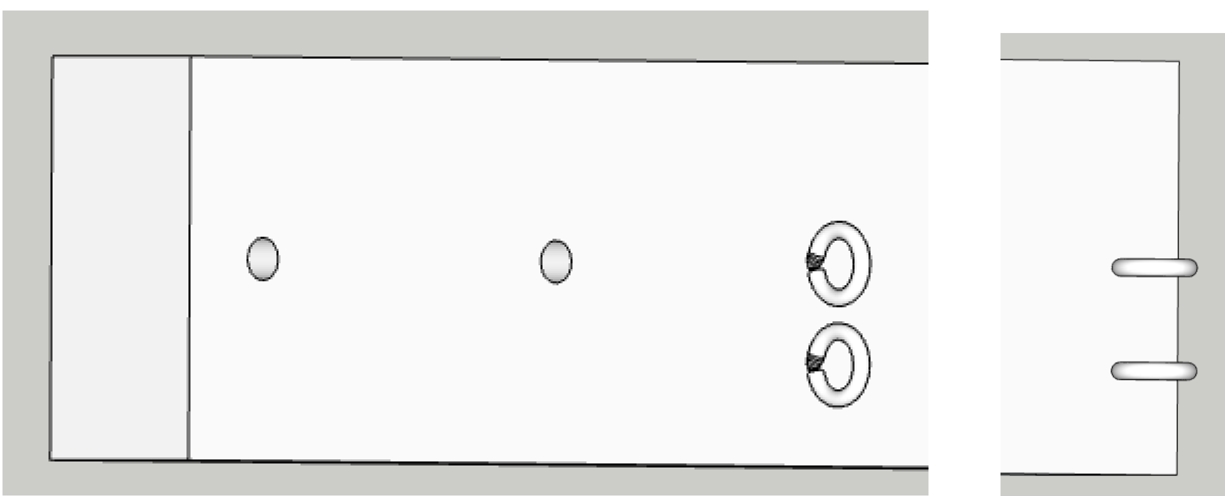
If you are doing the Boom Crane, you can skip this section.

TowerVertical: Cut two pieces of wood 13” long. It is important that they be the same length. One way of doing that is to cut the first piece a bit long (maybe 13½”), then line up the ends, and cut them both at the same time.

TowerArm: Cut one piece of wood 39” long. At one end, mark and drill as shown. At the other end, mark and drill as shown.

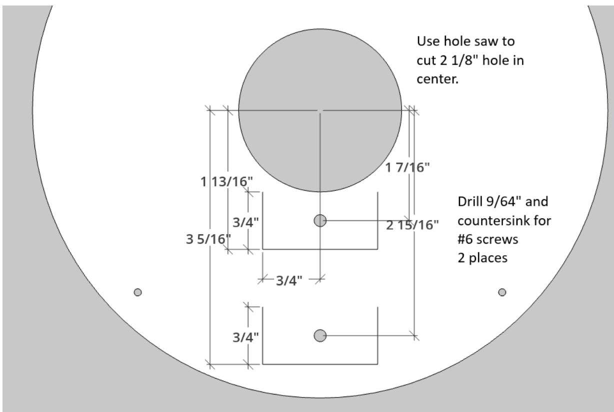


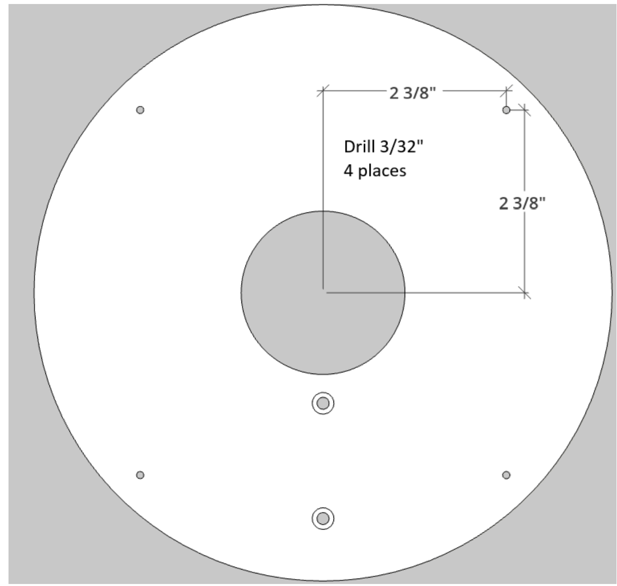
TowerArmAssembly: Screw in 4 #216.5 screw eyes in the #60 holes as shown:



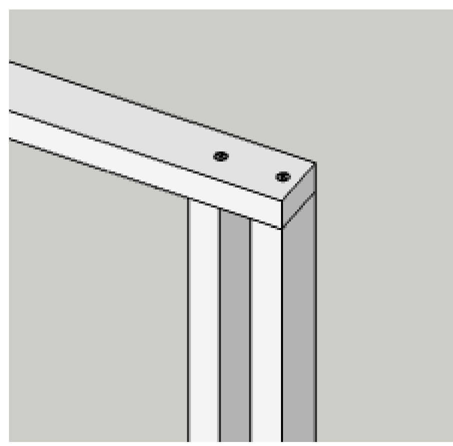
TowerBase: Use the pre-cut round wood. Before cutting the center hole,
there is a small hole at the center. On the top side, draw a line through the center to help with marking the wood. Mark hole and lines locations, drill and countersink from the opposite side as shown.

On the bottom side, draw a line through the center to help with marking the wood. It is important to align the top and bottom lines. Mark and drill as shown. Use a hole saw to cut a 2⅛” hole at the center. Run the drill at the lower speed setting, cut half way through, pulling the saw out from time to time to clear the sawdust. Once half way through, cut from the other side to complete the hole. Drill the other holes.

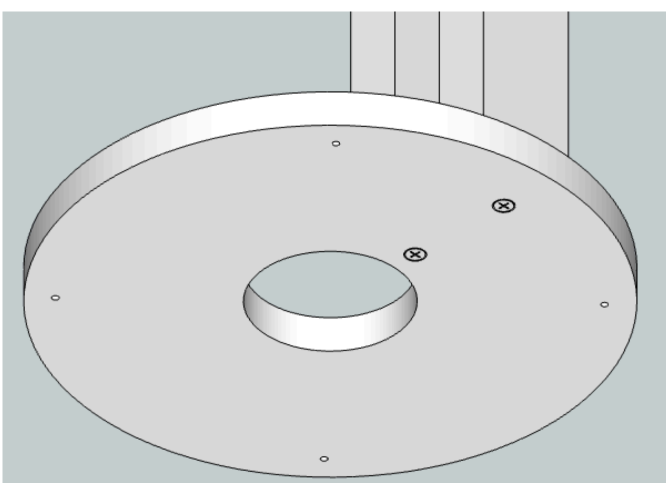




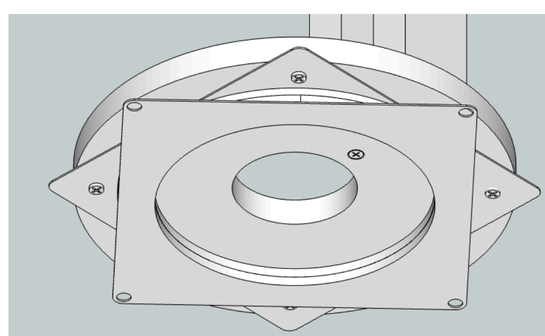
TowerAssembly: Attach the TowerVerticals to the TowerArmAssembly with two #6x1¾“ wood screws as shown to the right:



Attach the TowerBase, aligning the TowerVerticals to the lines drawn on the top side of the TowerBase, using two #6x1¾“ wood screws as shown below:

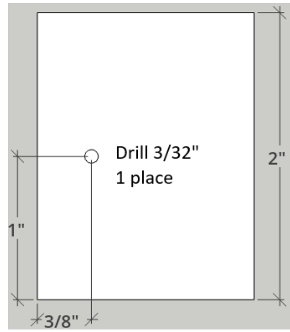


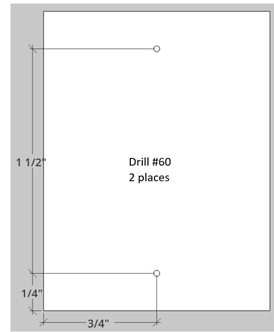
Attach the lazy susan bearing with four #6x½” sheet metal screws as shown to the right:



TowerTrolleyBlock: Cut, mark, and drill one piece of wood as shown.

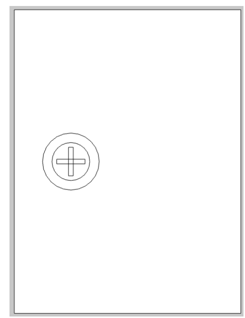
Turn over, and mark and drill as shown.

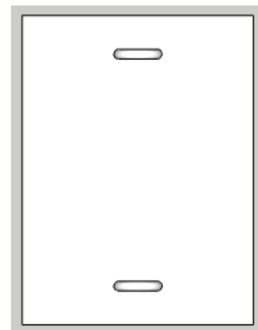




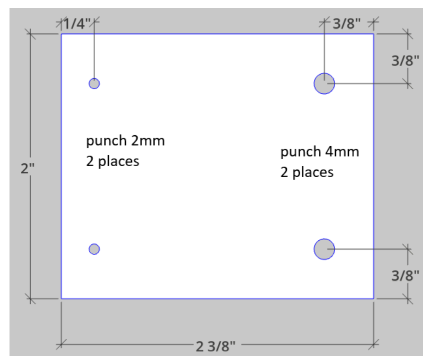
TowerTrolleyBlockAssembly: Place one #6 washer and screw in one #6x½” screw as shown.

Turn over, and screw in two #216 screw eyes as shown.

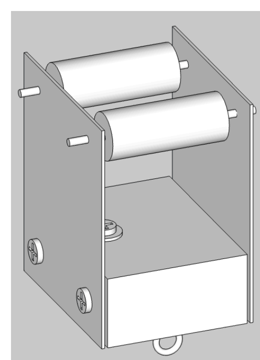




TowerTrolleySide: We make this out of sheet metal. ***CAUTION: sheet metal edges can be very sharp. Handle with care, and file edges to remove burrs after cutting.*** Cut, mark, centerpunch, and punch two pieces of sheet metal as shown.



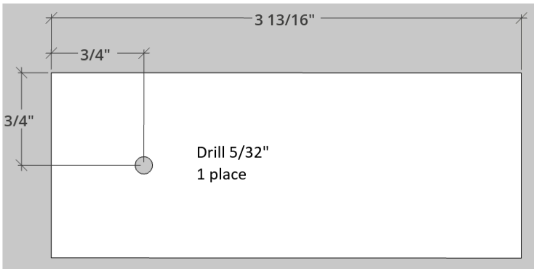
TowerTrolleyAssembly: Attach the TowerTrolleySides to the TowerTrolleyBlockAsembly with four #6 washers and four #6x½“ sheet metal screws. Note the washers (not visible) go between the side and the block. Add the two rollers and hold in place with two 2x50mm rods.



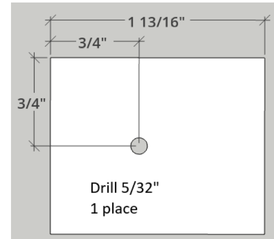
The TowerAssembly is complete.

Final Assembly

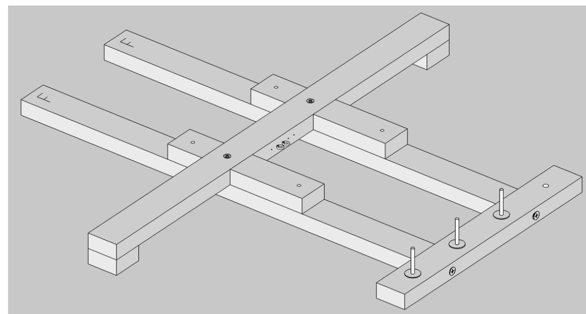
BaseBottomForwardBlock: Cut, mark, and drill two pieces of wood as shown.

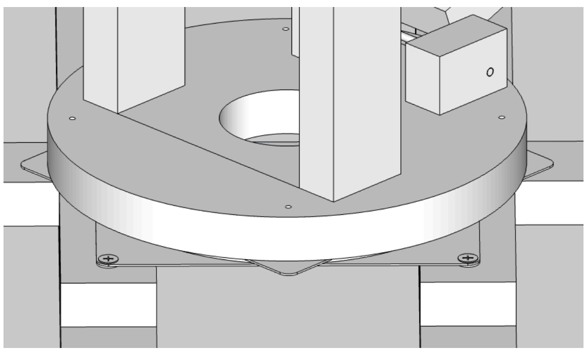


BaseBottomBackwardBlock: Cut, mark, and drill two pieces of wood as shown.



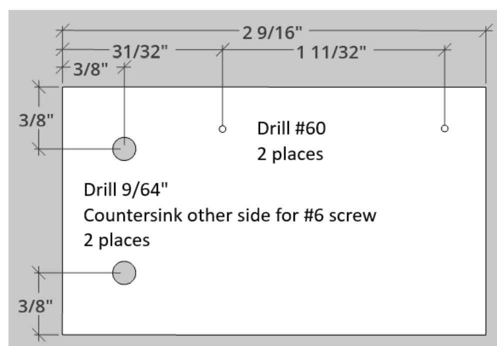
Place these as shown on the baseAssembly:

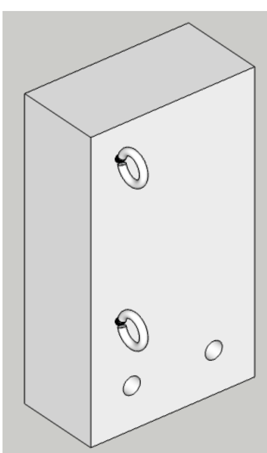




Align and place the boomAssembly or TowerAssembly, then screw in four #8x1¼“ deck screws as shown:

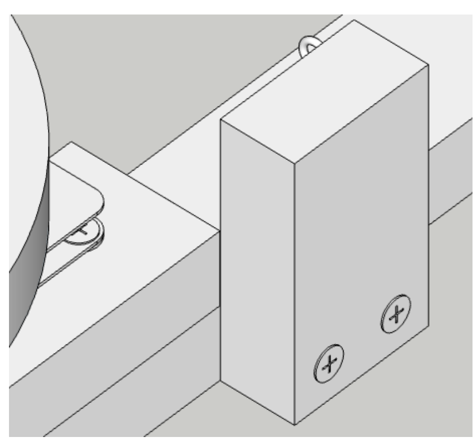
BaseGuide: Cut, mark, and drill one piece of wood as shown:





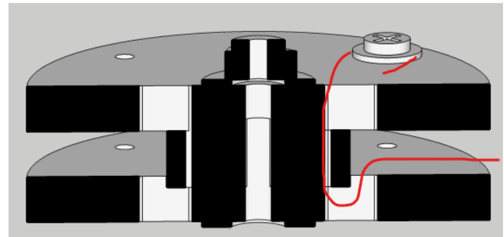
baseGuideAssembly: Add two #216 screw eyes as shown:

Attach with #6x1¼“ wood screws as shown:

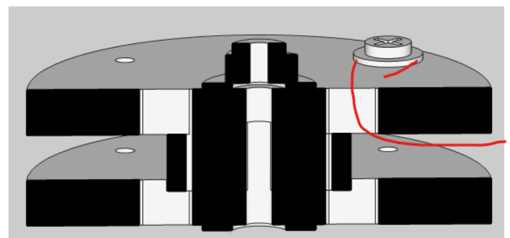


Strings

Spools



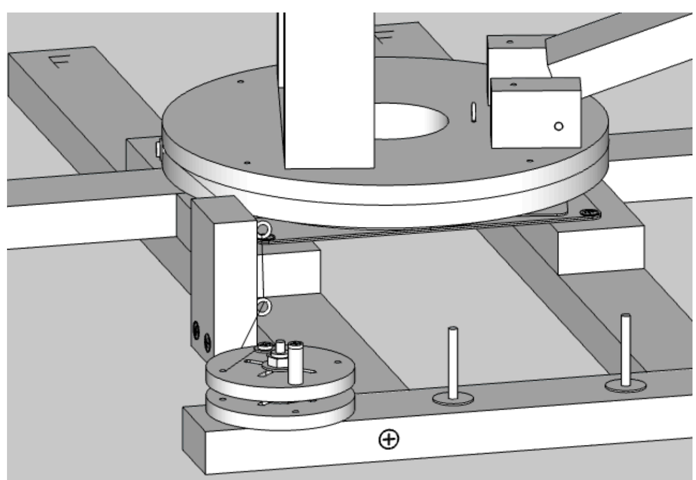
First, let us learn how to attach a string to the spool. There are two ways, to the bottom, and to the top. Below we have a cross section (as if cut in half) view of a spool. The red line shows how to thread the string for the bottom attach: in the middle of the spool, through a hole to the bottom, then up to the top through a small hole, and under a #6 washer with a #6-32x¼" machine screw to hold the string tightly. This type of attachment can be done only before the spool is in place on the control board, otherwise you cannot get to the bottom of the spool to thread the string.



For a top attach, here is how the string goes: in the middle of the spool, through a hole to the top, and under a #6 washer with a #6-32x¼" machine screw to hold the string tightly. This type of attachment can be done after the spool is in place on the control board.

Base

Cut an 8' (foot) piece of string. We like to cut a polymer (plastic) string by the hot knife method. The hot knife melts the string as it cuts it, which seals the ends so they do not frey (fuzz out). Ideally the knife is hot, but what is important is the hot, not the knife. You gently pull the string and heat it up where you want to cut it. You can use a hot knife (hard to find), a soldering iron (easier), or an open flame (match, candle, lighter – pretty easy to find). The plastic will get hot, melt together, and stretch until it breaks (cut).

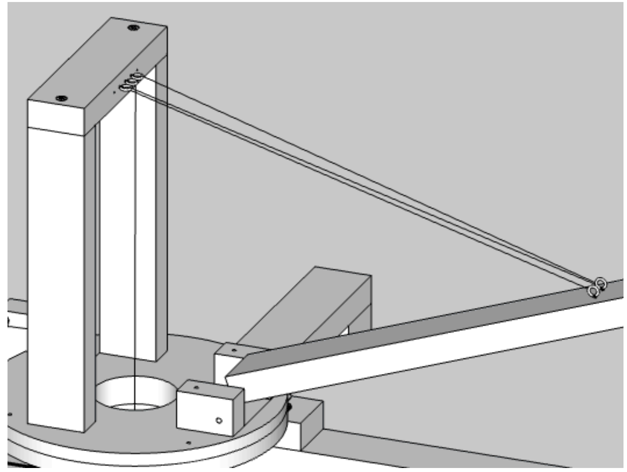


Find the middle of the string, wrap it around the screw under the washer in the side of the base (either boom crane or tower crane), and tighten the screw. Then wrap each end all the way around the base (opposite directions for the two strings) and hold in place temporarily with a piece of tape.

Imagine a dial clock face. The small hand (hours) points straight forward at 12 o'clock. Imagine the arm of the crane is that small hand, when it points directly away from the control board, it is in the 12 o'clock position.

Move the crane to the 4 o'clock position. Take the string on the left and feed it through the two eyes on the base guide assembly, first the top eye (from front to back) then the bottom eye (front to back again). Now attach the string using the bottom method to a spool. Attach the spool to the far left position of the control board by dropping it over the #10-24 screw, then place a #10 washer, and use a #10-24 lock nut to keep it in place. This spool wants to turn freely, so don't tighten the nut too much. Hold the string so it has some tension on it, and turn the spool counter-clockwise (opposite the way clocks turn). Once all the slack in the string is wound up, the crane will start to turn. Continue as the crane turns from 4 o'clock to 12 o'clock and stop when it gets to 8 o'clock. Thread the other end of the string through the base guide assembly the same way, and attach to the spool using the top attach method. The string should be tight. Turn the spool clockwise to turn the crane to the 4 o'clock position, then back to the 8 o'clock position. The first couple of times the strings on the spool may interfere with each other and make the turning harder, but that usually fixes itself. You may need to tighten the string again. Do this in the 8 o'clock position – remember which screw you used for that string!

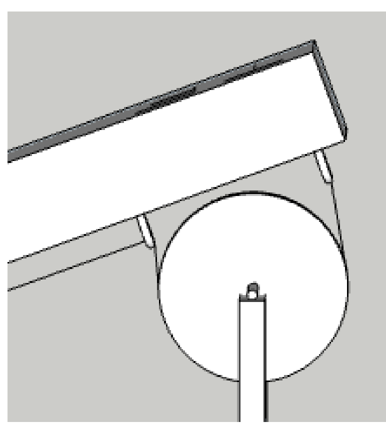
Boom Crane

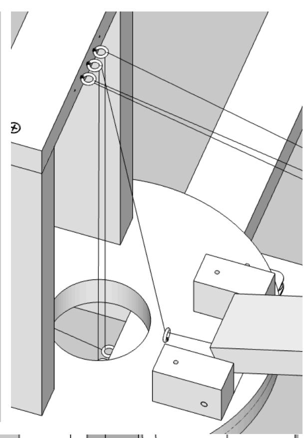


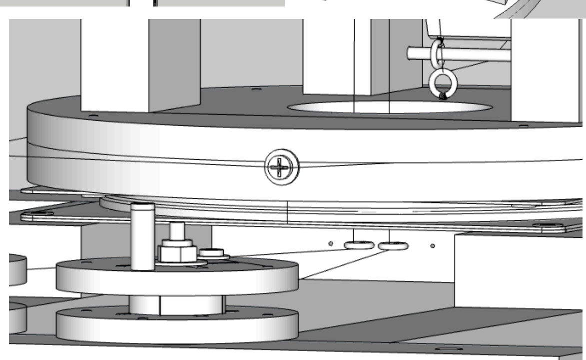
Cut a 7’ piece of string. We need to tie one end around an eye. There are three ways you can do this: just tie it around the eye (but this typically comes undone), use a bowline knot (very good, but harder to tie), or make a loop and attach that (probably the easiest way that will work for you). If you want the bowline, which is the best by far, look up how to tie one on the web. We will explain how to do the loop and attach here.

Fold a short length of string over, then tie a simple overhand knot (the knot you all know how to do, but probably do not know it called an overhand knot. Now we have a small loop in the end of the string. Take the other end of the string, pass it through the left eye on the boom and then through the loop and pull tight. Now the string is well attached to the eye.

Take the free end of the string, feed it through the left eye on the boom tower from top to bottom, then through the right eye on the boom left to right, then the right eye on the boom tower top to bottom. The string goes through one more eye on the bottom (the right one), and to a spool on the right side of the control board with a top attach. For this spool, you attach it to the control board the same way (washer and lock nut), but you want the nut to be tight enough the boom does not fall on its own (while lifting the block), but still loose enough you can turn it (to raise or lower the boom) easily.



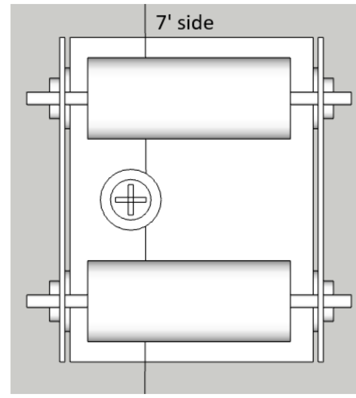




Cut a 13’ piece of string. Attach it the same away as before to the outermost eye on the bottom of the boom. Thread the free end through the carrier block pulley, the other eye on the bottom of the boom, under the boom pivot rod, through the eye on the base, then center eye on the boom tower (top to bottom). Thread it through the remaining eye on the base, use the top attach method to attach to the last spool, mount on the control board near the center, using a washer and lock nut like before. Again, tighten the lock nut enough that the block stays up, but loose enough that it turns easily.

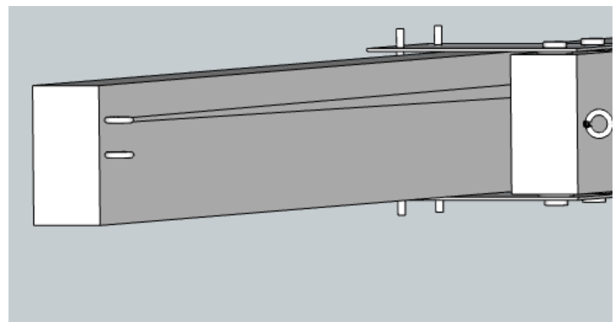
The boom crane is now built and ready for testing.

Tower Crane

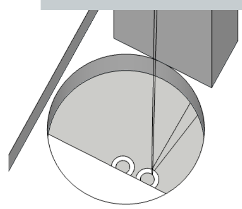


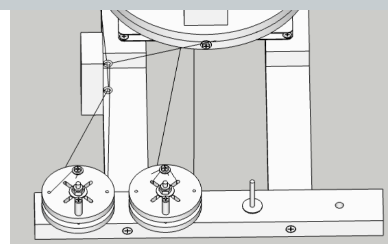
Cut a 12’ piece of string. Tie a knot in one end to identify it. Measure 7’ from that end. Attach that point to the TowerTrolleyAssembly by loosening the #6x½“ sheet metal screw, wrapping the string around it once at the specified point, and tightening it.

Slide the TowerTrolleyAssembly over the TowerArm so the 7’ side is going outwards. Feed the sting through the screw eye not in the center of the end of the arm, and then back through the TowerTrolley Assembly. Feed both ends through the non-centered screw eye near the TowerVerticals. Feed both ends through the non-centered screw eye in the base.



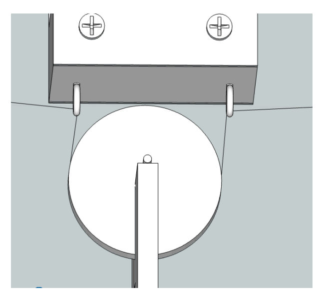
Attach the long string (with a knot in it) to a spool with the bottom side attach method. On the 2nd #10-24 screw, place the spool, a #10 washer, and a #10-24 lock nut. Tighten the nut enough that the spool doesn’t wiggle, but it still turns freely. Turn the spool clockwise until the trolley is at the far end of the arm. Use the top attach method to attach the other end of the string to the spool, drawing the string tight. Turn spool counter-clockwise to move the trolley in. The strings may bind a bit, but this usually resolves once you have moved the trolley back and forth.





Cut a 10’ piece of string. Tie it to the center eye at the end of the TowerArm. There are three ways you can do this: just tie it around the eye (but this typically comes undone), use a bowline knot (very good, but harder to tie), or make a loop and attach that (probably the easiest way that will work for you). If you want the bowline, which is the best by far, look up how to tie one on the web. We will explain how to do the loop and attach here.

Fold a short length of string over, then tie a simple overhand knot (the knot you all know how to do, but probably do not know it called an overhand knot. Now we have a small loop in the end of the string. Take the other end of the string, pass it through the left eye on the boom and then through the loop and pull tight. Now the string is well attached to the eye.



Feed the end of the string through the first eye in the TowerTrolleyAssembly, around the pulley in the carrier module, and through the second eye in the TowerTrollyAssembly.

Feed the string through the center eye on the TowerArm near the TowerVerticals, then through the center eye in the base. Attach a spool to the 3rd #10-24 screw, a #10 washer, and a #10-24 lock nut. Attach the string to the spool using the top attach method. Turn the spool clockwise to raise the carrier module. Adjust the tightness of the lock nut so it is loose enough to turn, but tight enough to hold up the carrier when a module is attached.

The Tower Crane is now built and ready for testing.

Testing

Use the three knobs to control the three degrees of freedom. Make sure each knob operates over the range we need to access the work space. Make any adjustments necessary.

Try picking up a module. Rotate the crane so it is pointed at a module. Adjust the distance so it is over the module. Adjust the height until it is just over the module, but not yet touching. Adjust the carrier so that it lines up with the module. Lower the carrier until the magnets touch. (The magnets should self-align to some extent.) Raise the carrier – the module should come up as well.

Use the controls to move the module over a target. Lower the module to the target. When in place, gently hold the module down as you lift the carrier using the controls. The magnets will separate from the module.

Real World Applications

Cranes are used extensively in the real world. We see them most often in construction. Most commonly we can see boom cranes, but tower cranes are fairly common as well. Typically they are used to move materials from the truck that bring them to where they are needed in the workspace, especially if they are needed above the ground. Cranes are used in many other places as well. Usually ships are loaded and unloaded by cranes. They may not be a boom or tower crane, but they are cranes all the same. NASA and Space-X use cranes to assemble rockets. Can you think of other applications for cranes?

Log

No log since this wasn't done that way.