Fine Print

Licensing

Attribution

Authors' names and sponsor institutions referenced below must be attributed in any future modification or redistribution of these plans.

This project is a fusion of two instruction sets published by Stuart McFarlane/Oomlout[2]: CNC1/desktop CNC router[3] (2007) provided the basic design for a functioning CNC mill; How to Make Anything (Using Acrylic and Machine Screws)[4] (2009) details a solution for constructing 90° joints in laser-cuts stock using simple hardware.

The plans and source files presented below were adapted and expanded by:
Chris Reilly (www.rainbowlazer.com, www.chris-reilly.org) and Taylor Hokanson (www.taylorhokanson.com) with generous support in the form of funding and facilities from the School of the Art Institute of Chicago (SAIC)[5].

Special thanks go to Chad Gerth, the Computing Resources and Information Technology Dept. (CRIT), Brian Stansbury, and the Architecture, Interior Architecture, and Designed Objects (AIADO) Department at SAIC.

Disclaimer

We've taken every opportunity to make these plans as thorough as possible. That said, all of the information contained within is subject to change, or to be unintentionally erroneous. Further, working with shop tools and electricity always carries the risk of injury, even death. These plans are intended to help beginners enter the field of CNC technology, yet still assumes a baseline knowledge of tools, electricity and shop safety. We are not responsible for any injury caused in relationship to this instruction set, whether the injury occurs during construction or in conjunction with the operation of the completed device.

If you follow these plans to the letter and find that your device doesn't work, feel free to contact us. We're happy to help up to a point, but please be aware that we offer no warranty or guarantee that this kit will function. We assume no financial liability in the event that you are not satisfied for any reason.

In conclusion: We are confident that our results can be reproduced based on these instructions (although we have no proof that this is true). Now let's get to it!

Chris Reilly is a Chicago-based artist, writer and teacher. He received his BFA with a focus on New Media from the School of the Art Institute of Chicago in 2006. Chris is currently employed as manager of SAIC's Advanced Outptut Center[6], and a part-time faculty member teaching between SAIC's Design and Film/Video/New Media departments. Since 2003, Chris has shown work in several solo and group art exhibitions in the US and Europe; he works with modded video games, virtual/augmented reality, scripting/programming and kinetic sculpture.

Taylor Hokanson is an artist and educator based in Chicago. His studio practice fuses functional design (as exhibited by the **DIYLILCNC** project) with artworks of a more conceptual nature (such as his Sledgehammer-operated Keyboard). Taylor teaches digital production/fabrication at DePaul University and the School of the Art Institute of Chicago.

www.taylorhokanson.com

Introduction

The **DIYLILCNC** project is a set of plans for an inexpensive, fully functional 3-axis CNC mill that can be built by an individual with basic shop skills and tool access.

CNC devices are used to fabricate physical objects with a high degree of precision. Some CNC devices, including the **DIYLILCNC**, feature a gantry-mounted cutting tool (like a router) that can move in two or more directions. The operation of the tool is controlled by a computer, which is tasked with translating a digital design into actual tool movement.

The **DIYLILCNC** can be built for around $700. This cost includes all the stock hardware and sheet material used in construction. CAD files for custom laser-cut parts are distributed along with the plans. Anyone with access to a laser cutter can use these files to fabricate all the panel parts necessary for construction; those without ready laser-cutter access can use local or online laser-cutting services.

Plans and instructions for building the **DIYLILCNC** are distributed freely and intended for wide distribution and modification with few restrictions. The plans are formatted to facilitate easy fabrication, especially for beginners. The **DIYLILCNC** can be built by an individual, a student group, or a class. Besides being immensely fun, building the **DIYLILCNC** is a great way to learn about motion control and CAD/CAM/CAE.

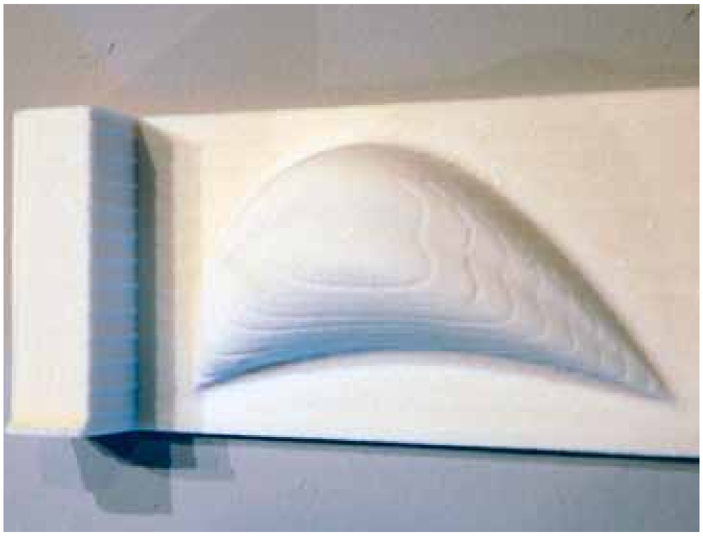
DIYLILCLC Components (Left to Right): Controller PC, Driver Board, Gantry/Mill.

Specs

- Cutting bed size: ~12” x 14” x 2”
- Spindle speed: 0-35,000 RPM
- Total cost for hardware, sheet material, motors and driver board: ~$700
- Tested cut materials: foam, hardwood, acrylic, MDF, thin copper sheet

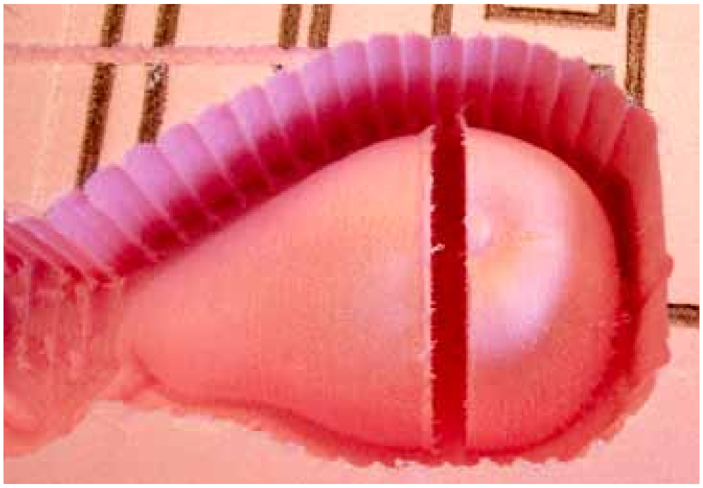
Material Examples

3/4” Acrylic.

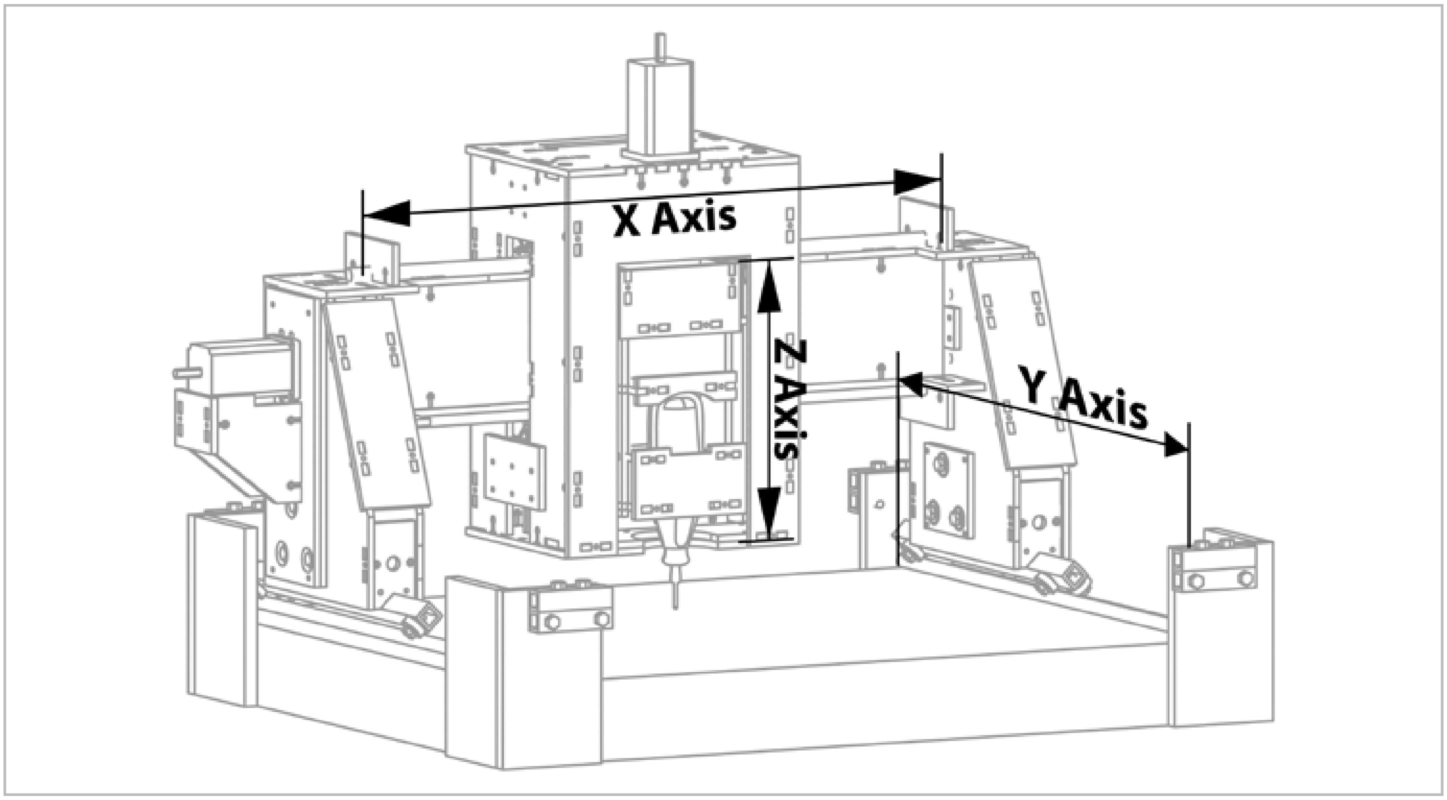


18# Proto-foam.

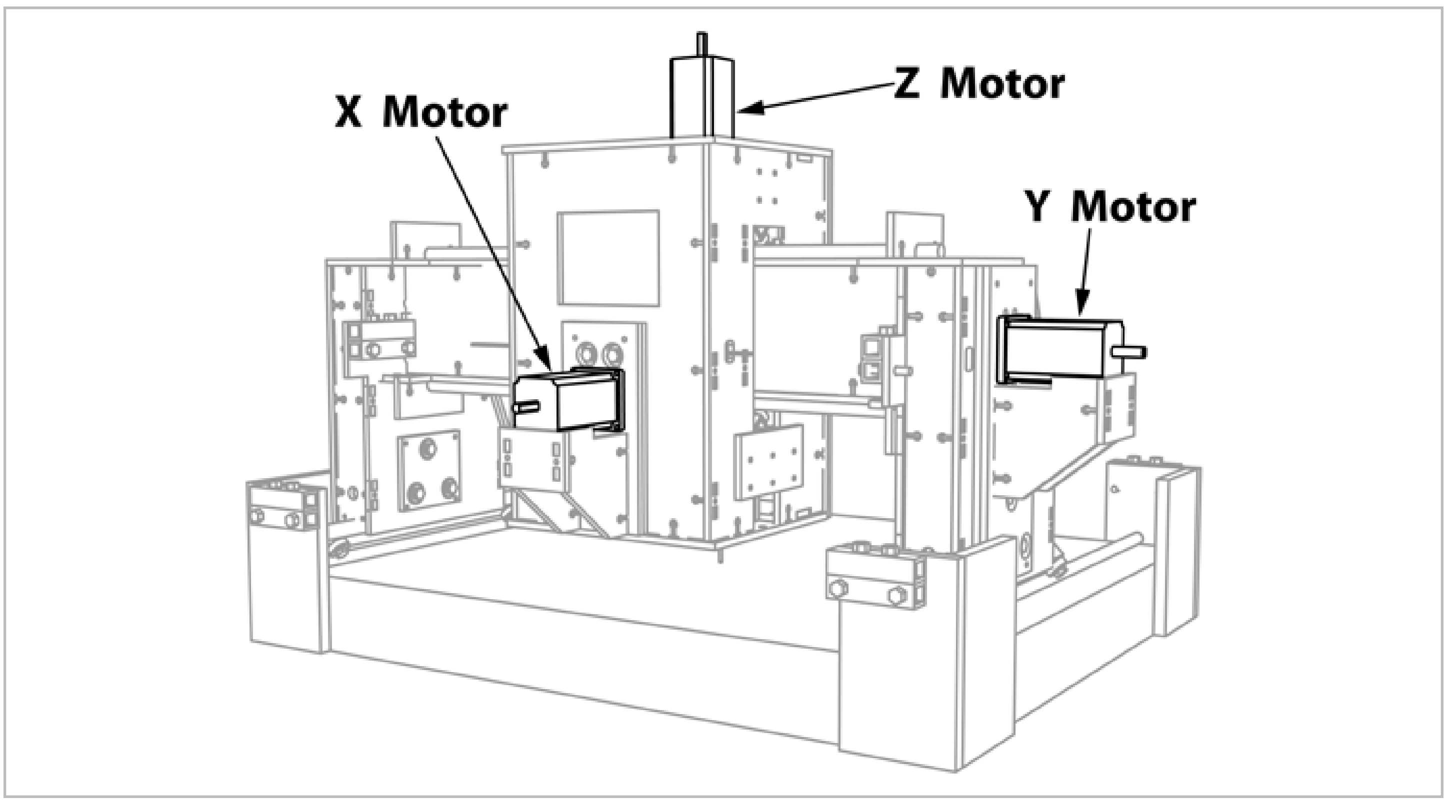
Hardwood.



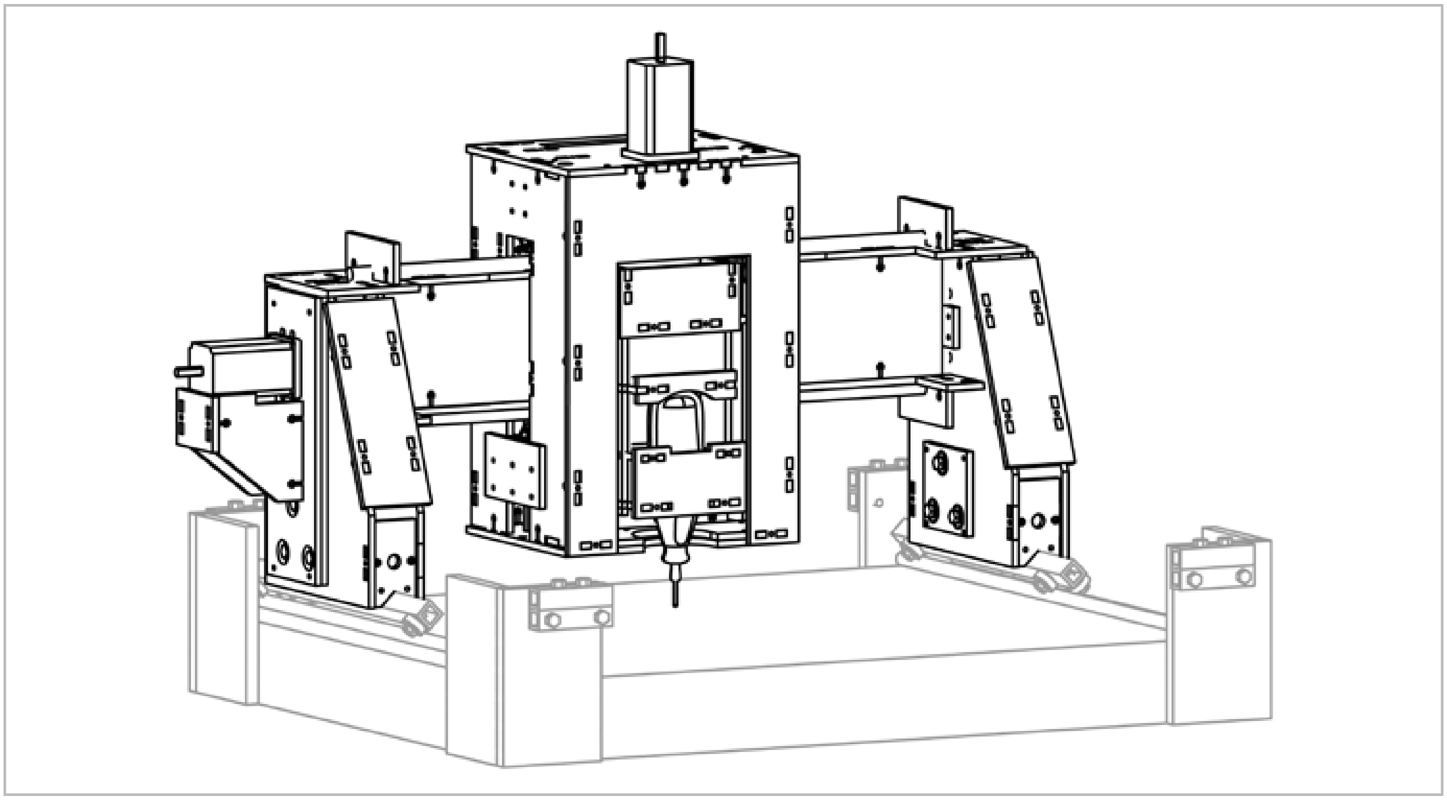
Polystyrene Insulation Foam.



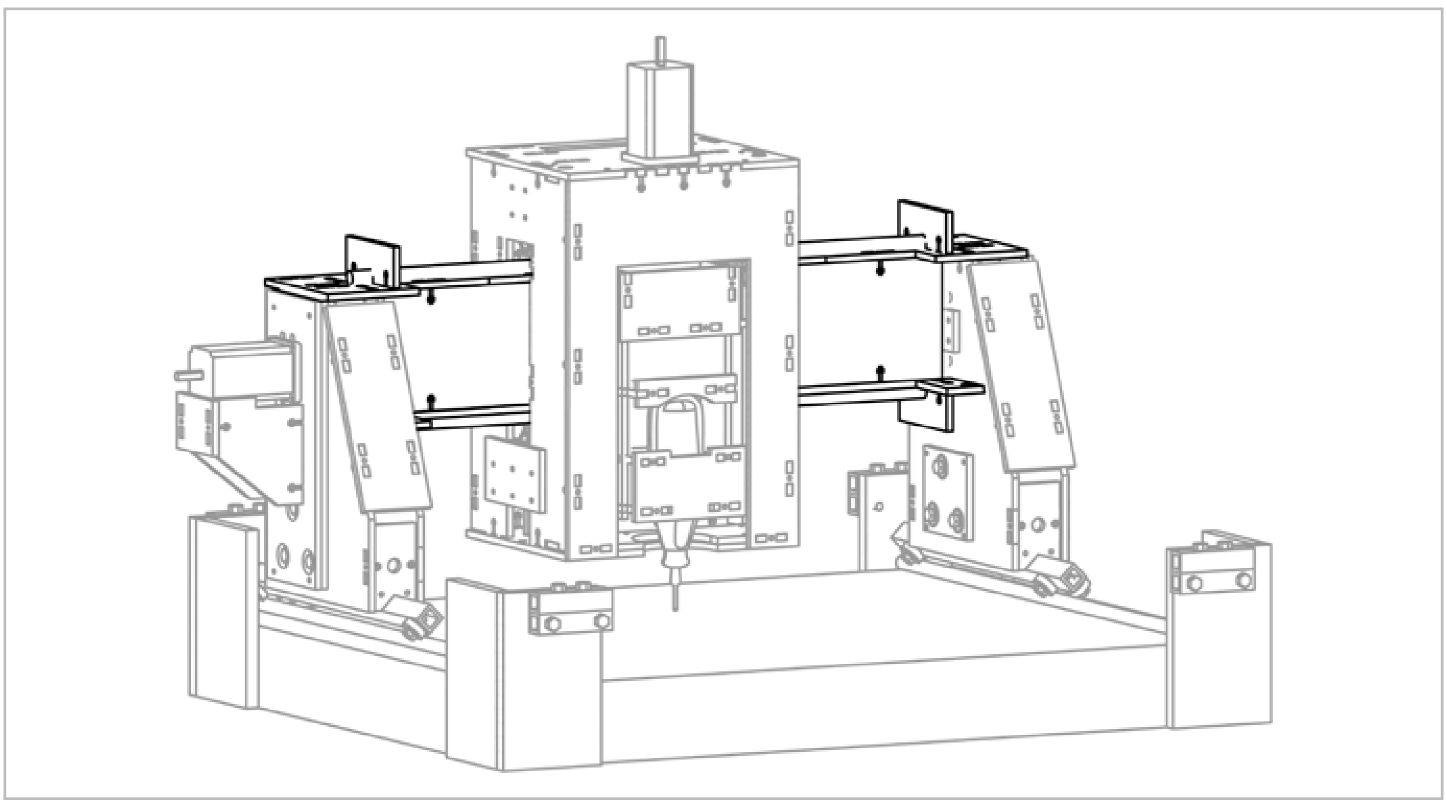
Axes of motion.



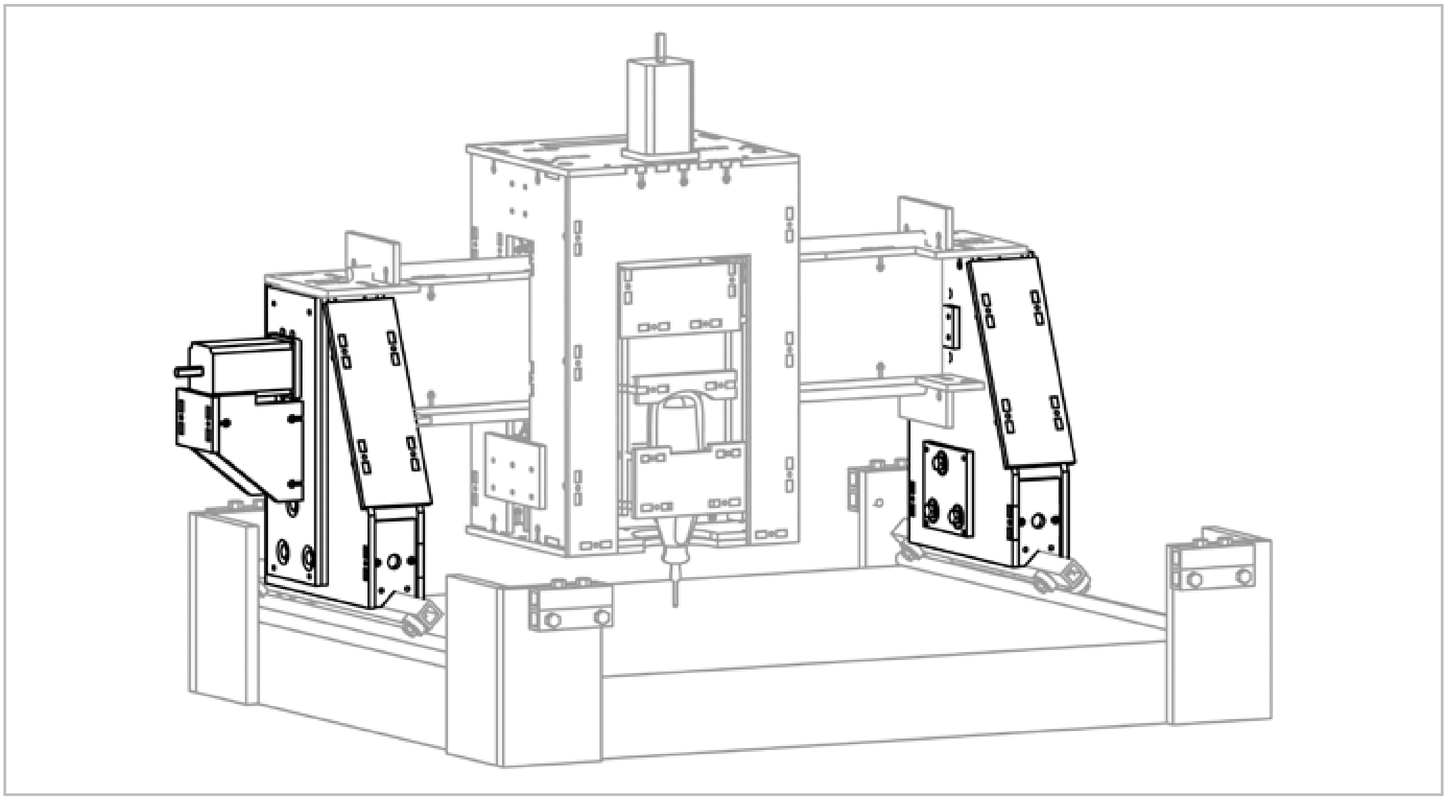
Motor Locations (view from rear).



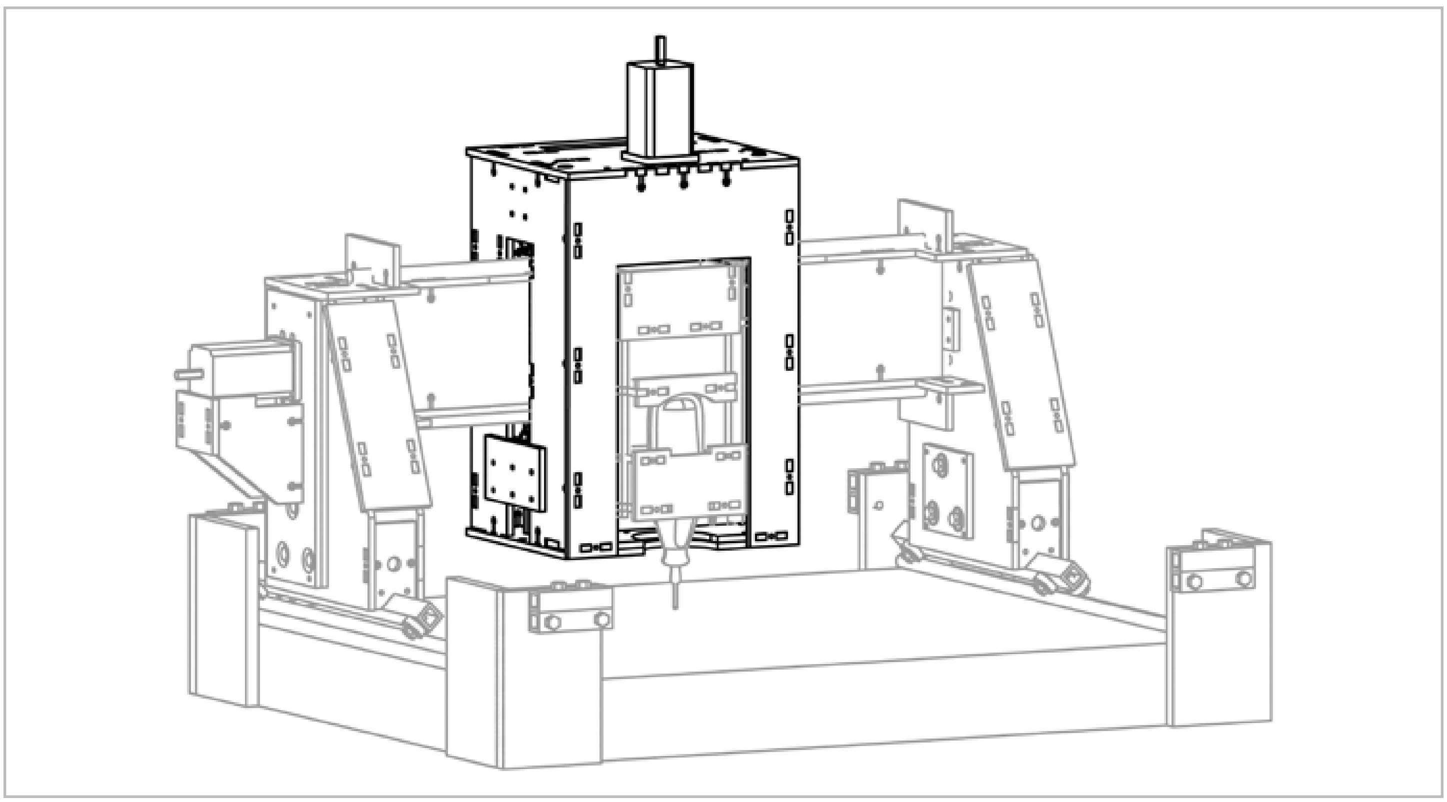
Gantry.



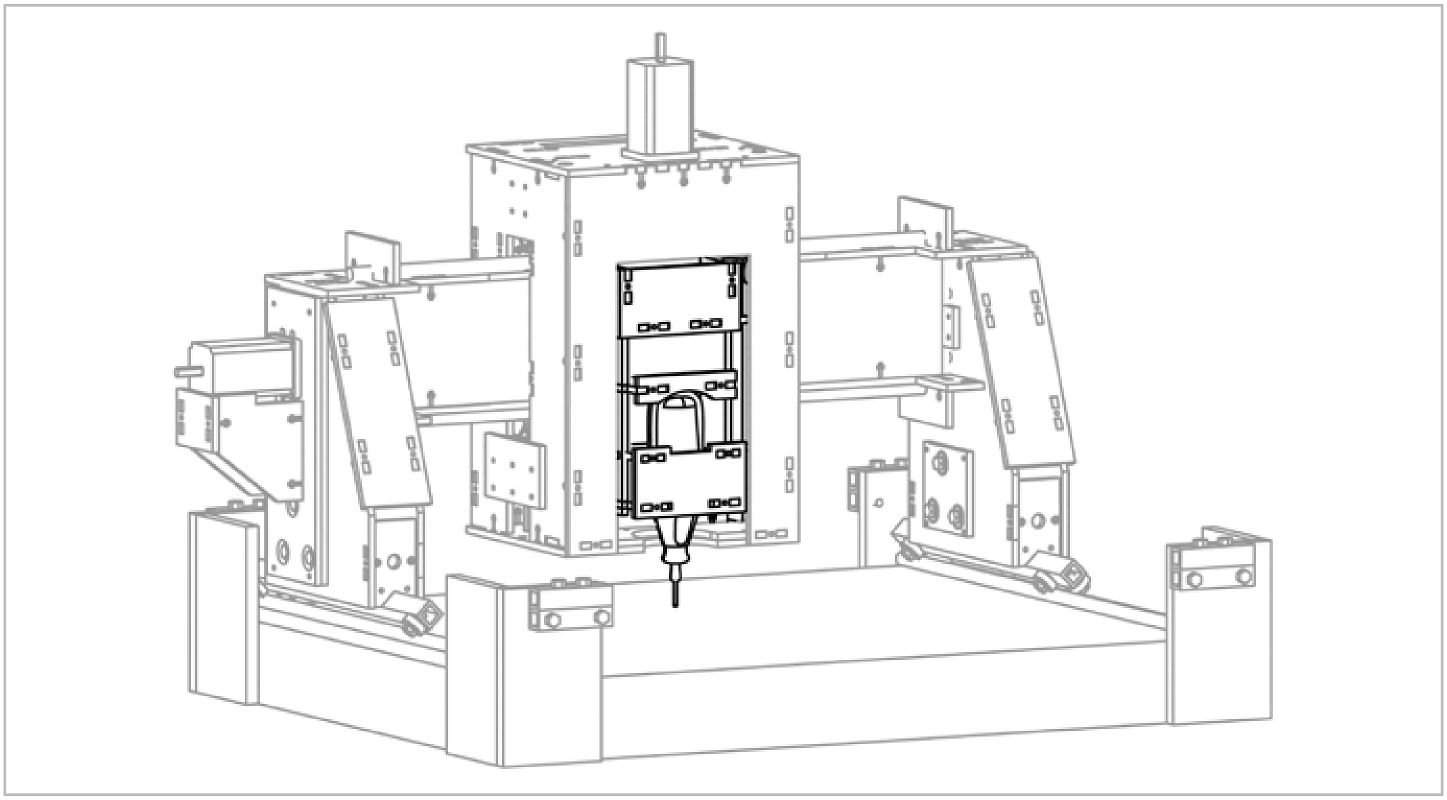
Gantry Components: X Beam.



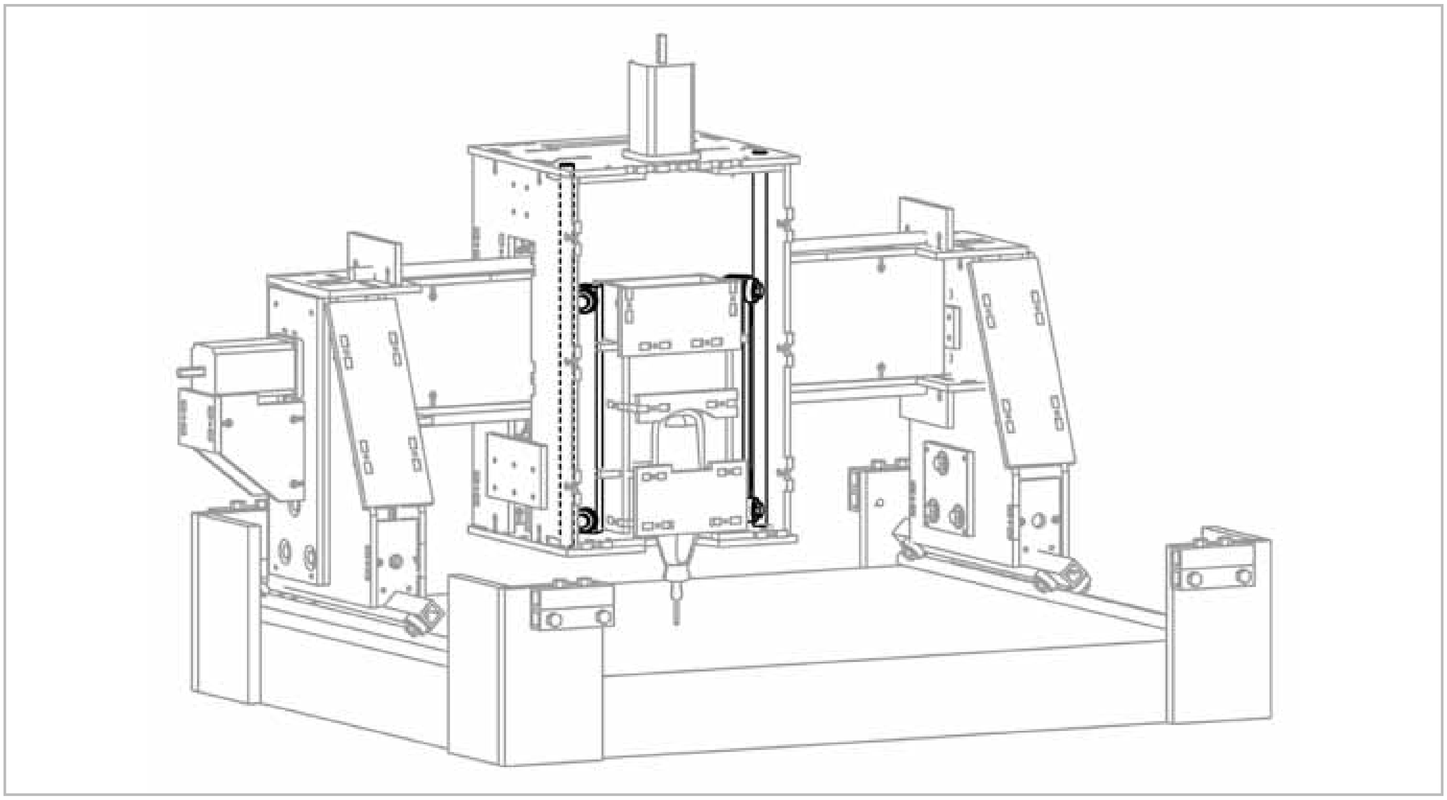
Gantry Components: Vertical Braces.



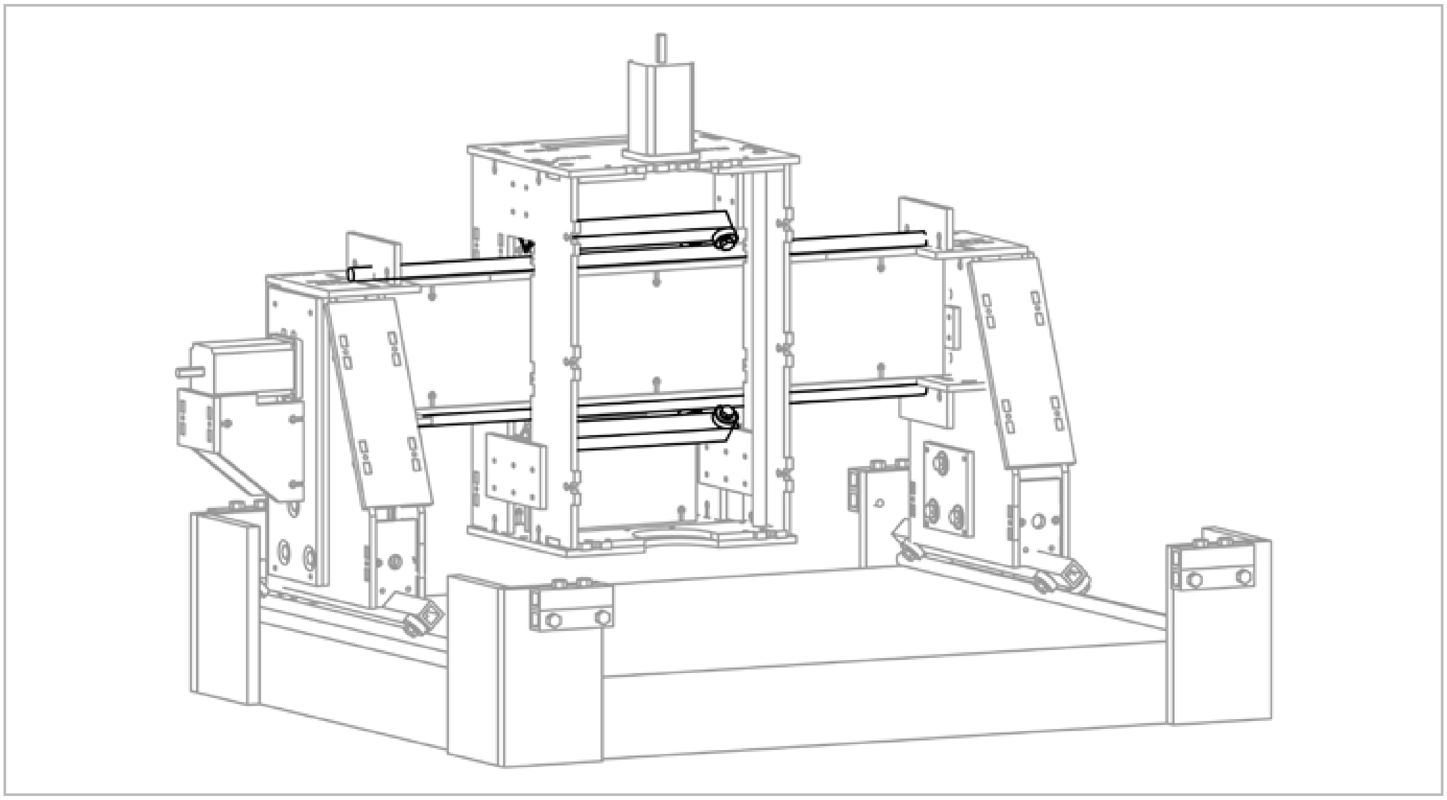
Gantry Components: Z-Cart.



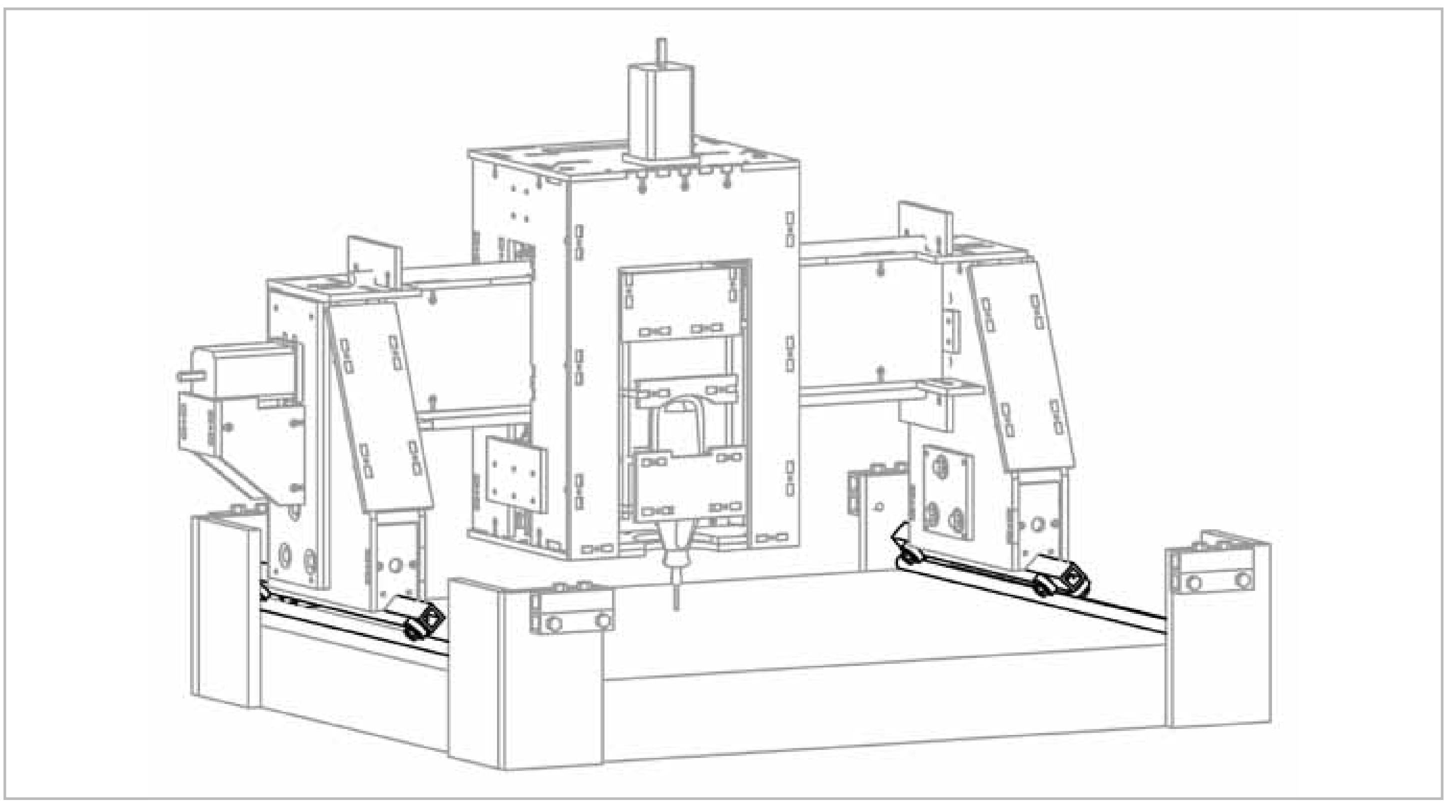
Gantry Components: Z Sled.



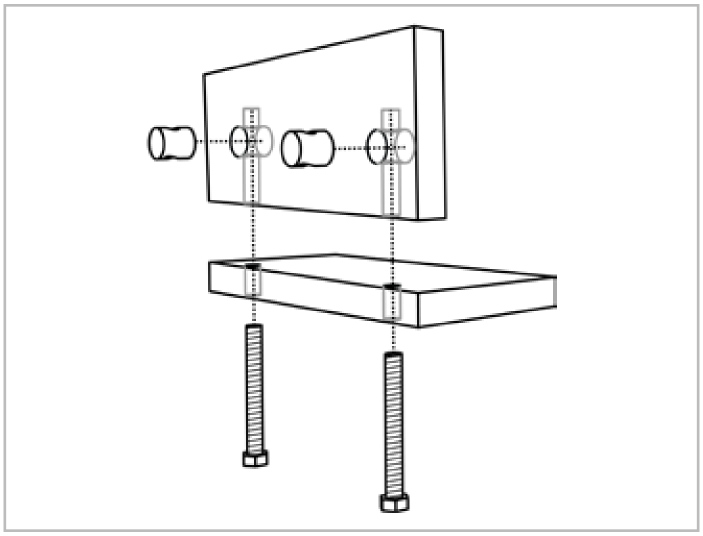
Gantry Components: Z rails and rail bearing assemblies (Z-cart face removed).



Gantry Components: X rails and rail bearing assemblies (Z-cart face, Z-sled and Z-cart interior reinforcement panel removed).



Gantry Components: Y rails and rail bearing assemblies.



Barrel nut joint.

Interlocking T-bolt joint.

Joinery
The joinery in the original design was based on a piece of hardware commonly found in pre-fab furniture kits, known technically as a barrel or cross nut. This technique required drilling many holes into the sides of the panel material used to construct the gantry. The side-drilling was tedious and easily botched, leading to faulty or misaligned joints. Our new design eliminates the need for side-drilling by using interlocking T-bolt joints. The panel pieces can now be screwed together after laser cutting with no additional hand fabrication.

Z-cart
To address the loose connection between Dremel and gantry, we took a 3D scan of the Dremel tool's outer chassis. This profile was used to cut form-fitting panels that lock the tool in place. The positioning of the Dremel in relationship to the gantry was also modified to give the tool greater travel in the Z-axis. This allows the **DIYLILCNC** to mill a wider range of stock thicknesses--from 1/16" circuit boards to 2" insulation foam. The connection between Z-cart and X-beam has also been changed to a clamping system to ensure a tight fit. This allows for periodic adjustments of the Z-cart tension, which can fall out of alignment over time. This change also addresses the tendency of the Z-cart to rack when slightly misaligned.

Belt Clamping
The original belt clamp design called for a couple of extra parts that were not used in any other area of the design. The new design employs small lengths of square tubing used in other parts of the design, which both improves function and reduces overall part count.

Wiring
This topic was loosely addressed in the initial design. Wires must be rated for high amperage and be relatively easy to dis/connect. While products do exist that meet these specs, they are expensive and hard to source in the US. After quite a bit of research we decided on daisy-chained lengths of computer power supply cabling.

Design Improvements

Documentation

The original design was perfectly functional. However, as educators, we have an eye for both the content and the way it is communicated. In addition to engineering improvements we've made great efforts to craft the instructions just as carefully as the actual, physical components that make up the project.

There are lots of further design improvements that could make the **DIYLILCNC** even better:

Cost Reduction

The finished version of our design cost us around $700, including all panel parts, hardware, steppers and driver board (basically, everything needed besides the computer running EMC2). Our cost does not include the service of laser cutting the panels. As our research continues, we'll post more information about online service bureaus that offer the best value.

Almost half the cost of the **DIYLILCNC** comes from the stepper motors and driver board. If we could spec some different/cheaper motors with similar torque/stepping characteristics we could further reduce costs. Oomlaut's instructable lists a cheaper transformer than what we used, which reduces costs for future builds.

Beyond motors and steppers, our second biggest cost was hardware. We tried to source as many parts as possible from McMaster-Carr for consistency's sake, though this tends to inflate the price of things that may be available cheaper from other vendors. Local hardware stores can be a good source for cheaper versions of the common hardware like machine screws, etc.

Those looking to really cut costs could use threaded rod and a coupling nut instead of the acme rod/nut in the Z-cart, as per oomlout's original plans[3]. This can save close to $60 off the total cost; however the trade-off is the need for more rotations on the Z-motor to keep the same speeds on the Z-axis, which may require you to lower overall feed speeds when milling to prevent losing steps.

Laser-Cut Gantry Panels

The gantry we constructed is made of masonite, a thin compressed wood material similar to MDF. While masonite is very inexpensive, a plywood material of similar thickness may offer more strength and durability. The 1/4" plywood that we have ready access to tends to have a good deal of warp in it, making it unsuitable for laser-cutting.

There are several joints in the gantry assembly that could be glued with wood glue during assembly, while still allowing access to motor drives and belts for occasional adjustments. As we run more tests and gauge the durability of the gantry sans glue, we may add gluing steps to the assembly instructions.

Bed Size/Cutting Area

The usable cutting area of the **DIYLILCNC** could be increased easily by extending the Y-axis with longer rails and a longer bed. The vertical cutting height could also be raised, however the Z-axis is also dependent on the cutting tool you're using; in order to be useful, the tip of the cutting tool must be able to reach the bottom of the cutting bed. This requires a longer bit as the Z-height increases. In order to prevent flexing of longer bits, a larger bit diameter is required. Since our dremel can only accommodate a 1/8" bit, we are limited to about 2" of usable cutting depth before we would need a tool that can use 1/4" or 1/2" diameter bits.

Conclusions

Metric Parts
While English-measurement parts are readily available to us in the US, we realize this is not the case for most of the world. At some point, we'd like to spec metric hardware and adjust the laser files accordingly.

Parallel Port
The fact that the driver board must run off a parallel port can be problematic, since most of the folks we know have hip new laptops without them. The connection to the driver must be real-time, so USB-to-parallel adapters are not an option either.

While we enjoyed the learning experience of working with EMC2, there exist other options out there that could negate the need for a parallel port, such as an intermediary microcontroller (eg, Arduino[8]) buffer that could run off a USB connection between the controller and the driver. We've begun to explore some options of engaging with the open-source hardware community to look at solutions to this problem.

Bearings & Tracks
The rollerblade bearings used for X/Y/Z movement are a great and economical solution. The original design called for metric mounting bolts with a tight fit-tolerance. We used 1/4-20 bolts which didn't fit exactly but could be tightened in place. This adds some room for error in the placement of the bearing tracks and subsequent friction fitting of other parts.

The relationship between the Z-cart and the X-beam is an ongoing challenge. In order to achieve a proper fit, the bearing tracks must make just the right amount of contact from both the top and bottom of the X-beam. We attempted to make an adjustable fitting bracket with limited success. One possible improvement would be to use aluminum square tube for the X-beam tracks instead of the 1/2" round rods. This could give the Z-cart a more stable balancing point and cause it to rock less if it is slightly loose.

The Z-cart design could also benefit from some attention to the balancing of the motors, Z-sled and dremel tool. This would probably have to be accomplished with some sort of counterweight, since the center of gravity of the Z-cart will change as the Z-sled moves up and down.

Y-Motor Positioning
Currently the motor controlling Y-axis movement is mounted on one side of the gantry; this leads to an uneven distribution of weight, and a slight lag in the transfer of motion from one side of the gantry to the other. A better way to control Y-axis motion would be to mount the Y-motor to the rear of the cutting bed, centered between the vertical braces. A similar Y-shaft would extend from either end of the motor's shaft, driving belts that were attached to the vertical braces.

Belts
The motion transfer system for the X and Y axes currently uses timing pulleys and flexible timing belts. In the first iteration of the mill, we encountered motion problems due to inconsistent belt tension. Maybe a better way to transfer motor movement from the X and Y motors would be to use a spur gear and rack on a stable track as opposed to the belt. Amazon.com seems to have some good sources for inexpensive gear/rack hardware.

Dremel Tool
The Dremel tool we used in both designs does fine for most materials, however it would be worth exploring similar-sized tools that could offer more cutting power and/or more flexibility with bit size; with the current tool we are limited to 1/8" diameter bits. During the course of design and testing, we burnt out the motor of one dremel, though this was probably caused by erratic plunging problems due to poor software tuning.

Limit Switches
We experimented with limit switches on our first build of the **DIYLILCNC**. They are relatively easy to set up, and both EMC2 and the driver board are pre-configured to accept the signals.

4th Axis
The board kit we use in this project can control up to four axes. We could imagine some really interesting possibilities for what an additional axis could do: control an extrusion device to function as a 3D printer, act as a rotary axis, etc.

Toolpath-Generating/CAM Software
While there are several robust options for free/open-source CAD design (eg, Blender[9]; BRL-CAD[10]), we have yet to find a corresponding CAM software solution for generating toolpaths that is not prohibitively expensive. We currently use RhinoCAM, which is great, especially since our institution foots the bill. We are currently exploring some other options (pycam[11], GCAD3D[12], HeeksCAD[13]/ HeeksCNC[14]) which may eventually give us the open-source 3D toolpath generation that we'd like. There are also opportunities here to engage more with the open-source software community in the development of such a product.

Related Projects & People

MIT Media Lab[15]
Neil Gershenfeld[16]
RepRap[17]
Adrian Bowyer[18]
CandyFab[19]
Maker Bot [20]
Open Source Initiative[43]
McMaster-Carr[44]

Axis
A straight line through space that describes the movement of a physical body in relationship to an abstract origin point. In our case, the individual directions in which the dremel can move on the gantry: right/left; forward/backward; up/down.

CAD (Computer Aided Design)

The use of software to develop the design of an object. While CAD can sometimes be followed by fabrication (CAM), it can also be a purely digital process.

CAE (Computer Aided Engineering)
The use of information technology to support engineers in tasks such as analysis, simulation, design, manufacture, planning, diagnosis, and repair.

CAM (Computer Aided Manufacturing)
The use of digital processes such as design software, toolpath-generating software and CNC devices to assist in fabricating physical objects.

CNC (Computerized Numerical Control)
CNC is used to describe the general technique of controlling the motions of fabrication machines via computers. For example, laser cutters, 3D printers, and CNC mills are all considered CNC devices.

Controller/Computer
The controller refers to the PC computer that reads G Code files and sends them through the driver board to the **DIYLILCNC**. Our controller happens to run Linux, with EMC2 as the control software. We sometimes use the phrase controller interchangeably to refer to either the control software or the PC's hardware.

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Driver Board
The electronics assembly that converts low-voltage signals from the controller PC's parallel port into high-current signals that drive the **DIYLILCNC's** motors.

EMC2 (Enhanced Machine Controller)
EMC2 is open-source software for control of CNC devices and it runs on the Linux operating system. EMC2 is what we use to send G Code instructions to our CNC mill. EMC2 is used for many different applications, even large commercial CNC mills.

G Code
Instructions for a CNC device that determine position, speed and other motion controls. While other types of CNC codes exist (there are M codes, S codes, etc.[21]), G Code is used as a general term for the entire programming language of CNC devices. G Code can be hand-coded, or generated from a digital model using toolpath-generating software like MasterCAM.

Gantry
A movable frame structure raised on side supports so as to span over or around something.

Linux
A free, open-source operating system. Linux comes in many versions for a wide range of hardware: desktops, laptops, cell phones, servers, watches, and even supercomputers. The version of Linux we used to control our **DIYLILCNC** is called Ubuntu 8.04.

Open Source
The term open source refers to a software program whose source code is available to the public for free, with the understanding that it can be reviewed, modified or developed for any purposes. Open source software tends to be written collaboratively, with peer review being an essential part of developing and improving software. As a general term, open source can refer to any project with a similar ethos of free sharing among peers for greater development. Open-source hardware designs are one example.

Stepper Motor
A motor whose driveshaft rotates in small, predictable steps rather than continuously.

Toolpath
A set of instructions that tell a CNC device where to move in space. In the case of a CNC mill, a toolpath would define where the cutting tool moves to remove material from a workpiece. For a 3D printer, a toolpath would define where an extrusion head moves to deposit material. A common format for toolpaths is a text file with a list of G Code instructions that describe how to produce an object.

Parts List

The parts costs for these plans include all of the hardware, stock and electrical components needed to build the mill/gantry, driver board and driver board enclosure. In addition to these parts listed below, you'll have to acquire a PC that can be used to run the controller software. The total cost does not take into account the cost of the controller PC, nor does it account for the cost of laser cutting services, should you need to use them.

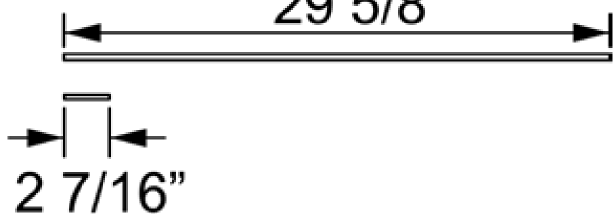
DIYLILCNC Part Name	Supplier's Description	Supplier	Part No.	Quantity	Unit Price	Total
Driver Board and Motors	HobbyCNC PRO Driver Board 3-axis Package (HCNCPRO driver board and (3) 305oz-in 4.2V 3A Steppers)[22]	HobbyCNC.com	N/A	1	$280.00	$280.00
X and Y Drive Shaft	W1 Tool Steel Rod .2500" Diameter, Trade Size E, 3' Length	McMaster-Carr	8890K36	1	$2.64	$2.64
Acme Rod/ Z Drive Shaft	1018 Carbon Steel Precision Acme Threaded Rod 1/4"-16 Sz, 1/16" Travel Distance/Turn, 3'L, Rh Thread	McMaster-Carr	99030A032	1	$21.90	$21.90
Shaft Couplers	Steel One-Piece Set-Screw Coupling 1/4" Bore, 3/4" Length, 1/2" OD, Without Keyway	McMaster-Carr	6412K11	3	$5.44	$16.32
Acme Nut	Bronze Precision Acme Round Nut 1/4"-16 Sz, 1/16" Travel Distance/ Turn, Rh Thread	McMaster-Carr	95072A881	1	$28.62	$28.62
Acme Flange Nut	Zinc-Plated Grade 5 Steel Thin Hex Nut 9/16"-18 Thread Size, 7/8" Width, 5/16" Height, 25ct	McMaster-Carr	94846A530	1	$4.88	$4.88

DIYLILCNC Part Name	Supplier's Description	Supplier	Part No.	Quantity	Unit Price	Total
Belt Pulleys	Mxl and XL Series Timing-Belt Pulley 1/4" Belt Width, .685" OD, 20 Teeth	McMaster-Carr	1375K39	3	$9.81	$29.43
Imperial Bearing	Steel Ball Bearing Plain Open for 1/4" Shaft Dia, 7/8" OD, 1/4" W	McMaster-Carr	6383K14	4	$3.88	$15.52
X and Y Belt	Trapezoidal-Tooth Neoprene Belting Mxl Trade Size, .080" Pitch, 1/4" Width	McMaster-Carr	7959K21	12 feet	$1.81	$21.72
X and Y Belt Bearing Bolts	Metric 8.8 Zinc-Pltd Steel Hex Head Cap Screw M8 Size, 85mm L, 1.25mm Pitch, Partially Threaded, 10 ct.	McMaster-Carr	91280A559	1	$4.81	$4.81
X and Y Belt Bearing Nuts	Metric Plain Steel Hex Nut Class 8, M8 Size, 1.25mm Pitch, 13mm W, 6.5mm H, 100 Ct.	McMaster-Carr	90592A022	1	$4.29	$4.29
X and Y Belt Bearing Washers	DIN 125 Zinc-Plated Class 4 Steel Flat Washer M8 Screw Size, 16mm OD, 1.4mm-1.8mm Thick, 100 ct.	McMaster-Carr	91166A270	1	$2.73	$2.73
Square Tubing for Rail Bearings	Architectural Aluminum Tube (Alloy 6063) Square, 3/4" X 3/4", 1/8" Wall, 3' Length	McMaster-Carr	88875K523	3	$6.23	$18.69
X, Y and Z Rails	W1 Tool Steel Rod .5000" Diameter, 3' Length	McMaster-Carr	8890K45	5	$8.10	$40.50

Parts List

DIYLILCNC Part Name	Supplier's Description	Supplier	Part No.	Quantity	Unit Price	Total
1/4-20 Nuts	Plain Grade 8 Steel Hex Nut 1/4"-20 Thread Size, 7/16" Width, 7/32" Height, 100 Ct.	McMaster-Carr	90499A029	1	$2.75	$2.75
1/4-20 Washers	Plain Steel Type A SAE Flat Washer 1/4" Screw Size, 5/8" OD, .05"-.08" Thick 222ct	McMaster-Carr	91083A029	1	$3.73	$3.73
3/4" 1/4-20 Bolts	Znc-Pltd Stl Low-Strength Hex Head Cap Screw 1/4"-20 Thread, 3/4" Length, Fully Threaded 100ct.	McMaster-Carr	91309A540	1	$4.14	$4.14
2" 1/4-20 Bolts	Grade 5 Zinc-Plated Steel Hex Head Cap Screw 1/4"-20 Thread, 2" Long, Fully Threaded	McMaster-Carr	92865A549	1	$8.68	$8.68
Machine Screw Nut	Znc-Pltd Stl Undersized Machine Screw Hex Nut 6-32 Thread Size, 1/4" Width, 3/32" Height, 100 ct.	McMaster-Carr	90760A007	2	$2.36	$4.72
1/2" Machine Screw	Zinc-Pltd Stl Pan Head Phillips Machine Screw 6-32 Thread, 1/2" Length, 100ct.	McMaster-Carr	90272A148	1	$1.95	$1.95
3/4" Machine Screw	Zinc-Pltd Stl Pan Head Phillips Machine Screw 6-32 Thread, 3/4" Length 100ct.	McMaster-Carr	90272A151	1	$2.40	$2.40

DIYLILCNC Part Name	Supplier's Description	Supplier	Part No.	Quantity	Unit Price	Total
1" Machine Screw	Zinc-Pltd Stl Pan Head Phillips Machine Screw 6-32 Thread, 1" Length, 100 ct.	McMaster-Carr	90272A153	1	$2.92	$2.92
Transformer	24V CT (12-0-12) 10A TRANSFORMER[23]	mpja.com	LP520	1	$18.95	$18.95
Dremel Tool	Dremel 395 Variable Speed MultiPro Kit	TylerTool.com	DREMEL 395	1	$54.95	$54.95
Skate Bearings/ Rail Bearings	100 Ct. ABEC-7 Sealed Skateboard/ inline/Rollerblade Skate Bearings[24]	www.vxb.com	kit708	1	$44.95	$44.95
Wiring Harness	12-inch Molex 4-Pin LP4 Power Extension Cable M/F[25]	xsfans.com	LP4EXT12	14	$1.99	$27.86
Masonite	4' x 8' sheet of 1/4" Masonite	Home Depot (or Local Supplier)		1	$10	$10.00
MDF	4' x 4' sheet of 1/2" MDF	Home Depot (or Local Supplier)		1	$6	$6.00
					Grand Total	690.93



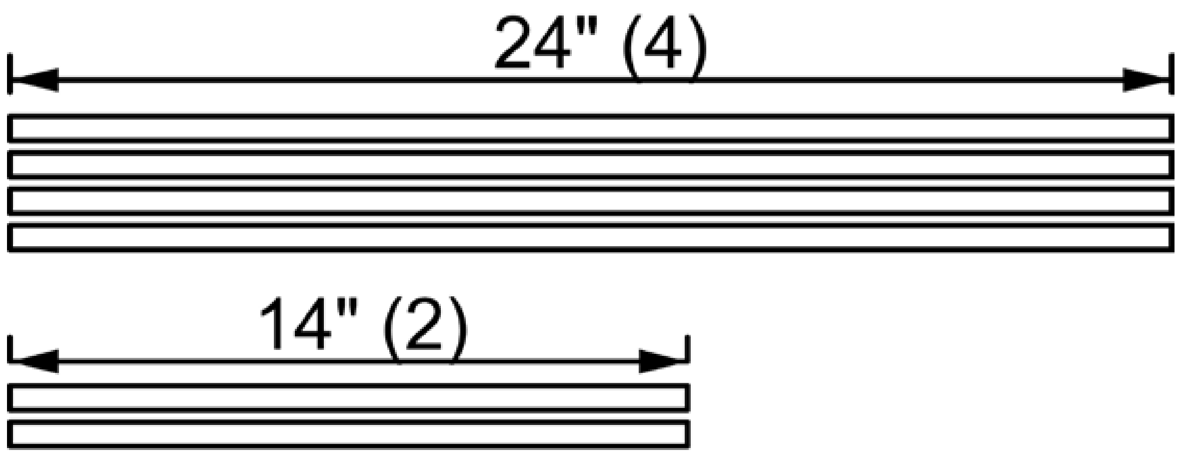
X and Y Drive Shafts: 1/4” Steel Rod.

Stock and Hardware needed for these steps:

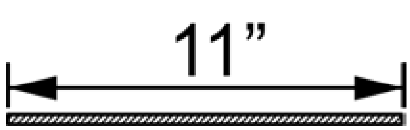
1/4” Steel Rod 3’ Length (1)
1/2” Steel Rod 3’ Length (5)

Tools needed for these steps:

Horizontal Bandsaw or Hacksaw
Flat File



X, Y and Z Rails: 1/2” Steel Rod.

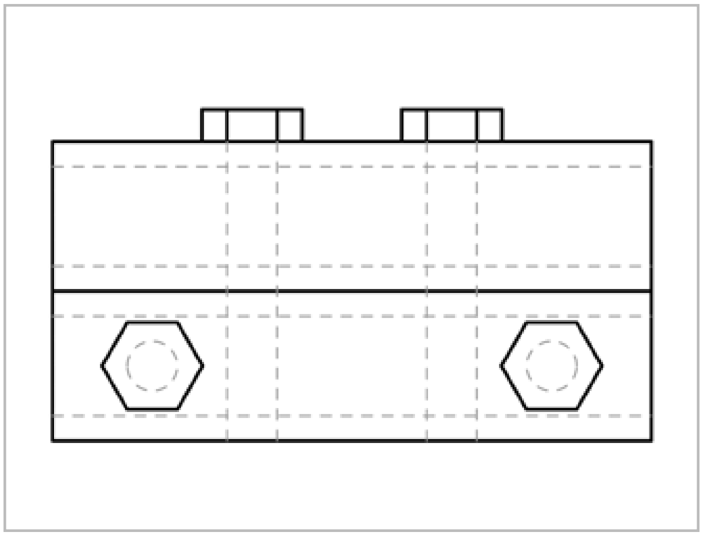


Z Drive Shaft: 1/4” Acme Rod.

Cut the **X** and **Y drive shafts** from **1/4” steel rod**. Rounding the ends slightly with a file makes it easier to attach pulleys, collars and couplers.

Cut the **X**, **Y** and **Z rails** from **1/2” steel rod**. The **X** and **Y** rails are the same length. Rounding the ends of the **Z rails** with a file makes seating the **Z-sled** easier.

Cut the **Acme rod** for the **Z drive shaft** to 11”. Rounding the ends slightly with a file makes it easier to thread into the Acme nut.

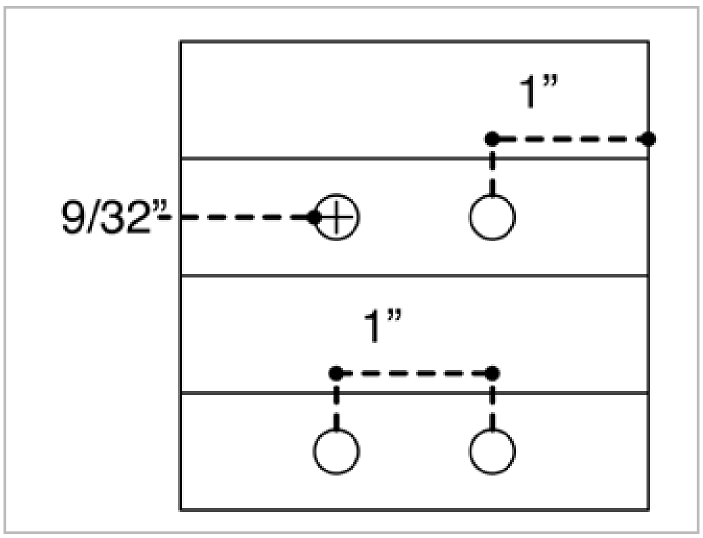


Stock and Hardware needed for these steps:

3’ Aluminum Tube (1)
2” 1/4-20 Bolts (24)

Tools needed for these steps:

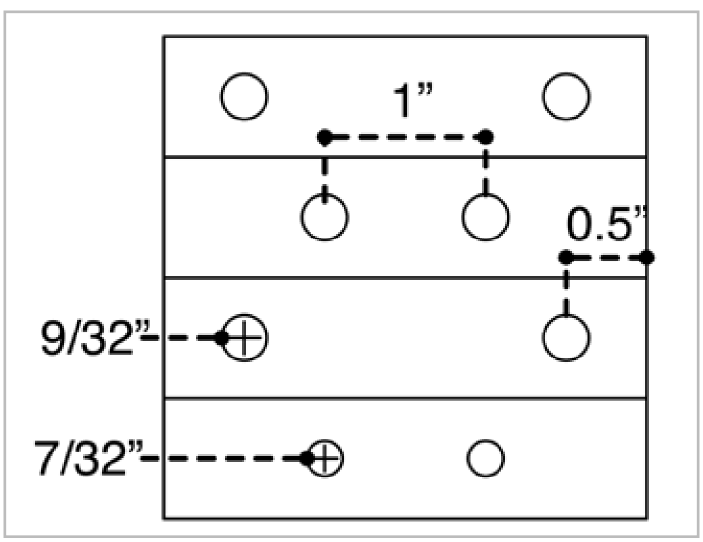
Drill Press
1/4-20 Thread Tap
Horizontal Bandsaw or Hacksaw



Clamp top: Diagram shows front, bottom, back, top.

Cut the **aluminum tube** into (12) 3” sections.

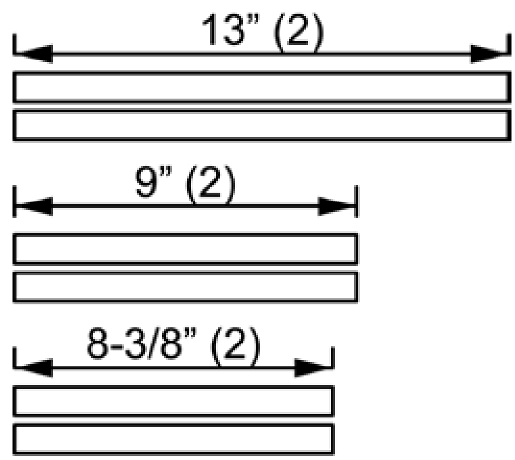
Six of the sections will become clamp tops. Drill holes with a 9/32” bit through each section. Do not tap the holes.



Clamp bottom: Diagram shows front, bottom, back, top.

The remaining six sections will be clamp bottoms. Tap the 7/32” holes with a 1/4-20 thread tap.

Assemble belt clamps with 1/4-20 bolts. When installed, belts pass between tube segments. Vertical bolts tighten the assembly around the belt. Horizontal bolts/nuts attach the assembly to the gantry or the base.

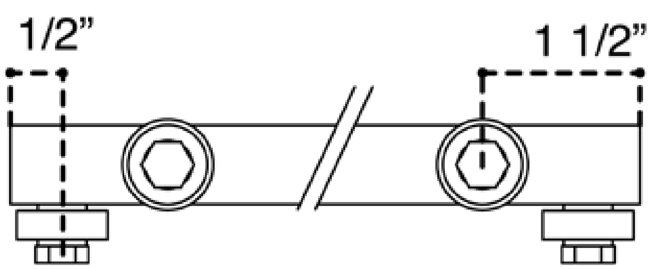


Stock and Hardware needed for these steps:

3’ Aluminum Tube (2)
3/4” 1/4-20 Bolts (24)
1/4-20 Washers (48)

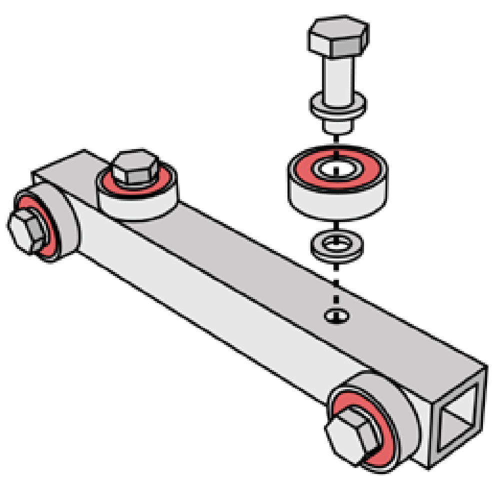
Tools needed for these steps:

Drill Press
1/4-20 Thread Tap
Horizontal Bandsaw or Hacksaw

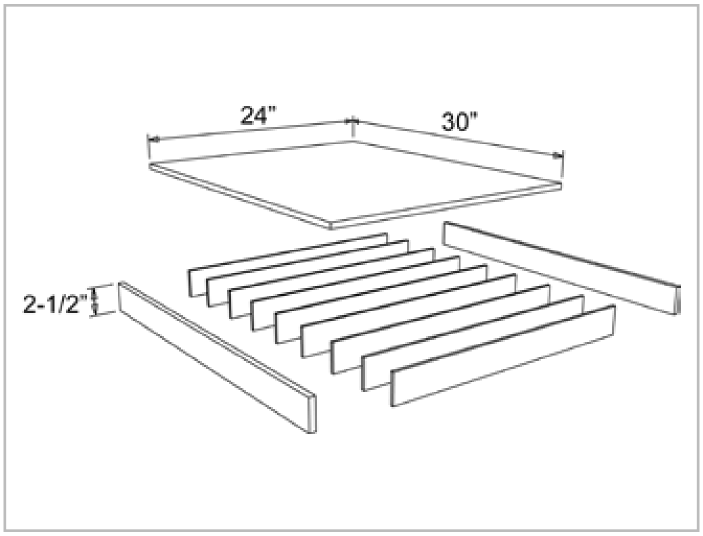


Bearing assembly pairs come in three different lengths, but the attachment points for the bearings themselves are the same throughout. The first pair of bearings sit on the same face, 1/2” in from either end of a tube segment. The second pair of bearings share an adjacent face, sitting 1-1/2“ in from either end of the segment.

Bearing mount holes are 7/32”, tapped for 1/4-20. Holes do not penetrate both parallel faces of the tube segment.



Use 1/4-20 x 3/4” bolts to mount the bearings to the tube segments. Add washers to the bolt both before and after the bearing is added - this will allow the bearing to spin more freely. Add more washers (or employ washers of varying thickness) to fine-tune the fit between bearing assembly and gantry.

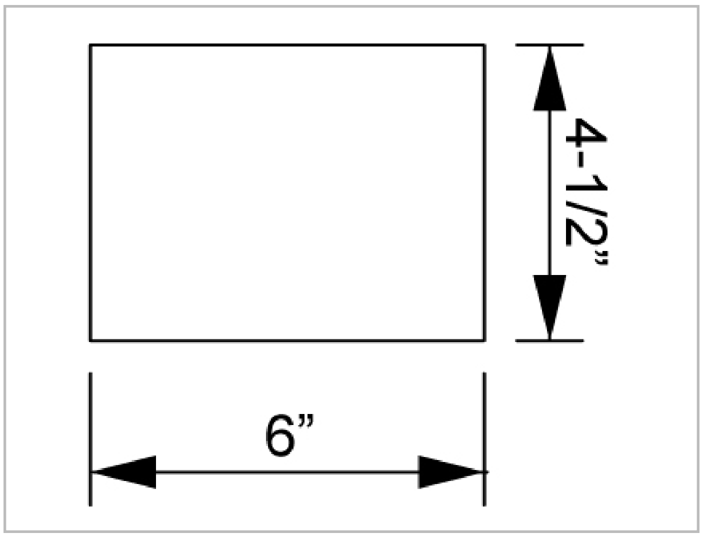


Stock and Hardware needed for these steps:

1/2" MDF (4'x4' Sheet)
Wood Screws or Nails

Tools needed for these steps:

Table Saw or Circular Saw




We added extra internal spans to our cutting bed.

The base of the **DIYLILCNC** is constructed of a sheet of 1/2" MDF cut to 30" wide by 24" deep. This base is attached to risers or side-panels that are 2 1/2" high. We constructed our base with intersecting internal spans for extra support.

You'll also need (8) 4 1/2" x 6" pieces of the same 1/2" MDF to construct the Y-belt wall panels. Screw the Y-belt wall panels to each corner of the cutting to form 90° corners. The panels parallel to the front and back of the bed should overhang the sides by 1/2". We recommend using wood glue for the 90° joint.

Panel Fabrication

CAD files for laser-cut parts can be downloaded from http://www.diylilcnc.org.

We used Adobe Illustrator to layout all our panel contours. The slots that make up the T-bolt system are all instances of the same symbol in this file. This allows the file to be easily modified in response to variations in material thickness (1/4" Masonite can vary between .2" and .25"). This will prove especially important if you aren't doing the laser cutting yourself. If you are, remember to measure your stock with a micrometer and to adjust slot thickness accordingly.

The panel layouts below are set up for 16"x32" sheets; you should be able to cut down a 4'x8' sheet into (9) 16"x32" sheets. As different laser cutters vary in bed-size, the parts may need to be re-arranged prior to cutting. Red and green paths are for cuts; black paths are engravings.

Online Service Bureaus

If you don't have direct access to a laser cutter, there are service bureaus that will laser-cut CAD files for you. Many of these are local; you can find a good long list on the Thomas Register[26], sortable by locale. Additionally, here are a couple of online bureaus that will ship your materials out:

Ponoko custom laser cutting:	http://www.ponoko.com/
Pololu custom laser cutting:	http://www.pololu.com/catalog/product/749

We've had no direct experience with these laser-cutting services, so we can't vouch for or against any of them. We would be curious to know about your experience if you do choose to use one.

Panel Assembly Tips

We recommend using red thread-locker for all threaded connections. The motor vibrations can easily dislodge nuts and bolts.

Unless specifically stated, all connecting panels should be secured with 6-32 machine screws where connections exist at the time of assembly.

Securing machine screw nuts into receiving slots with tape can save time during assembly.

Cut Sheet 1

Y Motor Mount
Outer Panel (1 of 1)

Y Motor Mount
Inner Panel (1 of 1)

X Motor Mount
Outer Panel (1 of 1)

X Motor Mount
Inner Panel (1 of 1)

X-Belt Bearing Trap (1 of 1)

Motor Mount
Bracket Cap (2 of 2)

Z-Rail Upper Bracket (1 of 1)

Z-Rail Lower Bracket (1 of 1)

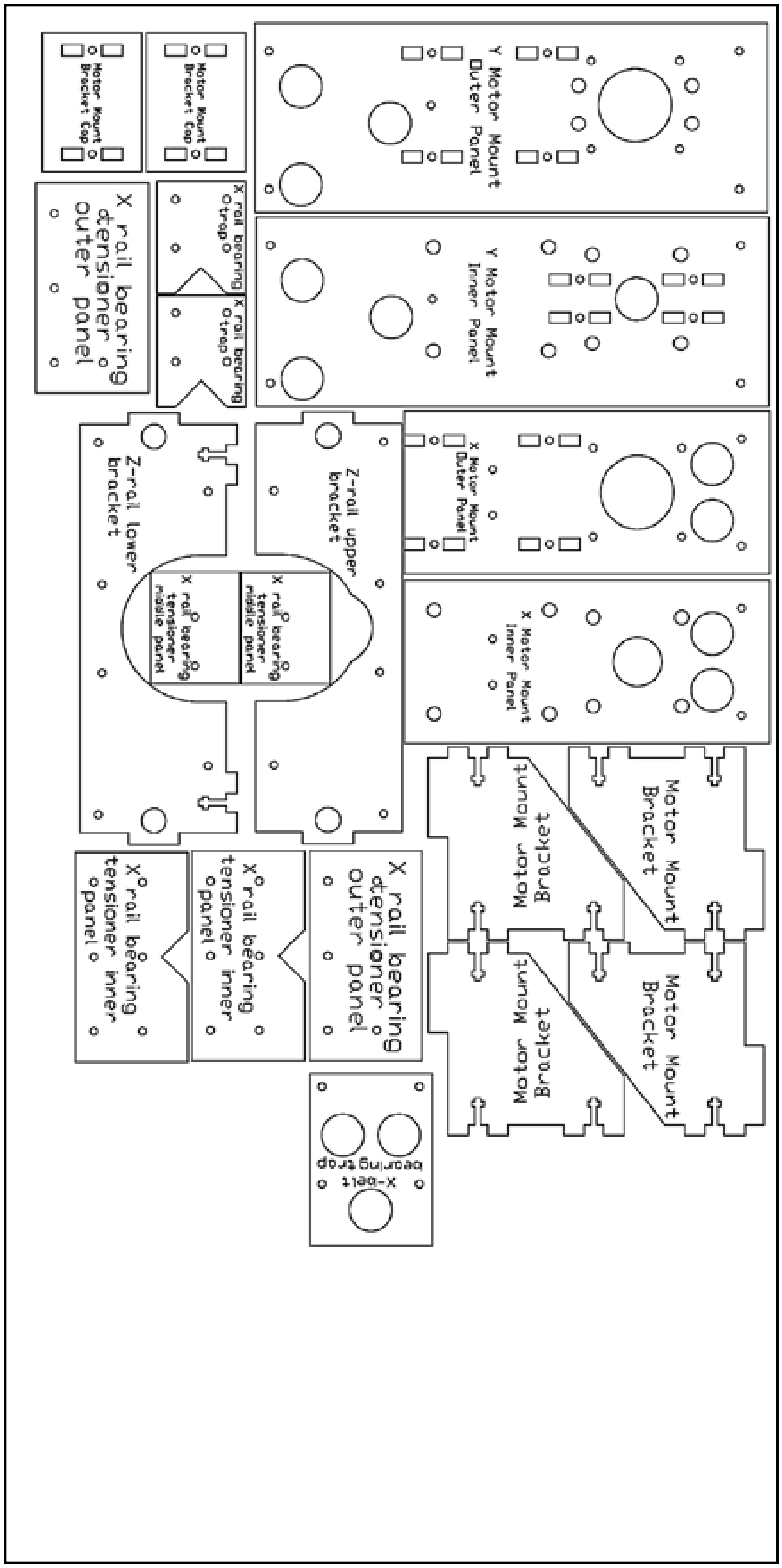
X-Rail Bearing Trap (2 of 2)

X-Rail Bearing Tensioner
Outer Panel (2 of 2)

X-Rail Bearing Tensioner
Middle Panel (2 of 2)

X-Rail Bearing Tensioner
Inner Panel (2 of 2)

Motor Mount Bracket (4 of 4)



Cut Sheet 2

Z-Cart Side Panel (2 of 2)

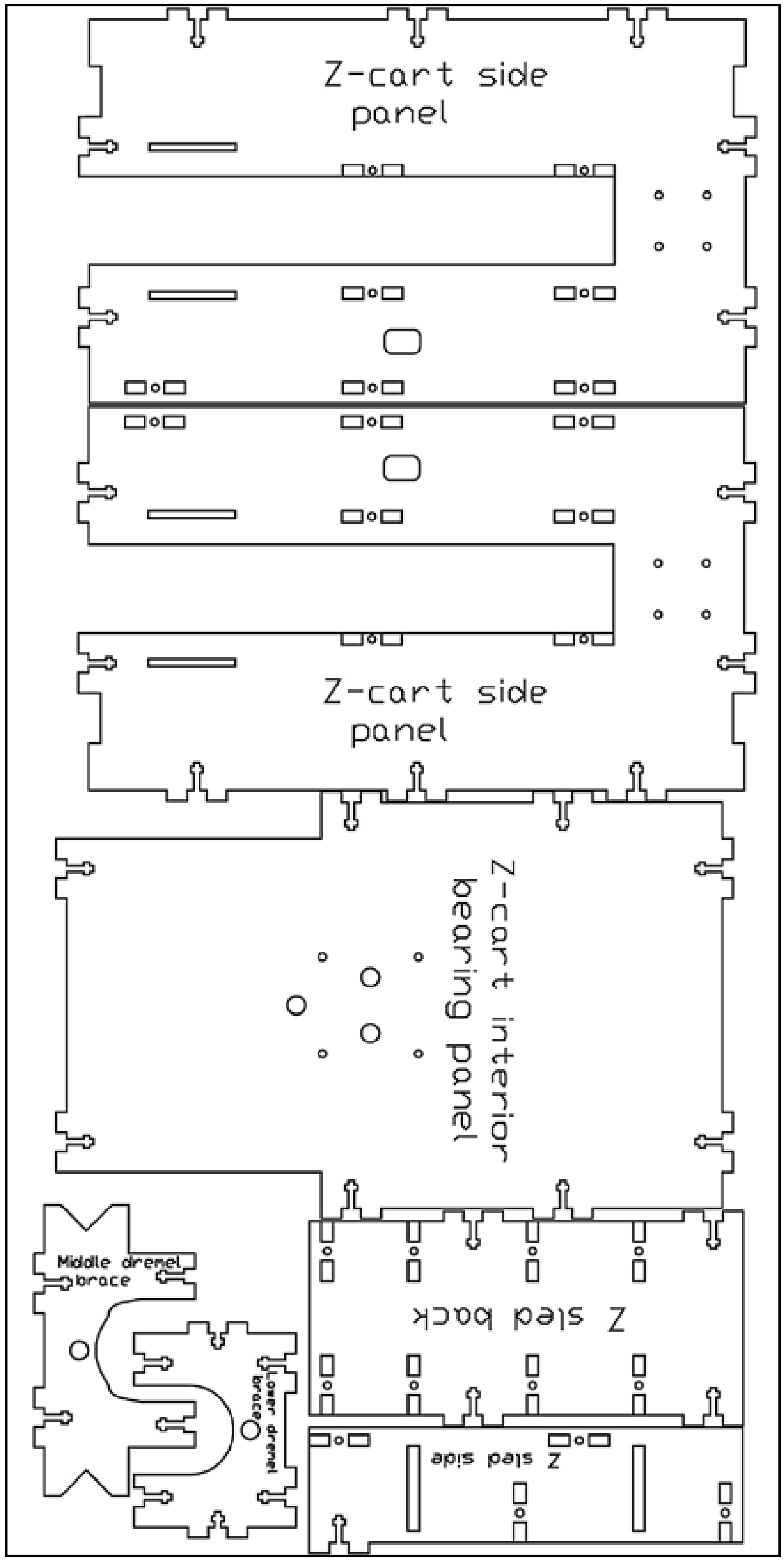
Z-Cart Interior
Bearing Panel (1 of 1)

Z-Sled Back (1 of 1)

Z-Sled Side (1 of 2)

Middle Dremel Brace (1 of 1)

Lower Dremel Brace (1 of 1)



Cut Sheet 3

Z-Cart Face (1 of 1)

Upper Dremel Brace Cap (1 of 1)

Upper Dremel Brace (1 of 1)

Z Sled Front (1 of 1)

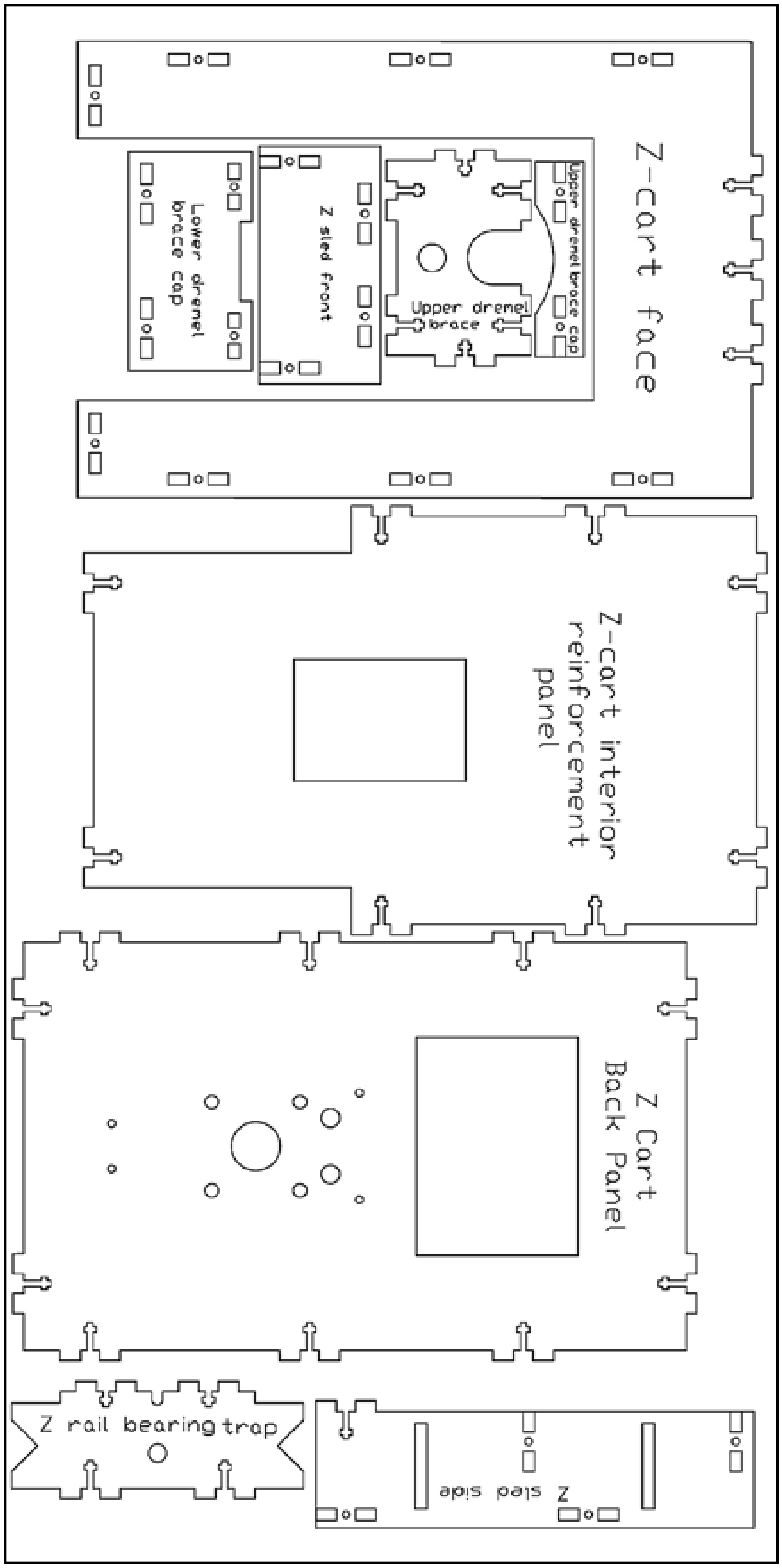
Lower Dremel
Brace Cap (1 of 1)

Z-Cart Interior
Reinforcement Panel (1 of 1)

Z-Cart Back Panel (1 of 1)

Z-Sled Side (1 of 2)

Z-Rail Bearing Trap (1 of 2)



Cut Sheet 4

Z-Cart Bottom (1 of 1)

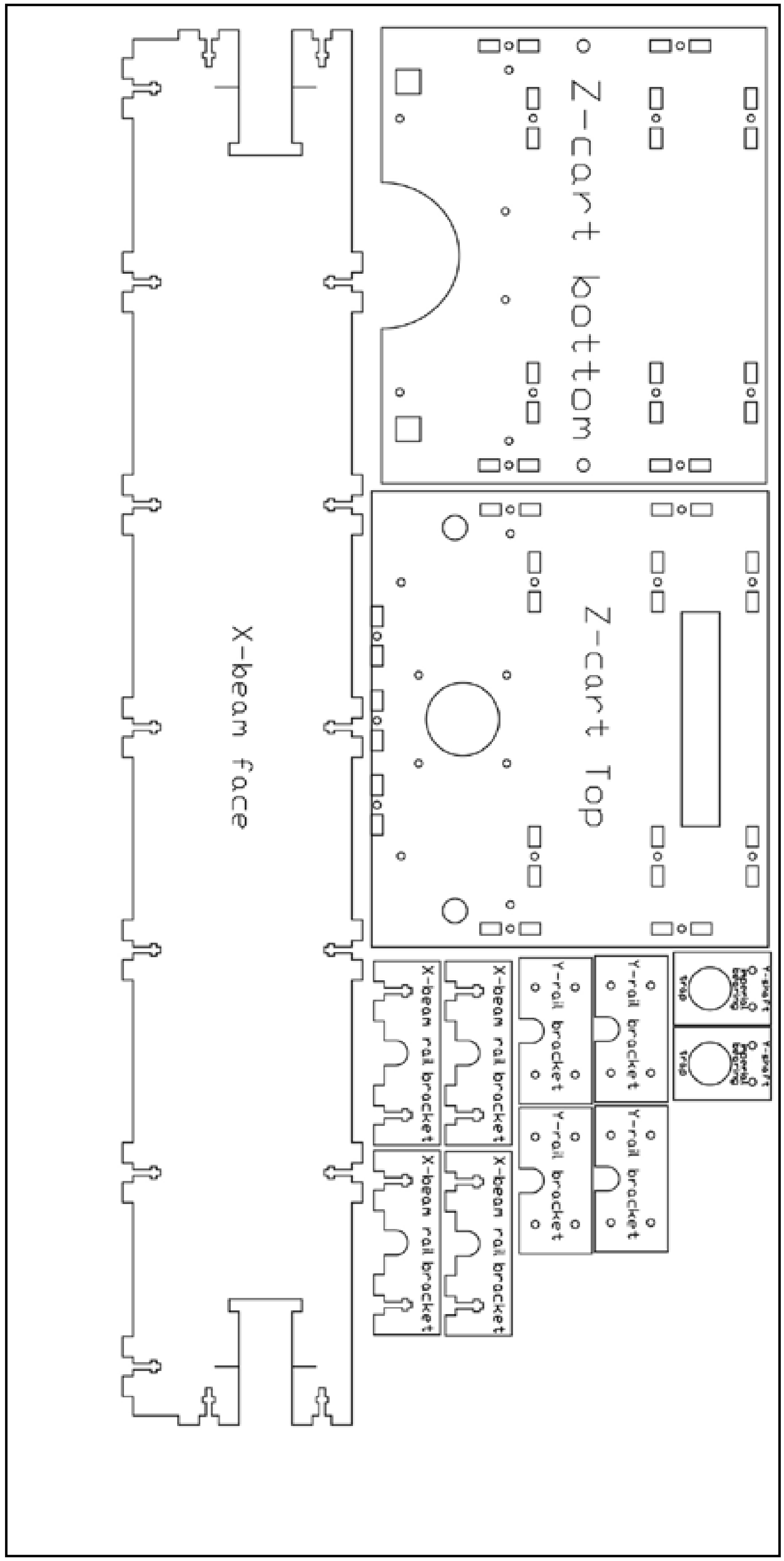
Z-Cart Top (1 of 1)

Y-Shaft Imperial
Bearing Trap (2 of 2)

Y-Rail Bracket (4 of 4)

X-Beam Rail Bracket (4 of 4)

X-Beam Face (1 of 2)



Cut Sheet 5

X-Beam Bottom (1 of 1)

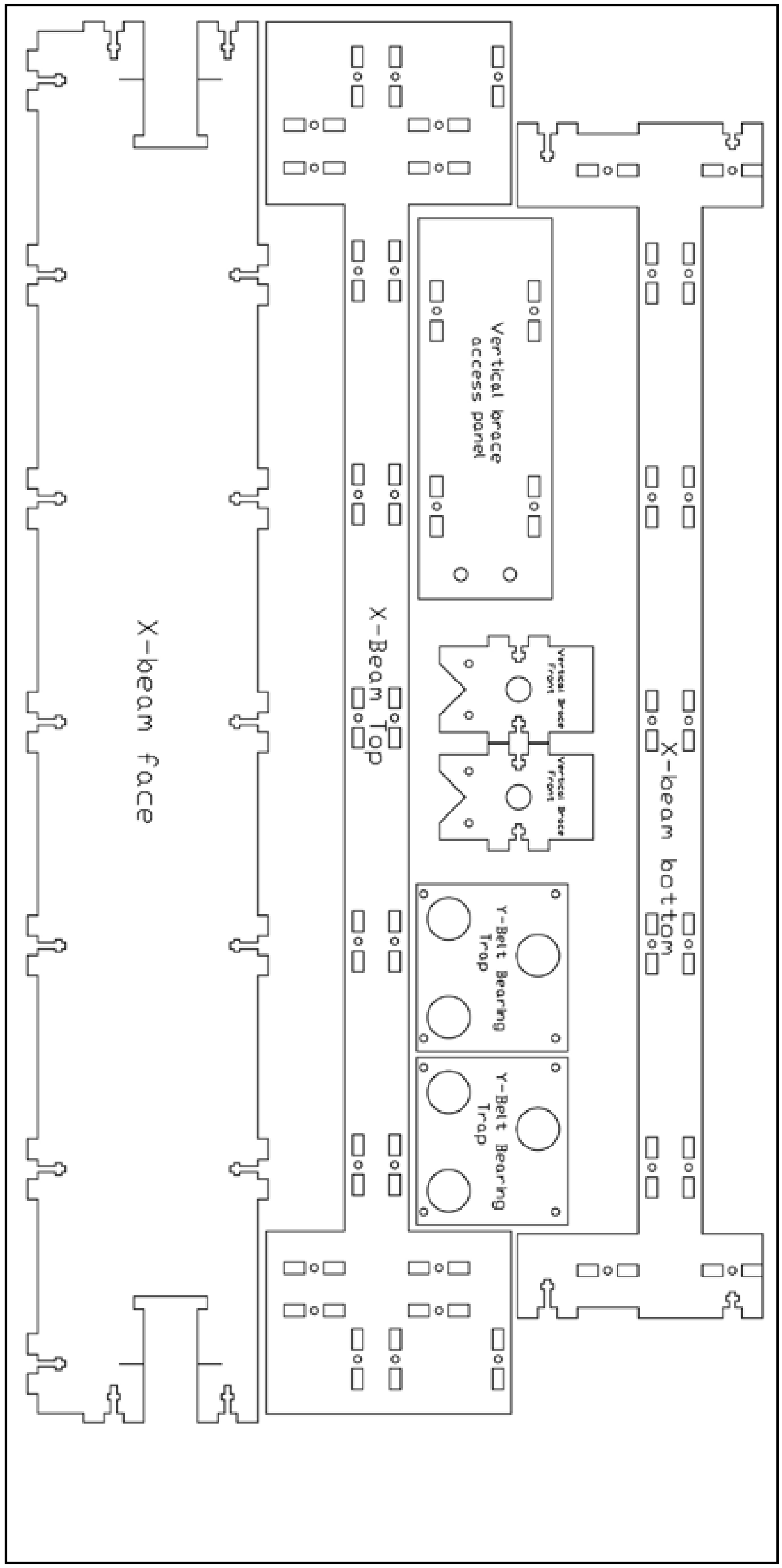
Vertical Brace
Access Panel (1 of 2)

Vertical Brace Front (2 of 2)

Y-Belt Bearing Trap (2 of 2)

X-Beam Top (1 of 1)

X-Beam Face (1 of 2)



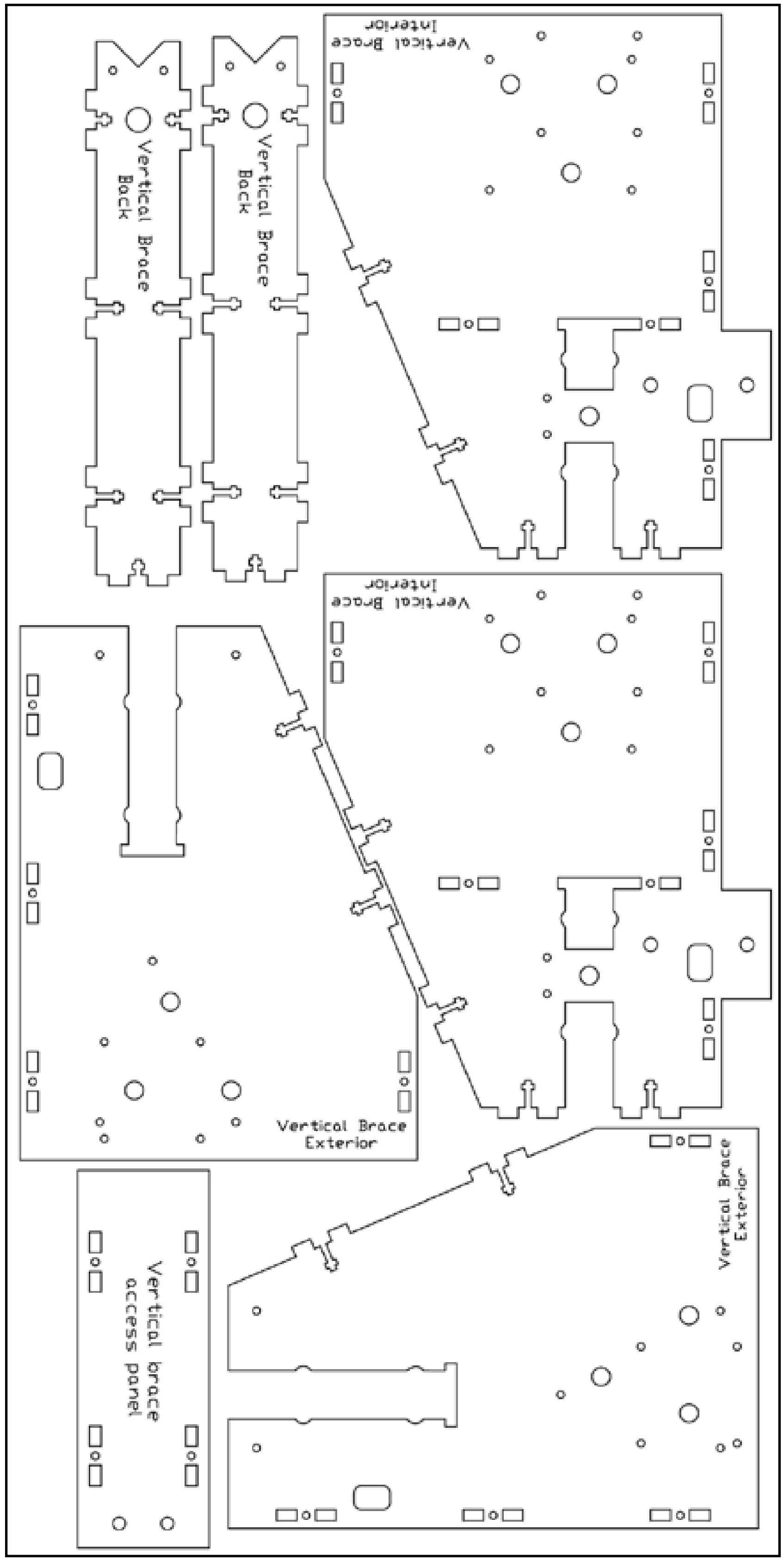
Cut Sheet 6

Vertical Brace Access Panel (1 of 2)

Vertical Brace Back (2 of 2)

Vertical Brace Exterior (2 of 2)

Vertical Brace Interior (2 of 2)

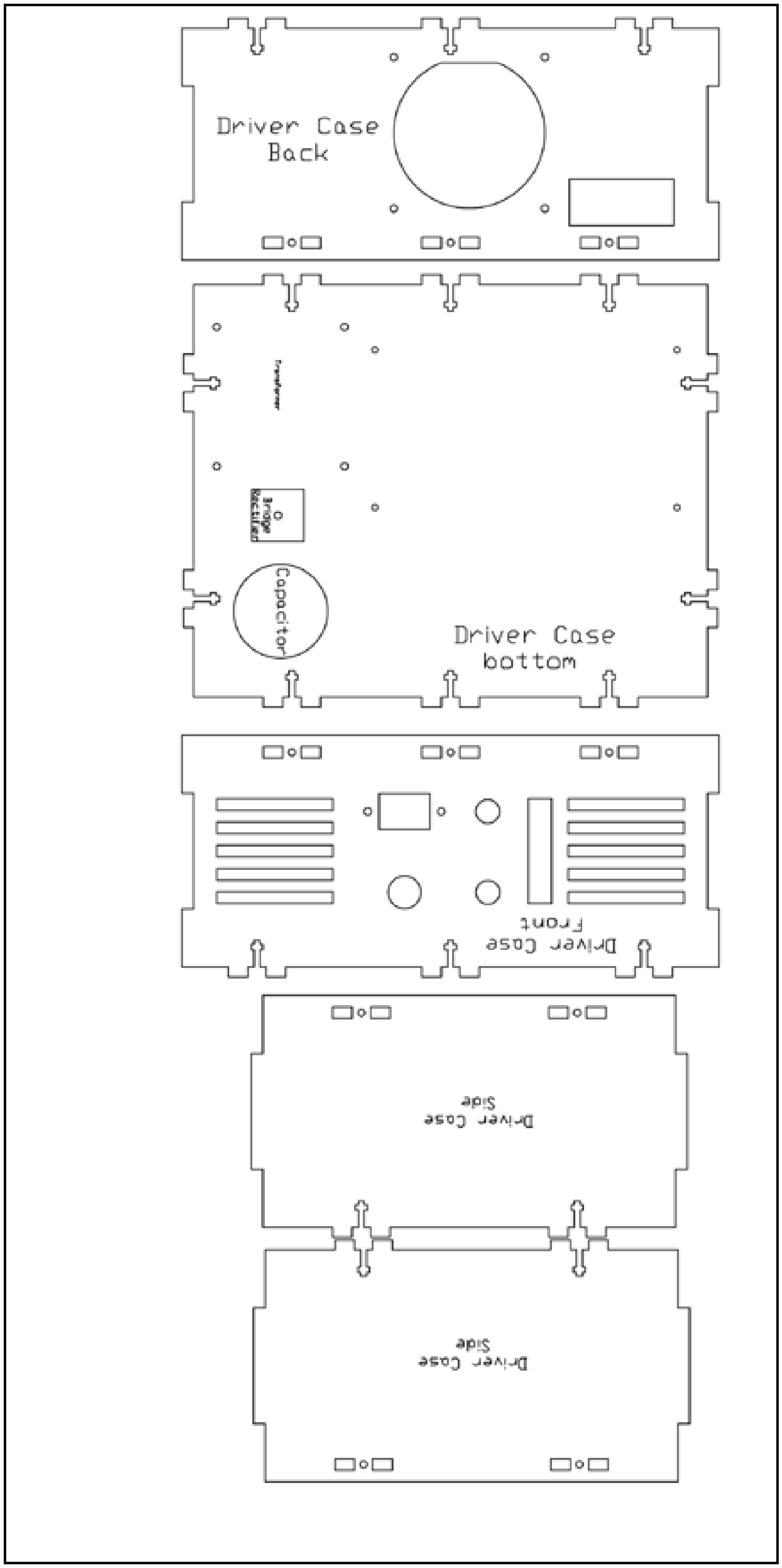


Cut Sheet 7
(Optional Driver Case Parts)

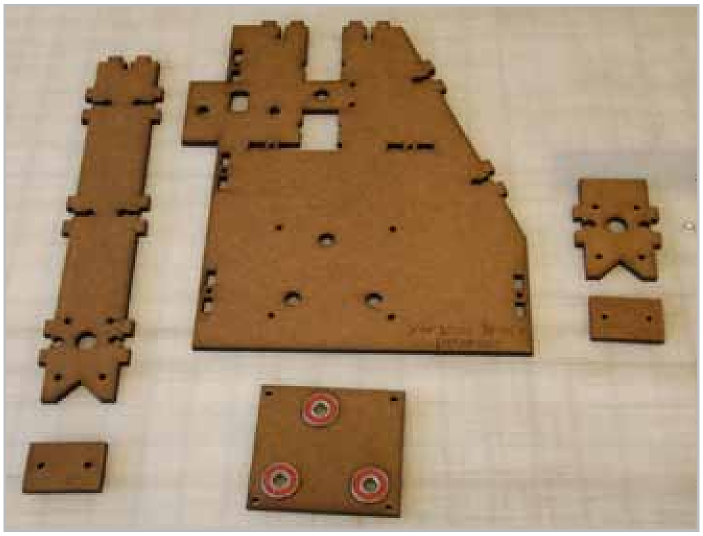
Driver Case Back (1 of 1)vv
Driver Case Bottom (1 of 1)

Driver Case Front (1 of 1)

Driver Case Side (2 of 2)



Vertical Braces: Partial Assembly

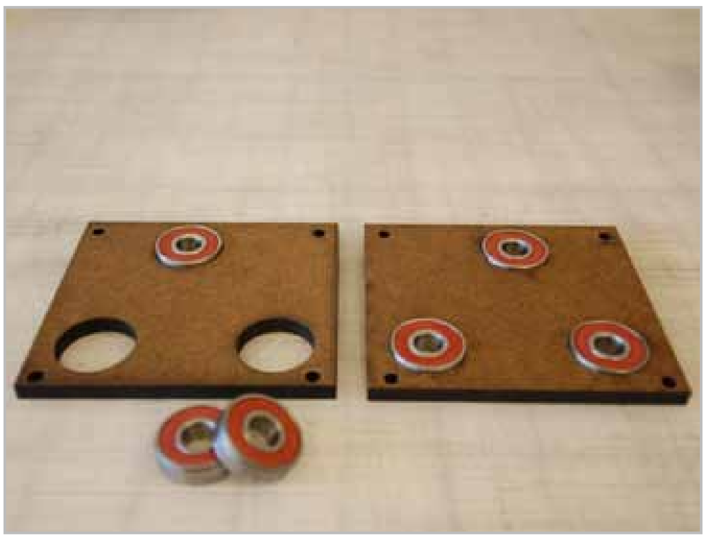


Panel pieces for the following steps:

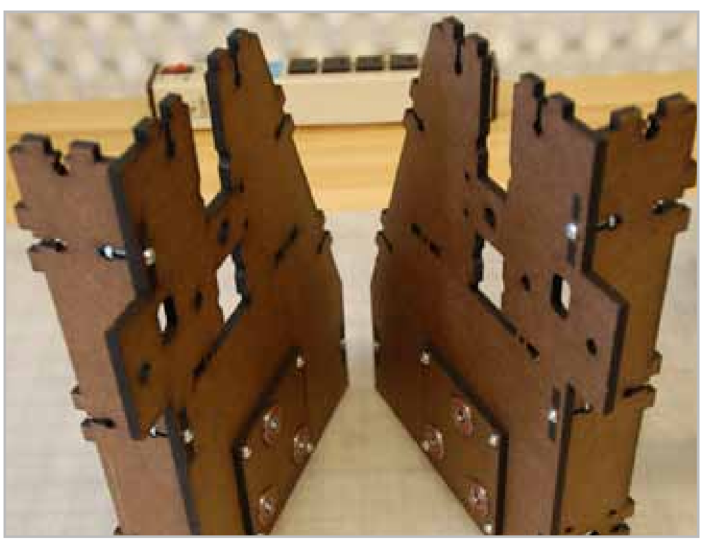
Vertical Brace Interior (2)
Vertical Brace Back (2)
Vertical Brace Front (2)
Y-Belt Bearing Trap (2)

Hardware for the following steps:

Skate Bearings (6)



Insert skate bearings into **Y-Belt Bearing Trap**. Bearings may protrude slightly depending on your material thickness. May need a tap with a mallet!



Attach **Y-Belt Bearing Traps** to **Vertical Brace Interiors**.

Attach **Vertical Brace Back** and **Vertical Brace Front** to **Vertical Brace Interiors**.

Panel pieces for the following steps:

X-beam top (1)
X-beam bottom (1)
X-beam face (2)
X-beam rail brackets (4)

Hardware for the following steps:

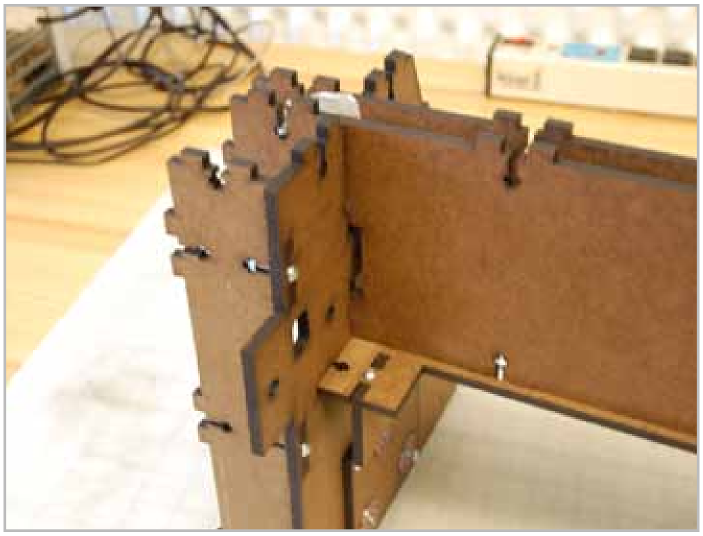
X-rail (2)

Attach **X-beam rail** to **X-beam Top** with **X-beam rail brackets**.

Do the same with **X-beam bottom**.

Attach **X-beam faces** to **X-beam bottom**.

Join Partial X-Beam & Vertical Braces



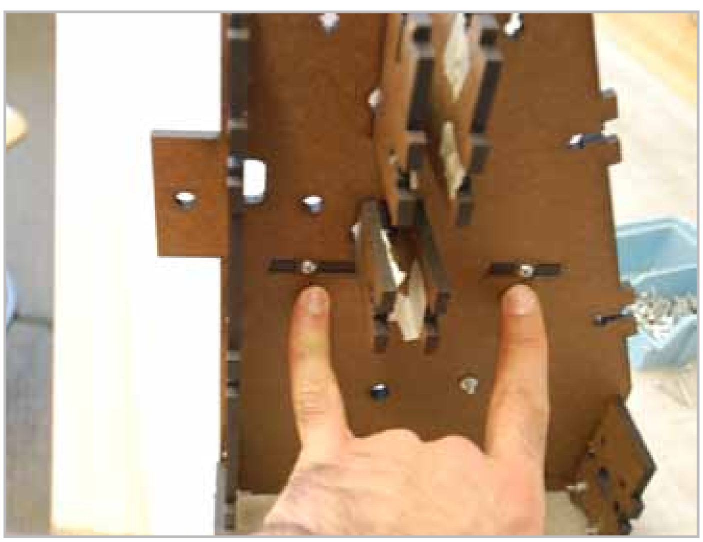
Panel pieces for the following steps:

Partially Assembled X-Beam (1)
Partially Assembled Vertical Braces (2)
Y-Shaft Imperial Bearing Traps (2)

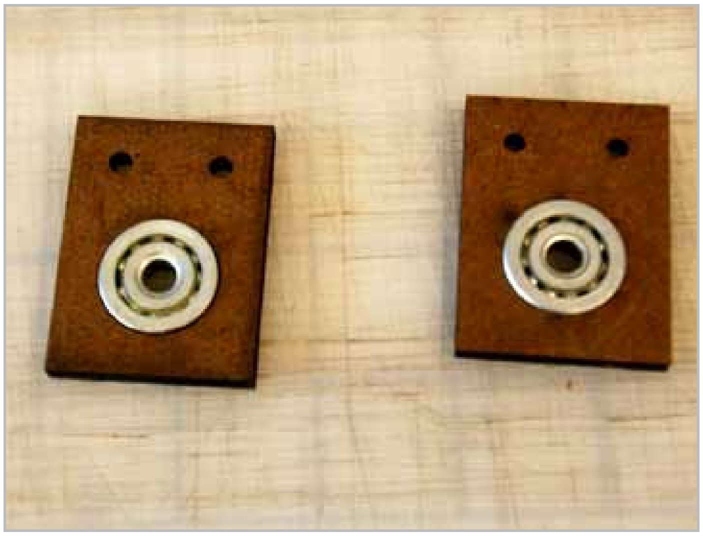
Hardware for the following steps:

Imperial Bearings (2)
Y Drive Shaft (1)
Belt Pulleys (2)

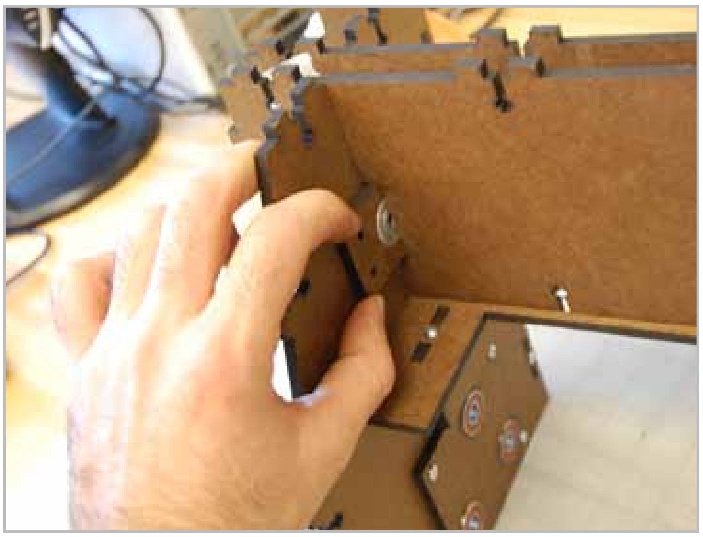
Attach partially assembled **vertical braces** to partially assembled **x-beam**.



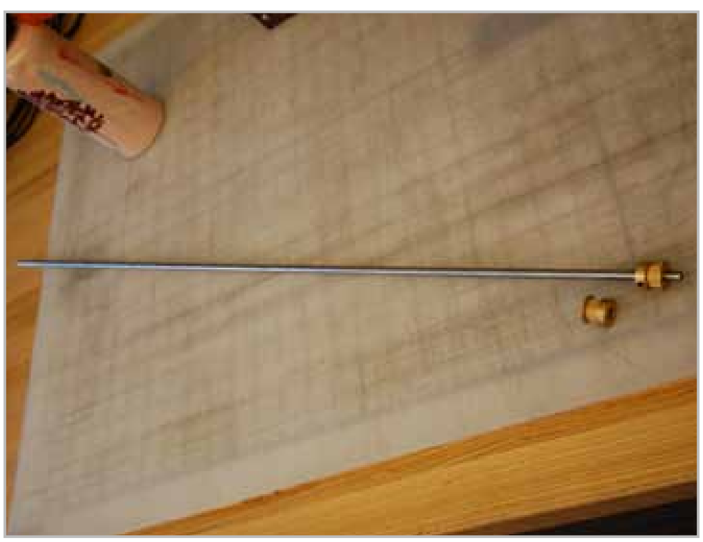
Attach with machine screws through the **vertical brace interiors**.



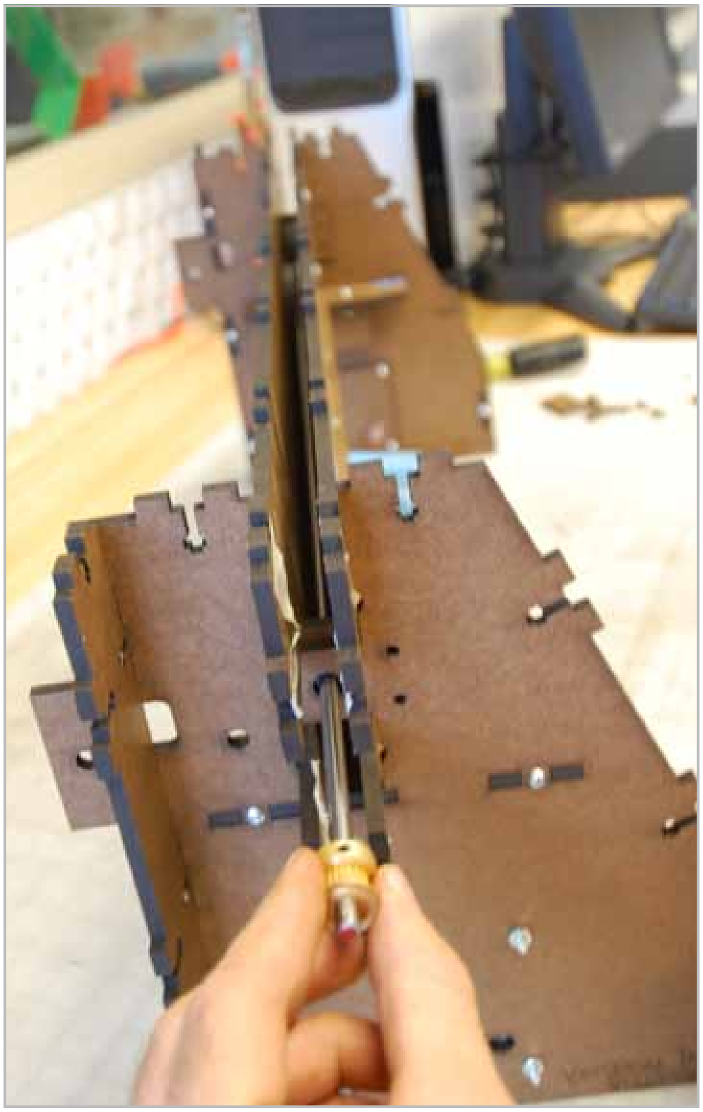
Insert **Imperial bearings** into **Y drive shaft imperial bearing traps**.



Slide each bearing trap into the space between **vertical brace interiors** and **x-beam faces**. Don't screw down the bearing traps yet.

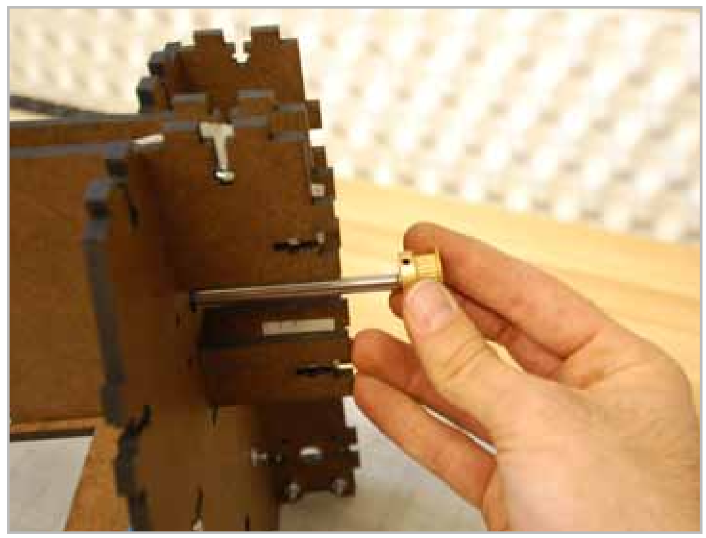


Slide one of the **belt pulleys** onto the end of the **Y drive shaft** with the set screws facing the middle of the shaft. Leave about 1/2" sticking out and gently tighten the set screws.



On the side of the **X-beam** where you want the **Y-motor** to mount*, insert the **Y-shaft** through the **imperial bearing**, through the **x-beam**, and out through the other **imperial bearing**.

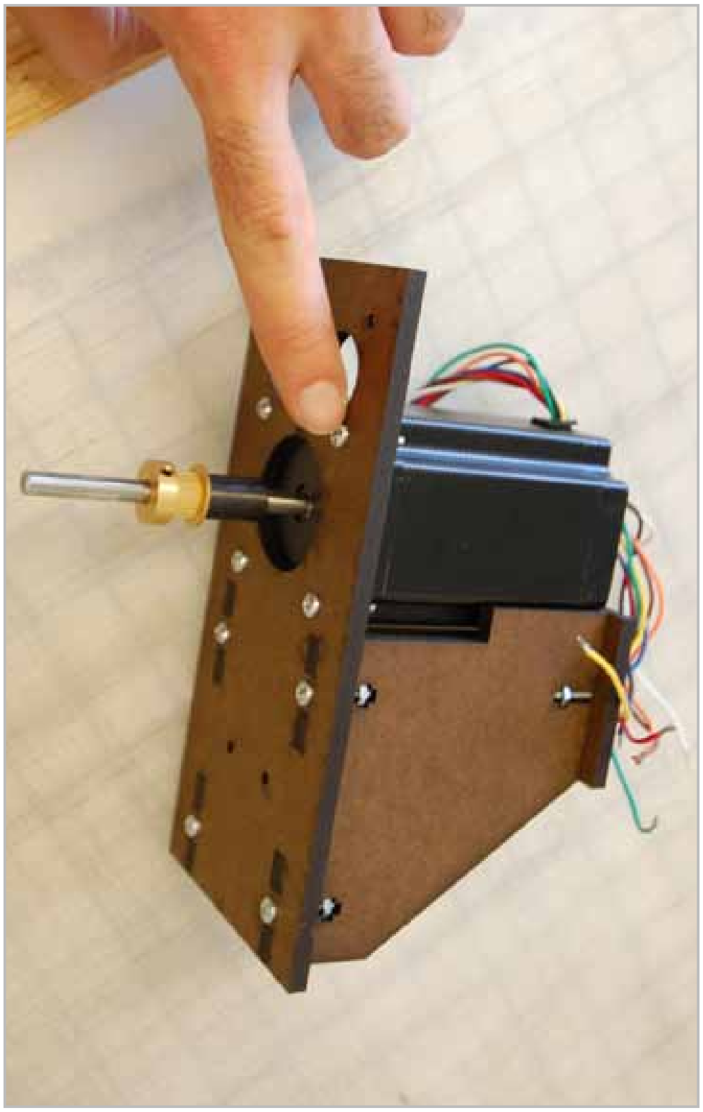
Slide the other **belt pulley** onto the open end of the **Y-shaft**. Don't tighten this one yet.



Tighten screws for **Y drive shaft imperial bearing traps**.

Attach the **X-beam top**.

*The **Y-motor** can mount on either side, and if you change your mind later, the **Y-shaft** can be reversed fairly easily.



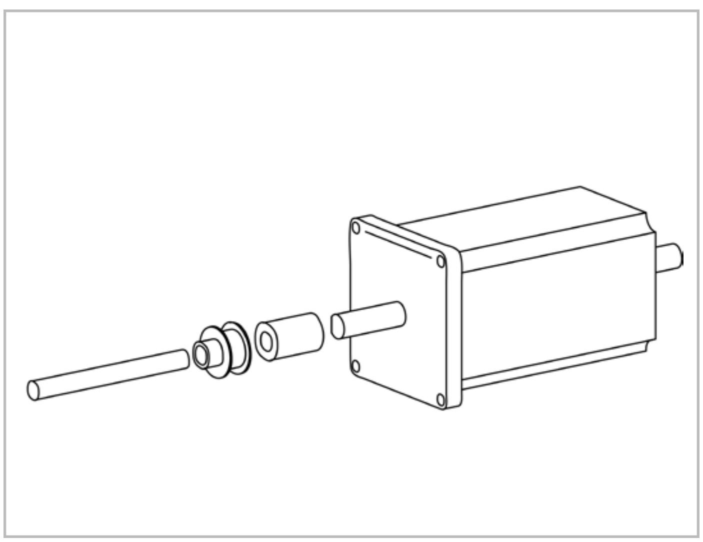
Panel pieces for the following steps:

Motor Mount Bracket (2)
Motor Mount Bracket Cap (1)
X Motor Mount Outer Panel (1)

Hardware for the following steps:

Belt pulley (1)
Shaft coupler (1)
X drive shaft (1)
X Motor (1)

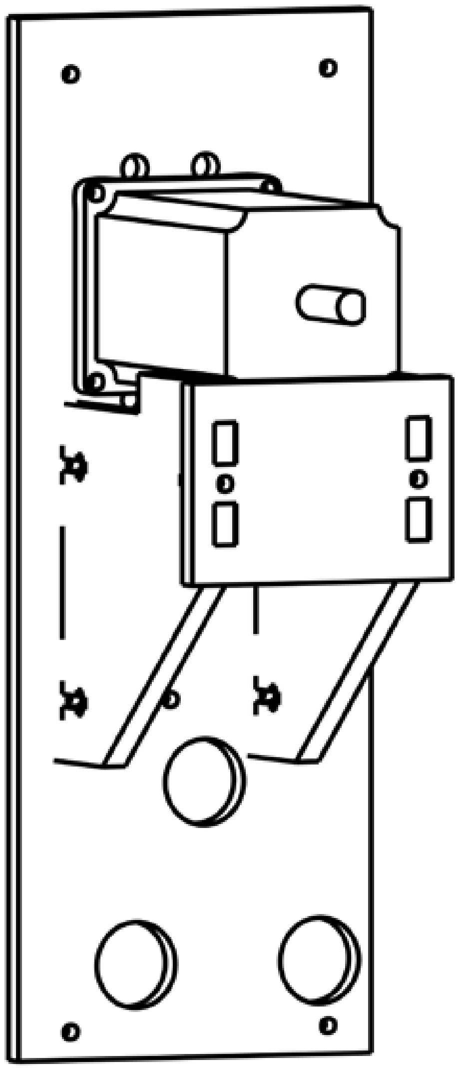
Mount the **X motor** to the **X motor mount outer panel**. Attach both **motor mount brackets** and **motor mount bracket cap**.



Attach the **shaft coupler** to the **X motor's** shaft, then attach the **X drive shaft**.

Slide the **belt pulley** onto the **X drive shaft** with the set screws facing away from the motor.

Y Motor Mount Assembly



Panel pieces for the following steps:

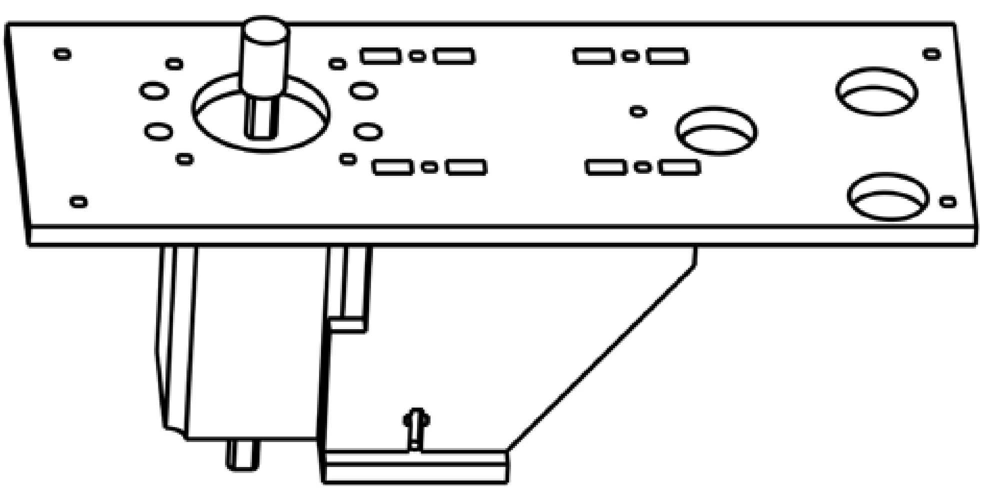
Motor Mount Bracket (2)
Motor Mount Bracket Cap (1)
Y Motor Mount Outer Panel (1)

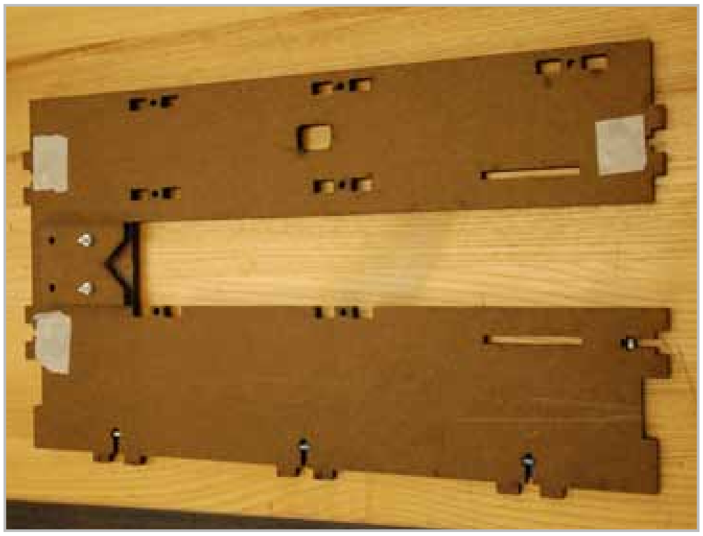
Hardware for the following steps:

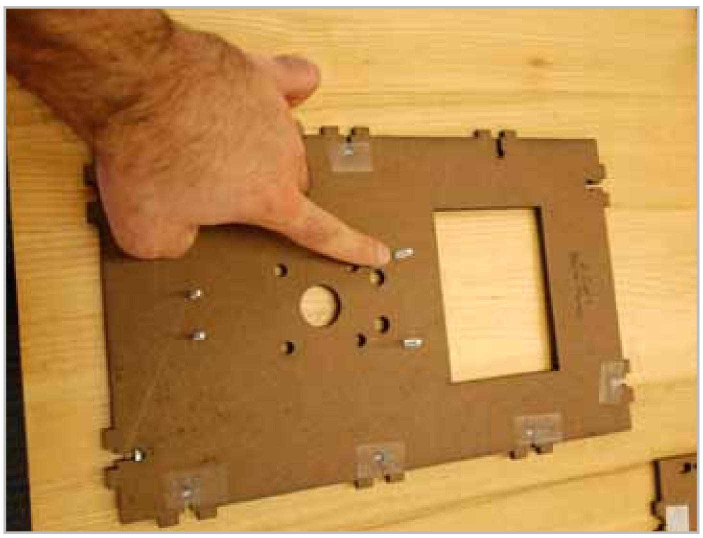
Shaft Coupler (1)
Y Motor (1)

Mount the **Y motor** to the **Y motor mount outer panel**. Attach both **motor mount brackets** and **motor mount bracket cap**.

Attach the **shaft coupler** to the **Y motor's** shaft.







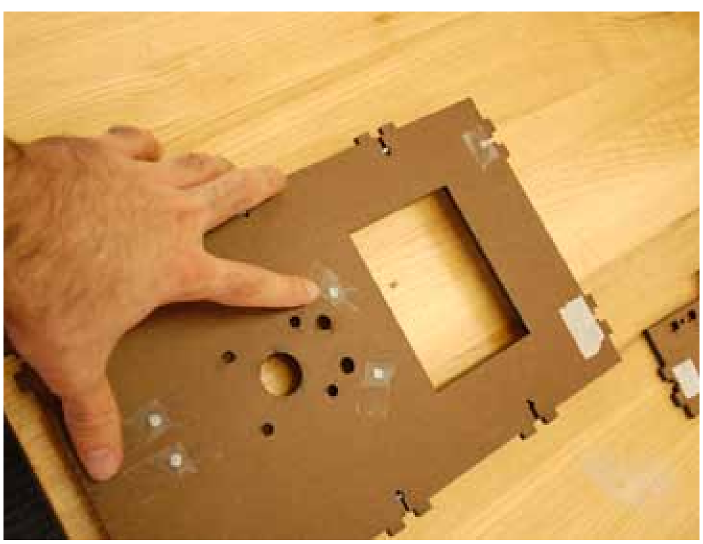
Panel pieces for the following steps:

Z-Cart Side Panel (2)
Z-Cart Back (1)
Z-Cart Interior Bearing Panel (1)
Z-Cart Interior Reinforcement Panel (1)
Z-Cart Top (1)
Z-Rail Upper Bracket (1)

X-Motor Mount Inner Panel (1)
X-Rail Bearing Trap (2)
X-Belt Bearing Trap (1)
X-Rail Bearing Assembly (1)

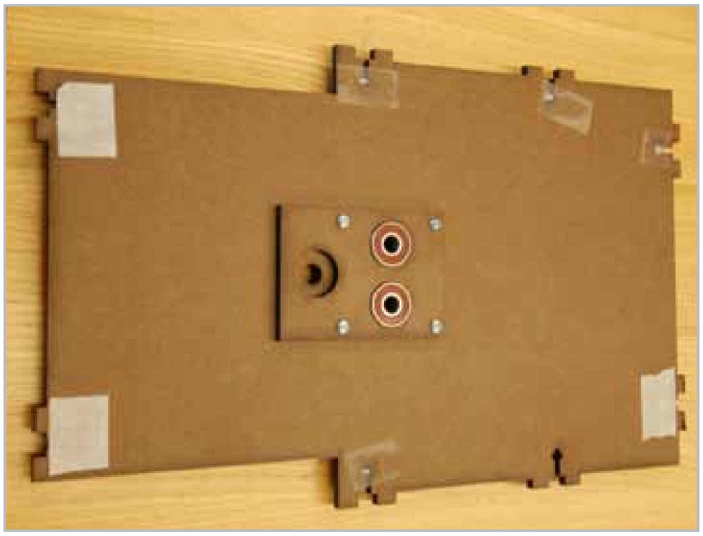
Hardware for the following steps:

X-Belt (1) 4' Section
Imperial Bearing (1)
Skate Bearing (2)
Shaft Collar (1)



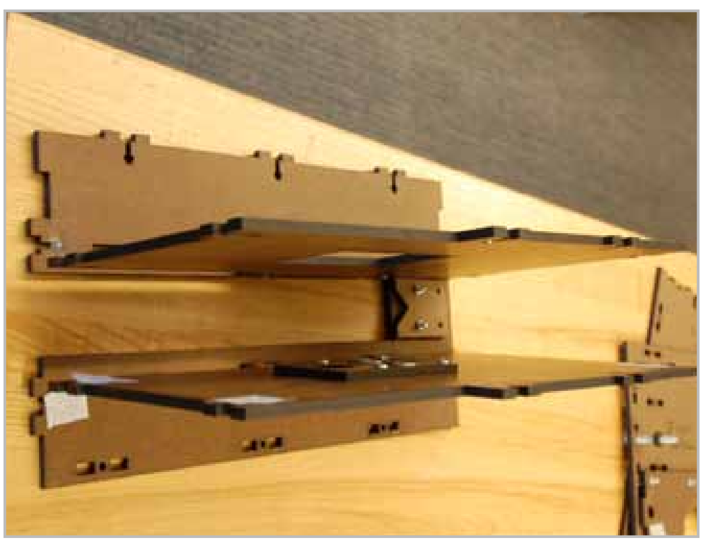
Attach an **X-rail bearing trap** to each **Z-cart side panel**. Use all four screws!

Insert 1" machine screws through the four small holes in the **Z-cart back**. Tape over the heads to keep them in place.



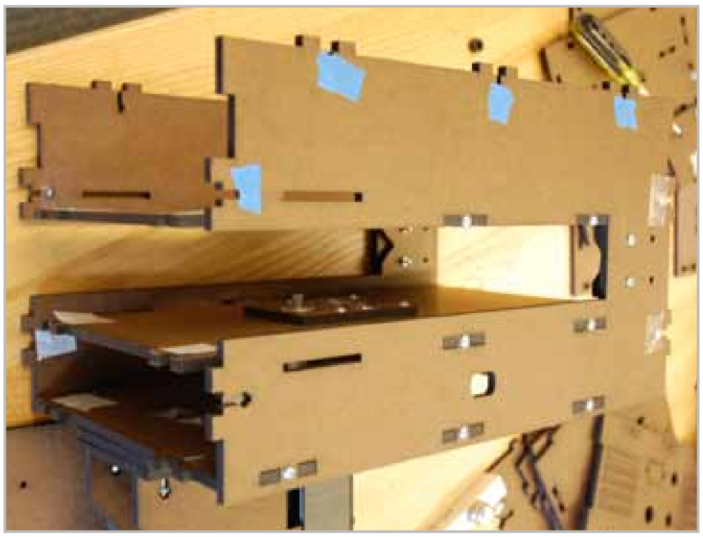
Insert two **skate bearings** into the top holes of the **X-belt bearing trap**. Insert the **imperial bearing** into the bottom hole of the **X-belt bearing trap**. Attach the **X-belt bearing trap** to the **Z-cart interior bearing panel**.

Attach the **Z-cart interior reinforcement panel** to one of the **Z-cart sides**.



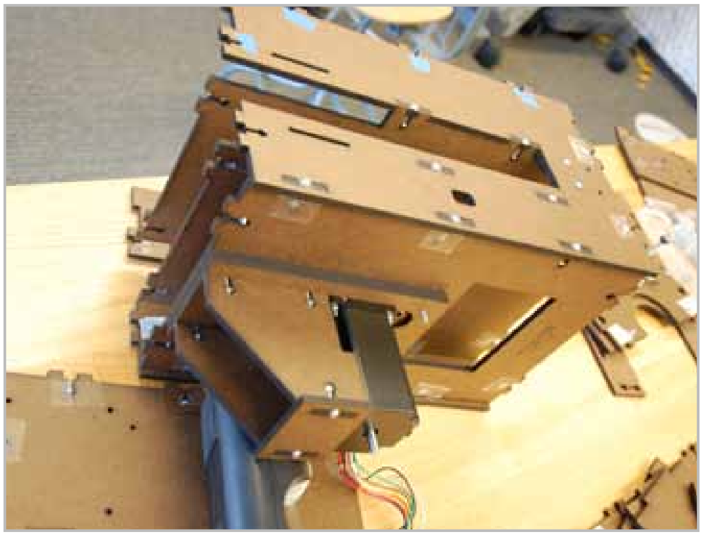
Attach the **Z-cart interior bearing panel** to the **Z-cart side**.

Attach the **Z-cart back** to the **Z-cart side**.



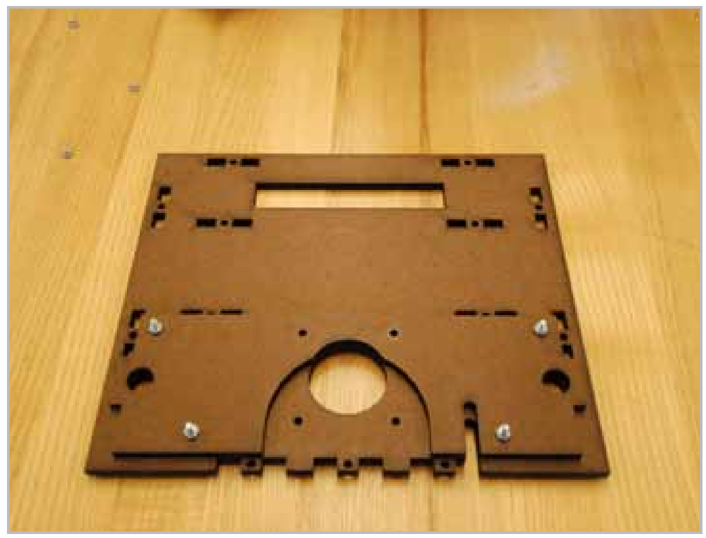
Attach the other **Z-cart side panel**.

Slide the **X-motor mount inner panel** onto the **Z-cart back**, but don't attach with nuts yet.



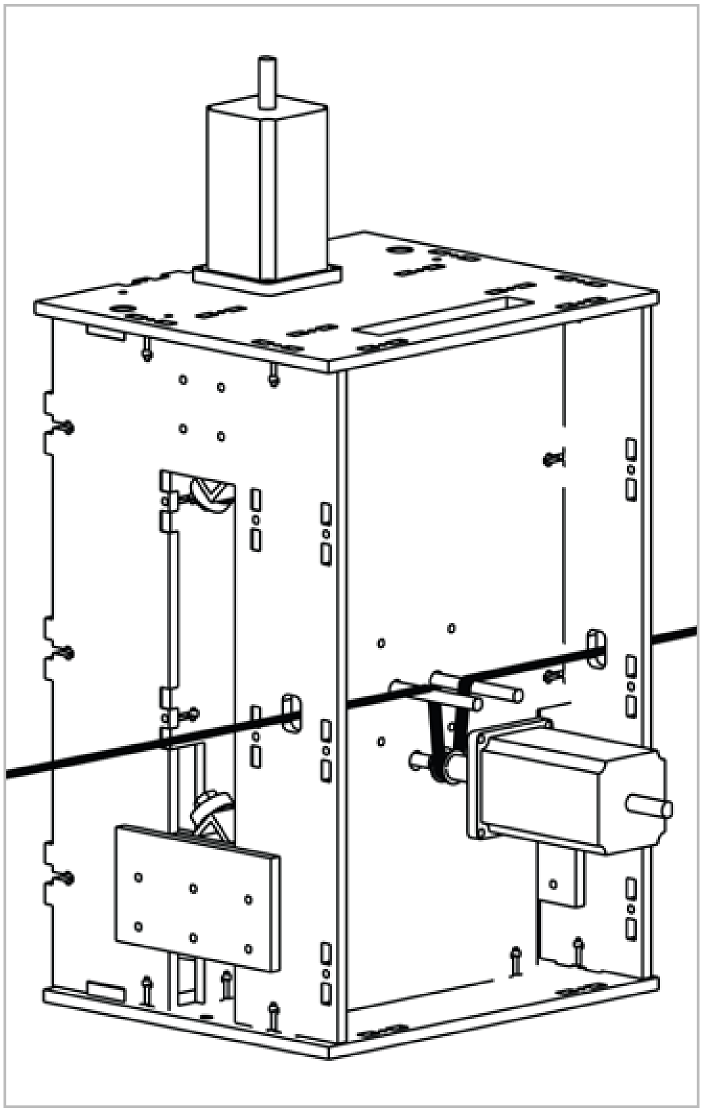
Attach the **X-motor mount**, sliding the **X-drive shaft** through the **imperial bearing**.

Attach the **shaft collar** to the end of the **X-drive shaft**. Tighten the set screw with an allen wrench.



Attach the **Z-rail upper bracket** to the **Z-rail top**. Don't put machine screws in the four small holes surrounding the large hole -- those are for the **Z-motor**.

Attach the **Z-cart top** to the rest of the **Z-cart assembly**.

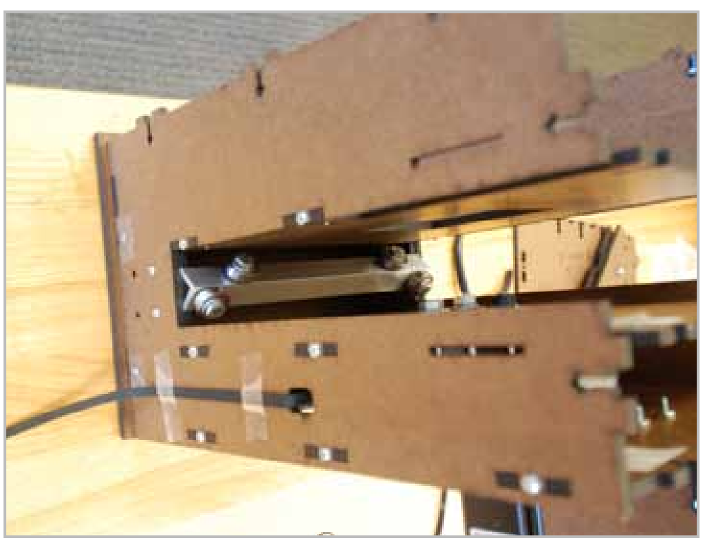


Right-side up view from back of Z-cart (Z-cart back panel hidden for clarity).

Orient the **X-belt** with the teeth facing up. Thread the **X-belt** through the rectangular hole in one of the **Z-cart** sides, under the **X drive shaft pulley**, and out the other **Z-cart** side.

Flip the **Z-cart** upside-down. From each side, push an extra length of **X-belt** inside the **Z-cart**, then insert the bearing bolts through both sides of the **X-belt bearing trap**. The ends of the bolts should be coming out the back of the **Z-cart** above the **X-motor assembly**. Secure the bolts with nuts above the **X-shaft**.

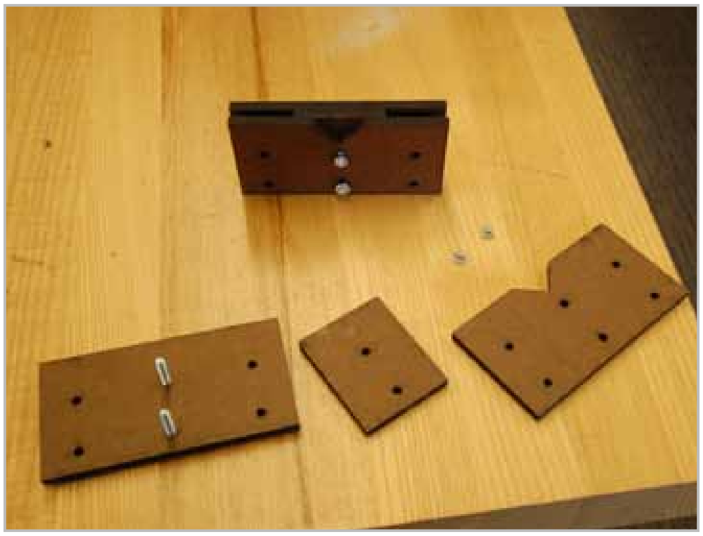
View from bottom.



Pull the **X-belt** taut, then tape the ends to the sides of the **Z-cart** to prevent the belt from slipping off the pulley.

Insert one of the **X-rail bearing assemblies** into the **X-rail bearing traps**.

Mount Z-Cart to X-Beam

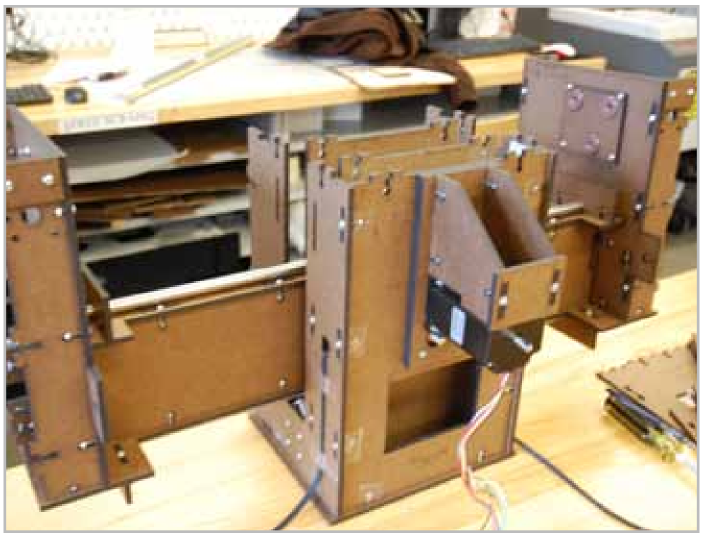


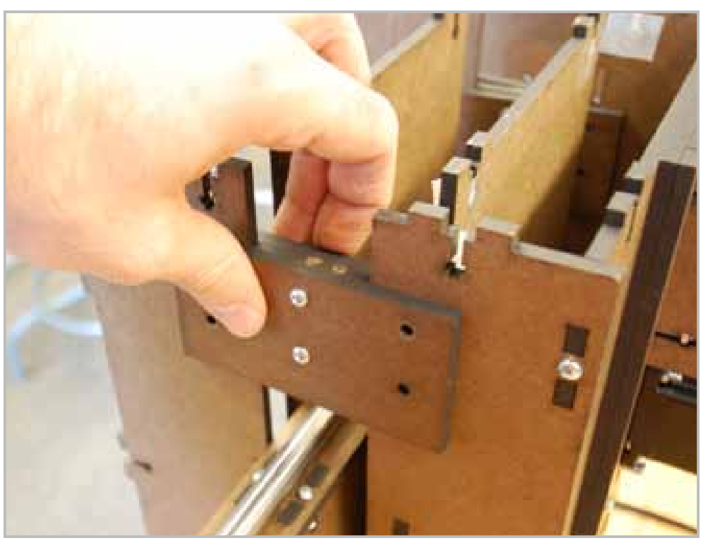
Panel pieces for the following steps:

Z-Cart Bottom (1)
Z-Rail Lower Bracket (1)
X-Rail Bearing Tensioner Inner Panel (2)
X-Rail Bearing Tens. Middle Panel (2)
X-Rail Bearing Tensioner Outer Panel (2)
Partially Assembled Z-Cart
X-Beam/Vertical Brace Assembly

Hardware for the following steps:

X-Rail Bearing Assembly (1)
2" 1/4-20 Bolts (2)
1/4-20 Nuts (2)

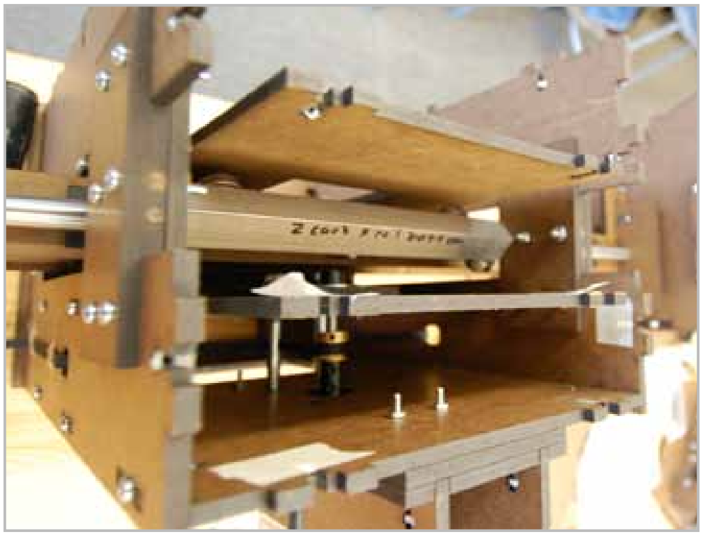




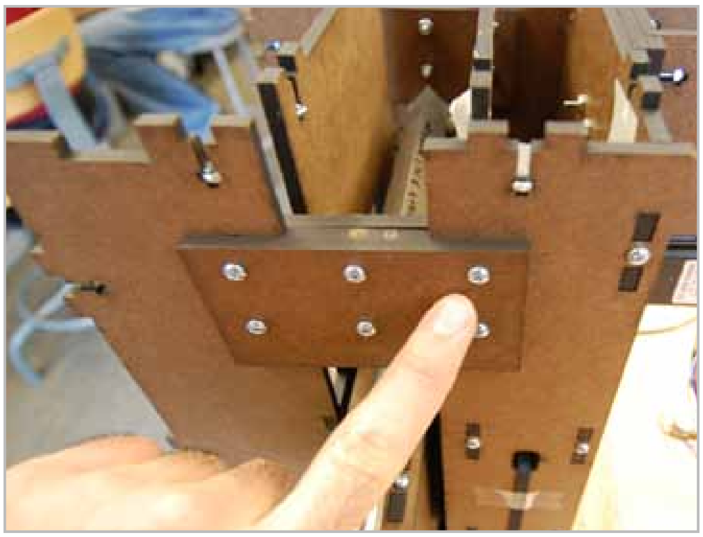
Loosely bolt together the **X-rail bearing tensioner inner**, **middle**, and **outer panels**.

With the **Z-cart** still upside-down, flip the partially assembled **X-beam/vertical brace assembly** upside down, and slide it into the **Z-cart**. The straight backs of the **vertical braces** should face the back of the **Z-cart**.

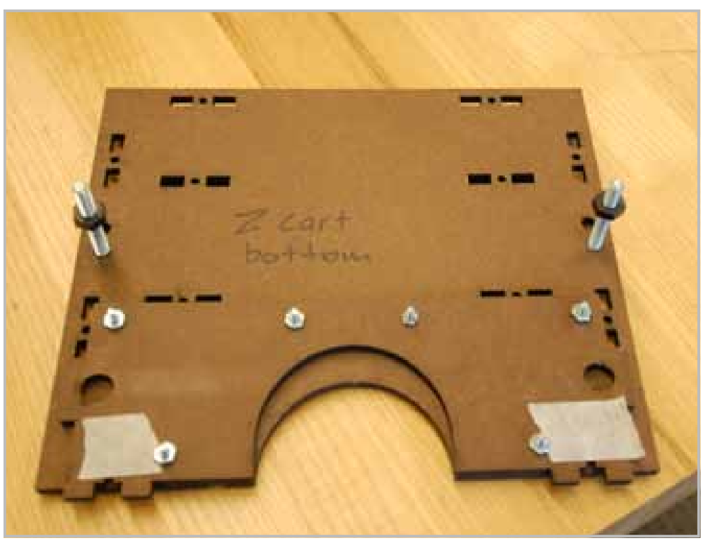
Loosely insert the **X-rail bearing tensioners** into both sides of the inverted **Z-cart**.



Place the second **X-rail bearing** on the bottom **X-rail**. Loosely push the **X-rail bearing tensioners** down onto the ends of the **X-rail bearing**.



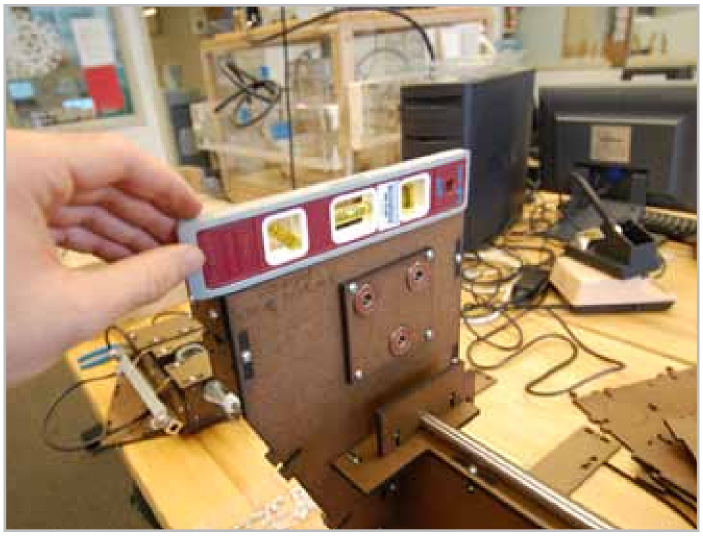
Loosely attach 1” machine screws through the outer holes of the **X-rail bearing tensioners**.



Attach the **Z-rail lower bracket** to the **Z-cart bottom**. Loosely thread 1/4-20 bolts up through the bottom of the panel.

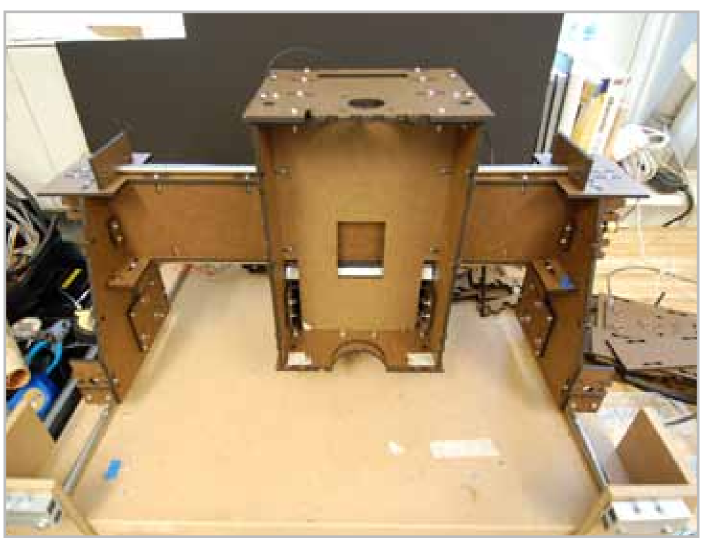
Attach the **Z-cart bottom** to the rest of the **Z-cart assembly**. The **Z-rail lower bracket** should face the interior of the **Z-cart assembly**.

Mount Z-Cart to X-Beam

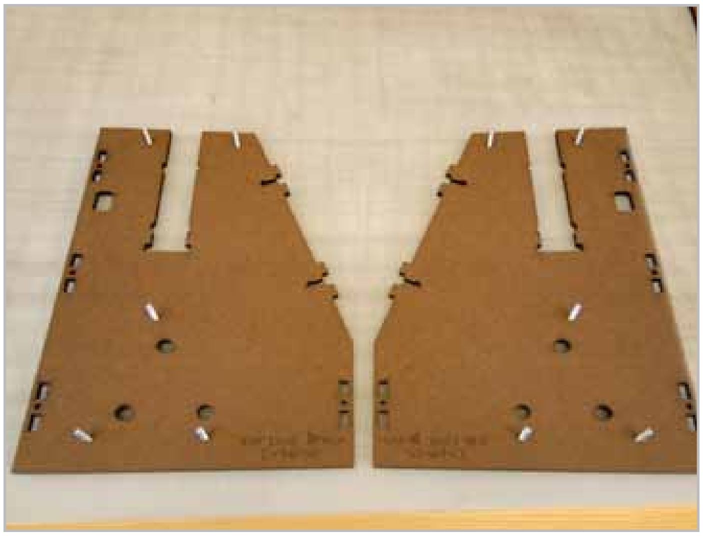


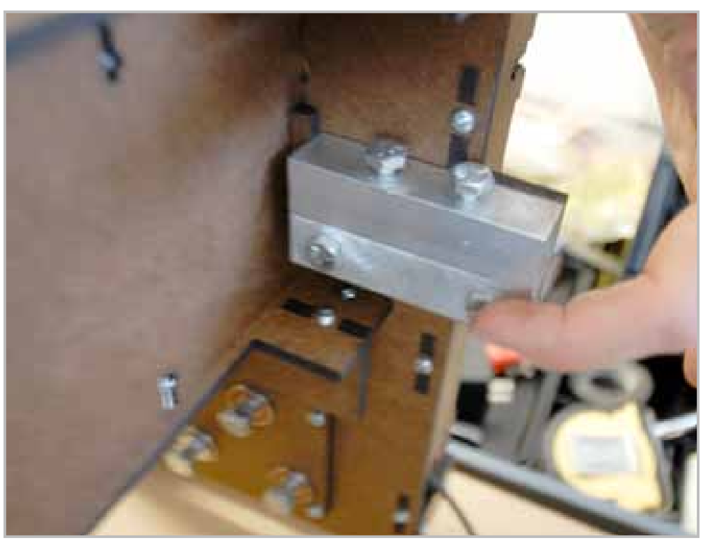
Check the **X-beam/Vertical brace** for level.

Use the 1/4-20 bolts on the **Z-cart bottom** to help adjust seating of the **X-beam**. Once level, tighten all the bolts on both.



Flip the whole assembly right-side up.





Panel pieces for the following steps:

Vertical Brace Exterior (2)
Vertical Brace Access Panel (2)
Y-Motor Mount Inner Panel (2)
Y-Motor Assembly (1)

Hardware for the following steps:

Y-Belt (2) 4' Sections
X-Belt Clamp (2)
Skate Bearings (6)
Imperial Bearings (1)
Shaft Collar (2)
2" 1/4-20 Bolts (4)
1/4-20 Nuts (4)

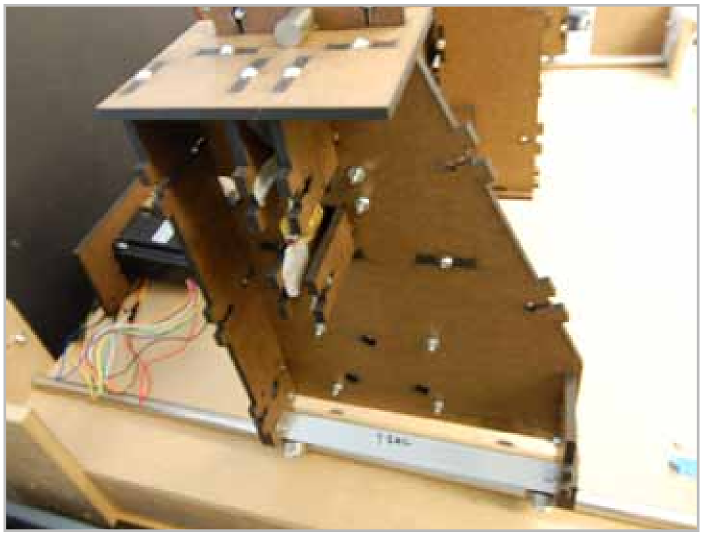
Insert 1" machine screws through the five small holes in each **vertical brace exterior**. Tape over the heads of the bolts to keep them in place.

Insert **skate bearings** in the three lower holes of each **Y-motor mount inner panel**.

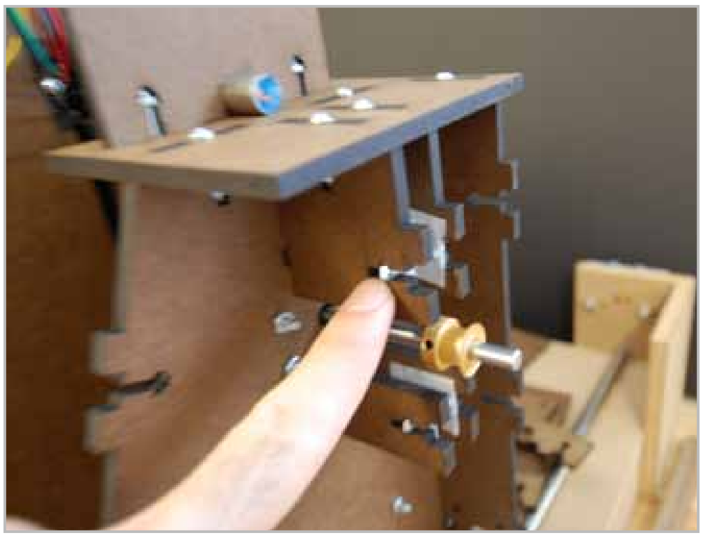
Insert an **imperial bearing** into the upper hole of just one of the **Y-motor mount inner panels**.

Attach **X-belt clamps** to each **vertical brace interior**. Secure with **1/4-20 bolts**. When correctly attached, the tensioners both face the **Z-cart**.

Finish Vertical Brace Assembly

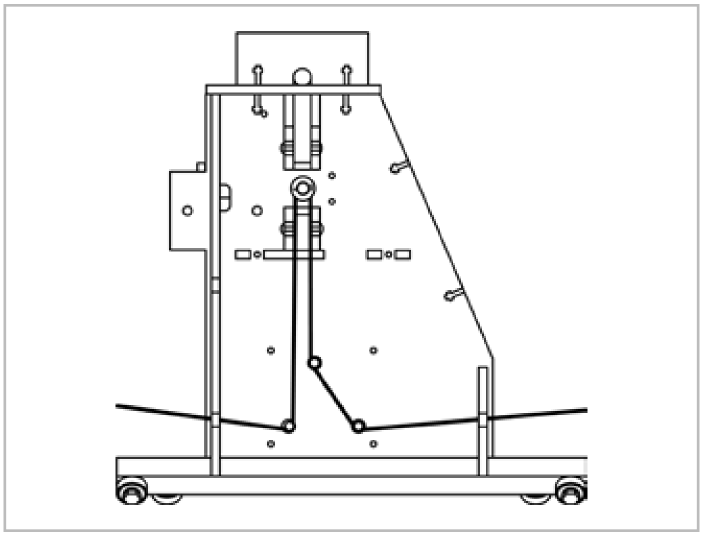


Insert the **Y-rail bearing assemblies** into the bottom of the vertical braces (assemblies pictured are shorter than they should be).



Use tape to secure machine screw nuts into the four tabs on both ends of each **X-beam face**.

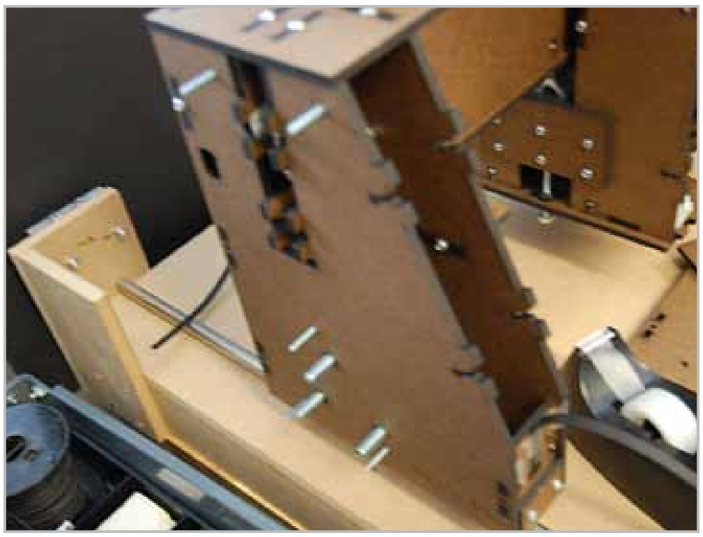
On the each side of the **X-beam/Vertical brace** assembly, insert three bearing bolts through the **Y-belt bearing trap**.



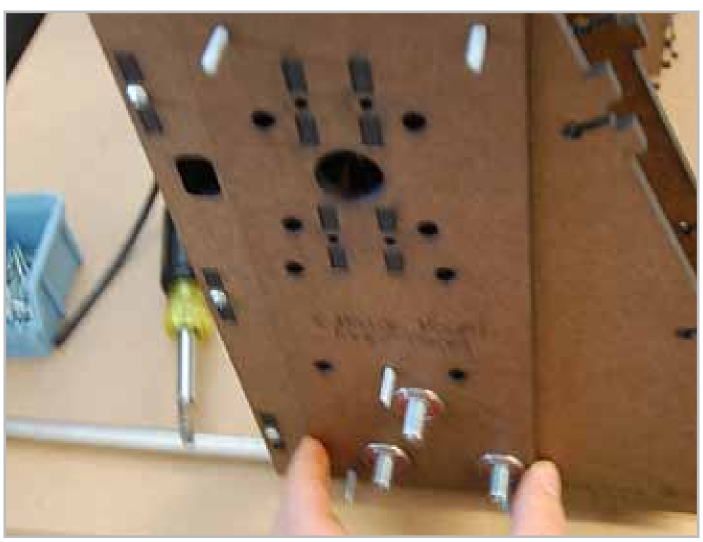
Thread one of the **Y-belts** through the hole in the **vertical brace back**, around the pulley and bolts, then out the hole in the **vertical brace front**.

Tape the ends of the **Y-belt** to the **vertical brace front** and back to prevent it slipping off the pulley.

Do this for both vertical brace assemblies.

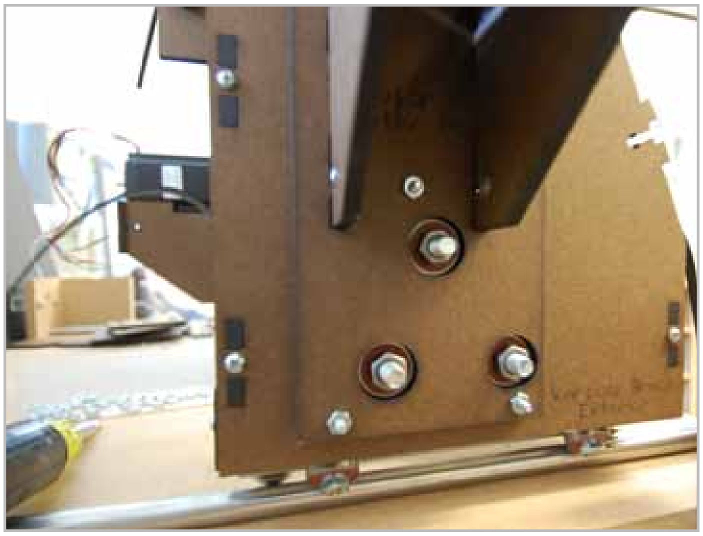


Attach the **vertical brace exterior** to the side where the **Y-motor will mount**.

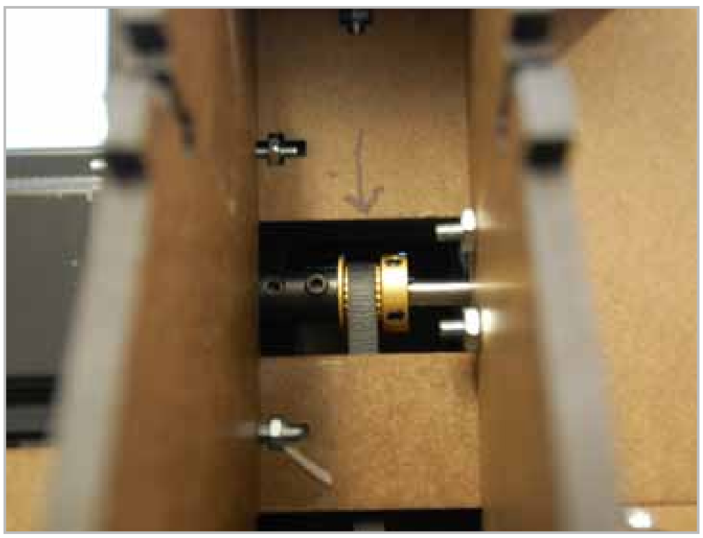


Attach the **Y-motor mount inner panel** without the imperial bearing. Attach machine screws gently, being sure the tabs of the **X-beam faces** don't stick out past the face of the **Y-motor mount inner panel**.

Finish Vertical Brace Assembly

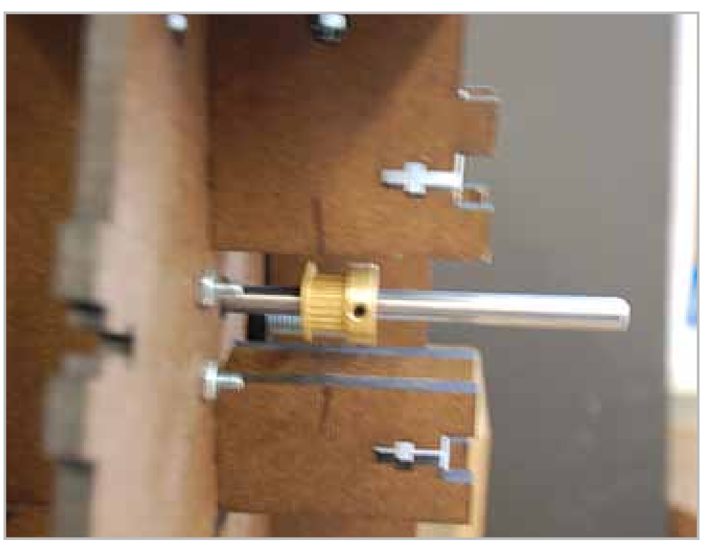


Attach the **Y-motor assembly**, and attach nuts and washers to the **Y-bearing bolts**.

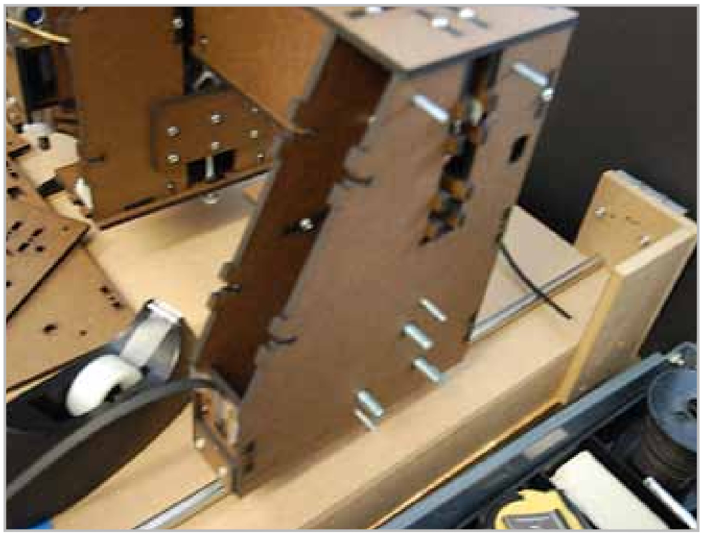


Push the **Y-shaft** into the **Y-motor's shaft coupler**. The center of the **belt pulley** should be aligned with the vertical marks on the **X-beam face** (adjust it as needed).

Once aligned, tighten the **shaft coupler** and **belt pulley** set screws.



On the side of the **X-beam** opposite the **Y-motor**, align the **belt pulley** so that the center of the teeth line up with the vertical marks on the **X-beam face**. Tighten the set screws.



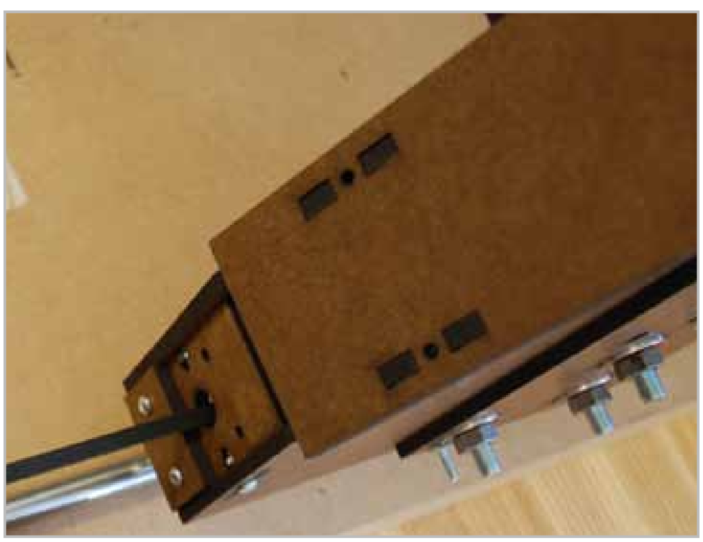
Attach the other **vertical brace exterior** to the side opposite the **Y-motor**.

Slide a **shaft collar** loosely onto the protruding end of the **Y-shaft**.

Slide on the **Y-motor mount inner panel** with the **imperial bearing**. Take it back off, and tighten down the **shaft collar**.

Replace the **Y-motor mount inner panel** and attach with machine screws.

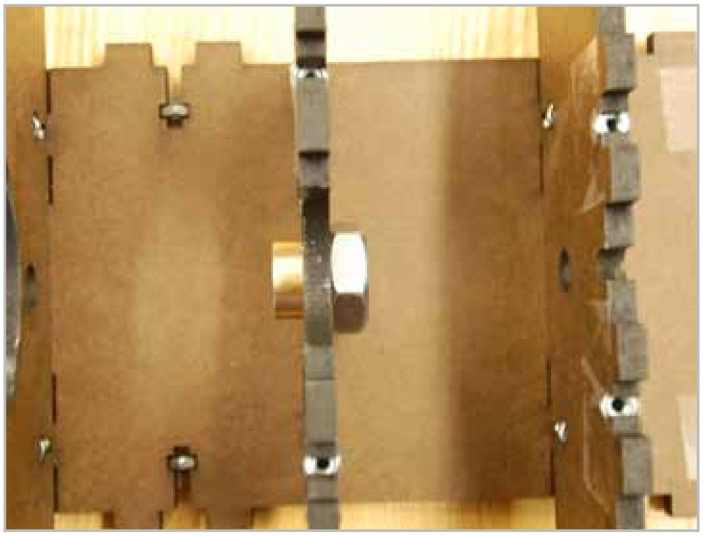
Place another **shaft collar** on the end of the **Y-shaft** to trap the **imperial bearing** in place.



Attach the **vertical brace access panels** to the open fronts of each **vertical brace**.

The panels are cut with bolt holes that allow for optional attachment of a cross-bar for added gantry stability. We used a 1” x 29 7/8” piece of 1/2” plywood.

Z-Sled Assembly

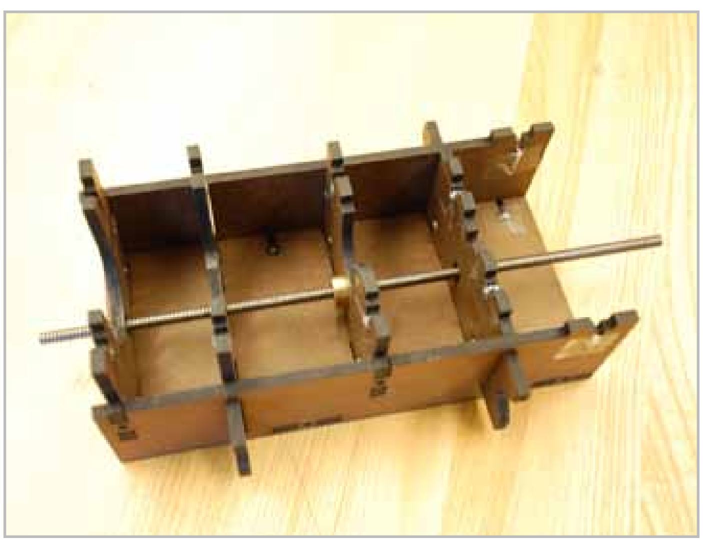


Panel pieces for the following steps:

Z-Sled Back (1)
Z-Sled Front (1)
Z-Sled Side (2)
Z-Rail Bearing Trap (1)
Lower Dremel Brace (1)
Middle Dremel Brace (1)
Upper Dremel Brace (1)
Lower Dremel Brace Cap (1)
Upper Dremel Brace Cap (1)

Hardware for the following steps:

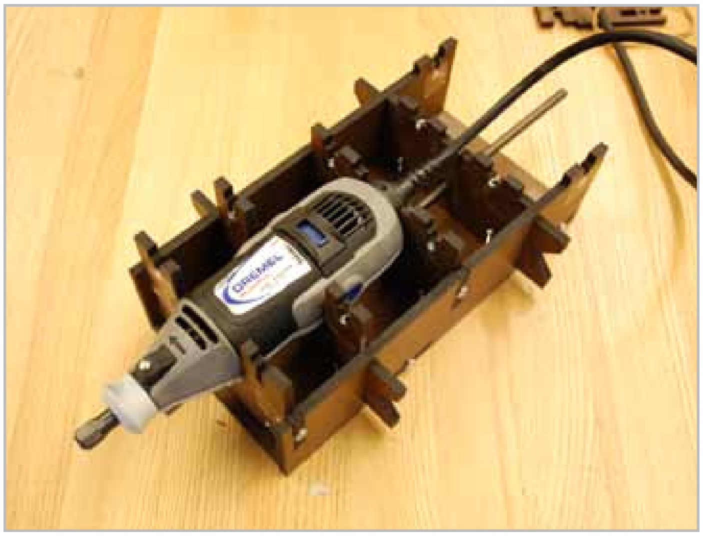
Z-Rail Bearings (2)
Acme Nut (1)
Acme Flange Nut (1)
Acme Rod (1)
Dremel Tool



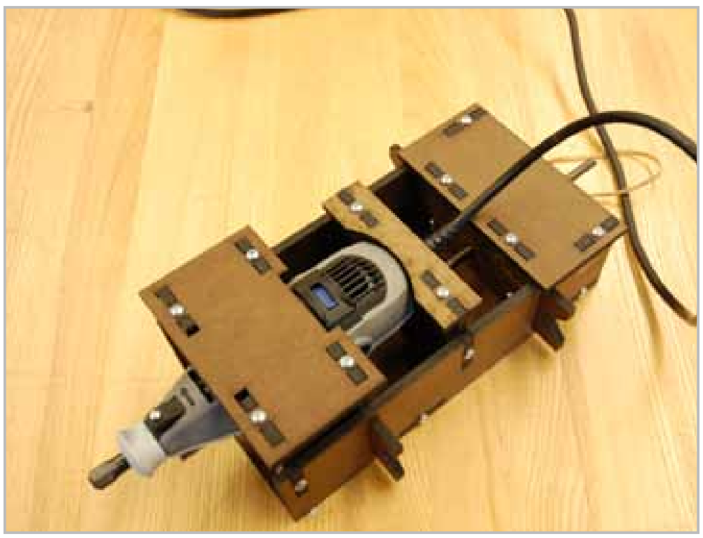
Attach the **acme nut** to the **upper dremel brace** with the **flange nut**.

Attach the **lower dremel brace**, **middle dremel brace**, **upper dremel brace** and **Z-rail bearing trap** to the **Z-sled back**.

Thread the **acme rod** through the **acme nut assembly**.

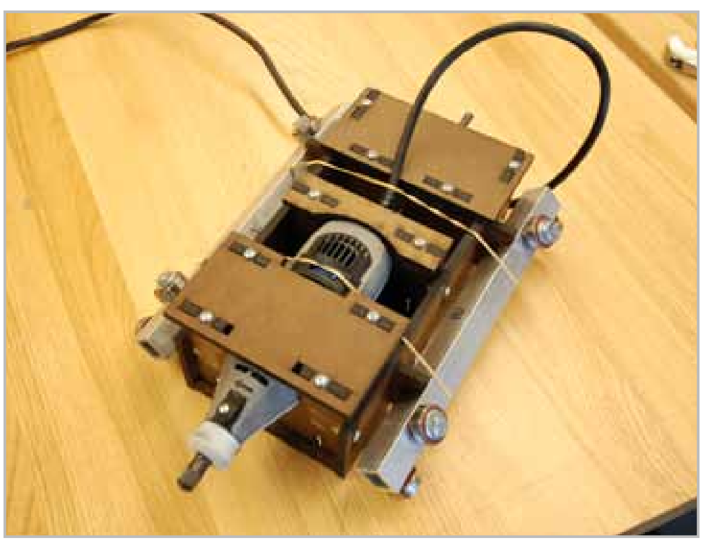


Insert the **dremel tool** into the **Z-sled**.



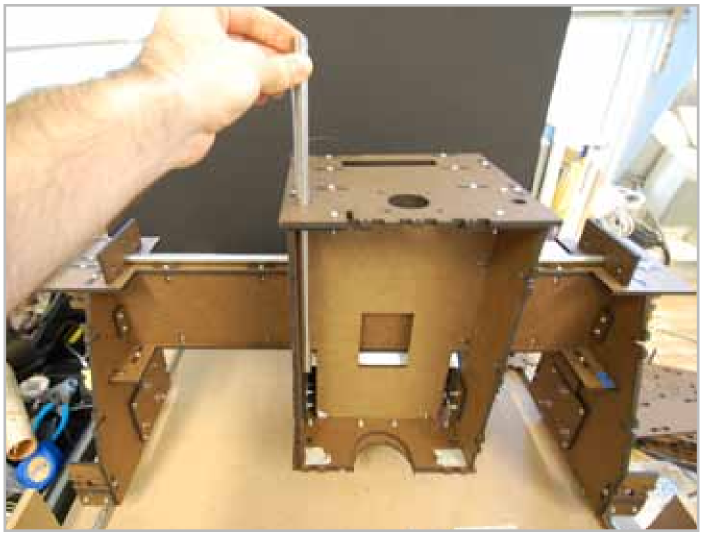
Attach the **lower dremel brace cap**, **upper dremel brace cap** and **Z-sled front** to the **Z-sled assembly**.

Run the cord of the **dremel tool** outside the **Z-sled**.



Use rubber bands to temporarily attach the **Z-rail bearings** to the **Z-sled**.

Join Z-Sled and Z-Cart

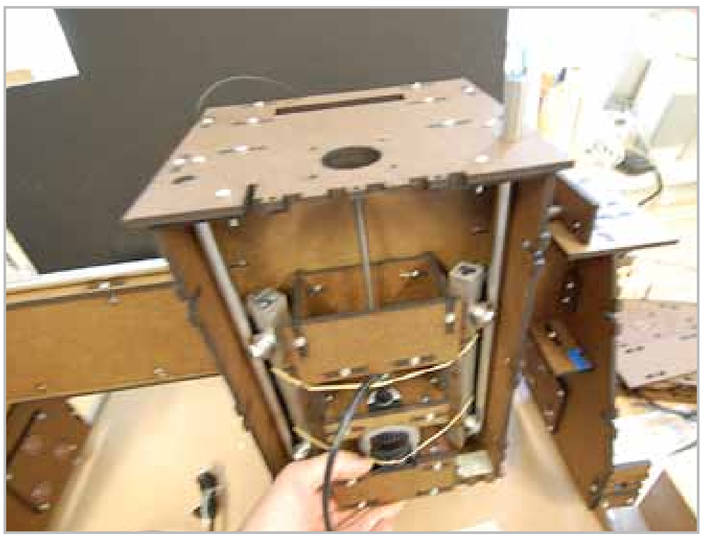


Panel pieces for the following steps:

Z-Cart Face (1)

Hardware for the following steps:

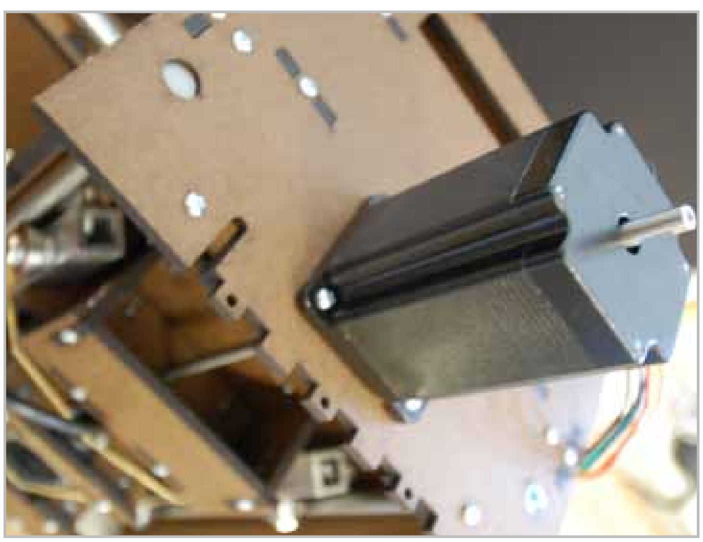
Z-Cart/X-Beam/Vertical Brace Assembly
Z-Sled Assembly
Shaft Coupler (1)
Z-Rail (2)
Z-Motor



Drop one of the **Z-rails** through the brace opening in the top of the **Z-cart** and seat it in the brace at the bottom.

Align the **Z-rail bearings** with the inserted **Z-rail**, then drop the other **Z-rail** into the **Z-cart**. Make sure the **Z-rail bearings** are aligned with both **Z-rails**.

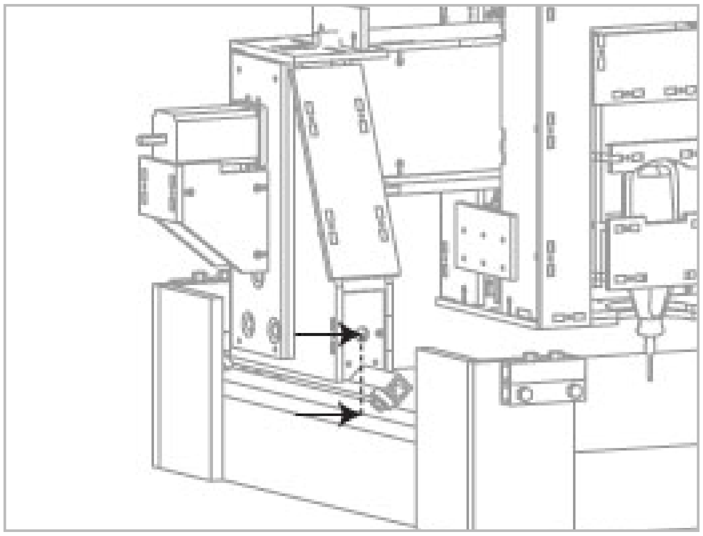
Seat the second **Z-rail** into the brace at the bottom of the Z-cart. It may take a few careful taps with a mallet.



Attach a **shaft coupler** to the **Z-motor's** shaft. Mount the **Z-motor** onto the top of the **Z-cart**.

Raise the **Z-sled** until the top of the **acme rod** inserts into the open end of the **shaft coupler**. Tighten the **shaft coupler** onto the **acme rod**.

Attach the **Z-cart face**, again being sure to route the **dremel tool's** cable out the front of the **Z-cart**.



Panel pieces for the following steps:

Y-Rail Brackets (4)

MDF pieces for the following steps:

Cutting Bed Assembly

Hardware for the following steps:

Y-Rails (2)
Y-Belt Clamps (4)

Temporarily place the **Y-rails** and gantry assembly on the cutting bed.

Measure the height of the **Y-belt** coming out of the **vertical brace front panel**. Mark the height on each **Y-belt wall panel**, then remove the gantry assembly.

Use the **Y-rail brackets** to position and secure the **Y-rails** on either side of the **cutting bed assembly**. The edge of each **Y-rail bracket** should line up with the inner edge of each **Y-belt wall panel assembly**.

On each **Y-belt wall panel assembly**, drill a 1/2" belt-hole above the center of the **Y-rail** at the height previously marked.

Drill 1/4" mounting holes and mount the **Y-belt clamps** to the front and back of each **Y-belt wall panel assembly**. Position clamps so the **Y-belt** will pass between the square tubes.

Hardware for the following steps:

Gantry Assembly
Cutting Bed Assembly

Mount the **gantry assembly** on the **Y-rails**. Make sure the bearings are making contact on both sides.

Being careful not to unseat the belt from the pulley, untape each **Y-belt** from the back of each **vertical brace** and thread it through the back **Y-belt wall panel assembly**. Use a wrench to tighten the belt into the **Y-Belt tensioner**.

Do the same for the front **Y-belt tensioner**, and the two **X-belt tensioners**.

We strongly recommend following the directions included with the HobbyCNC PRO driver board for electronics assembly. Some particulars to pay attention to:

Safety
Read and follow the instructions for assembling the board. The driver board carries a lot of current and should always be treated carefully. Be especially cautious with the large capacitor, as it can hold a charge even after the power is disconnected.

Board Adjustment
Before connecting the motors, you'll need to set a potentiometer for each axis to ensure the correct amperage and voltage are served to each motor. For the motors we used, we had to make sure that idle current reduction was disabled before we adjusted our board. Again, read the instructions.

Jumper Position/Microstepping
You'll also control microstepping[27] for each motor by setting jumpers to connect different pins together on the board. In a nutshell, microstepping sets the balance between torque and resolution of a stepper motor. Less microstepping means more torque but a coarser resolution, and requires less of the controller computer's available signal. More microstepping means less torque but finer resolution, and requires more of the controller computer's available signal.

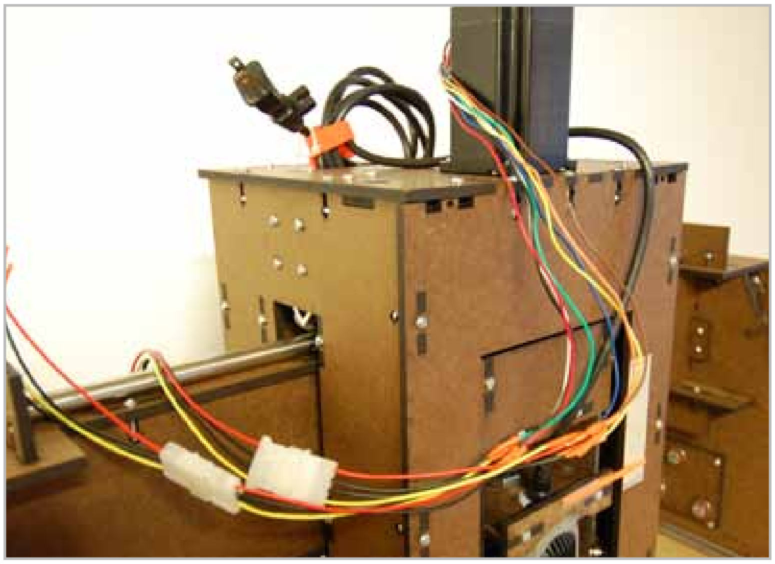
You'll have to figure out what microstepping settings work best for your motors, gantry and PC. On our build, we found that half-stepping on the X and Y axes leads to a decent balance of torque and resolution, while our Z-axis needed at least quarter-stepping to keep the acme rod from binding.

Jumper

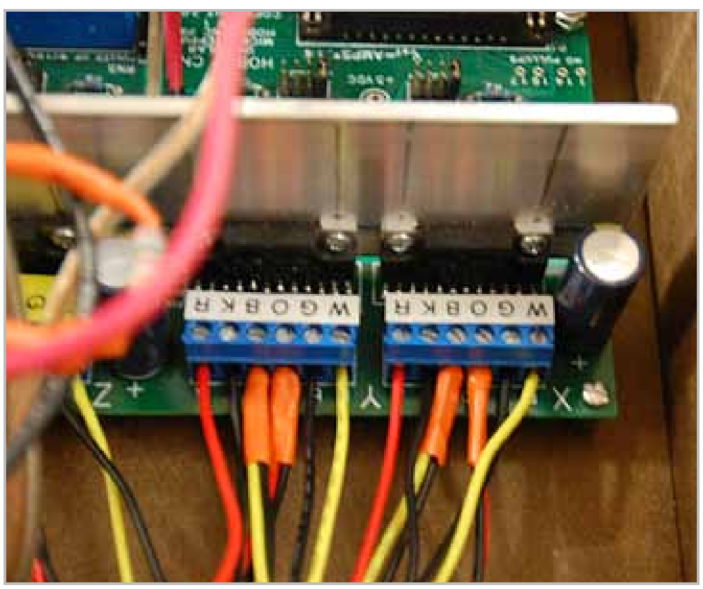
Driver Board Case
HobbyCNC recommends a couple of ready-made project enclosures for the driver board. We made our own out of laser-cut masonite. We're aware that our choice of material presents more of a fire risk, so take care. In any case, make sure you have an enclosure for your board.

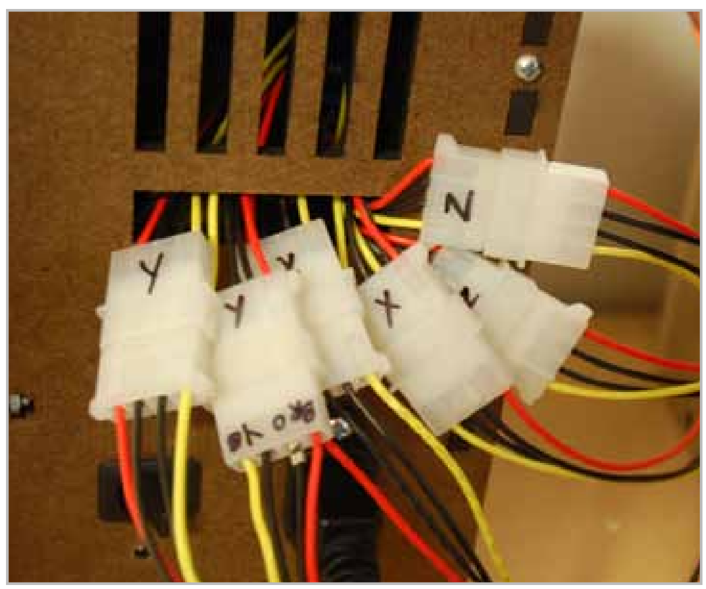
Wiring

We chose 4-pin Molex power cables to connect the driver board to each motor. We use two cables for each axis since there are eight wires per motor. The cable connections make it easy to disconnect or extend the cables.



The Molex cables are male on one end, female on the other. Going into the board, each axis has one male and one female connection. This way we can arrange the wiring of each axis so as to make it impossible to accidentally cross the wires by attaching the wrong connections.





Make sure that the Molex wires match up with the wiring diagram and lead to the correct pinouts on your driver board. We found it helpful to label the pinouts on the board, as well as labeling the Molex connectors with axis and wire coloring information.

Linux & EMC2

To control our **DIYLILCNC**, we use a version of Linux[28] called Enhanced Machine Controller[29] that includes some special software for controlling machines in real time. This is one way to control and send NC files to your mill, known generally as software stepping. EMC2 is extremely well-documented, and is a robust enough program to be used in many commercial setups.

The real-time aspect of software stepping is extremely important, as even very small timing differences (microseconds!) between the control computer's signals and the motors' actions can lead to big problems when milling.

Suggested System Requirements for EMC2
Beyond the base requirements for installing Ubuntu[30], the control computer running Linux/EMC2 should have the following specs. For more details see the Hardware Requirements for current versions of EMC2[31].

- x86 PC Desktop
- Parallel port
- Non-Nvidia video card
- Pentium II or III processor, 400MHz or higher
- At least 256MB of RAM (512MB is preferred)
- 4GB or more of HDD space

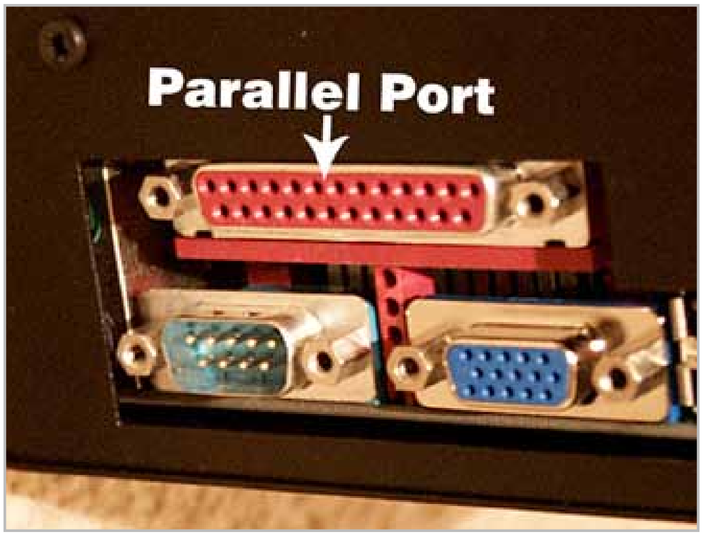


Photo by Dominic Cleal.

Downloading/Installing
You can download a copy of Linux with EMC2 already installed[32] from LinuxCNC.org. Burn the ISO image onto a CD[33], then use the CD to boot your computer[45]. The ISO is a "Live CD," which means that once booted, you'll have the option to run Linux/EMC2 directly from the CD, or do a full-fledged installation. Follow the simple install instructions[34] or get fancy[35] if you're already a Linux expert.

Software Tuning
For general EMC2 knowledge, and step-by-step setup instructions, read the EMC2 Documentation[36] for your version. For details on software tuning, read EMC2's Integrator Manual[46]. Additionally, the EMC2 Documentation Wiki[47] offers a good run-down of these software tuning steps[37].

Unlike motors that send feedback to the controller about their shaft positions (like servos, for example) the stepper motors that we use operate in an "open loop" system, only receiving signals from the controller--they don't report anything back. This means the motors are flying blind; if there's ever any interrupt between the two, the controller and motors may not be in sync.

An open loop system can operate reliably and effectively with enough information about the controller, driver and motor -- we can use that information to "tune" the software to the requirements of the hardware, and thus generate signals and motor movements effectively.

Software tuning sets the timing for signals to be sent from the computer to the motors via the driver board. The goal of software tuning is to strike a balance between using the computer's hardware to get the fastest motor speeds possible, without freezing the computer or signaling too fast for the motors to sync to the signals.

The two most important pieces of info needed for software tuning are the computer's latency and the timing requirements of the stepper/controller combo.

Latency
Let's start with latency; first, you'll run a latency test[38] (again, read the integrator's manual[46]). This will give you a number, in nanoseconds, that represents the amount of timing error that may be present in the computer's signals. The latency test is now integrated into the EMC2 StepConf Wizard, making it easier than ever to test your computer's latency.

Timing Requirements
Second, you'll need to find the timing requirements of the motor/driver. There are four important components:

- Required Step Length
- Required Step Space
- Required Direction Setup
- Required Direction Hold

Timing requirements for the Hobbycnc.com PRO Driver Board and #23-130-DS8/#23-205-DS8/#23-305-DS8A stepper motors can be found here[39]. If you're using different motors, check the manufacturers specs (or Google) for your motors' timing requirements.

Base Period
The base period is "the heartbeat of the computer," or the shortest time in which the controller computer will decide whether or not to send a signal to the motors. If the base period is too short, EMC2 will lock up, display the "Unexpected real time delay" error, or the motors will lose steps; if the base period is too long, the motors will be stuck with slow step rates.

You can let EMC2's StepConf Wizard[42] (see below) decide the base period for you, or you can use this handy spreadsheet[41] to help you calculate base period from the latency and timing requirement numbers.

Max Velocity/Accelleration
For each axis of motion--in our case X, Y and Z--you'll set limits for the fastest allowable travel speed (velocity) and the time taken to speed up to or slow down from that speed (acceleration). The velocity and acceleration values are determined partly by the base period, partly by the degree of microstepping, and partly by the mechanical limitations of the gantry and motors. The settings we used are listed below.

	Max Velocity	**Max Acceleration**
X Axis	6 inches/second	10 inches/second^2
Y Axis	6 inches/second	10 inches/second^2
Z Axis	0.7 inches/second	8 inches/second^2

Leadscrew Pitch

Depending on how you set up your motor drives, you may have to adjust the software settings to account for leadscrew or pulley rotations. For the **DIYLILCNC**, you'll want to use these settings for leadscrew pitch, and leave the Motor:Leadscrew ratio at 1:1.

	Leadscrew Pitch
X Axis	.62536324 rev/inch
Y Axis	.62536324 rev/inch
Z Axis	16 rev/inch

If you're feeling nerdy, you can calculate the leadscrew pitch based on the number of revolutions your drive components need to make for 1 inch of linear travel. For example, our Z-axis leadscrew is rated at 1/16" travel distance per revolution, so it would take 16 revolutions to carry the Z-cart one inch.

Putting it All Together

All the software tuning information discussed above gets combined in a set of configuration files used by EMC2 to run your mill. These are text files that contain information used by EMC2 to run your CNC mill. You can hand-code all of your config files if you want to, or you can use EMC2's StepConf Wizard[42] which will take you through step-by-step prompts to gather the necessary information.

Toolpaths & CAM Software

We currently use RhinoCAM to generate toolpaths since we have free access to it. See the Conclusions section for more info.

Test Files

EMC2 comes with a good batch of example NC files that you can run right off the bat.

URL's

1 http://creativecommons.org/licenses/by-sa/2.5/

2 http://oomlout.com/

3 http://oomlout.com/cnc1.html

4 http://www.instructables.com/id/How_to_Make_Anything_Using_Acrylic_and_Machine_Sc/

5 http://www.saic.edu/

6 http://crit.artic.edu/aoc

7 http://www.instructables.com/files/orig/FQS/WJK5/F3HY3S20/FQSWJK5F3HY3S20.pdf

8 http://www.arduino.cc/

9 http://www.blender.org/

10 http://brlcad.org/

11 http://sourceforge.net/projects/pycam/

12 http://www.gcad3d.org/

13 http://code.google.com/p/heekscad/

14 http://code.google.com/p/heekscnc/

15 http://en.wikipedia.org/wiki/Mit_media_lab

16 http://en.wikipedia.org/wiki/Neil_Gershenfeld

17 http://en.wikipedia.org/wiki/Reprap

18 http://en.wikipedia.org/wiki/Adrian_Bowyer

19 http://en.wikipedia.org/wiki/CandyFab

20 http://makerbot.com/

21 http://en.wikipedia.org/wiki/G-code

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