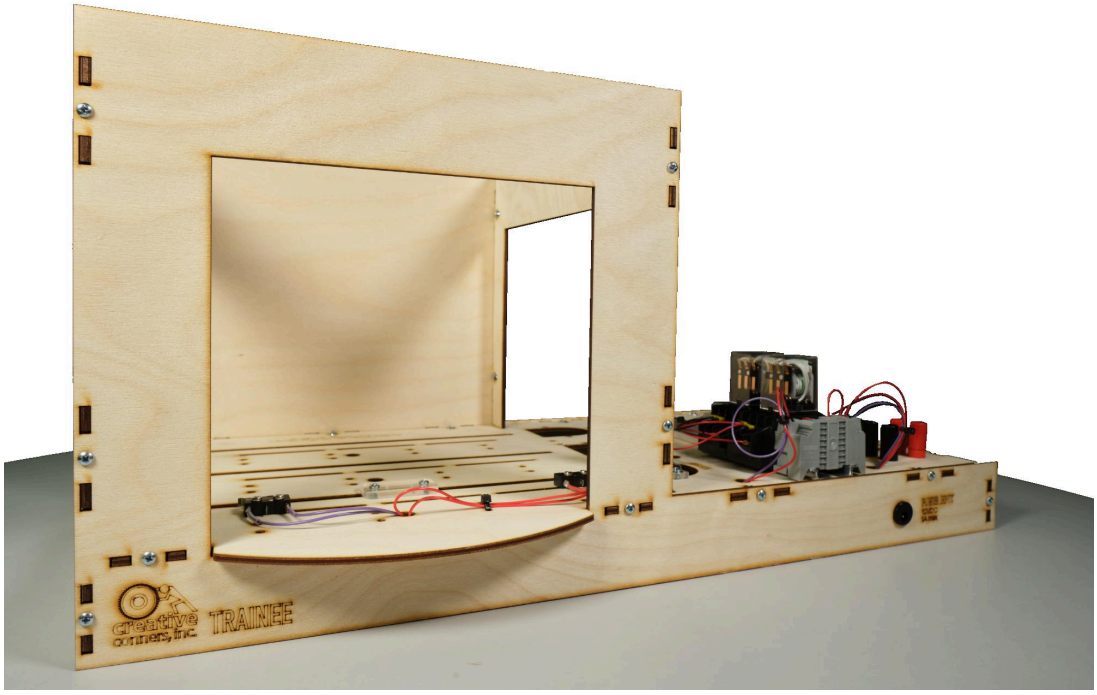

TRAINEE

Assembly Instructions

make it move
creative conners, inc.

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GETTING STARTED

A Word About Safety

Scenic automation, in full-scale, has numerous hazards that should be carefully assessed and mitigated. Thankfully, **Trainee** greatly reduces those risks by scaling down the mechanical and electrical power used for motion. The little motors inside **Trainee** machines operate with minimal force and the 12VDC supply that powers **Trainee** has much lower potential energy than the typical 230VAC 3-phase power used for a big deck winch or turntable machine. But there are still safety concerns to consider and you should learn to work carefully at this small scale in preparation for working on larger machines and higher voltage control systems.

Mechanical Safety

When the motors spin, model pieces slide around the “stage”. When the parts slide, there are spots where you could pinch a finger or tangle your hair. The resulting injury would be minor. The motor will stall, or a piece of the machinery will break, but it would be unpleasant for you and damage the equipment. Start forming good habits now when working with machinery, even though it’s tiny machinery.

- Keep your hands away from moving parts
- Tie back your hair securely to prevent it from becoming entangled in the machine
- Do not wear dangling jewelry that can become entangled in the machine

Electrical Safety

The Trainee operates on 12VDC with a 700mA power supply. This low-energy system poses little risk, but basic electrical safety precautions are required.

- Unplug the Trainee when not in use
- Unplug the Trainee before adding, removing, or changing the wiring
- Be careful to avoid short circuits that could damage the power supply, the motor, or the wiring
- Do not touch exposed terminals while the Trainee is plugged in

Experimentation is fundamental to learning and we hope to encourage you to experiment with less worry. Don’t let these warnings scare you off from experimenting with your new Trainee. We’ve made every effort to make the Trainee as safe as possible while still being useful.

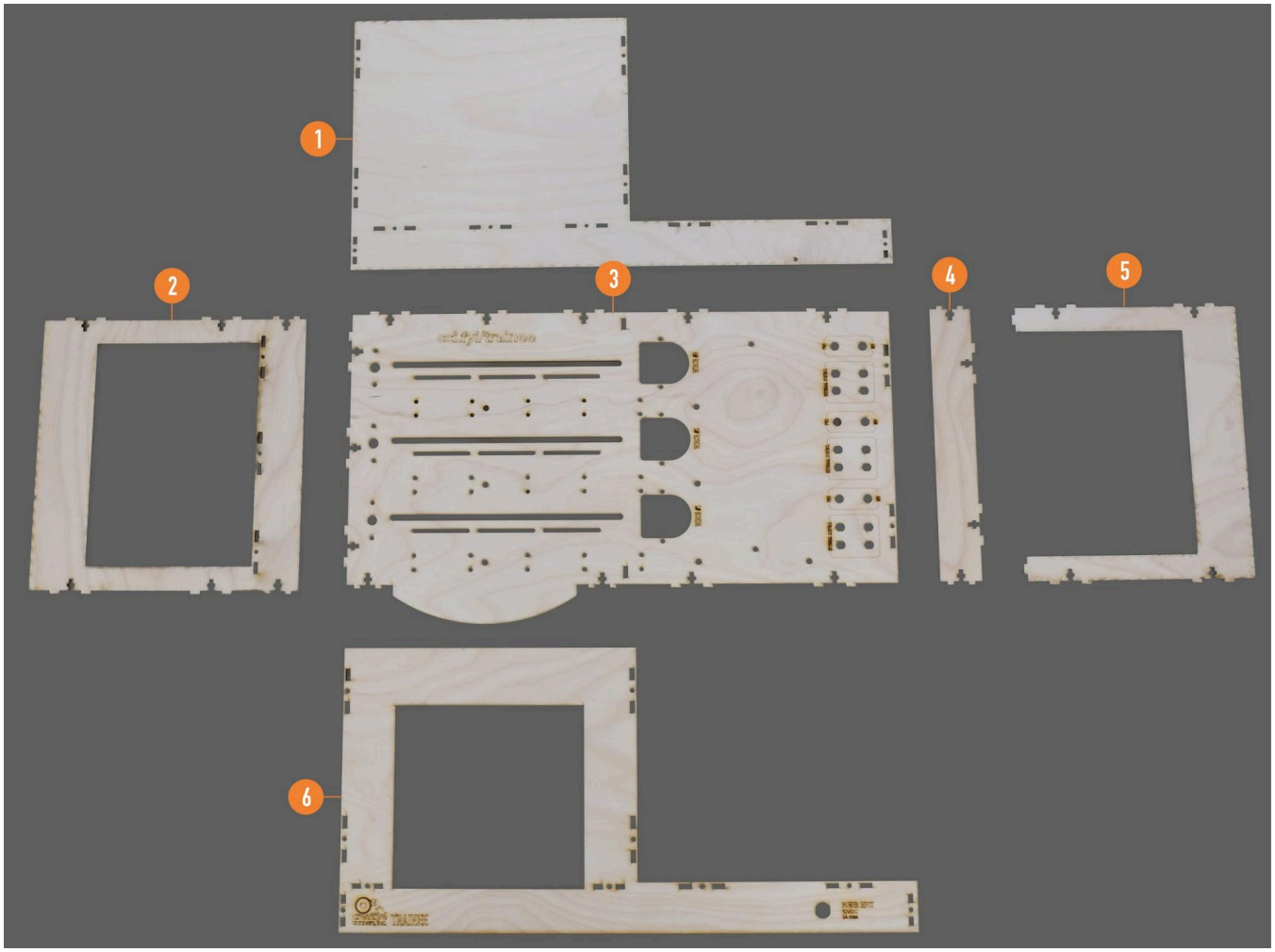
What's included

Trainee comes with:

- ¼"-scale (roughly) stage model that can accept up to three deck winches
- your first deck winch
- all the hardware required to assemble

In detail

The Stage

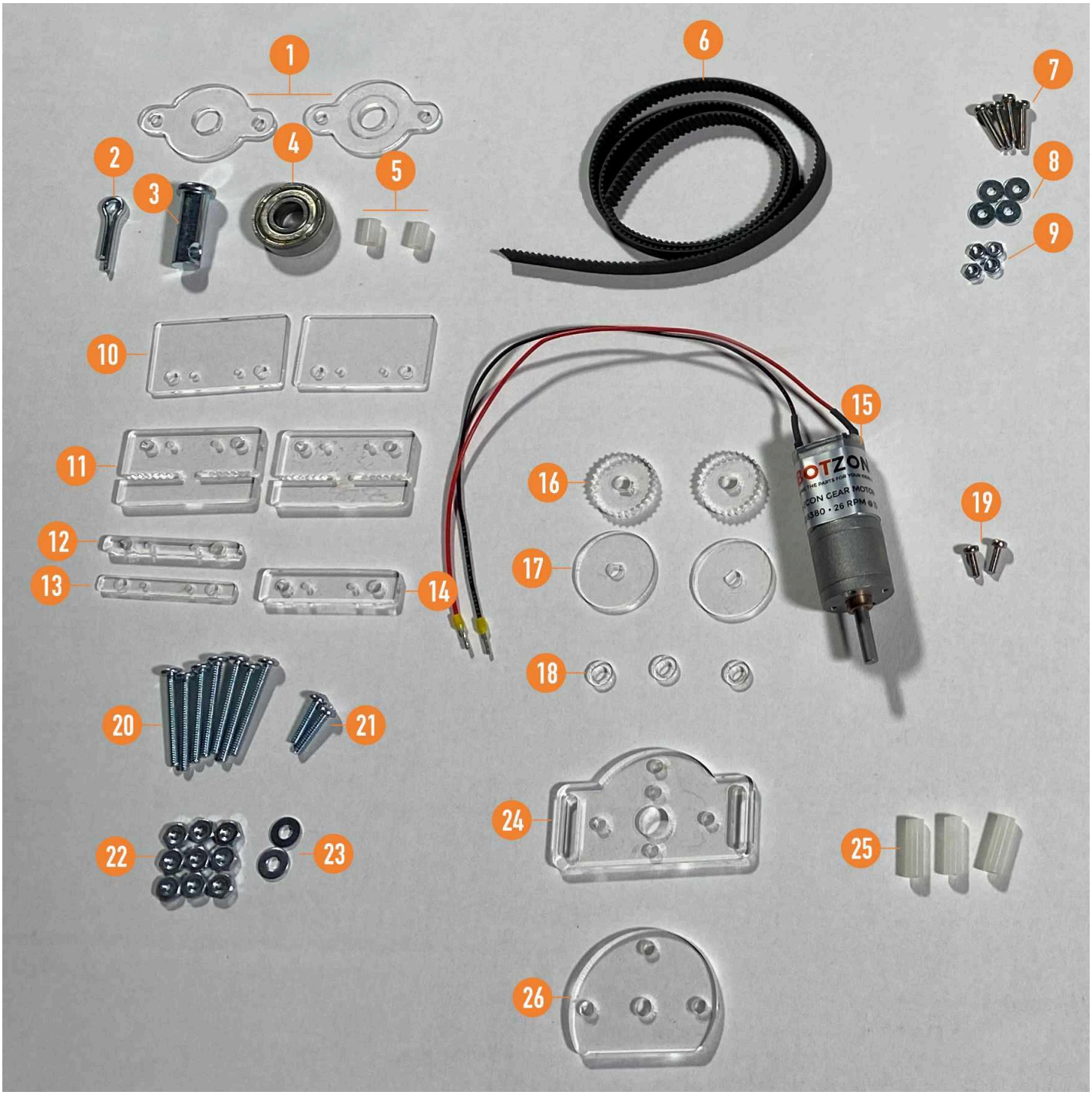


Item	Qty	Item
1	1	Back Wall
2	1	SR Wall
3	1	Stage Floor
4	1	SL Support
5	1	SL Wall
6	1	Proscenium



Item	Qty	Item
1	28	#4-40 nuts
2	28	#4-40 X ½” panhead machine screws
3	2	#8-32 X ½” panhead machine screws
4	2	#8-32 nuts
5	1	DIN rail

Winch



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Item	Qty	Item
1	2	Idler pulley cheek plates
2	1	Cotter pin
3	1	Clevis pin
4	1	Idler bearing
5	2	#4 X 9/32”L spacer
6	1	GT2 timing belt
7	4	M2.5 X 14mm panhead machine screw
8	4	M2.5 washer
9	4	M2.5 hex nut
10	2	Dog capture plate
11	2	Dog belt grip
12	1	Dog spacer - ⅛”
13	1	Dog spacer - 1/16”
14	1	Dog top plate
15	1	Gearmotor
16	2	Timing belt pulley
17	2	Timing belt pulley cheek plate
18	3	Motor shim
19	2	M2.5 X 8mm panhead machine screw
20	7	#4-40 X 1” panhead machine screw
21	2	#4-40 X ½” panhead machine screw
22	9	#4-40 hex nut
23	2	#4 flat washer
24	1	Motor mount

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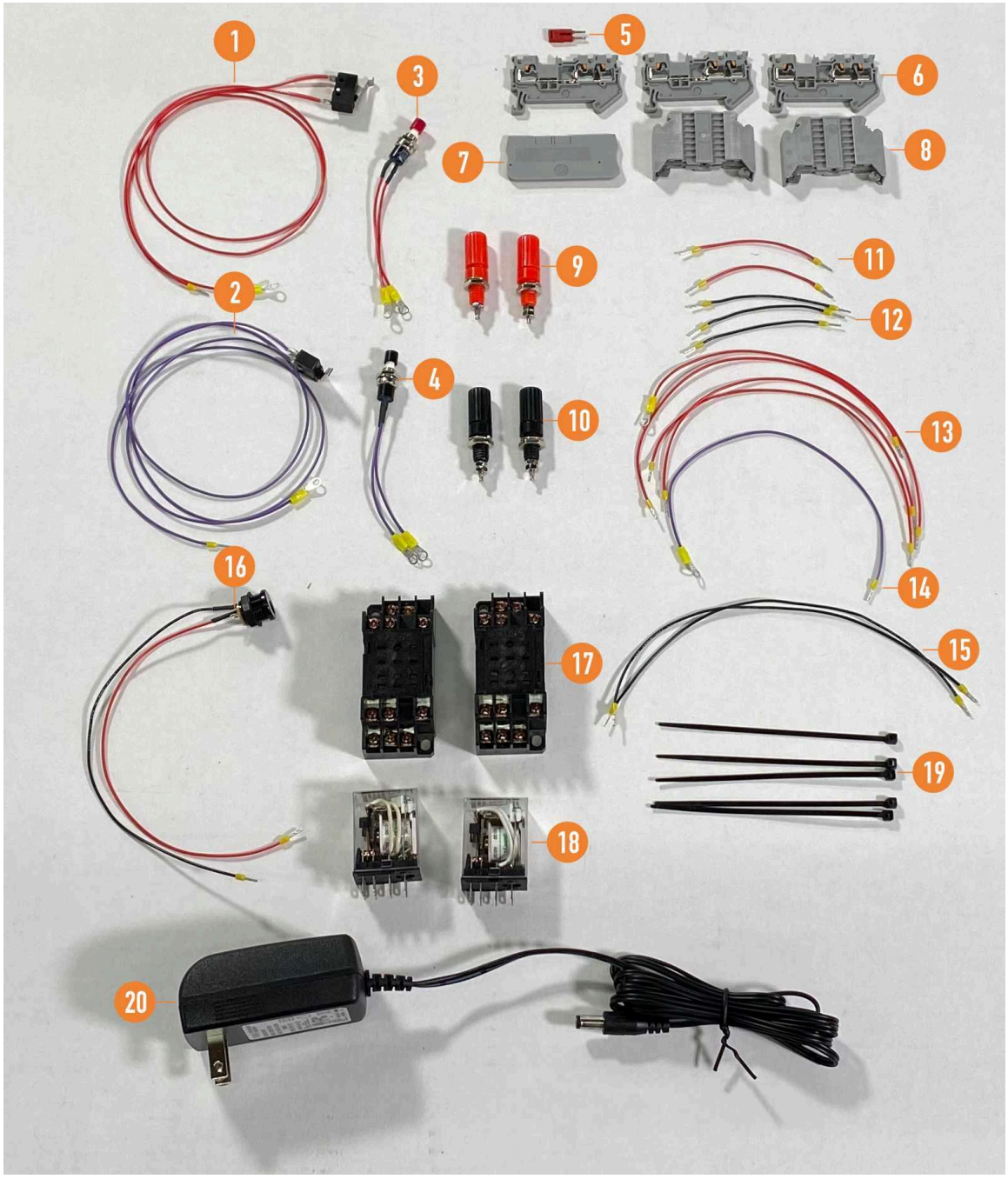
25	3	#4 X 9/16”L spacer
26	1	Timing belt pulley capture plate

The acrylic parts may have shipped with a protective paper or film. Go ahead and peel that off as you’re taking inventory of all the parts.

Electrical



Item	Qty	Item
1	1	Reverse limit switch (red wires)

2	1	Forward limit switch (purple wires)
3	1	Reverse push-button switch (red wires)
4	1	Forward push-button switch (purple wires)
5	1	DIN terminal jumper 3.5mm
6	3	DIN terminal blocks
7	1	DIN terminal block cover
8	2	DIN end clamp
9	2	Banana jack (red)
10	2	Banana jack (black)
11	2	Red wire - 3” long
12	3	Black wire - 3” long
13	4	Red wire - 8” long (1 with ring terminal)
14	1	Purple wire - 8” long
15	2	Black wire - 8” long
16	1	Power jack
17	2	3PDT relay socket
18	2	3PDT 12V coil relay switch
19	8	Zip tie - 4” long
20	1	Power supply 12VDC 700mA

If you’re missing any part, give us a call (401-289-2942) or send us an email (support@creativeconners.com) so we can get you all the bits you need.

Required Tools

- #1 Phillips screwdriver
- Small flat blade screwdriver

- Medium flat blade screwdriver
- Small adjustable wrench or needle nose pliers

Optional, Handy Tools

- 7/16” socket wrench
- 10mm open-end wrench
- Small magnet (like a magnetic tip holder for your screw gun)

Features

When we set out to design **Trainee**, we took an informal poll around the shop to find out when each of us had first learned how relay switches work, and when we learned to design a control system using them. Most of us didn’t gain that knowledge until our first or second jobs after school. A few on the team learned the basic concepts late in college, but without practical application – or as we like to say “using them in anger.” We want **Trainee** to give you a leg up, teaching you valuable skills you will continue to use throughout your journey in automation.

Trainee is an affordable assemble-it-yourself kit to teach the basic principles of scenic automation while having fun. It is focused on fundamentals rather than complexity,]d

eschewing encoders for limit switches, promoting relay logic over PID control. Not because encoders and PID control are unimportant — they are important — but because even as your sophistication in automation grows you never outgrow the basics. You will continue to use limit switches and relay logic in nearly every project, either as supplemental techniques or aspects of a more complex system. Furthermore, some effects are better served by simpler techniques. If you don’t study the basics, it is difficult to properly grasp more advanced techniques and you won’t be able to judge when a project could be achieved in a simpler manner.

Trainee can be used on its own, but is best used alongside the *Scenic Automation Handbook* by Gareth Conner (Focal Press 2018, ISBN 1138850276). Reading about automation techniques and then practicing those techniques hands-on is the perfect way to cement your understanding. We hope you have fun and learn lots!

In detail

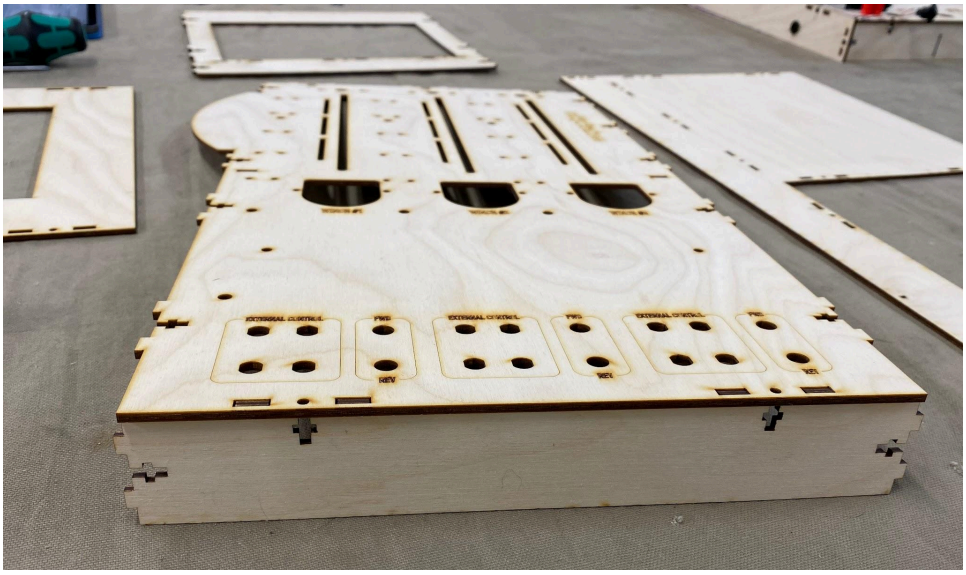
- Laser-cut birch plywood stage model
- Up to three (3) deck winches with cross-stage tracks
- Winch driven by a DC gearmotor
- Miniature deck dog for moving scenery back and forth
- Adjustable forward and reverse limit switches for positioning
- Relay logic for fixed-speed motor control
- Momentary push-button operation
- Auxiliary input jacks for external control (e.g. Stagehand FX, PLC, Arduino)

Pro Tip

Throughout the instructions, when there's an extra nugget of information you'll see a box like this. These notes aren't critical to the assembly process, but offer deeper information about a related automation principle.

Assembly

The Stage



1. Insert the **SL Support** into the bottom of the **Stage Floor**. Align the tabs and slots between the two pieces and press them together.

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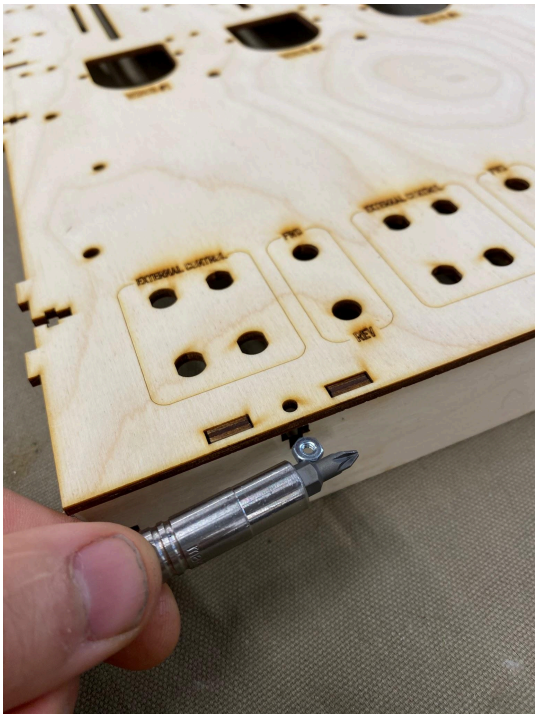
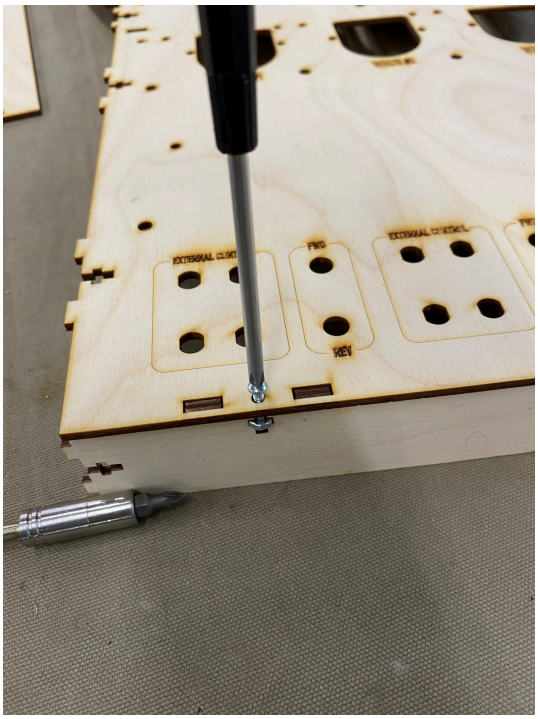


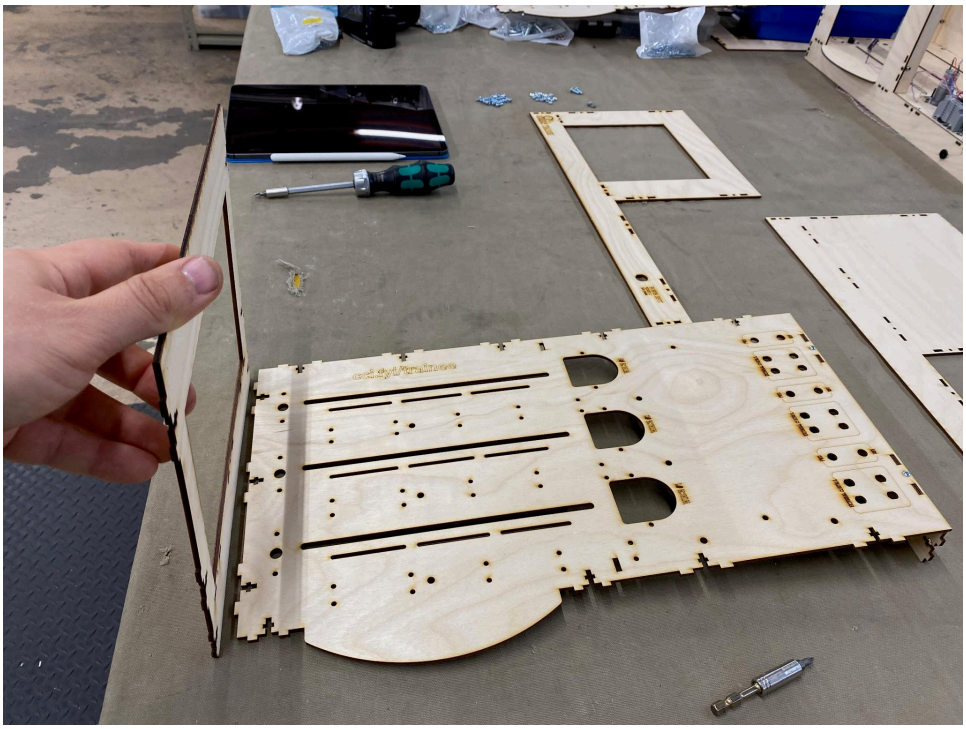
2. Insert **#4-40 nuts** into the small notches of the **SL Support**. As shown in the image, you can use a magnetic bit holder (or other magnet) to help.



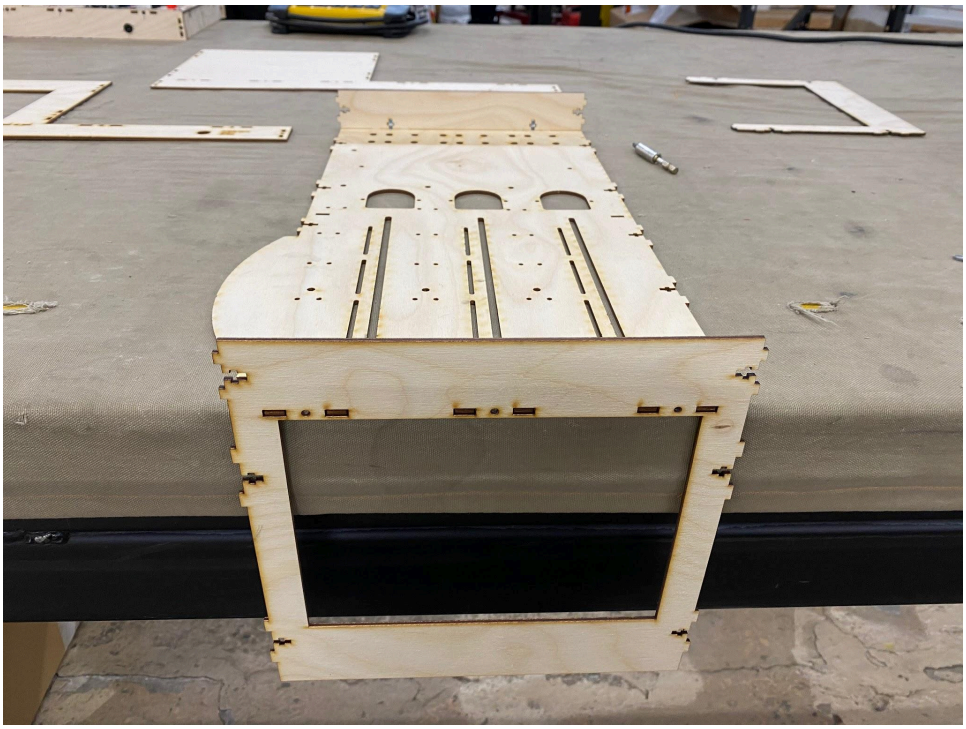
3. Using a small Phillips screwdriver, install a a **#4-40 X ½" panhead machine screw** through the **Stage Floor** and into the nut captured below. Repeat with a second screw to finish attaching the **SL Support** to the **Stage Floor**.

Tab and slot design

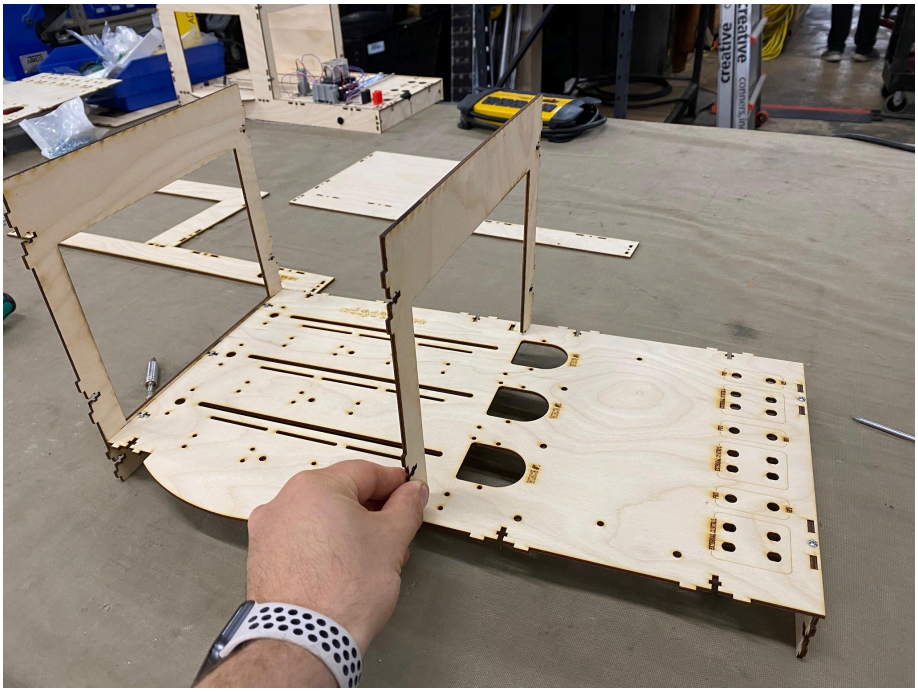
The construction of the stage model is just like we would design for a real machine. We wouldn't use birch plywood, but we would use the same connection details in aluminum plates. This eliminates welding and tedious layout. The pieces would be cut on a CNC waterjet or CNC laser cutter with all alignment features described in the CAD/CAM file. It makes assembling machines very fast.



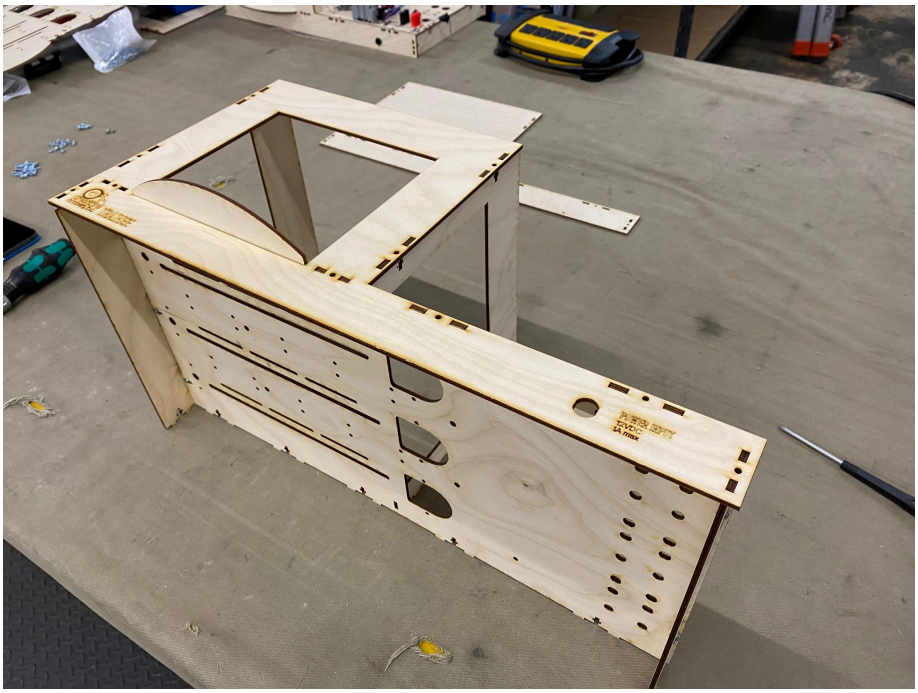
4. Next, attach the **SR Wall** to the **Stage Floor** in a similar manner by inserting three (3) **#4-40 hex nuts** into the stage floor and fastening the joint with three (3) **#4-40 X ½" panhead machine screws**.



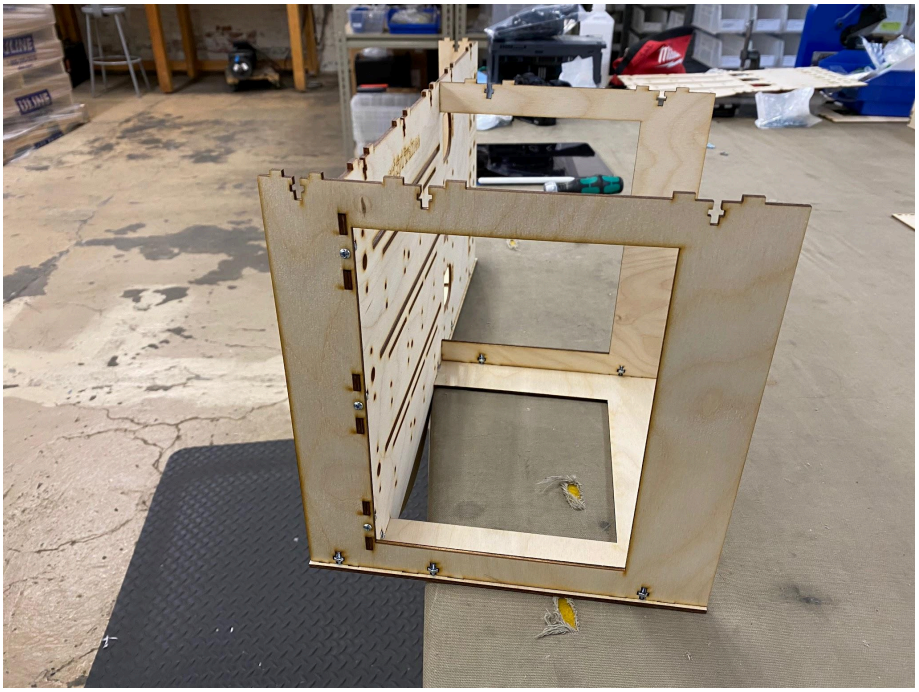
5. You may find it easier to flip the model upside down, and hang the **SR Wall** off the edge of your assembly bench.



6. Place the **SL Wall** in the notches of the **Stage Floor**. There aren't any screws to fasten the **Stage Floor** to the **SL Wall**, it gets captured in the next step.



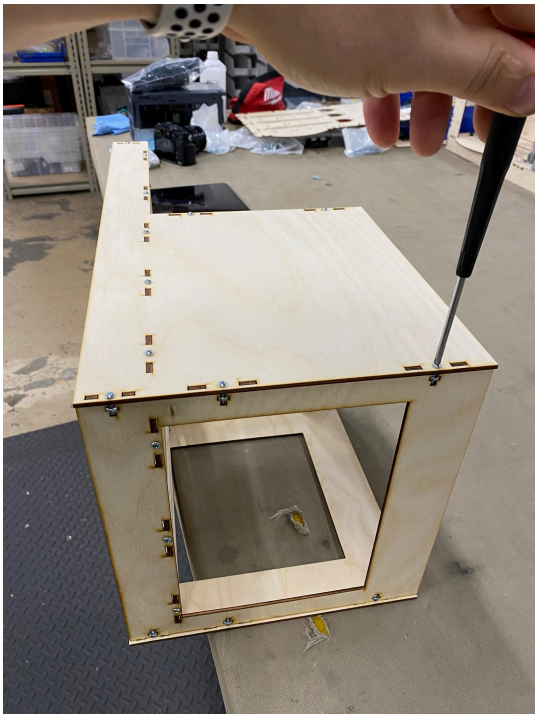
7. Tip the theatre onto its back side with the stage apron sticking up into the air. Align the **Proscenium** and affix it to the other pieces with ten (10) **#4-40 X ½" panhead machine screws**.



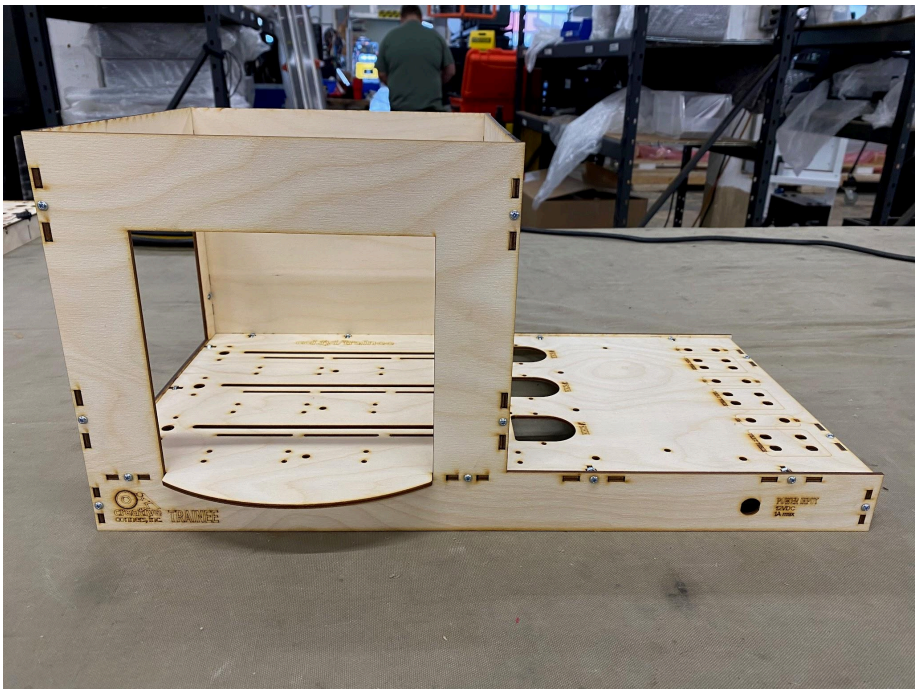
8. After the **Proscenium** is completely screwed into place, flip the whole thing over so the theatre is resting on your bench with the **Proscenium** face down. This will make it easy to attach the last piece — the **Back Wall**.



9. Place the **Back Wall** onto the theatre and align all the tabs and slots as you press it into place. It may take a little wiggling here and there, so start from one corner and work your way around until the whole panel is seated into place.

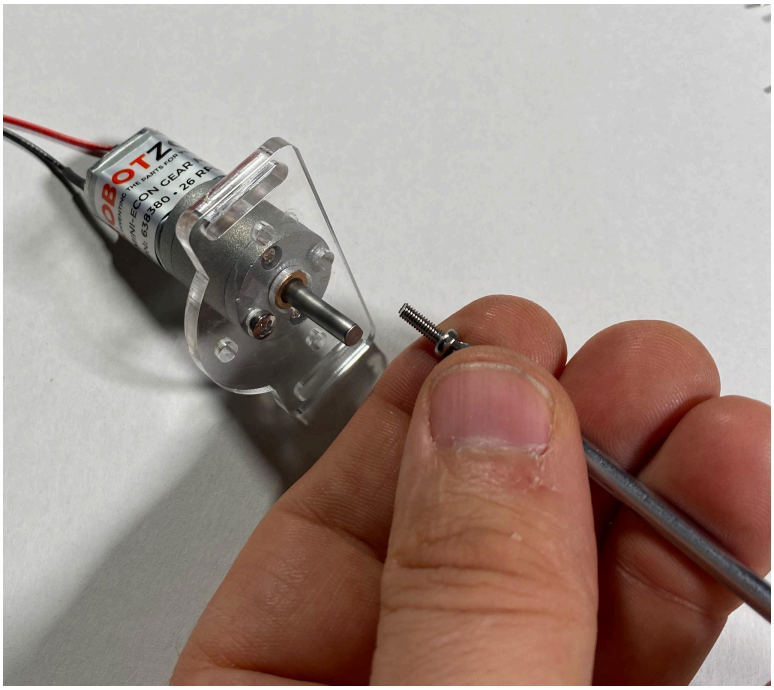


10. Install eleven (11) more **#4-40 X ½" panhead machine screws** to fasten the **Back Wall** onto the theatre.



11. Ta-da! Nice work, get ready to assemble the winch next.

Deck Winch





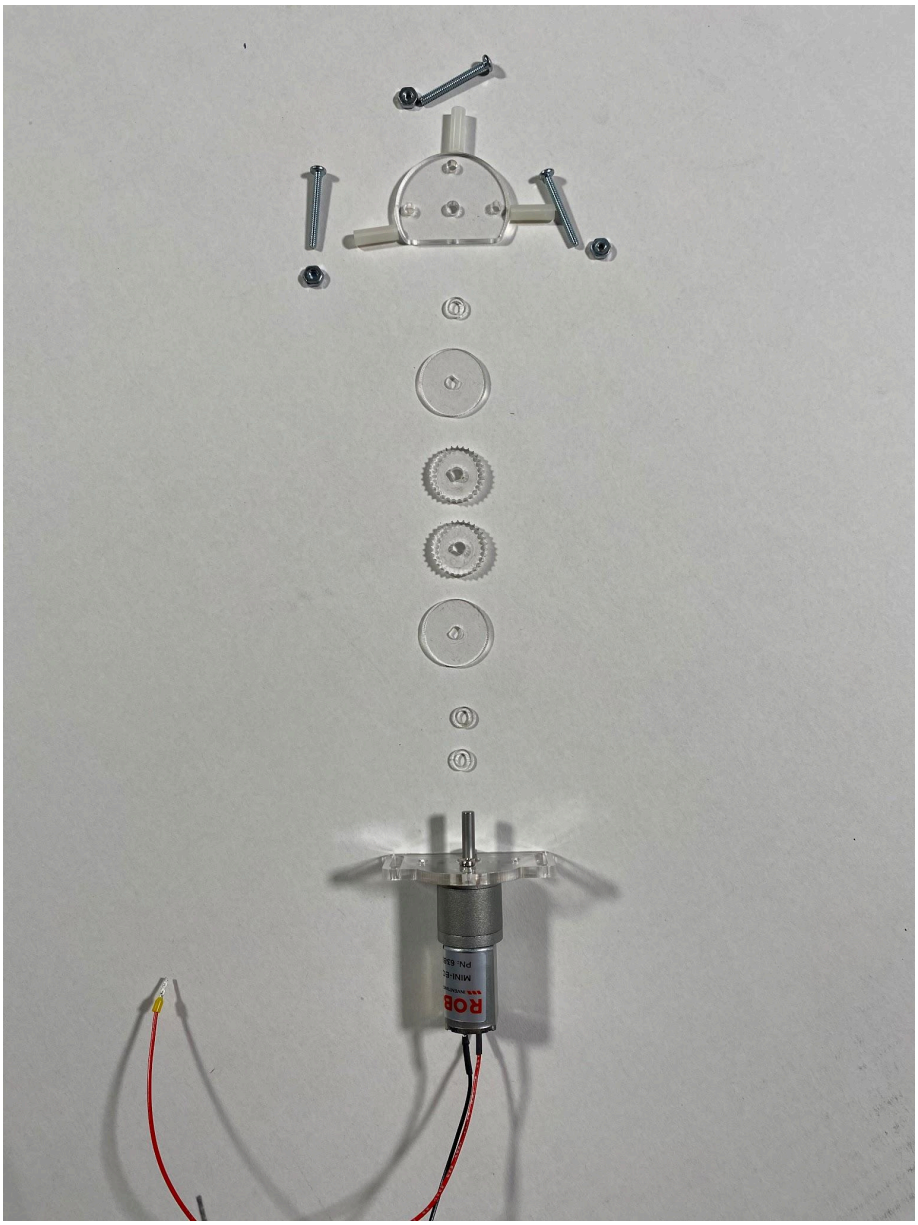
1. Fasten the **Motor mount** to the motor with two (2) **M2.5 X 8mm panhead machine screws**.

Motors and speed reducers

This motor has an integral gear box, or speed reducer. Motors typically operate at very high speeds with little twisting force (or torque). To make the motor more useful, a series of gears are used to reduce the speed and increase the torque. The relationship between speed and torque is inversely proportional for a given motor. As the motor speed is mechanically reduced, torque is increased. For instance, if the gears reduce the speed by ½, the torque doubles.

*The speed reduction is specified in a ratio (e.g. 2:1, 20:1, 60:1) which indicates how much slower the motor spins and how much torque is gained. A 20:1 reducer slows the motor 20x, and boosts torque by 20x. If the motor's speed is 1800rpm, the output speed after the speed reducer will be 90rpm. If the motor's torque is 3ft*lb, it will increase to 60ft*lb at the output side of the speed reduction.*

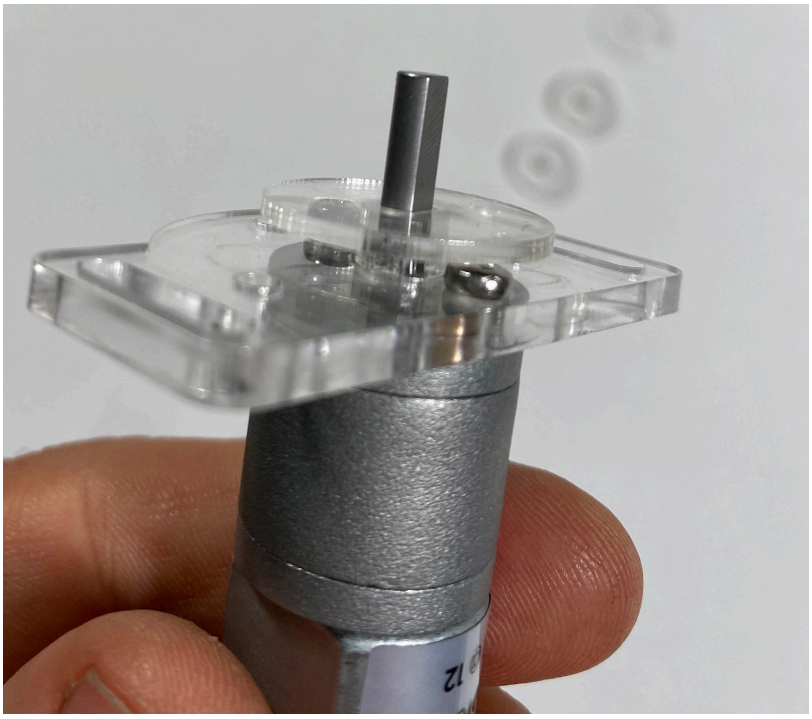
*The Trainee gearmotors have a gear ratio of 488:1. The output speed is 26rpm and the torque is 651 oz*in. What is the speed of the motor before the gear reduction? How about the motor torque before the gear reduction? Using the output specs after the speed reducer, how much can the motor pull using the included timing belt pulley? For more information on mechanical power, see pages 31-41 in the Scenic Automation Handbook.*



2. Next, you will stack up all the pieces that comprise the drive pulley on the motor. Gather them up and lay them out in the same order as the photo to make the installation easier:
    a. Three (3) **#4 hex nuts**
    b. Three (3) **#4 x 9/16” spacers**
    c. Three (3) **#4-40 X 1” panhead machine screws**
    d. One (1) **timing belt pulley capture plate**
    e. One (1) **motor shim**
    f. One (1) **timing belt pulley cheek plate**
    g. Two (2) **timing belt pulleys**
    h. One (1) **timing belt pulley cheek plate**
    i. Two (2) **motor shims**
    j. One (1**) motor**



k. Slip two of the motor shims onto the motor shaft.



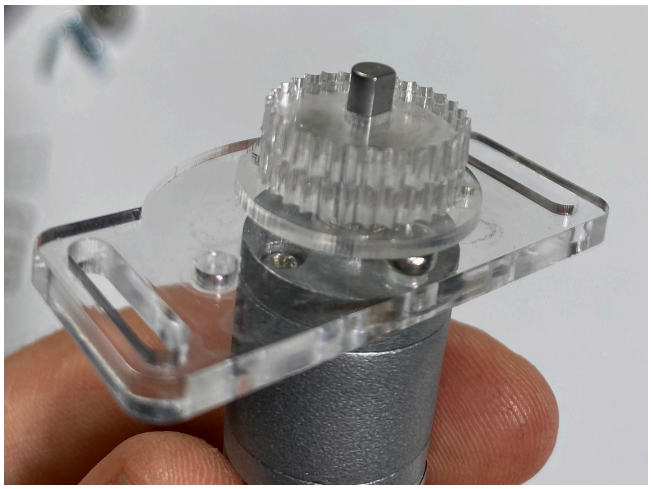
3. Slip on one **Timing belt pulley cheek plate**. Note that the motor output shaft has a flat spot, which gives the shaft a “D” profile. When you slip on the cheek plate, you have to align the flat

spot on the cheek plate to the flat spot on the shaft. Round peg, square hole, and all that sort of thing.

Motor Shaft Profiles

A round motor shaft needs to transmit rotary motion as it spins. The "D" shape of this motor shaft insures that as it spins, anything attached to the shaft will also spin, provided it has a mating "D" shaped hole. On larger motors, commonly you'll find a "keyway" cut into the motor shaft. The keyway is a square slot cut axially along the shaft. Mating components will have a similar keyway cut (or broached) into them. A square piece of steel, known as the machine key, is inserted into the keyway to pin the shaft and mating component (pulley, gear, sprocket, etc.). See page 42-43 in the Scenic Automation Handbook for more information.





4. Slip on both **Timing belt pulleys**. Why are there 2 pulleys? Just to build up the pulley to the same width as the belt it will drive.



5. Slip on the second **Timing belt pulley cheek plate**.



6. Place the last **Motor shim** on top of the stack.

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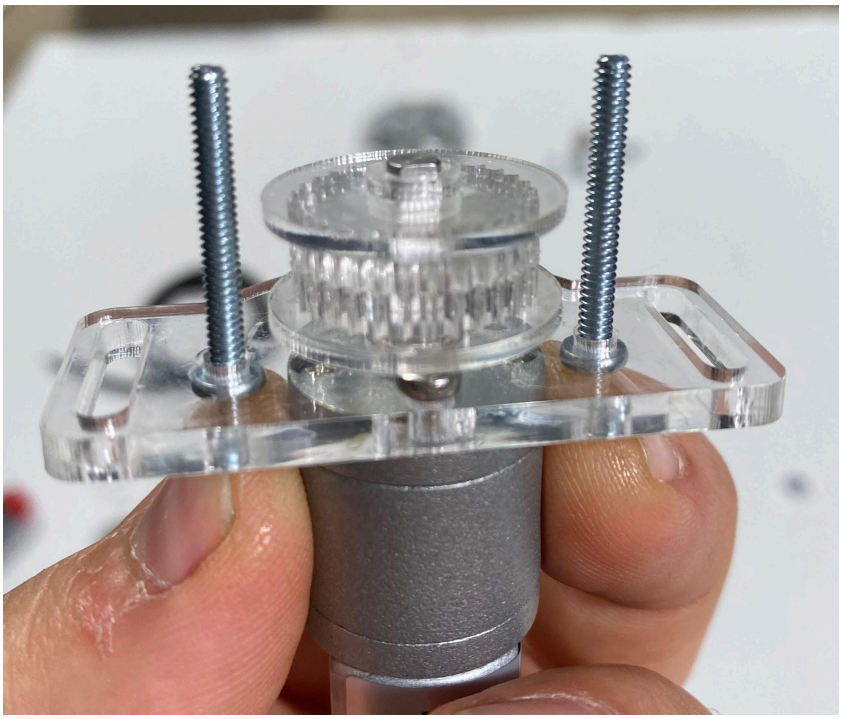
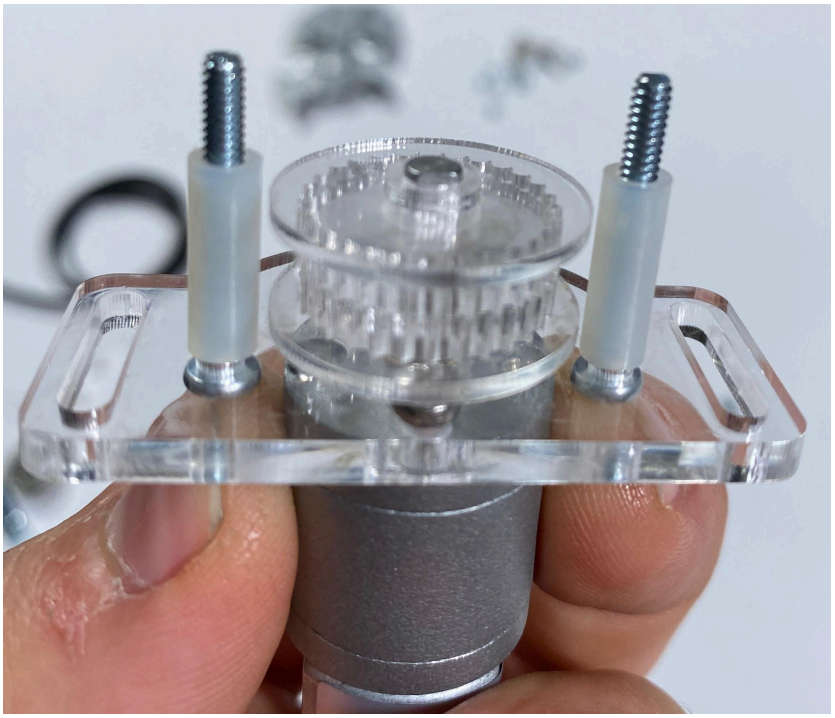
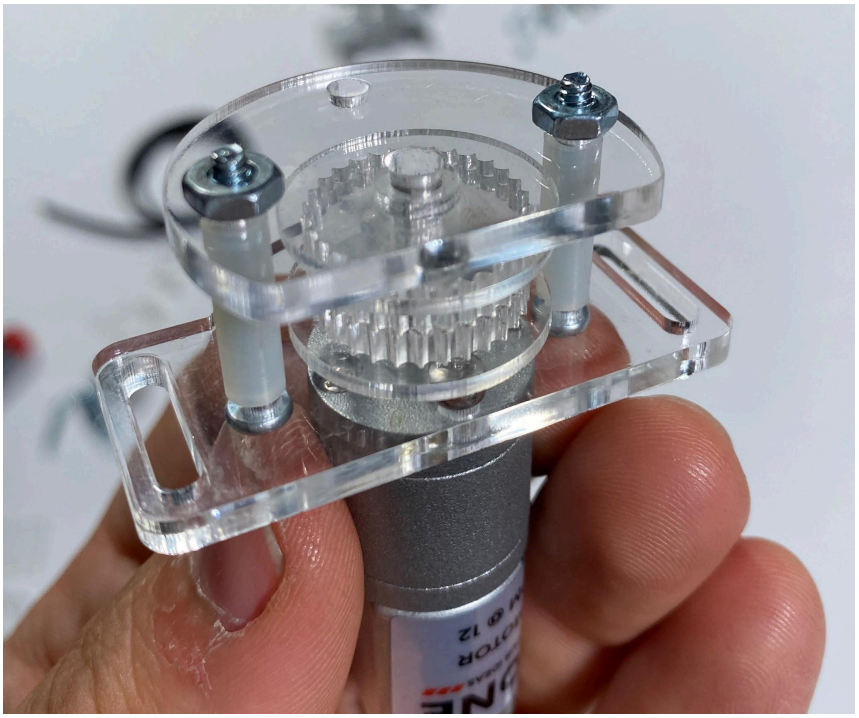


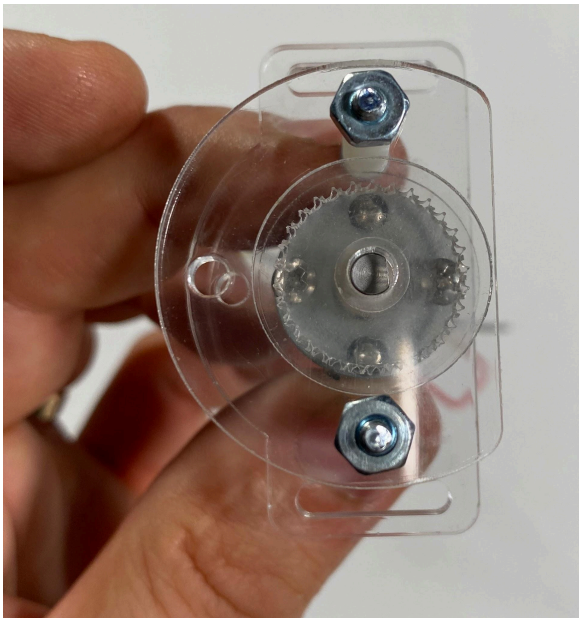
7. Next, poke two of the **#4-40 X 1" panhead machine screws** up through the **Motor mount**. This bit is a little tricky. You have to keep the whole assembly pointed upwards otherwise the pieces will slide off the motor. Try gripping it with your thumb & forefinger just below the screw heads to keep them in place. Assembling machinery often requires manual dexterity, even at small scale!



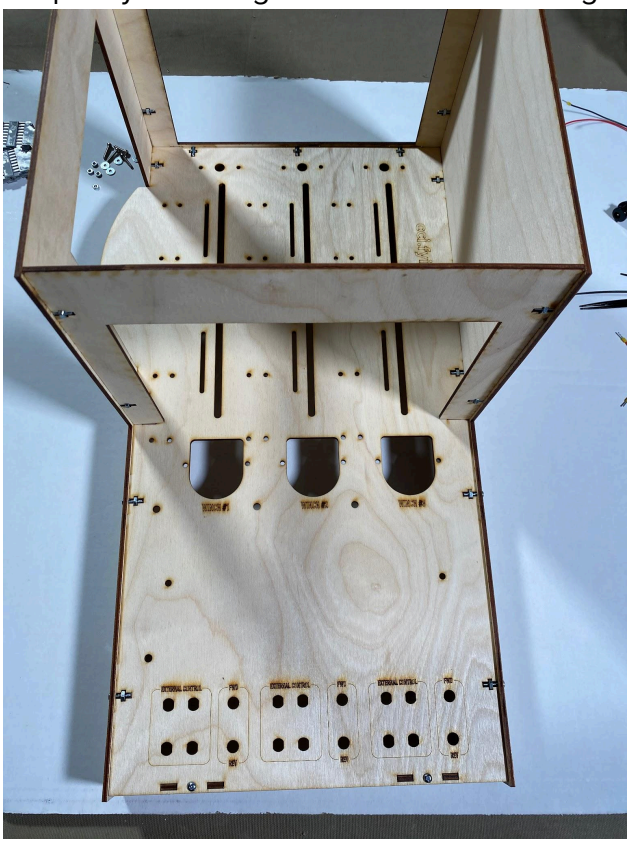
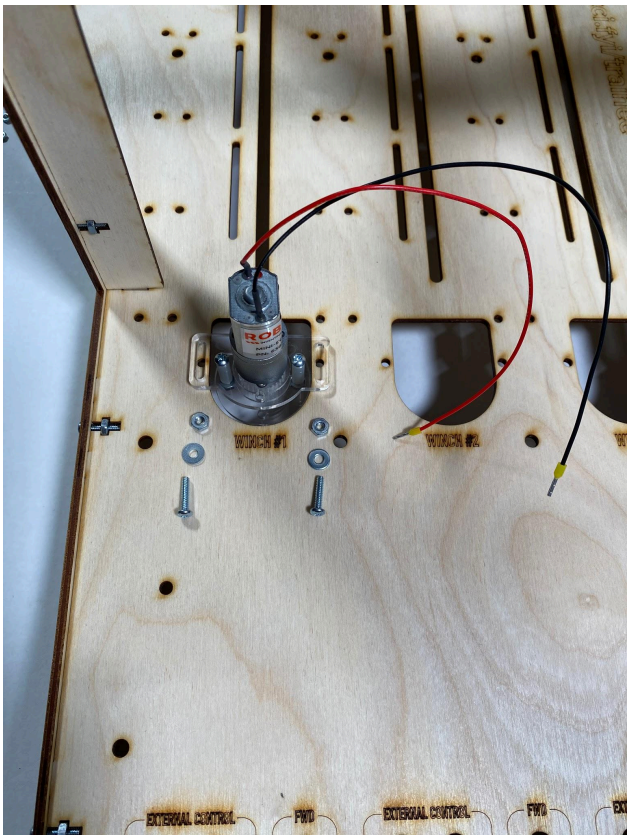
8. Slide two (2) **#4 X 9/16" spacers** over the screws you're pinching into place.



9. Place the **Timing belt pulley capture plate** on the stack and secure it with two (2) **#4-40 hex nuts.**

10.  

We've left the third screw and spacer off the winch at this point. This will allow easier access to the pulley as we rig the winch with a timing belt a little later.

11.  

Place the winch into the **Winch #1** opening on the **Stage Floor**. Grab the fasteners to connect it to the stage. Two of each:

a. **#4-40 hex nuts**
b. **#4 flat washers**

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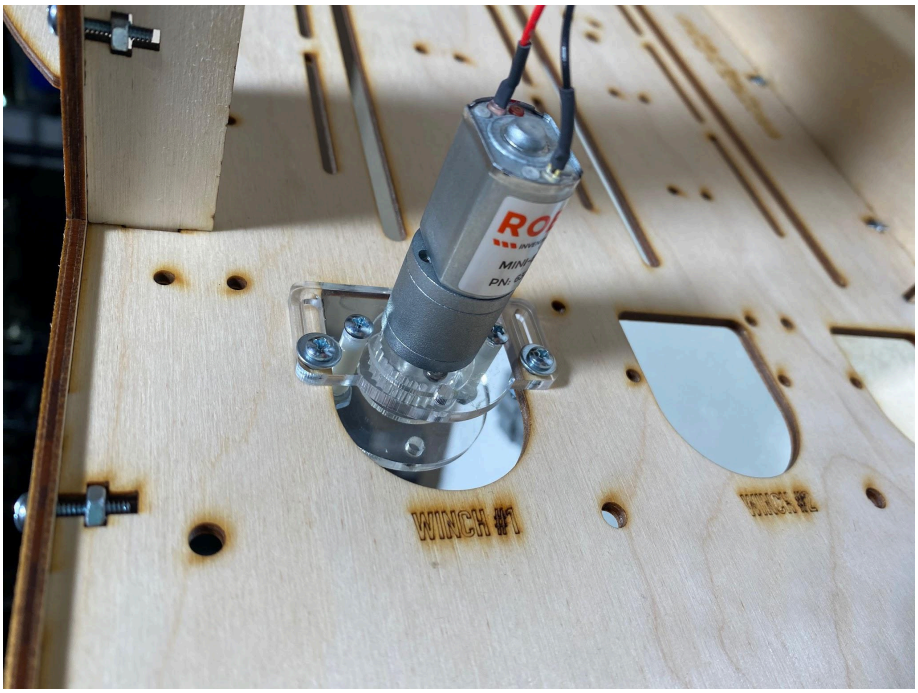
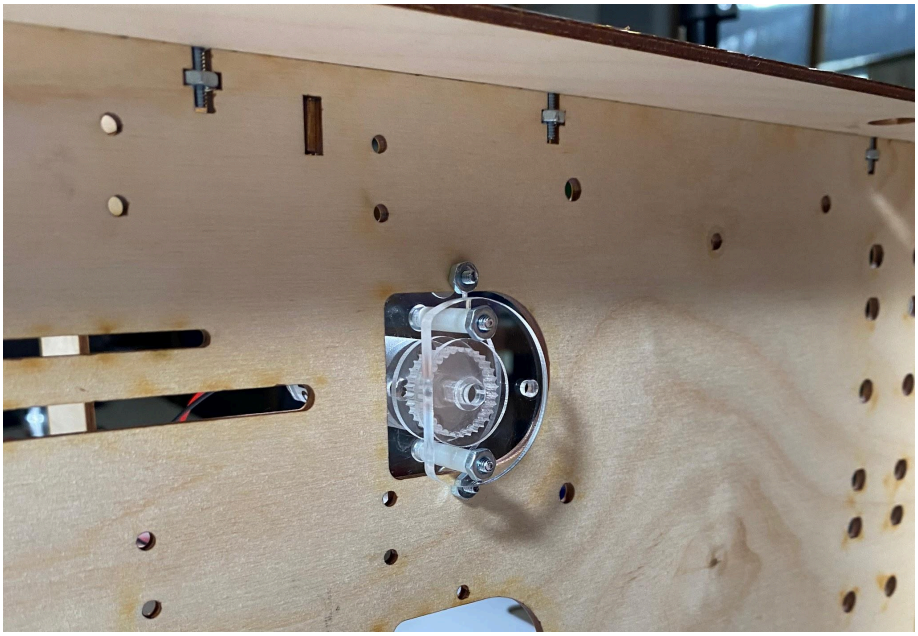
c. **#4-40 X ½" panhead machine screws**

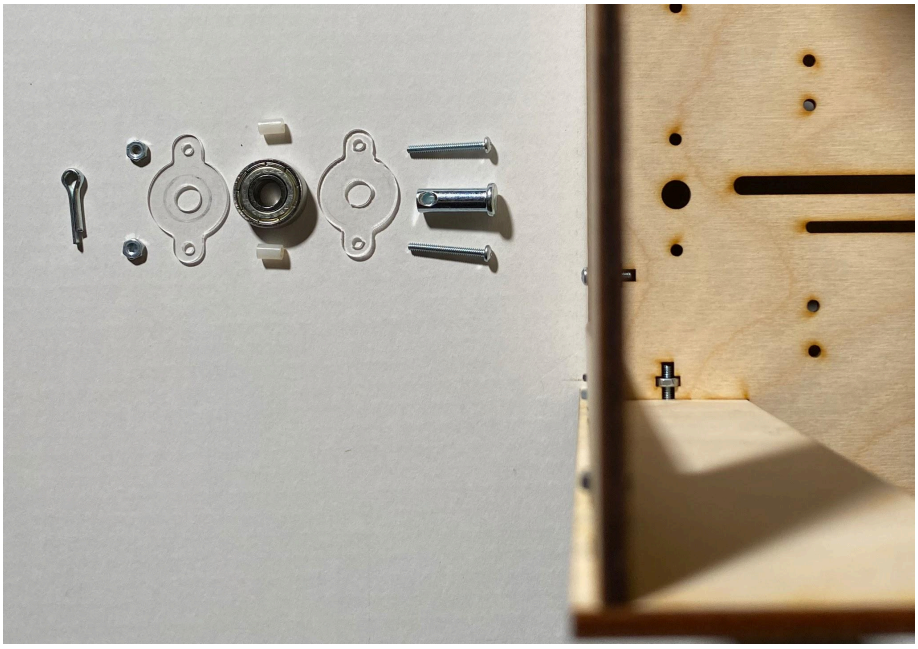


12. Attach the winch to the **Stage Floor**. Use the washers underneath the head of the screws to provide more clamping surface around the slots of the **Motor mount**.

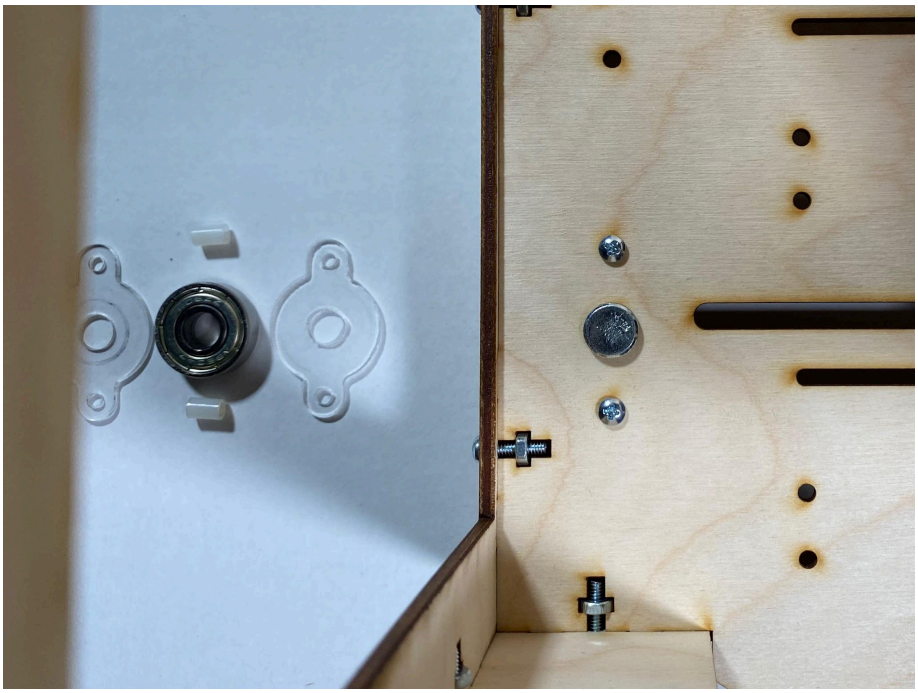


13. Hand-tighten the hex nuts below the **Stage Floor**. The **Motor Mount** should be loose enough that you can slide the winch onstage/offstage. Slide it as far onstage as the slots permit.

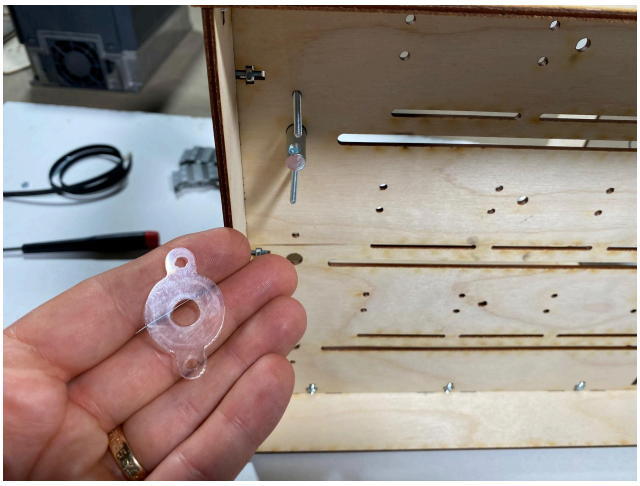
Turnaround Pulley

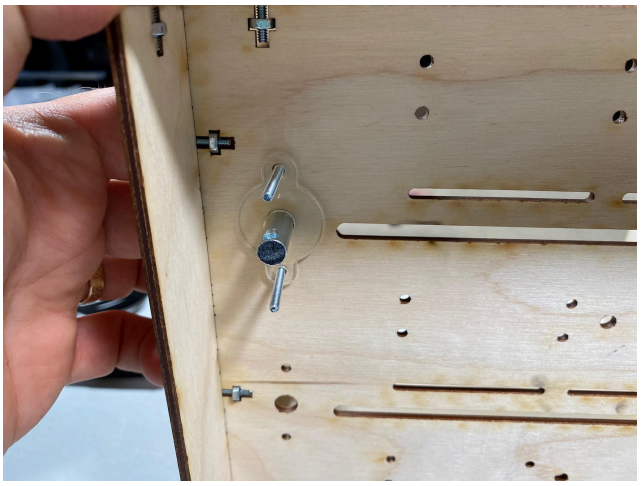


1. On the SR side of Winch Track #1, line up the pieces used for the turnaround pulley. From left to right in the photo:
    a. **Cotter pin**
    b. Two (2) **#4-40 hex nuts**
    c. One (1) **idler pulley cheek plate**
    d. **Idler bearing**
    e. Two (2) **#4 X 9/32” spacers**
    f. One (1) **idler pulley cheek plate**
    g. Two (2) **#4-40 X 1” panhead machine screw**s
    h. **Clevis pin**

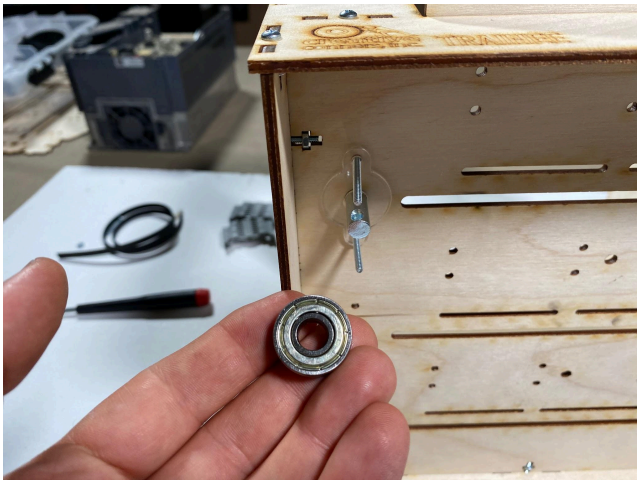


2. Insert the **clevis pin** and two (2) **#4-40 x 1” panhead machine screws** into the holes at the end of Winch Track #1.





3. Tip the theatre onto its back so you can work on the underside of the stage. Install one of the **idler pulley cheek plates** onto the screws and clevis pin.




4. Next place the **idler bearing** on the **clevis pin**.

Clevis Pins

Clevis pins are a common economical axle used to mount idler pulleys (free-spinning pulleys that aren't driven by a motor). The smooth shank is a good surface for the inner race of the bearing. The hole at the end of the clevis pin accepts a cotter pin (or roll pin) to prevent the clevis pin from falling out and won't loosen with vibration as a nut might. Other common axles are shoulder bolts or custom cut polished & ground shafts with either cotter pin holes or grooves for retaining rings.




5. Put a **#4 X 9/32"** spacer on each **panhead machine screw**.



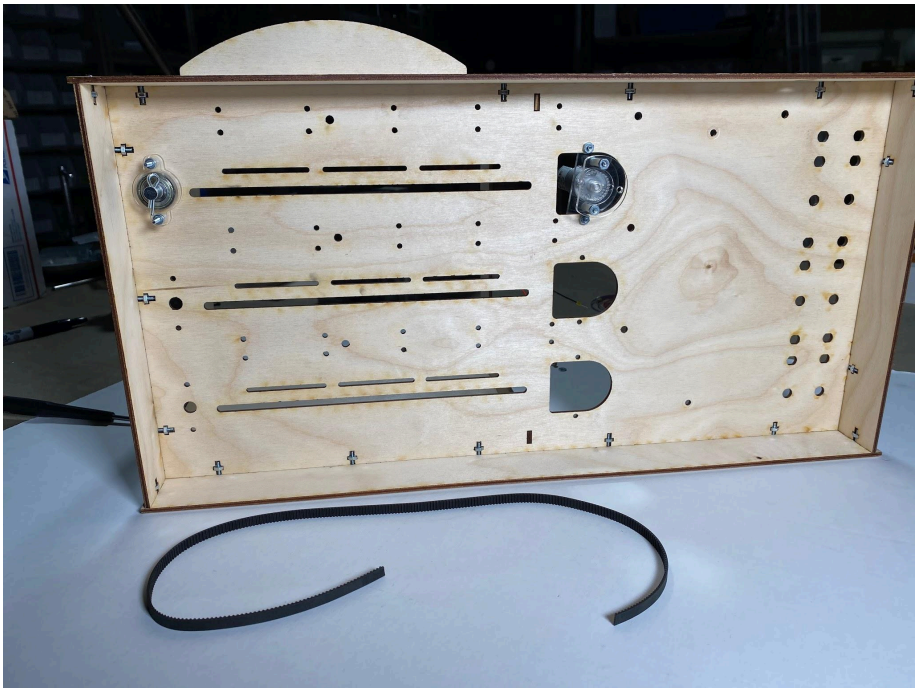
6. Place the last **idler bearing cheek plate** onto the **panhead machine screws** and **clevis pin**.



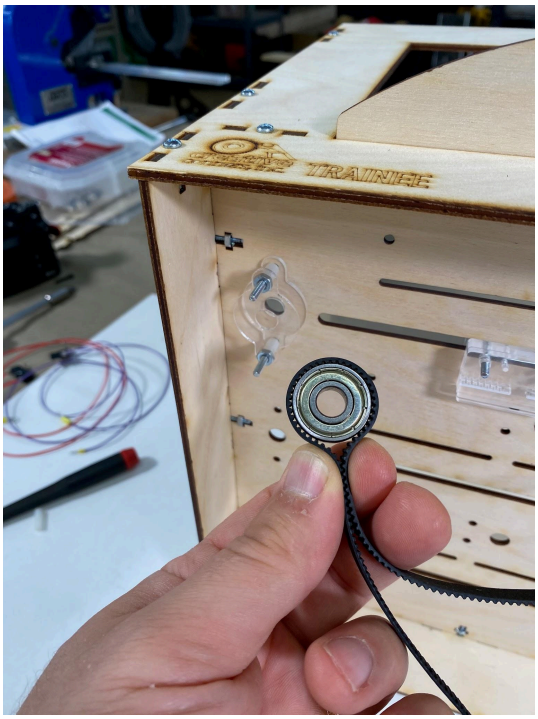


7. Secure the assembly with two **#4-40 hex nuts** and the **cotter pin**, but don't bend the **cotter pin** yet. You need to easily remove the **idler bearing** later on.

Rigging the Track



1. Find the **timing belt a**nd tip the theatre onto the **Back Wall.**



2. Pop out the **clevis pin** and remove the **idler bearing**. Wrap the **timing belt** around the **idler pulley** and pinch the belt together to hold the **idler bearing**.

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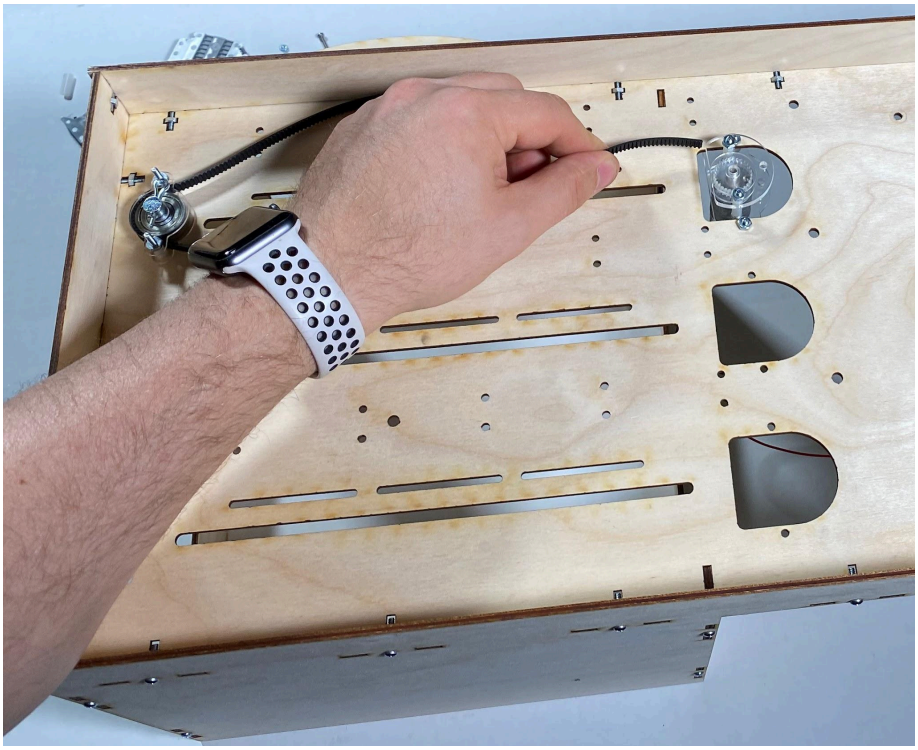
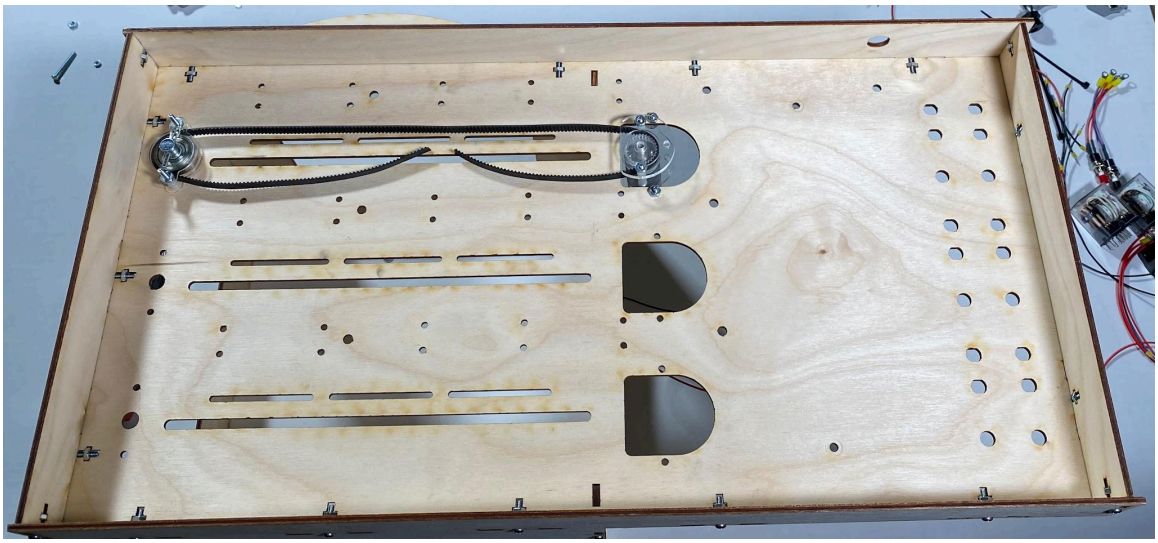
3. Pinching the **belt** to grip the **idler pulley**, reinstall the **idler pulley**.



4. Install the other end of the belt around the winch pulley.



5. The belt should now be installed with the free ends on the upstage side of the track (closer to the **Back Wall**).



6. To connect the ends of the belt, and create a means to attach scenery to the winch, we use a **deck dog**. Find the pieces of the deck dog and lay them out as shown.
    a. Two (2) **#4-40 X 1” pan head machine screws**
    b. Dog top plate
    c. Dog spacer - 1/16”
    d. Dog spacer - ⅛”
    e. One (1) **dog capture plate**
    f. Two (2) **dog belt grips**

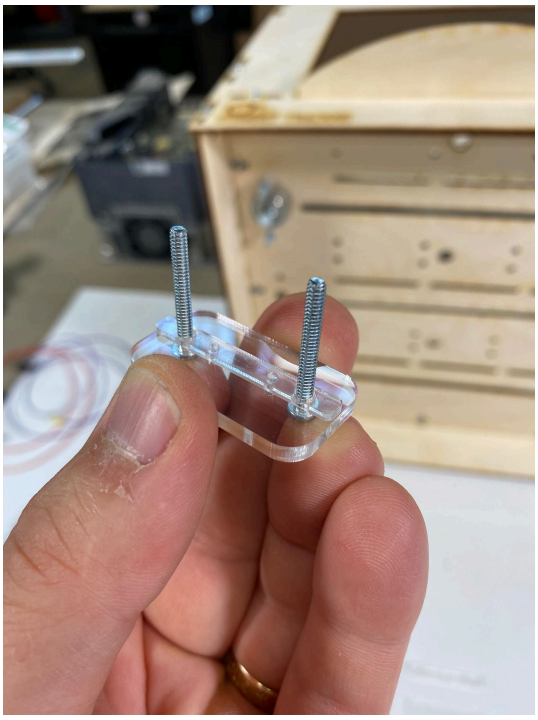
g. One (1) **dog capture plate**
h. Two (2) **#4-40 hex nuts**

Deck Dogs

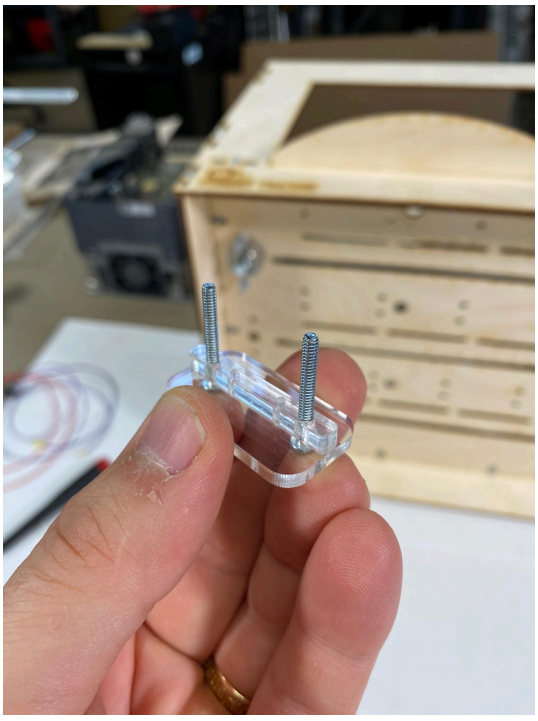
*If you're unfamiliar, a Deck Dog is the piece of hardware that grips the winch hauling line and creates an attachment point for scenery. The dogs run in a track below the performance surface, typically in a false floor or "show deck". There are countless ways to make deck dogs and folks have strong opinions about the *best* way to make a dog. We're not any different. If we are using a winch with wire rope and grooved drum, we prefer to terminate the cable at the drum *not* the dog. We like the dog to clamp onto the cable. Why? So we can change the dog's position on the cable without de-rigging the winch. For timing belt winches, we like to terminate the belt at the dog because it's an easy spot to make the splice, and timing belt winches aren't limited to finite drum capacity like a rope winch. You can see an example of our typical wire rope dog here.*



7. Begin assembling the deck dog by placing the two **#4-40 X 1" panhead machine screws** through the **dog top plate**.



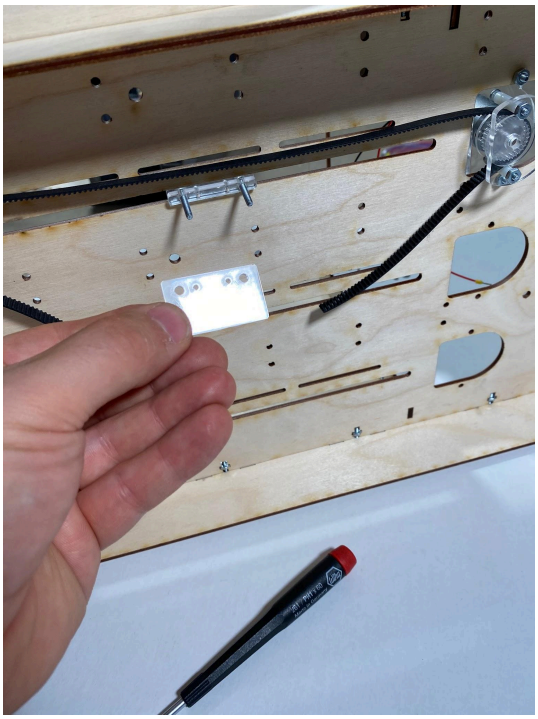
8. Add the **dog spacer - 1/16”**



9. Add the **dog spacer - ⅛”**



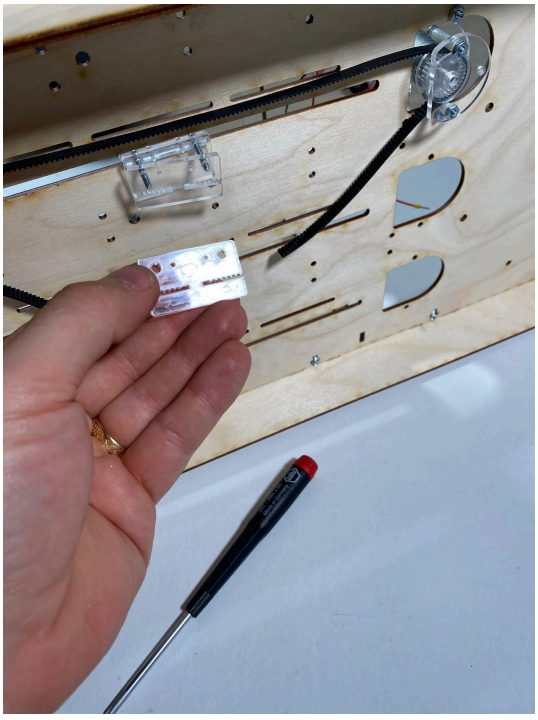
10. Insert the **dog** to Winch Track #1 from the top of the **Stage Floor**. The two spacers should slip into the track slot, but the top plate will stay on top of the **Stage Floor**.



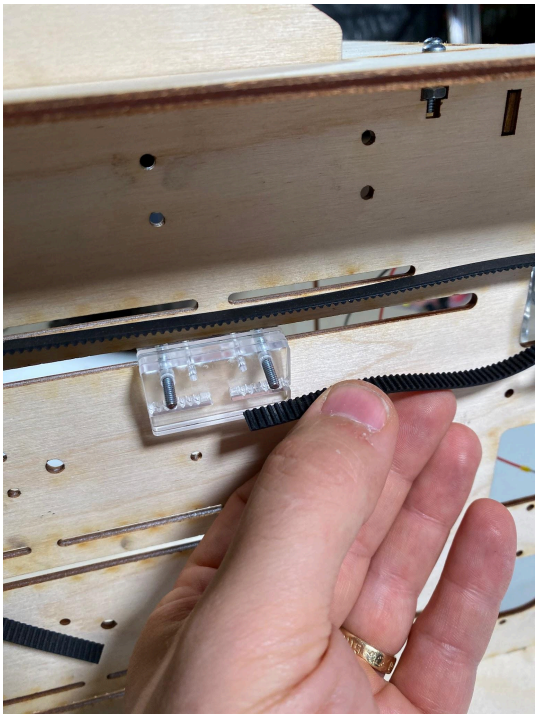
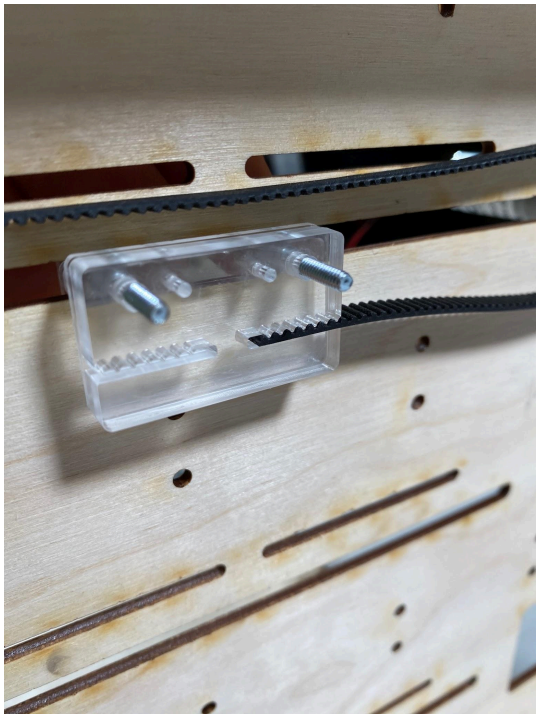
11. From the underside of the **Stage Floor**, hang one of the **dog capture plates** onto the protruding screws. The wide portion of the **dog capture plate** should point upstage, towards the back wall.



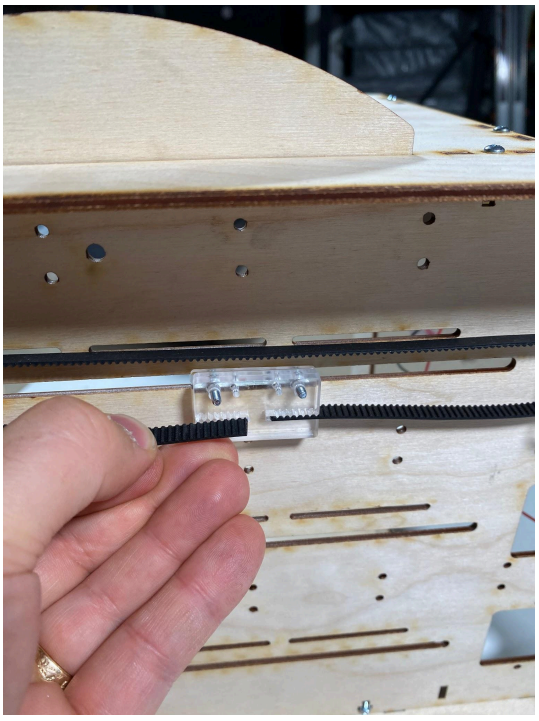
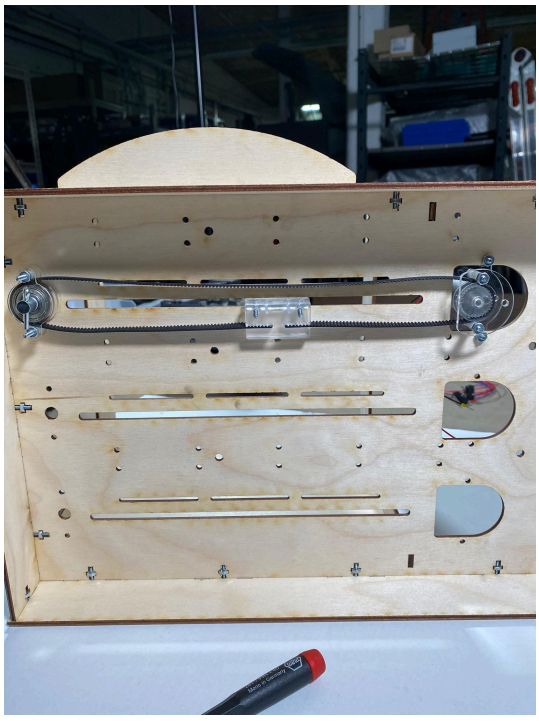
12. Next, add on the first **dog belt grip**.



13. And then the second **dog belt grip**.

14. Fit one end of the belt into the **belt grips**.

15. Fit the second end of the belt into the belt grips to complete the belt loop.

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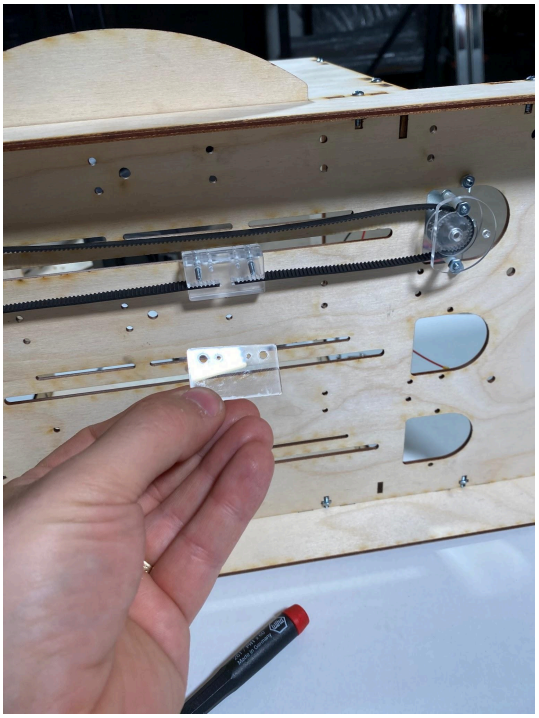
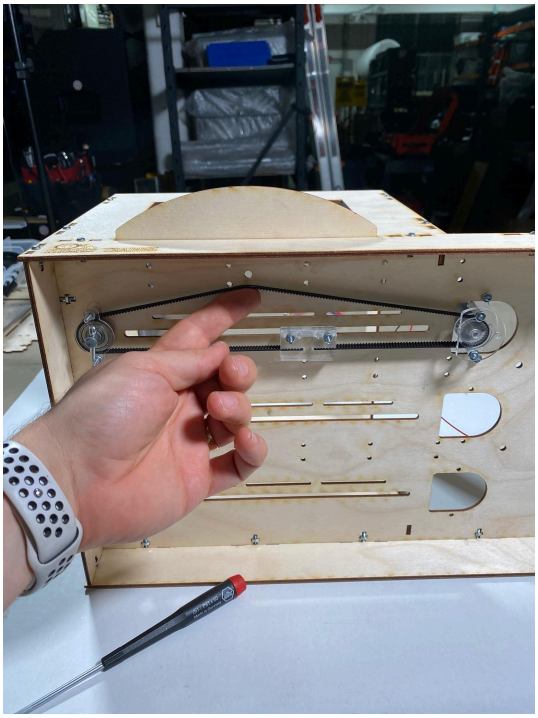
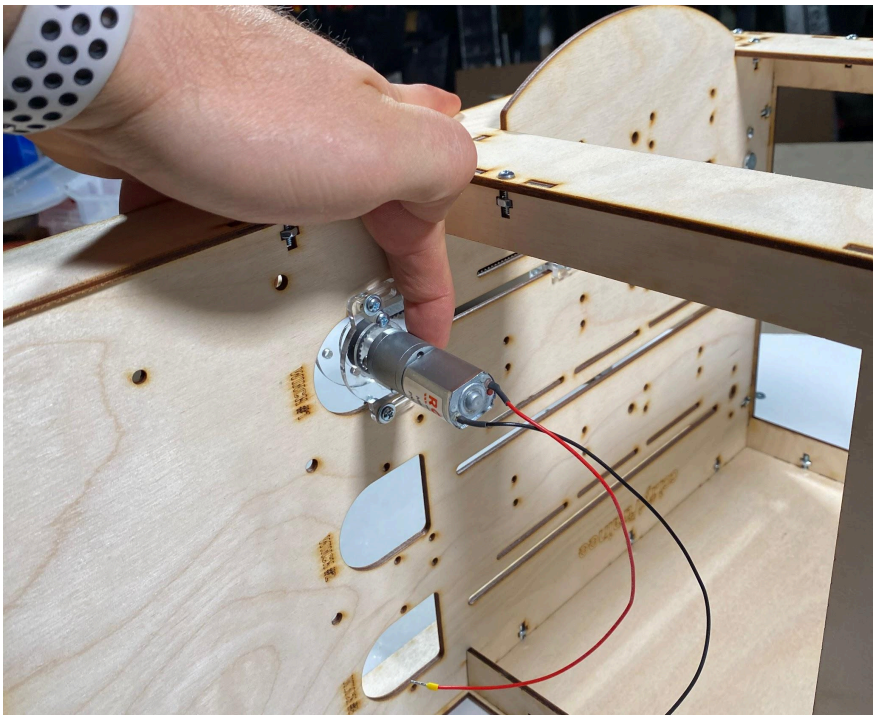




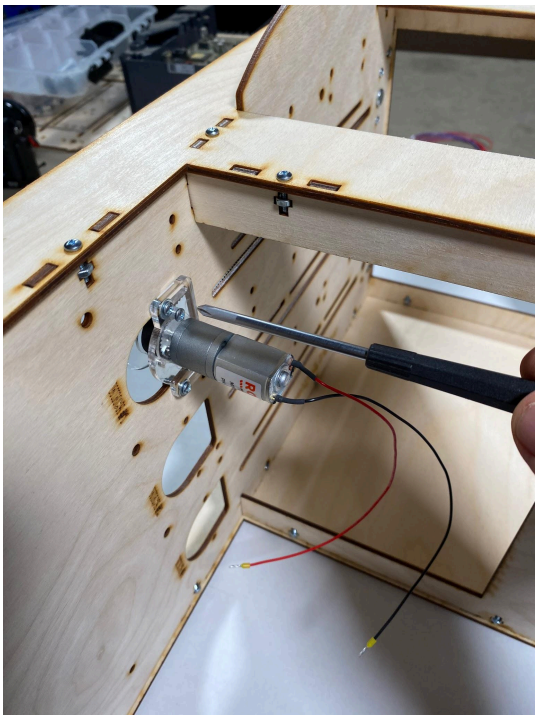
16. To complete the dog, install the last **dog capture plate** and secure the **dog assembly** with two (2) **#4-40 hex nuts**.



17. This is great, but the belt is too loose to drive the dog back and forth.



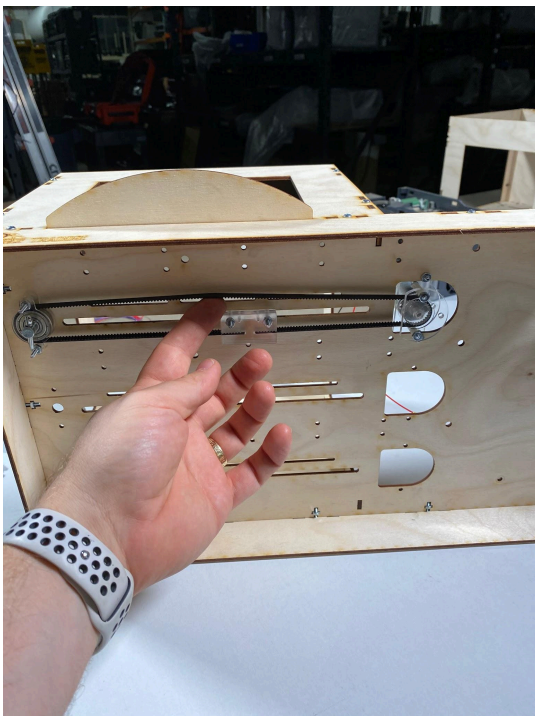
18. To tension the belt, slide the winch offstage.



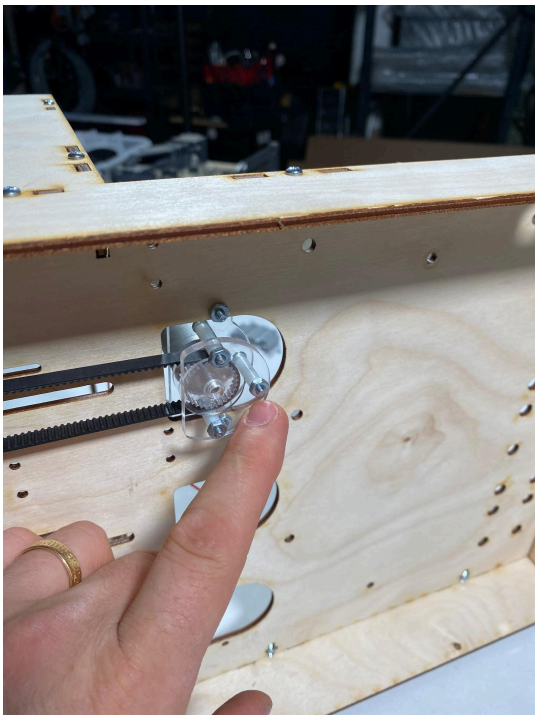
19. While holding tension on the winch belt, tighten the winch mounting screws to keep it in place.

Deck Winch Tensioning

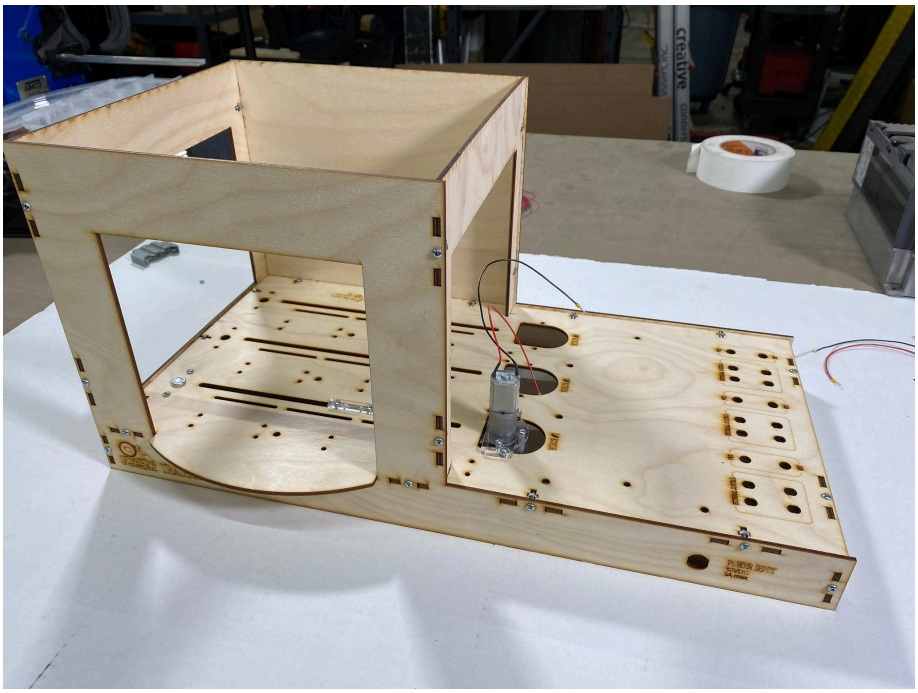
Whether you are using timing belt or wire rope on your winch, you need to design some way to tension the hauling line. The most convenient place to put the tensioning mechanism is at the winch, rather than making a separate device that has to live elsewhere in the winch track. You'll need access to the winches anyway, so if the tensioning mechanism is built into the winch you are guaranteed to have easy access. The more features you can pack into the winch, the easier it will be to make adjustments during load-in, tech, and run.



20. The belt will still have a little play but most of the slack should now be gone.



21. With the belt installed and tensioned, you can install the last #4 X 9/16” spacer on the winch.



22. Nice! The winch is now installed.

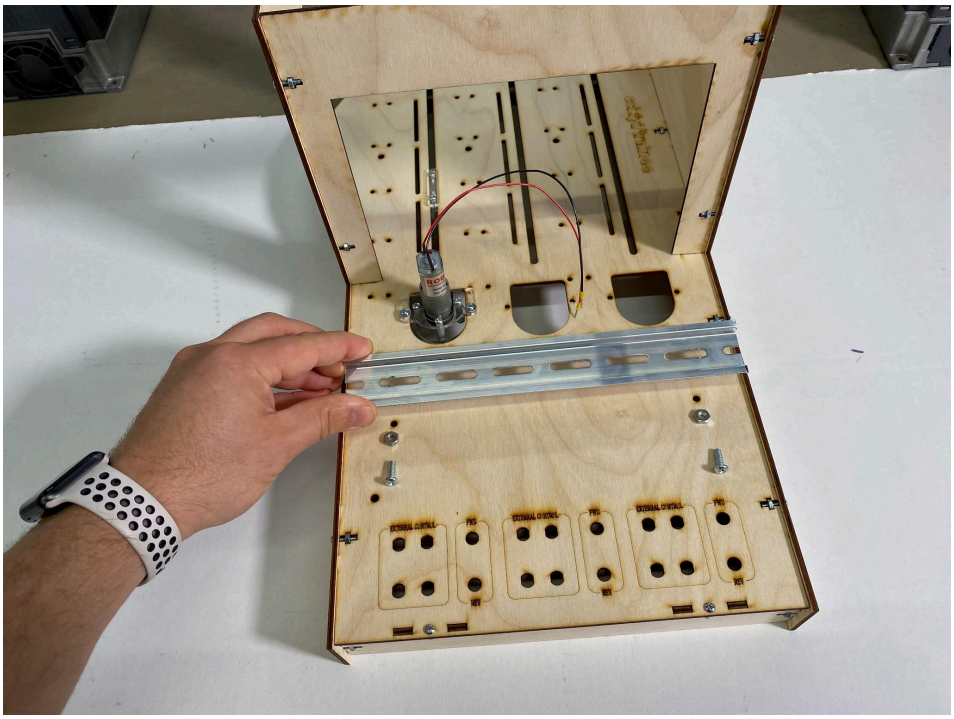
Wiring

In this section we will walk you through the wiring hookup to get your winch moving. But to learn more about the technical concepts behind the wiring and how it works, check out these other resources:

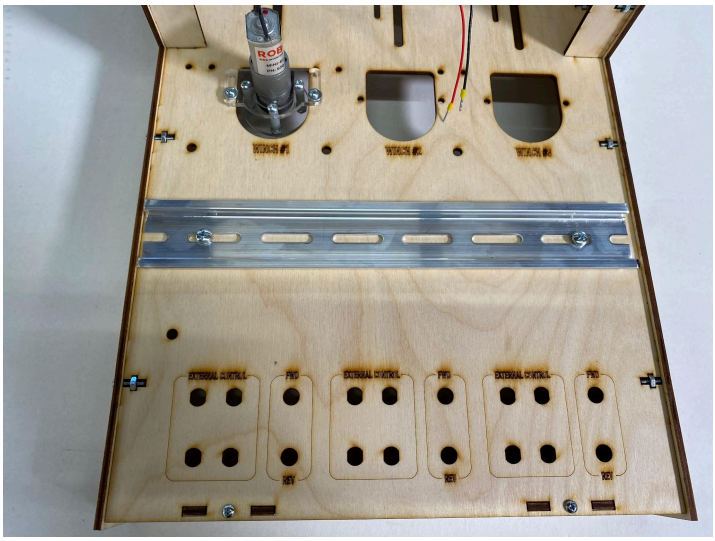
1. The electrical schematic
2. Our YouTube video that steps through the design process for developing this simple control schematic (https://cci.fyi/trainee-schematic)

Ok, onto the wiring...

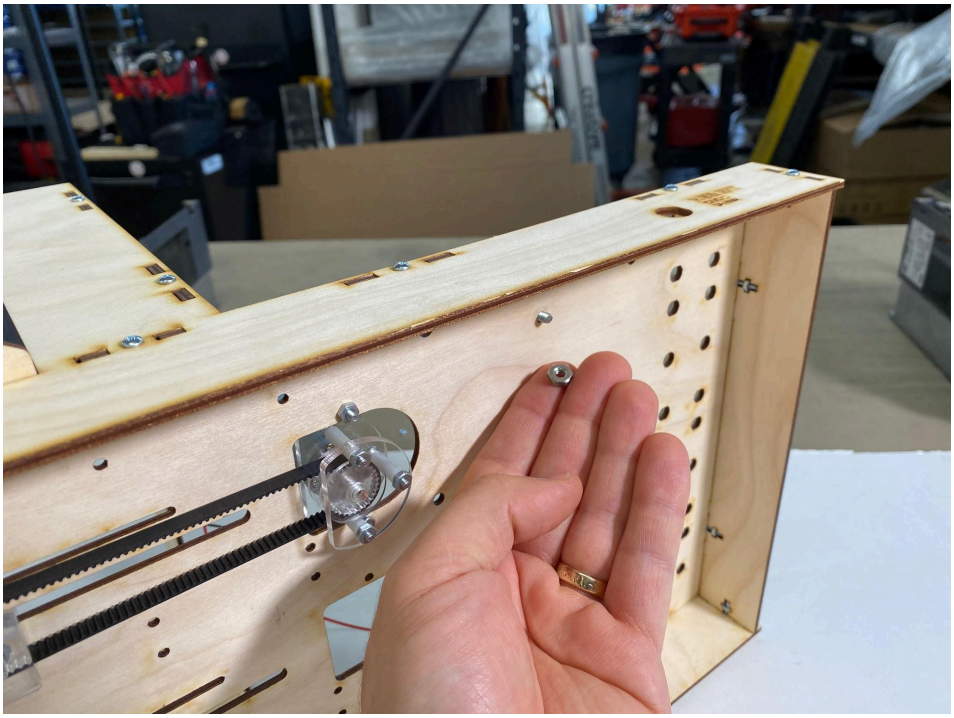
Mounting the DIN Rail



1. Locate the **DIN rail** (the aluminum channel), two (2) **#8-32 X ½" panhead machine screws**, two (2) **#8-32 hex nuts**.

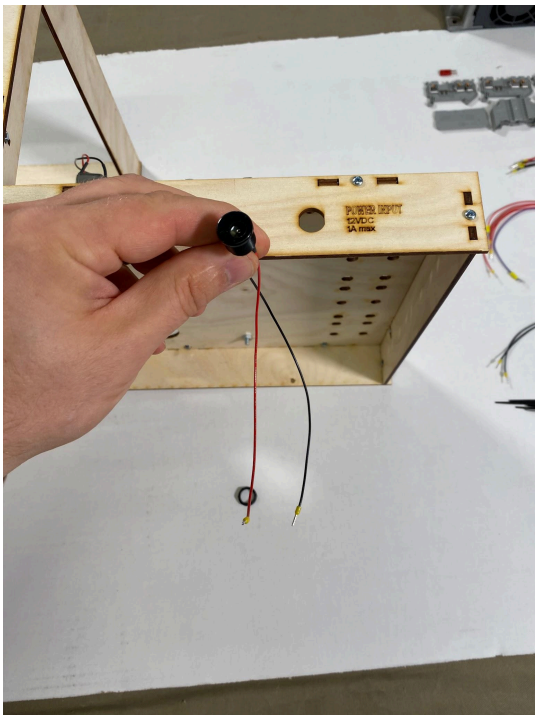


2. Place the **DIN rail** on the **Stage Floor** just offstage of the winch. Use the **#8-32 x ½" panhead machine screws** to secure it to the **Stage Floor**.

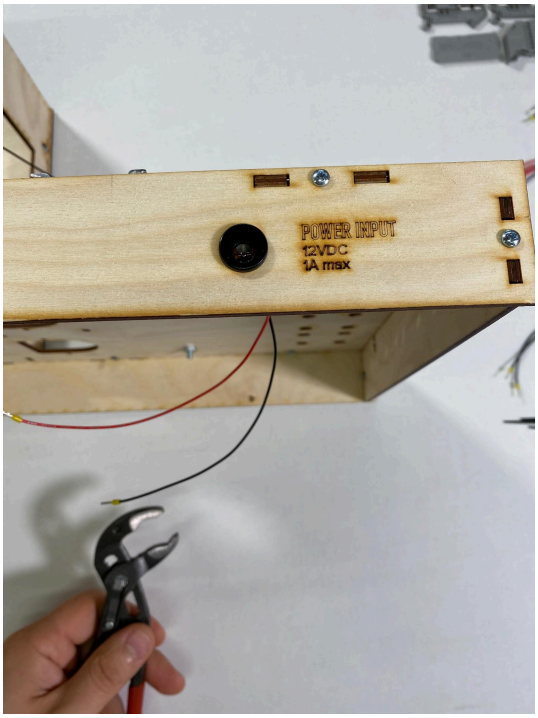


3. Use **#8-32 hex nuts** from the underside of the **Stage Floor** to secure the **DIN rail**.

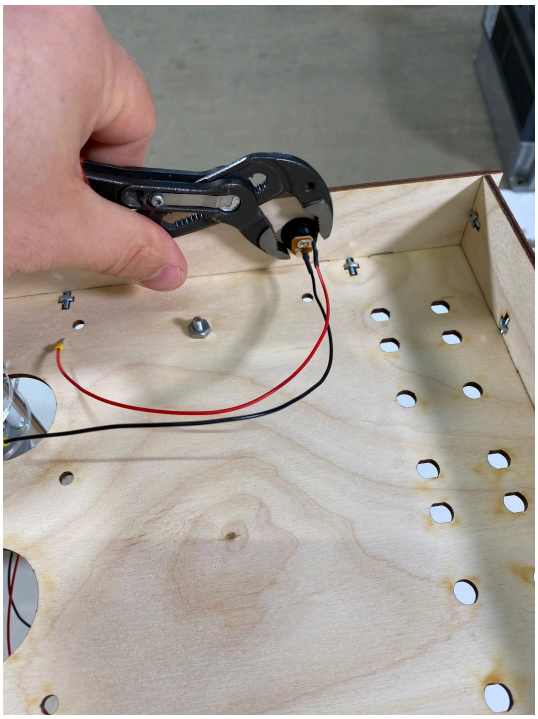
Power Jack



1. Remove the fixing nut from the back of the power jack.

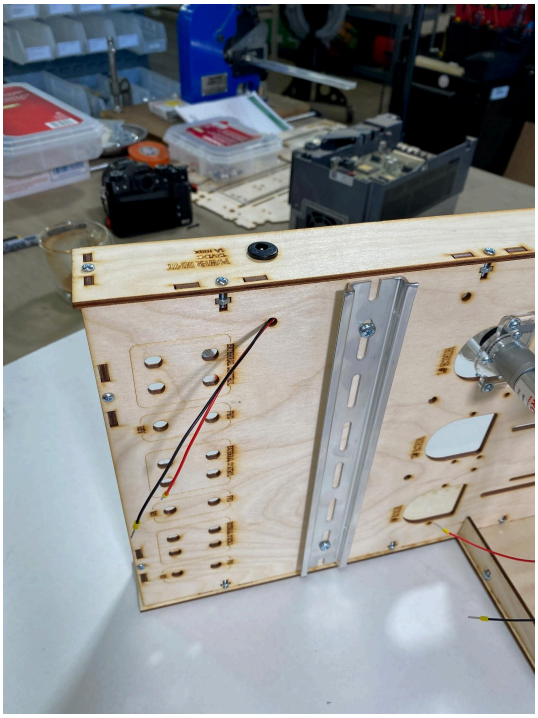


2. Feed the wires through the power jack hole in the **Proscenium** and mount the power jack.



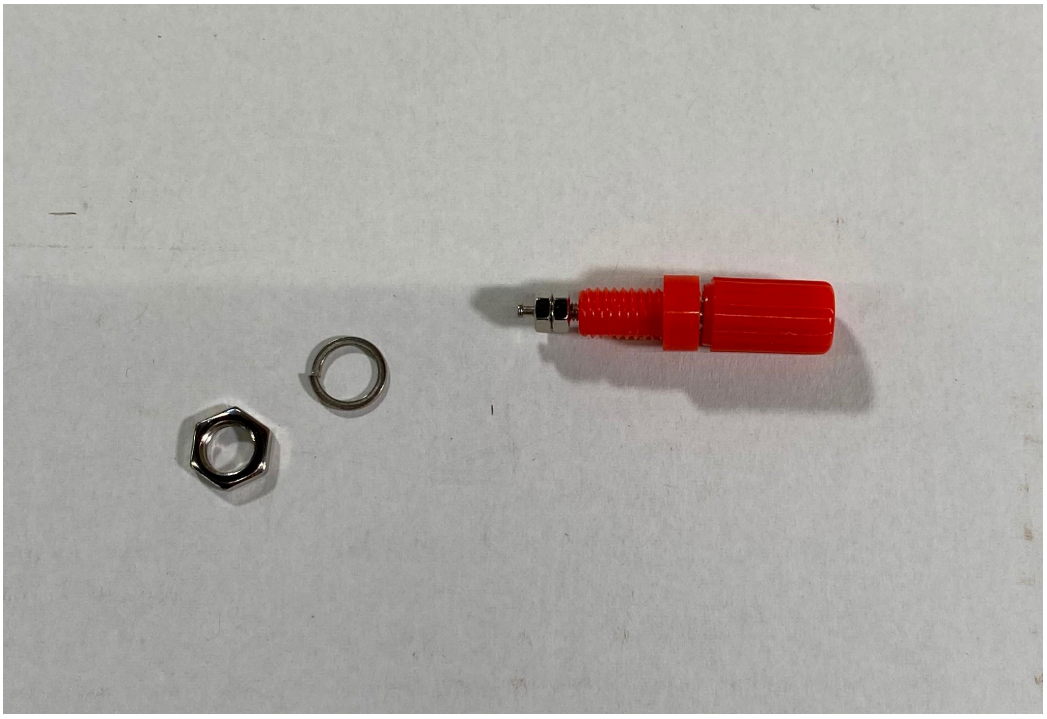
3. Reinstall the backing nut and tighten it snugly (but don't go crazy, it's all plastic).





4. Feed the red and black power wires through the chase hole in the **Stage Floor**.

Banana Jacks



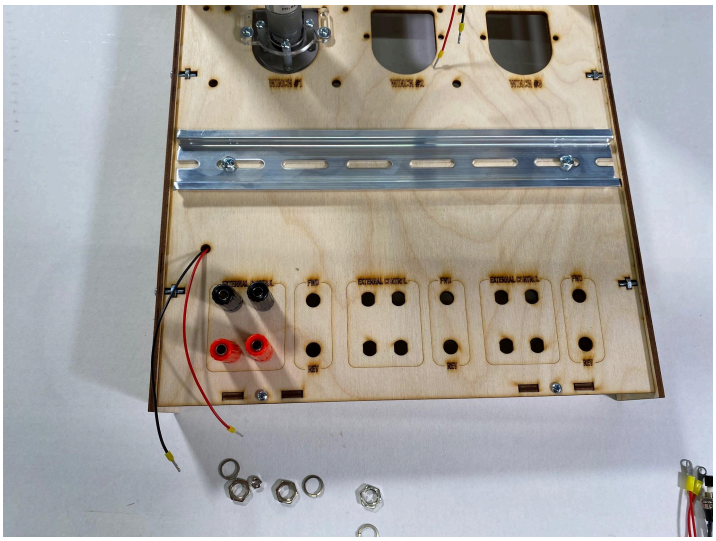
1. Find two (2) **red banana jacks** and two (2) **black banana jacks**. Remove the mounting nuts and lock washers as shown above.



2. Install the **red jacks** in the offstage position of the **External Control** area. For ease of remembering, we're going to designate the red jacks as the reverse direction (red = reverse). This is just a handy mnemonic, not a rule.

Conventions for convenience

We are slightly abusing the red *and* black *color conventions here. Normally* red *= positive voltage and* black *= common. In our case both jacks are positive voltage, so we've chosen* red *= reverse because it's easy to remember. We make up these conventions sometimes to make assembly and maintenance easier for our technicians. For instance when we number wires and one wire is* common *and the other is* positive *voltage, the lower number is always the* common*. Why? Well,* common *is also called* ground *(not protective earth ground, that's different. I know, the lingo gets a bit confusing) and* ground *is low. So the lower number is* ground *or* common*. When you're in a genie, or stuffed under a show deck, with a flashlight in your mouth trying to troubleshoot a connection and your paperwork is at the tech table it's nice to rely on a convention to make sense of the wiring. This is not a rule, nor even an industry standard, just a pragmatic tip.*

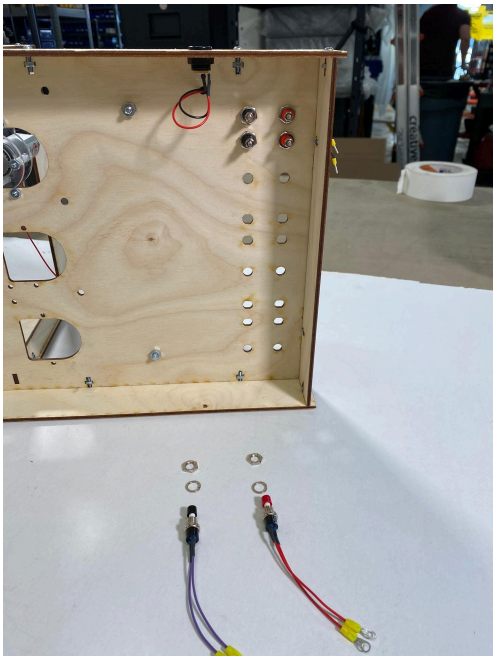


3. Install the black banana jacks in the onstage holes, as shown above.

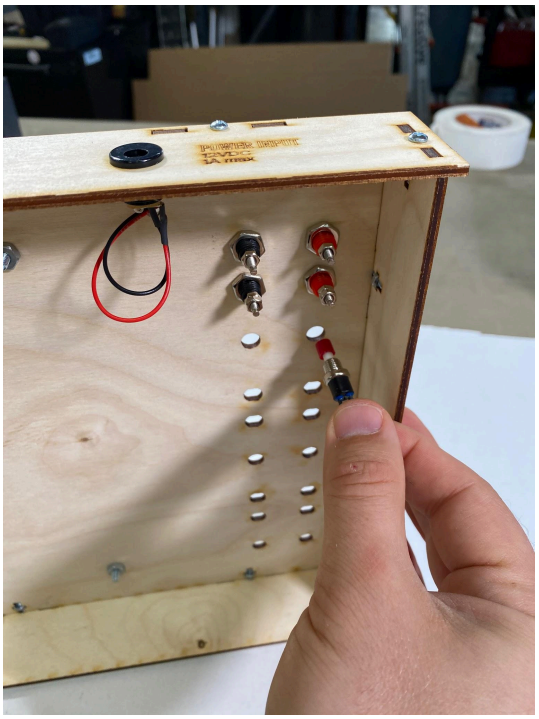


4. Secure the banana jacks with their lock washers and nuts from the underside of the **Stage Floor**. A 7/16” socket is handy for this step - do not over-tighten.

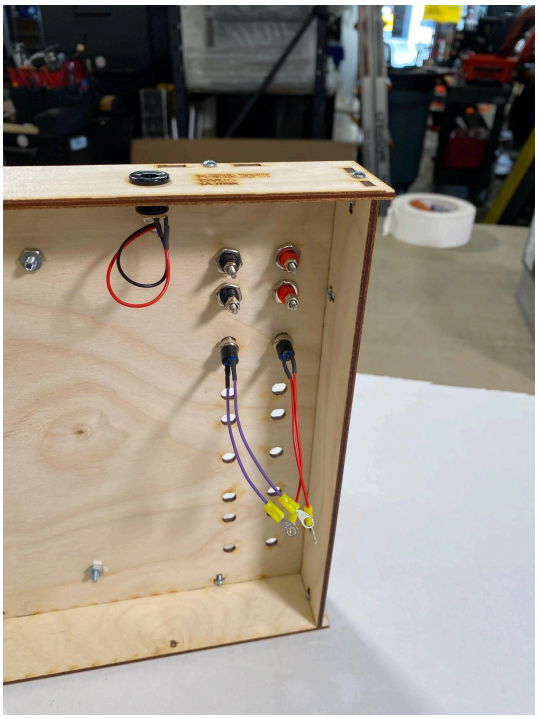
Push-button Switches



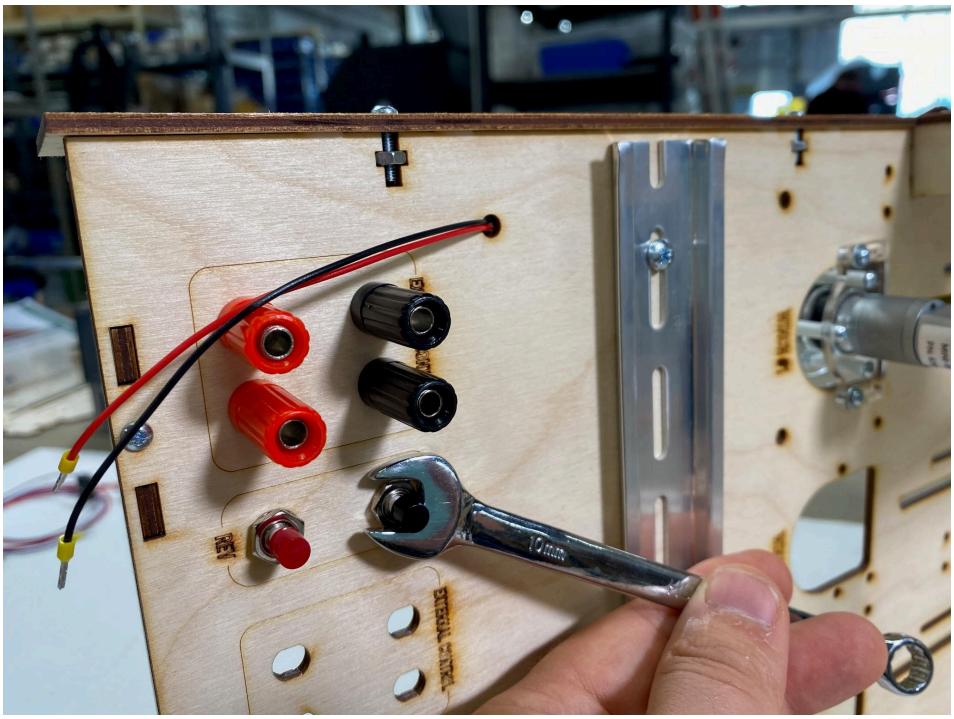
1. Find the **black** and **red push-button switches** and remove their mounting nuts and lock washers.



2. Insert the **red push-button switch** into the mounting hole directly upstage of the red banana jacks.

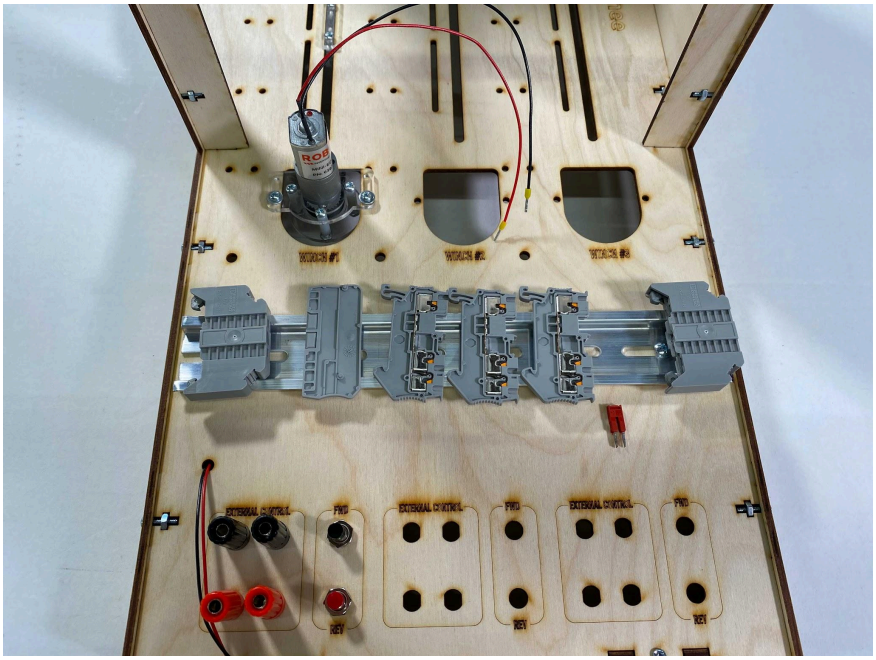


3. Insert the **black push-button switch** into the mounting hole directly upstage of the black banana jacks.



4. Secure the push-button switches from the top of the Stage Floor with their nuts and lock washers.

Terminal Blocks and Relay Switches



1. From downstage to upstage, arrange your components like so:
    a. **DIN end clamp**

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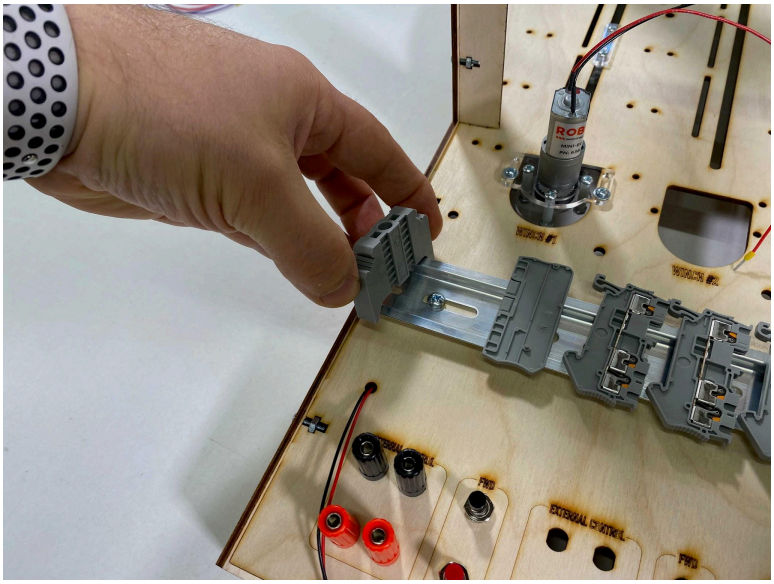
b. **DIN terminal cover**
c. Three (3) **DIN terminal blocks**
d. **DIN terminal jumper**
e. **DIN end clamp**

DIN Rail FTW

If you haven't used DIN rail before, it's delightful. The track is a standard size. If you buy aluminum DIN rail you can easily cut it with a wood saw. Loads of industrial electrical components are designed to snap onto DIN rail for quick mounting. This allows you to mount a chunk of DIN rail in your control panel and not have to fuss with mounting each component individually and drilling out numerous special hole patterns. You can also easily rearrange, add, remove parts from the DIN rail. You'll find DIN rail used in most commercially manufactured electrical control panels.



2. Begin placing the components on the DIN rail. Hook the DIN end clamp over one edge, then snap the other side down.

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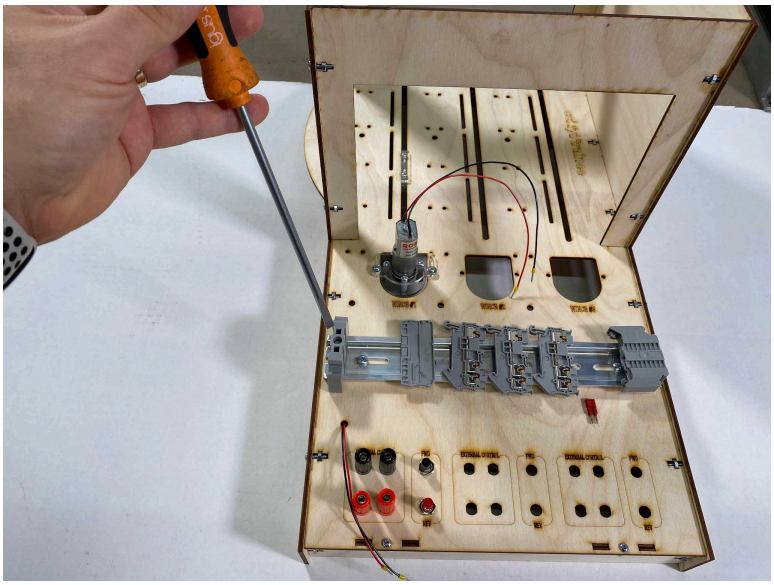
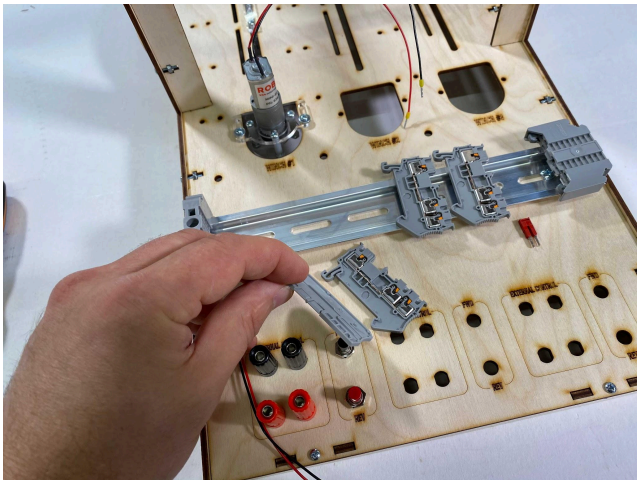
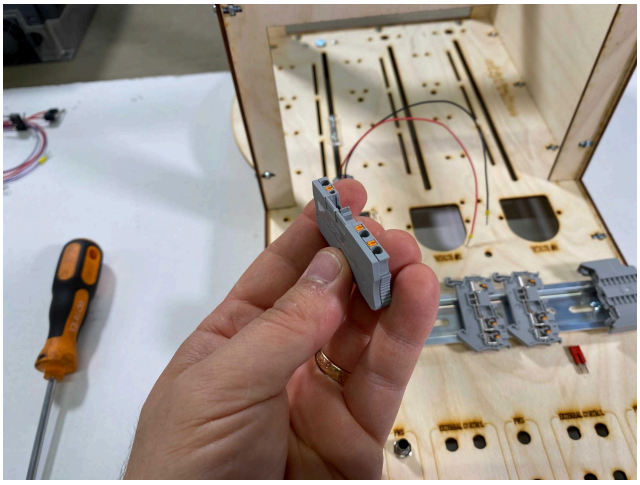
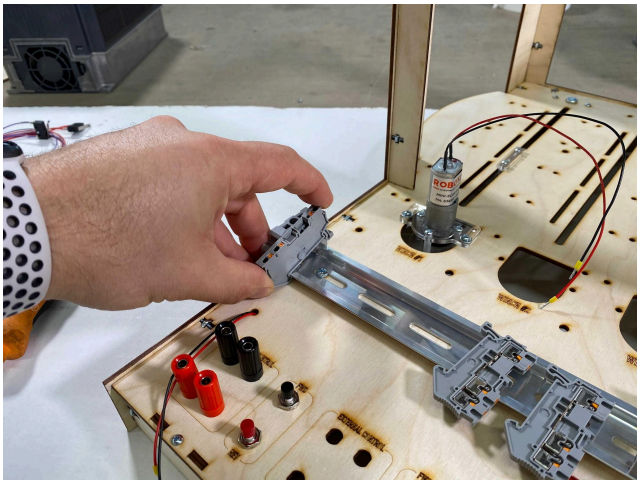


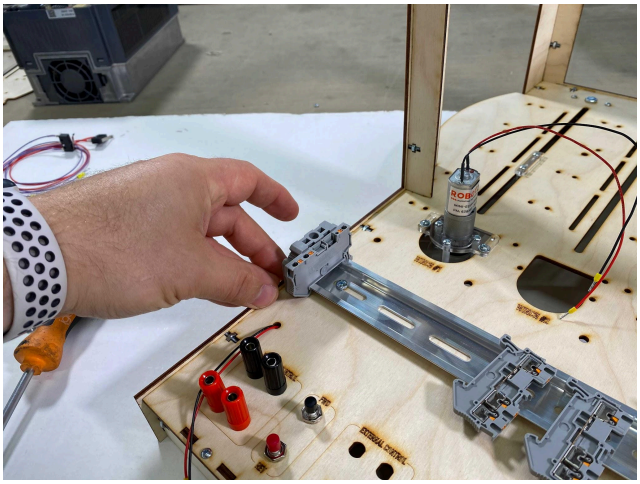
3. Secure the clamp at the end of the rail by tightening the center lock screw with a flat-blade screwdriver.



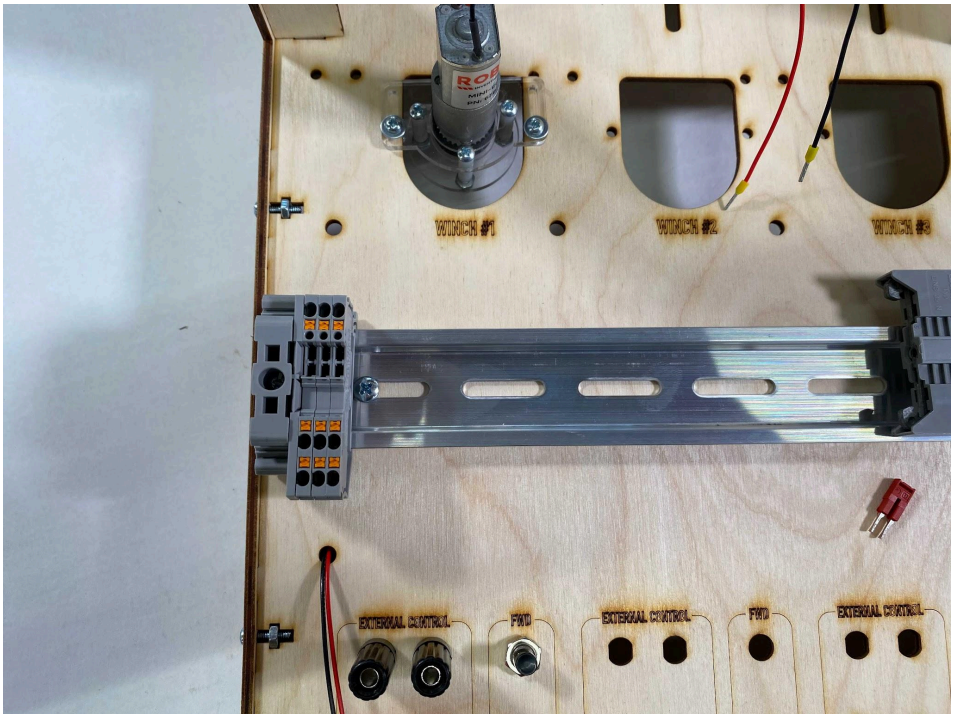


4. **DIN terminal blocks** have exposed electrical contacts on one face. Those contacts are typically insulated by the abutting terminal block. The last terminal block in the row requires a cover for insulation. Install the **DIN terminal block cover** onto the downstage **DIN terminal block**.





5. Install the first **DIN terminal block** by hooking it over the DIN rail, and then pressing down to snap it into place.



6. Repeat the process to install all 3 **DIN terminal blocks**.

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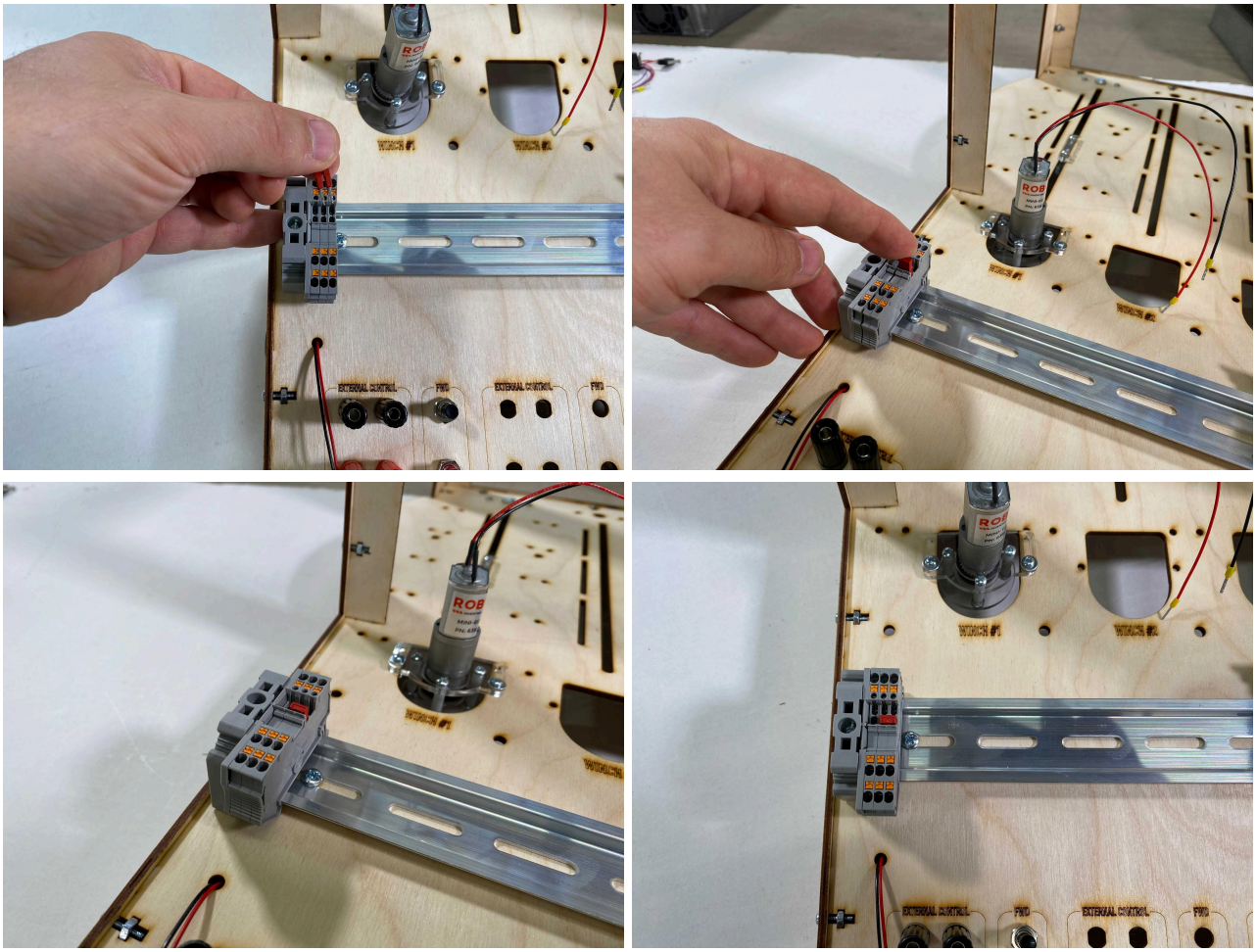
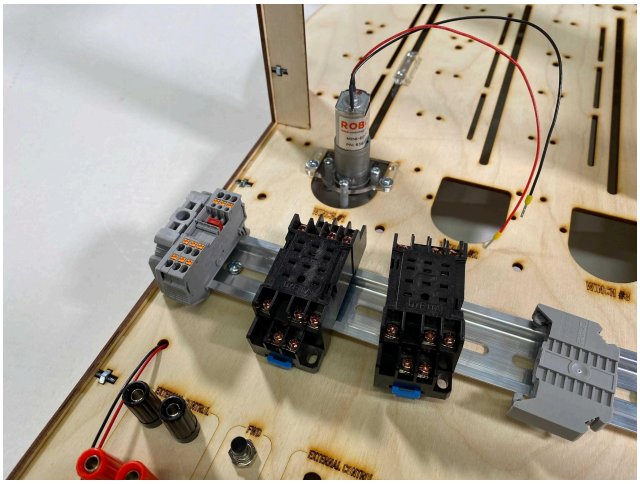
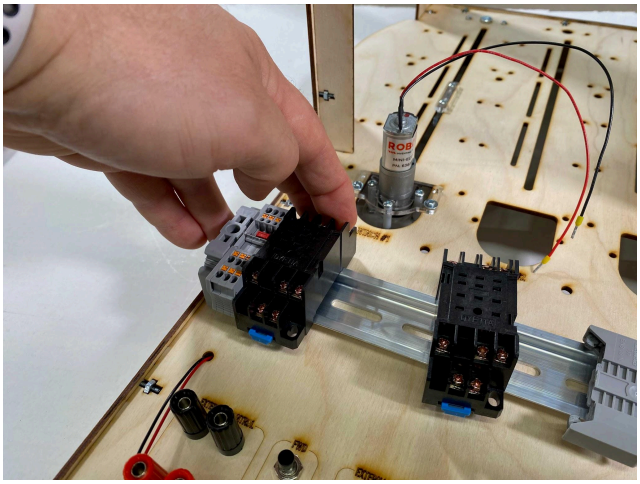
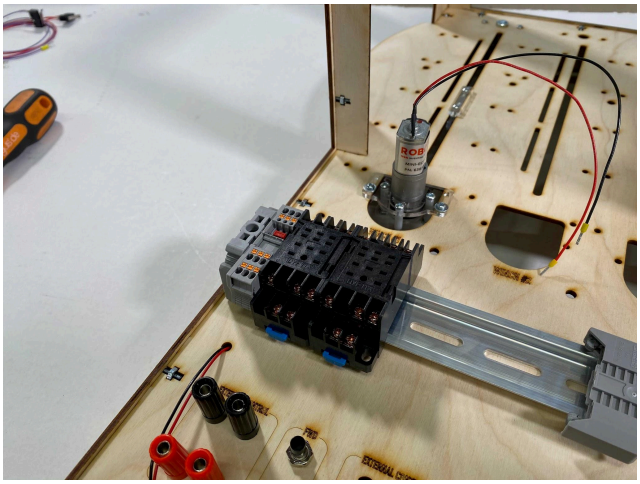
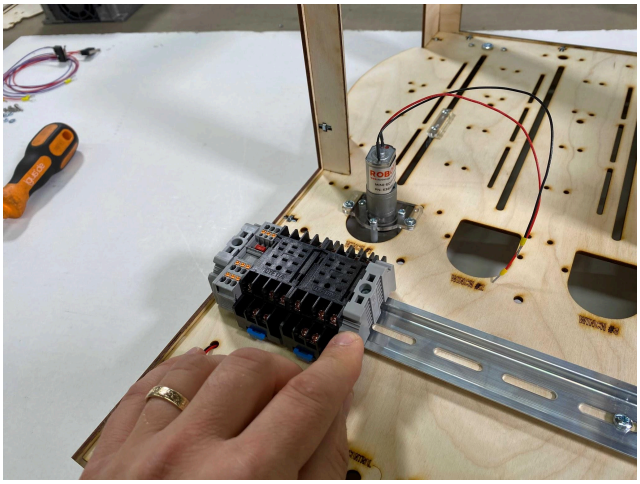


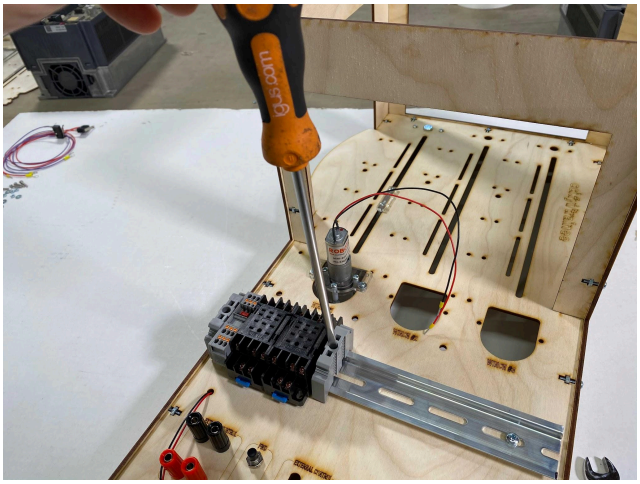
7. The upstage pair of **DIN terminal blocks** are going to become a bus for our +12VDC power – all ports in both **terminal blocks** will be electrically joined. To electrically connect terminal blocks, we can use a **DIN terminal jumper** (the red fork). Install it into the terminal blocks as shown above. Press it down firmly until the top of the jumper is flush with the terminal blocks. You can always remove this jumper by prying it up with a small screwdriver ***(with the power off!)***

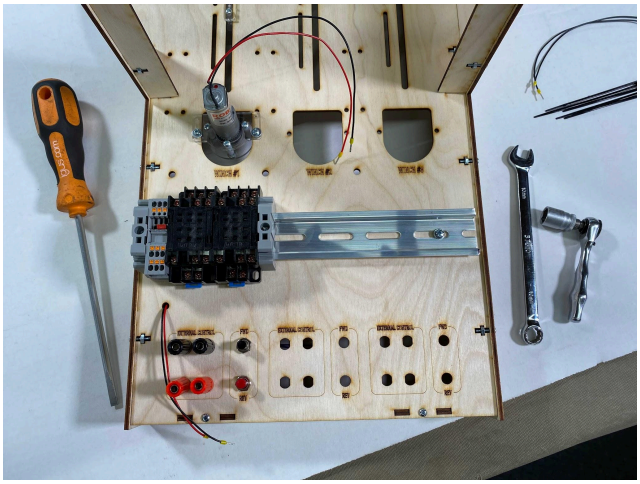



8. Next install the **3PDT relay sockets** onto the **DIN rail**. Pay attention to the orientation. The blue release tab should face offstage. Same process as before, hook it over the **DIN rail** and then press down. Isn't **DIN rail** easy to use?

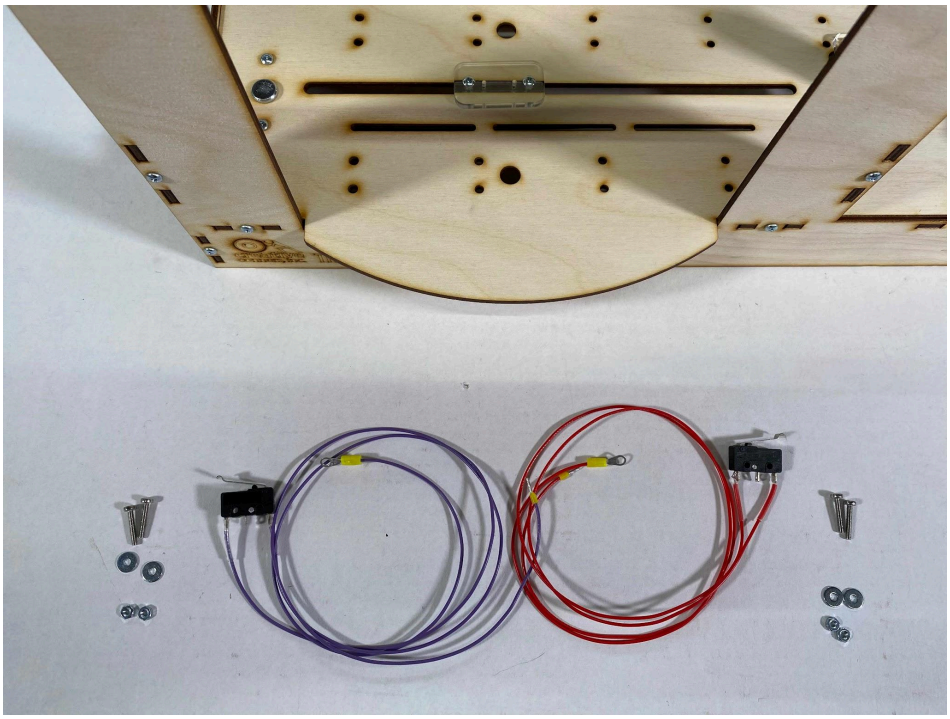
9. With both 3PDT relay sockets installed, place the second DIN end clamp on the rail. This will prevent your components from sliding around.





10. Tighten the DIN end clamp and voila! We're ready to start wiring next.

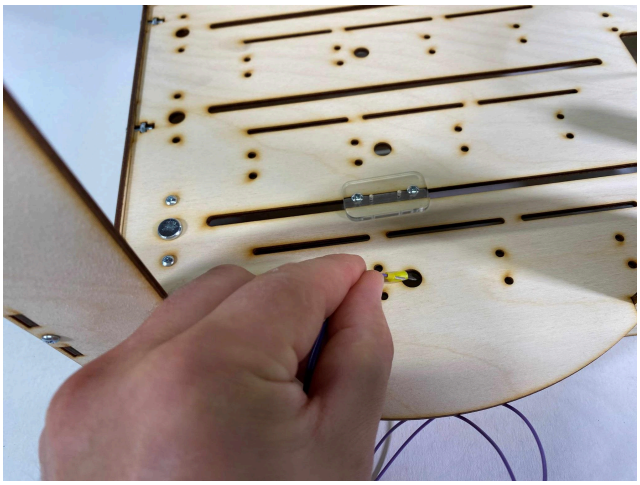
Limit Switches

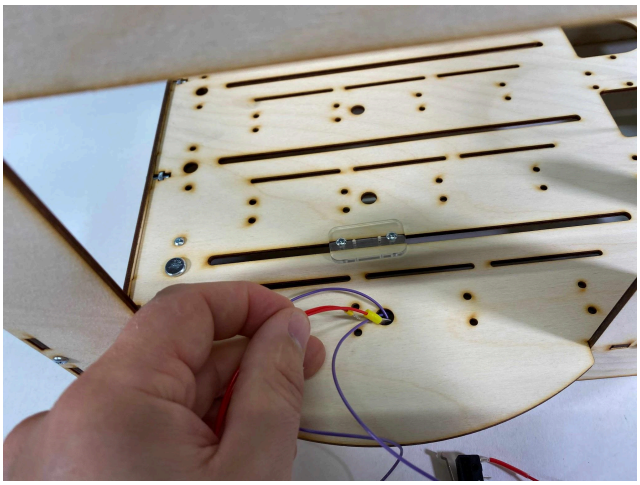


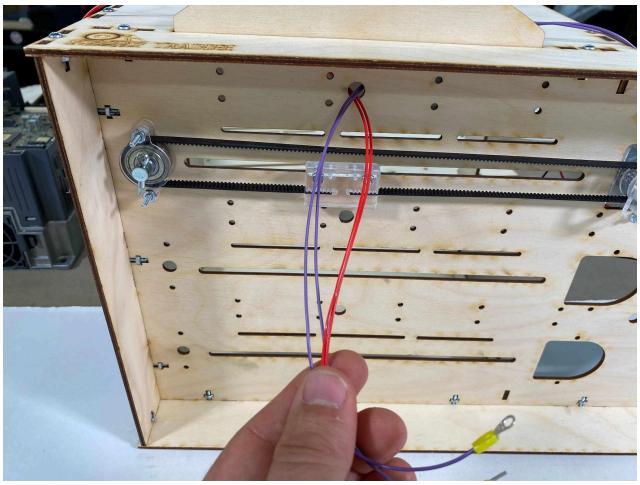
1. Collect the parts to mount the limit switches to Winch Track #1:
    a. Four (4) **M2.5 X 14mm panhead machine screws**
    b. Four (4) **M2.5 flat washers**
    c. Four (4) **M2.5 hex nuts**

d. **Forward limit switch** (purple wires)

e. **Reverse limit switch** (red wires)

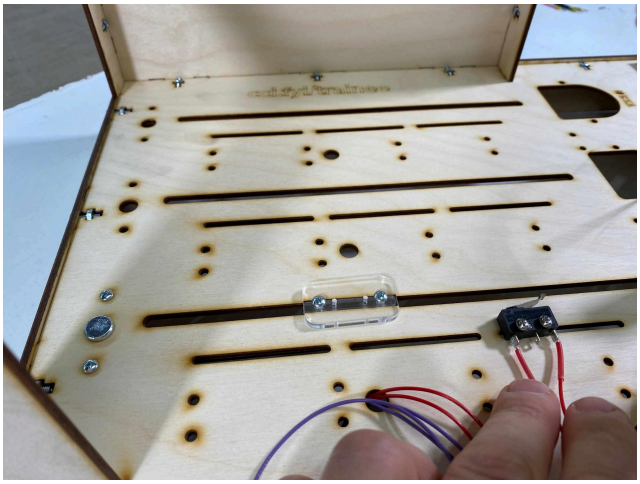




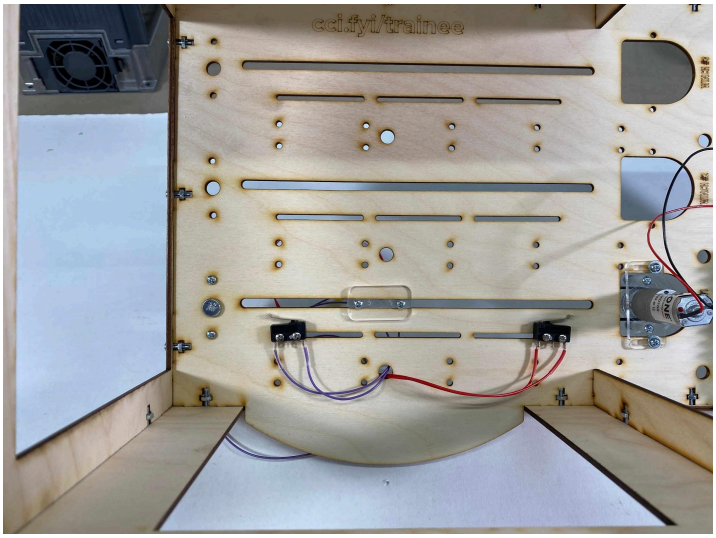


2. Feed all four wires from the limit switches down through the 5/16” hole downstage center. Tip the theatre up and tug all the slack to the underside of the **Stage Floor**.

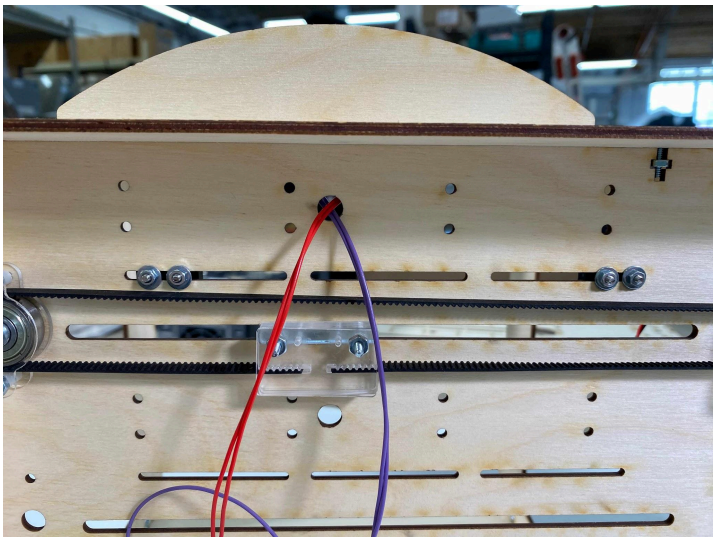




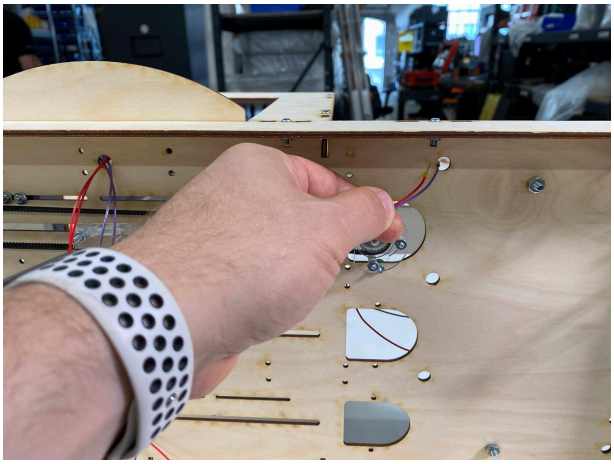
3. Use two (2) of the **M2.5 X 14mm panhead machine screws** to mount the **reverse limit switch** (red wires) on the furthest SL limit slot, located downstage of Winch Track #1. Pay attention to the orientation of the switch. The hinge of the actuator arm should be onstage as shown in the picture.

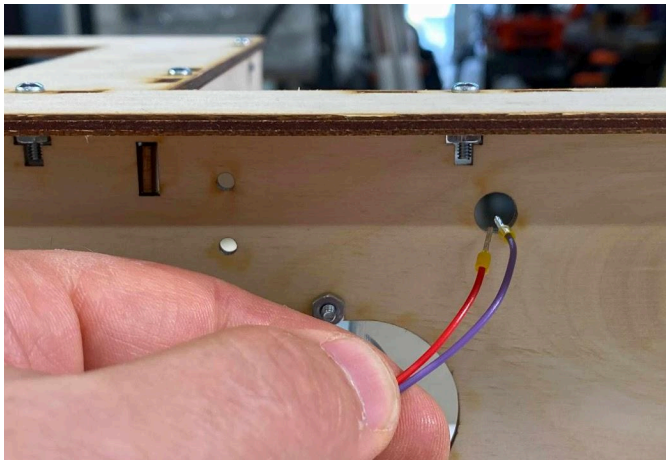


4. Repeat the same procedure to loosely place the forward limit switch (purple wires) in the furthest SR limit slot, located downstage of Winch Track #1. Pay attention to the orientation of the switch. The hinge of the actuator arm should be onstage as shown in the picture.

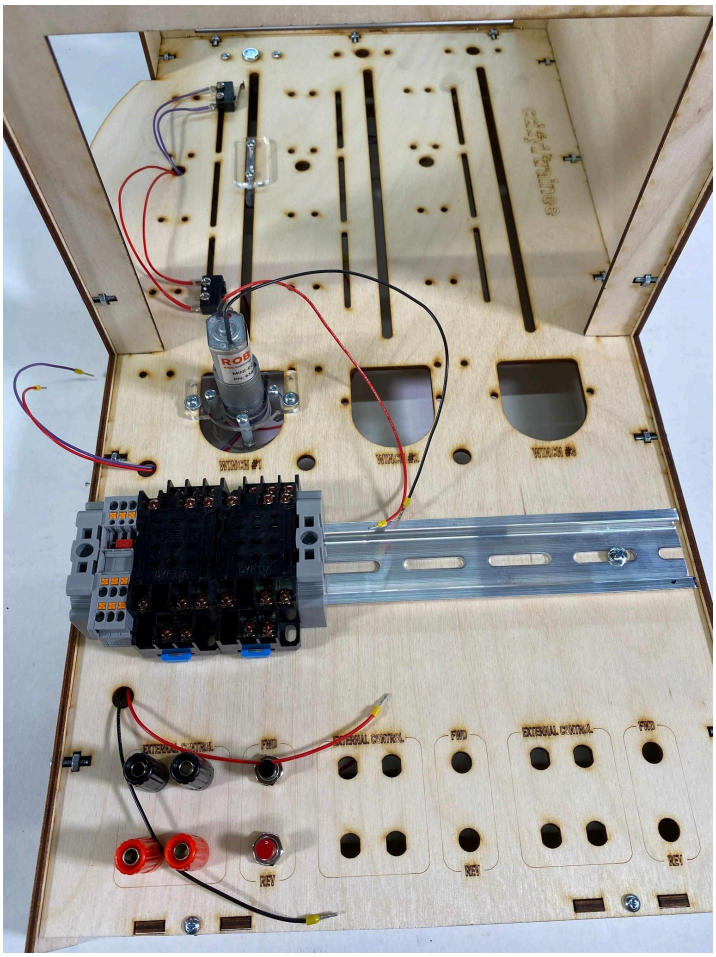


5. Tip the theatre onto its back, and secure the limit switch mounting screws with **M2.5 flat washers** and **M2.5 hex nuts** as shown.





6. Separate out the red and purple limit wires that have a ferrule crimped on the end (instead of a ring terminal). Take the ferruled ends and poke them up through the **Stage Floor** through the 5/16” chase hole near the **DIN rail**. Leave the wires with ring terminals under the stage.



7. Your wiring should look like the picture above at this stage (pun intended).

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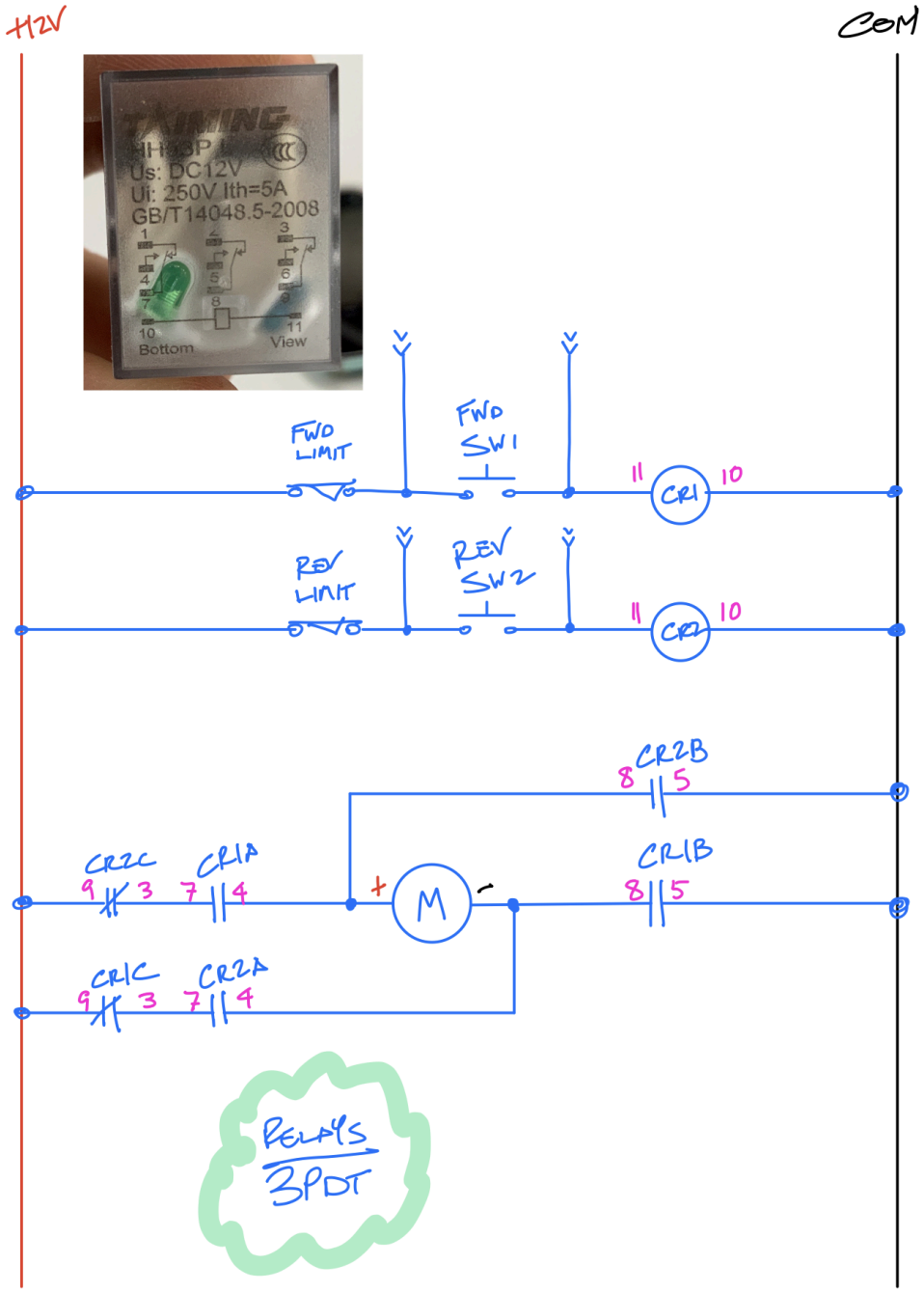
The Schematic



An electrical schematic shows the logical flow of electricity through the circuitry. Since we're going to start wiring the meat of the controls, let's pause and introduce our schematic. Schematics are commonly drawn in CAD, but simple ones can be sketched out on paper, like the Trainee control circuit. It doesn't need to be fancy, but drawing the schematic before you start wiring is important. I'm reminded of the old carpentry adage, "Everything is built twice. First time should be on paper."

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Symbols are used to represent the electrical devices such as limit switches, relay switches, and motors. The symbols are arranged to assist in describing the logic, they bear no relation to the physical location of the devices. In fact relay switch coils and contacts are typically drawn on different rungs of the schematic and their association is conveyed through labeling. For instance the coil of relay CR1 looks like:



The Normally Closed and Normally Open circuits on the relay poles bear the same CR1 label to indicate they are connected to the CR1 coil:



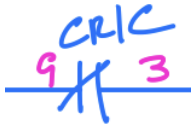
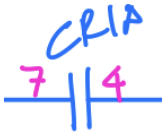


Relay Switches

Relay switches are essentially remote-controlled switches. By running current through the relay COIL, you can open or close one or more switches inside the relay. Each discrete switch is called a POLE. And each POLE has a THROW which describes the number of positions of the switch. A single-throw switch has only one current conducting path. Like a basic light switch it's either on or off. A double-throw switch has two current conducting paths. When one path opens, the other closes giving you a "this or that" behavior. Like... maybe "forward or reverse". In our schematic we are using 3PDT relays, meaning 3-Pole Double-Throw.

To read more about relay switches, and other simple control devices, check out Chapter 7 in the Scenic Automation Handbook.

We'll point out key parts of the schematic along the way, but here's a quick rundown of the symbols used:

Symbol	Device
	Normally-closed limit switch
	Input connector (banana jack in our case)
	Momentary, normally-open pushbutton
	Relay coil. The identifying label is in the center of the circle. On either side (in pink) are the terminal numbers on the physical device.
	Normally-closed relay contact
	Normally-open relay contact
	DC motor

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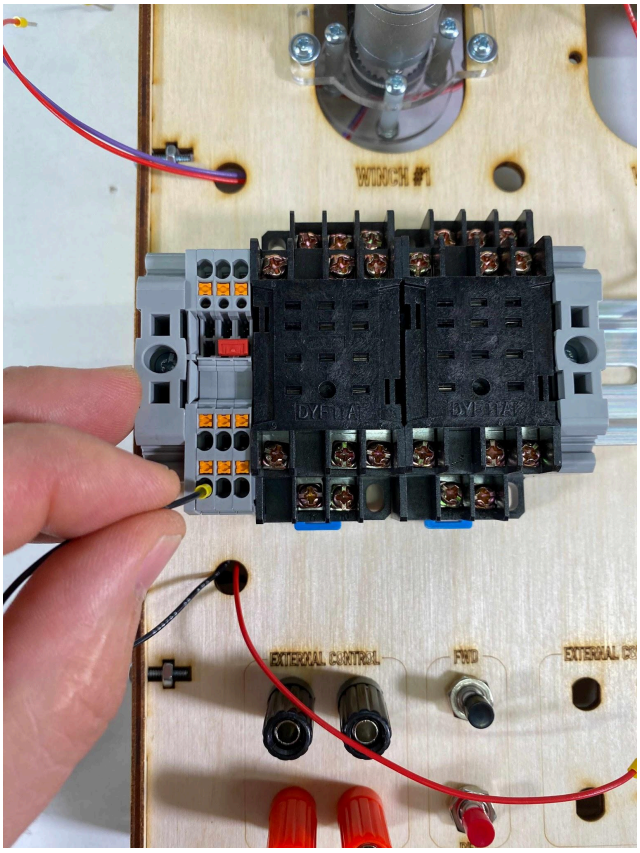
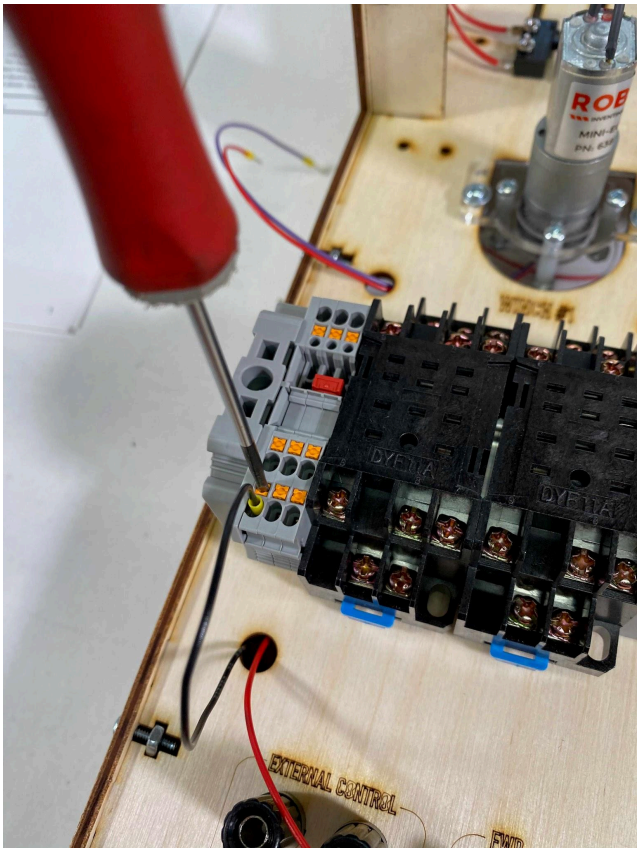
Schematics and Wiring Diagrams

There are loads of schematic symbols. To see the most common ones we use in scenic automation, and learn a bit more about creating and reading both schematics, refer to the Scenic Automation Handbook, Chapter 14.

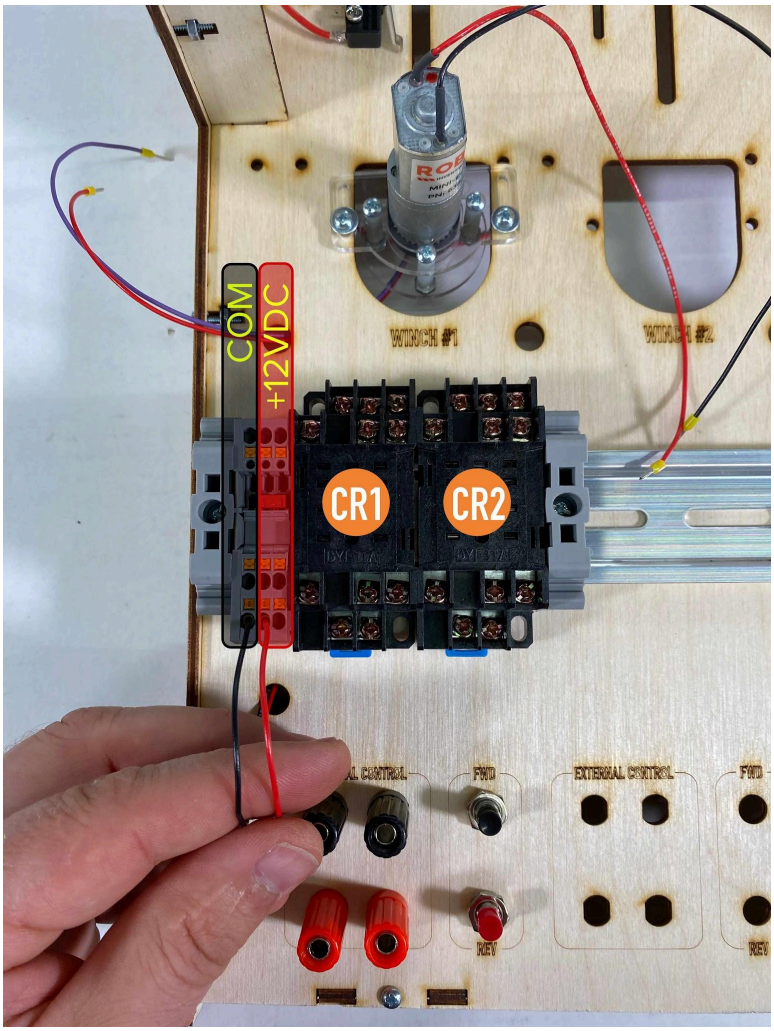
If you'd like to watch a short explanation of how the Trainee schematic was developed, check out the YouTube video at http://cci.fyi/trainee-schematic

Motor Control Circuit



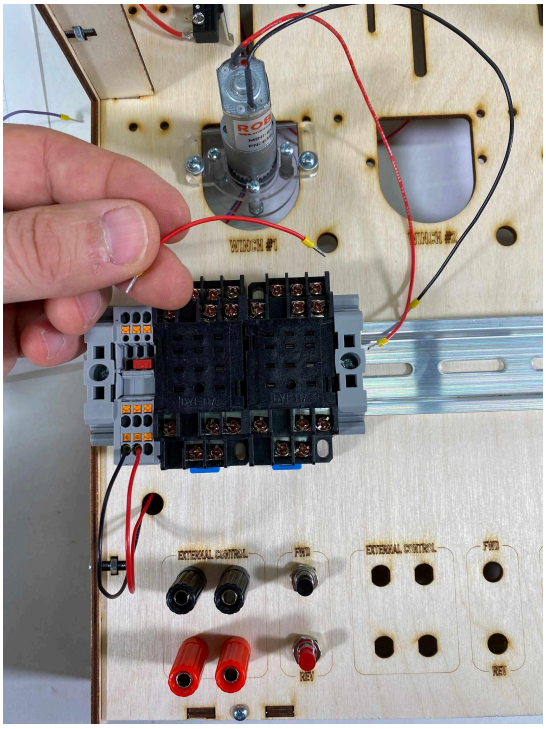
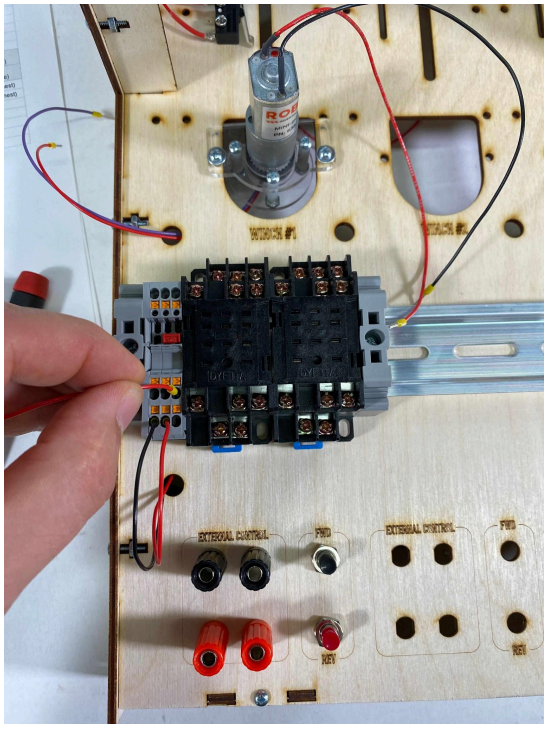


1. Take the black wire from the **power jack** and insert it into the downstage **terminal block**. The **terminal blocks** are push-to-connect, meaning that you only need to push the wire in to make an electrical connection (there's no screw to tighten). However, with small wires that are a bit floppy, sometimes you need to depress the orange button on the **terminal block** to release the wire clamp inside to make insertion easier. Once the wire is fully seated, the yellow insulation collar should be flush to the top of the **terminal block**.

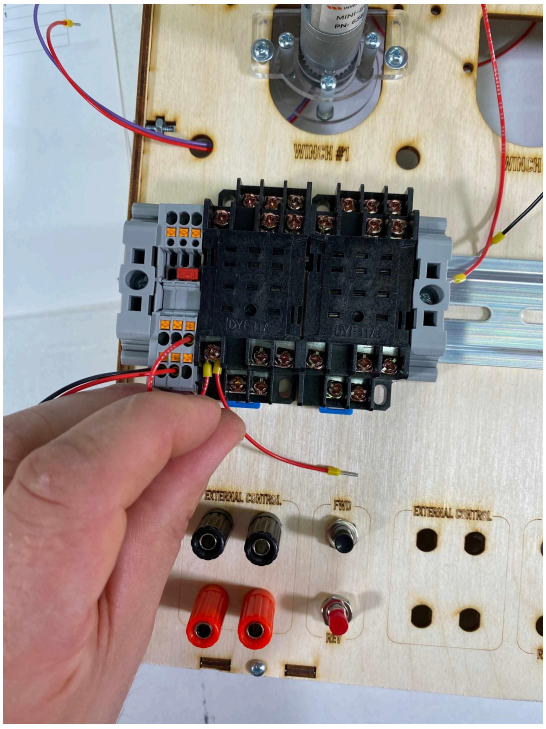
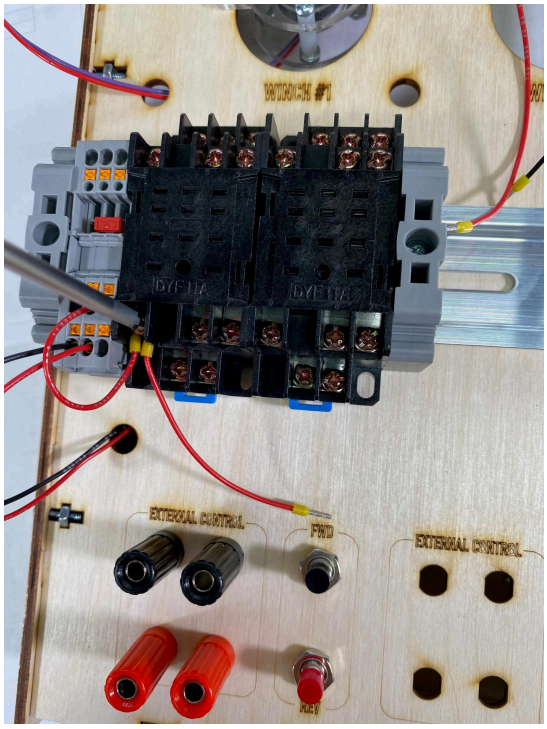


2. Take the red wire from the **power jack** and insert it into the middle **terminal block**. As the photo above illustrates, all ports on the downstage **terminal block** will be COMMON (0 VDC). Because we joined the middle and upstage **terminal blocks** with a **jumper**, all the ports on both **terminal blocks** will be +12VDC.

   Upstage of the **terminal blocks** are the two **relay sockets** that will house the **relay switches** to control the **motor**. The downstage relay is Control Relay #1 (or CR1 for short) and it will move the **motor** forward. The upstage relay is Control Relay #2 (or CR2 for short) and it will move the **motor** in reverse.

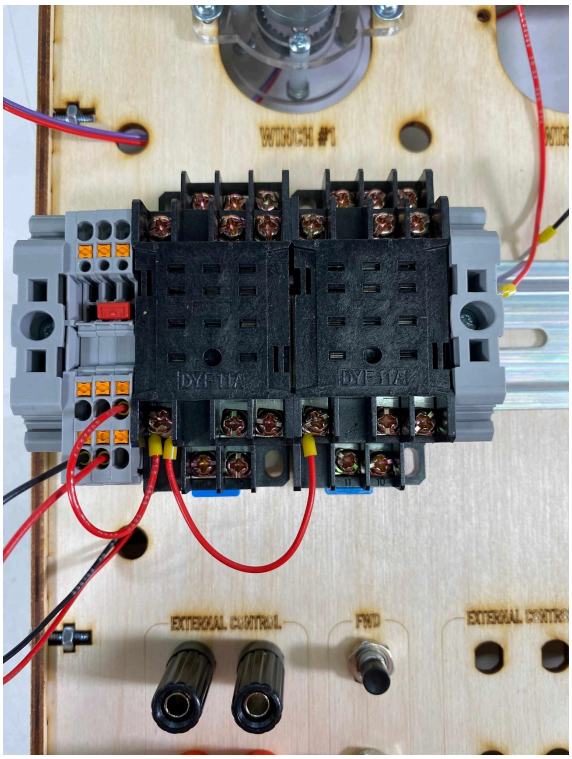



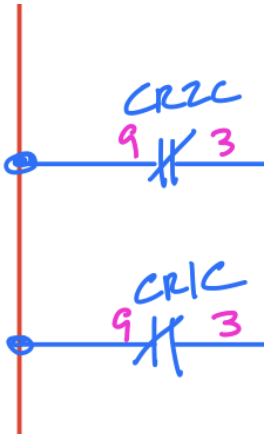
3. Insert a 3” red wire into one of the +12VDC terminals.

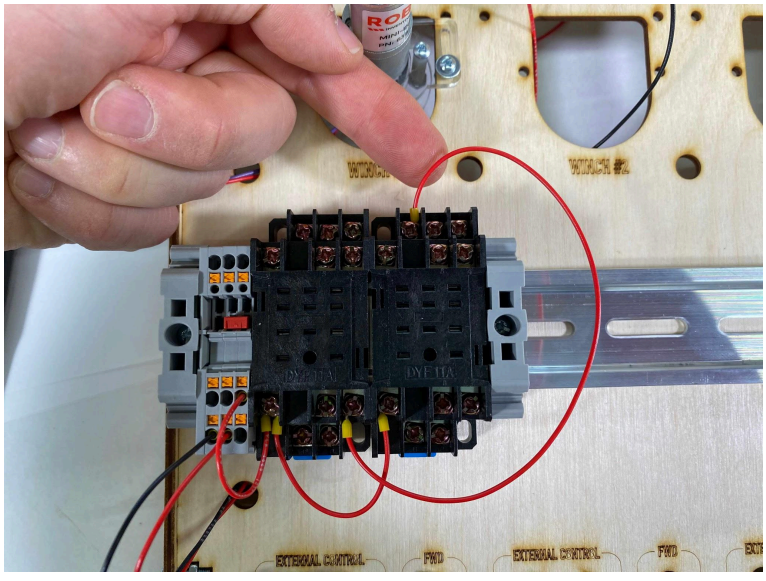
4. Loosen terminal #9 on CR1 with a Phillips screwdriver. Fit the other end of your first 3” wire into the terminal. Place a second 3” red wire under terminal #9 of CR1. You should have 2

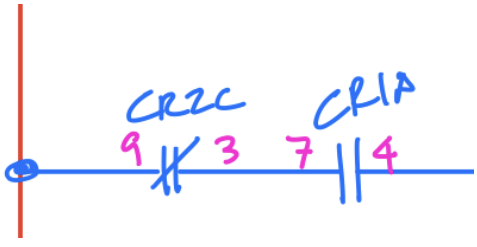
wires stuck into terminal #9. Put one on either side of the screw for a good connection and tidy appearance. Now tighten the terminal snugly with a screwdriver.





5. Put the end of the red wire into CR2, terminal #9. We've completed a portion of the lowest rungs of the schematic by daisy-chaining both CR1-#9 and CR2-#9 to +12VDC.





6. Connect an 8" red wire from CR2-#3 to CR1-#7.

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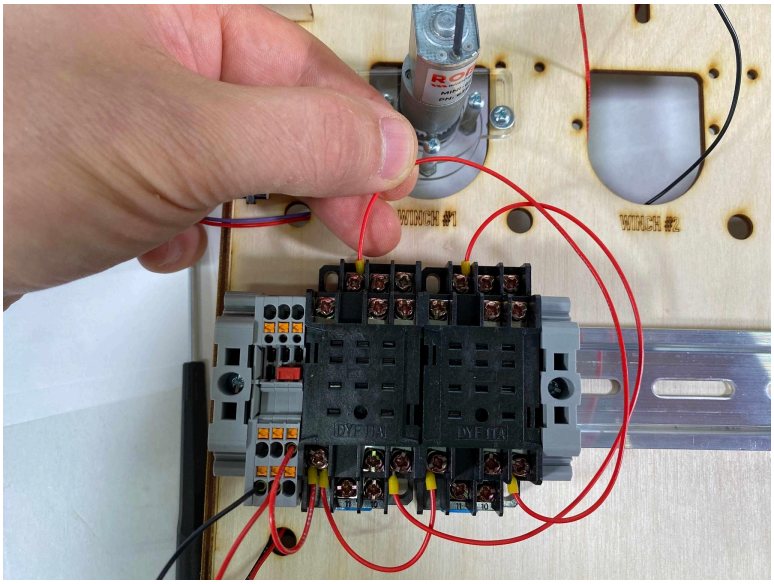
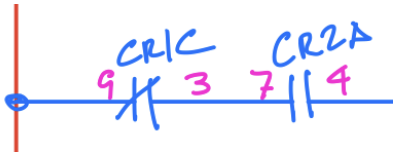
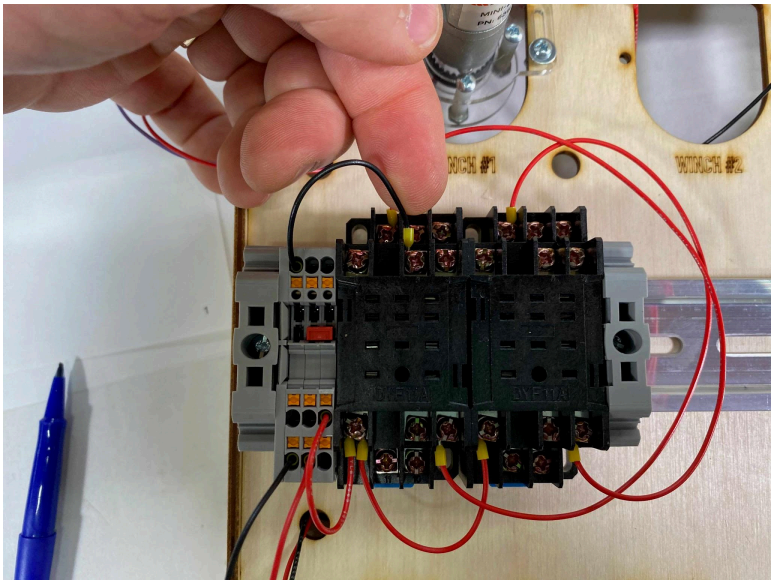
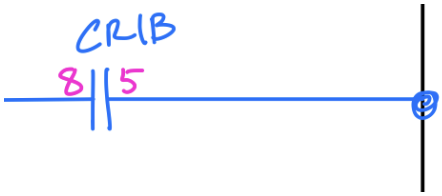




7. Connect an 8” red wire from CR1-#3 to CR2-#7.





8. Connect a 3” black wire from CR1-#5 to the COMMON terminal block. Leave the terminal loose to daisy-chain another 3” black wire.

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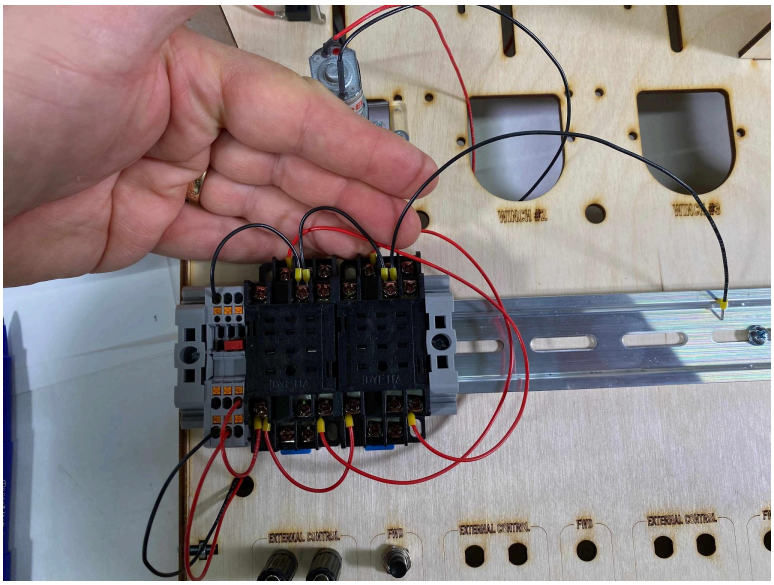
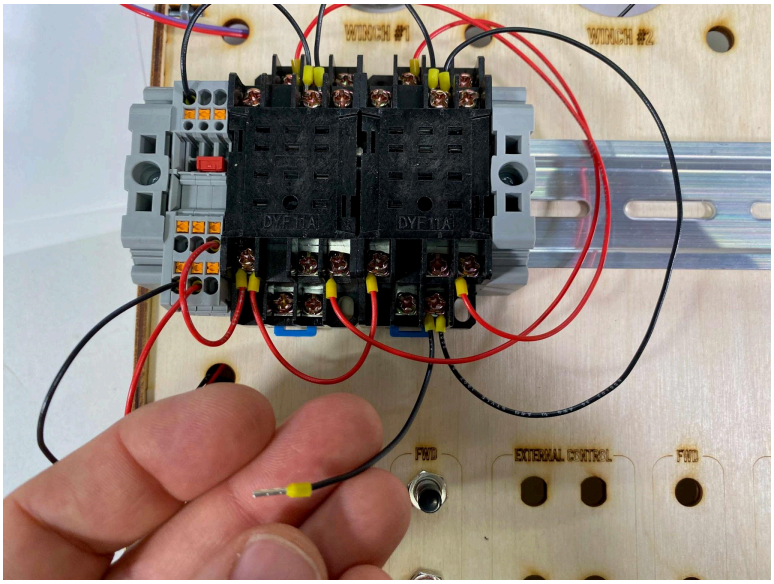
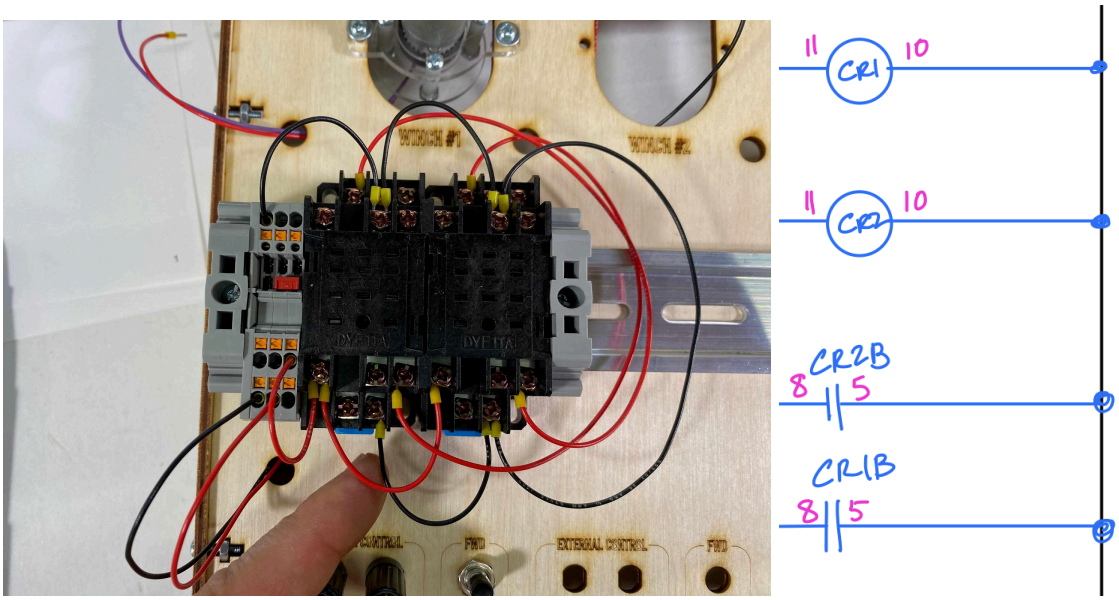


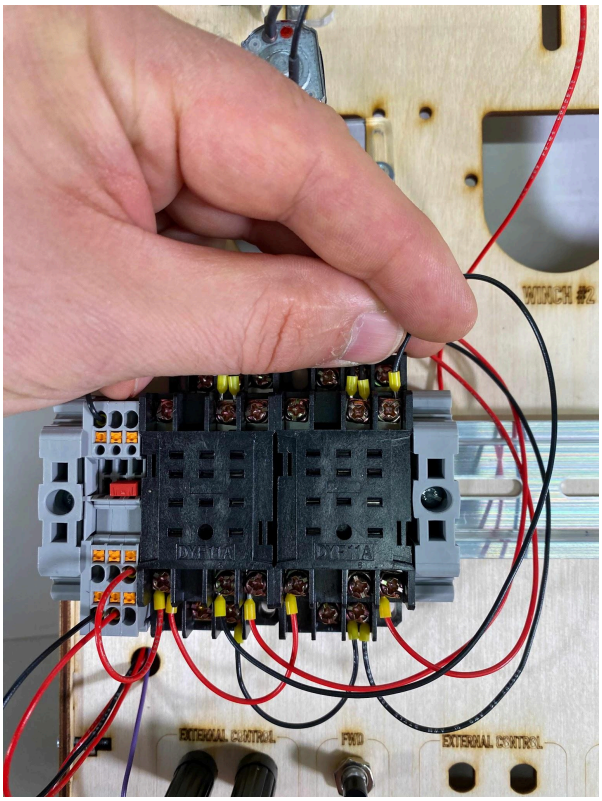
9. Connect a 3” black wire from CR1-#5 to CR2-#5. At CR2-#5 install a 8” black wire with the other end of the 3” black wire to daisy-chain further. Tighten down both CR1-#5 and CR2-#5. Each terminal should have 2 wires installed.



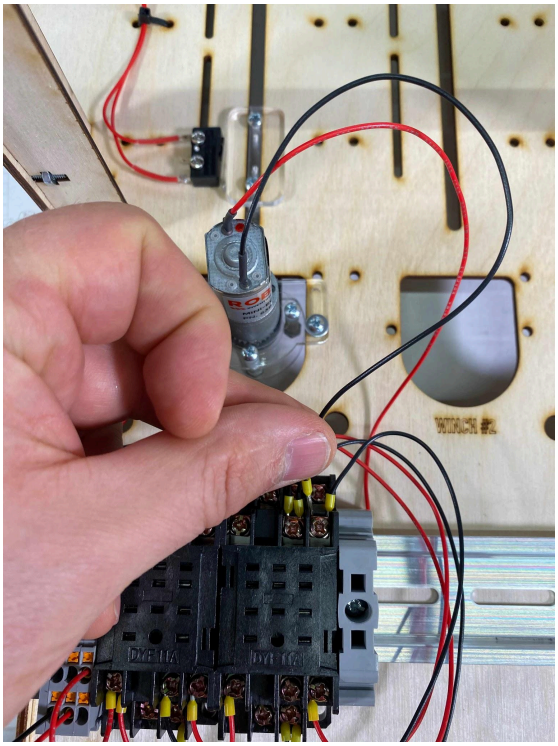
10. Continue the black daisy chain. Land the other end of your 8” black wire into terminal CR2-#10. At terminal CR2-#10 also insert a new 3” black wire to continue the daisy-chain. Tighten down CR2-#10 with two wires installed.

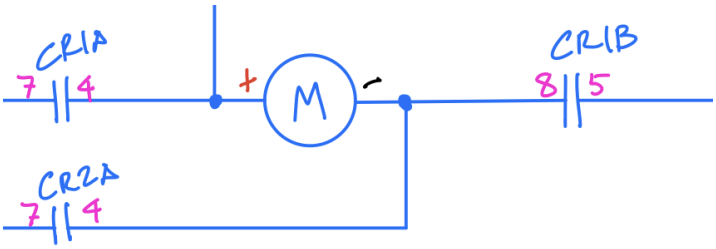


11. Finish the daisy chain by terminating the end of the 3” wire into CR1-#10. As you can see, we’ve completed the leftmost side of the schematic by connecting all those terminals to COMMON.



12. Connect an 8” black wire from CR2-#4 to CR1-#8. Tighten down CR1-#8, but leave CR2-#4 loose to accept another wire.

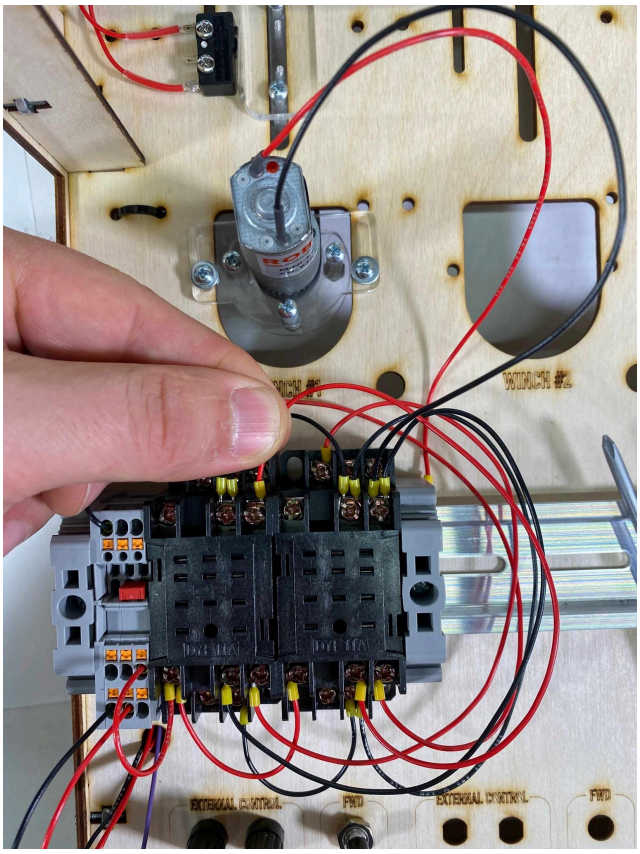




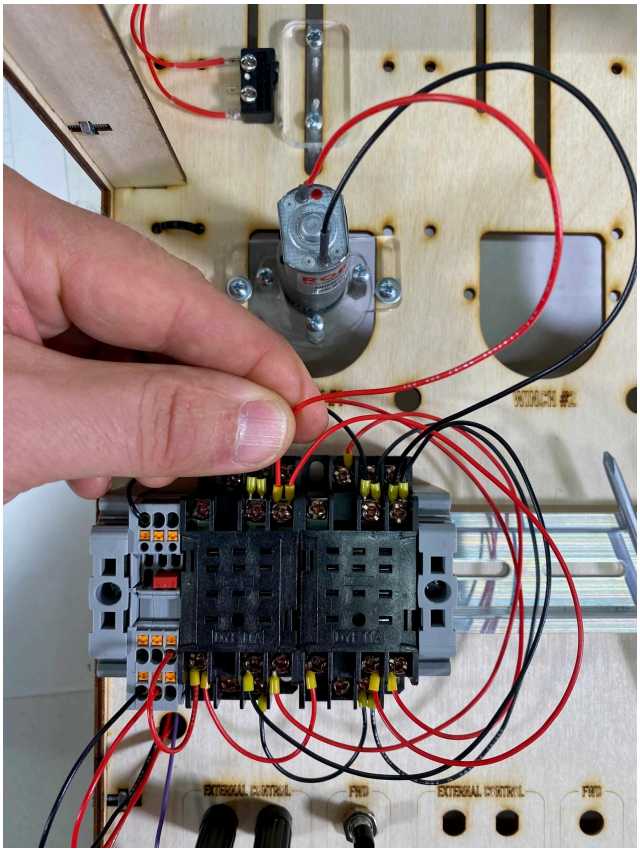
13. Connect the black wire from the motor to CR2-#4. Tighten down the terminal with two wires installed. We've now given two potential paths for the negative terminal of the motor: it can either connect to COMMON through relay CR1, or it can connect to +12VDC through relay CR2.

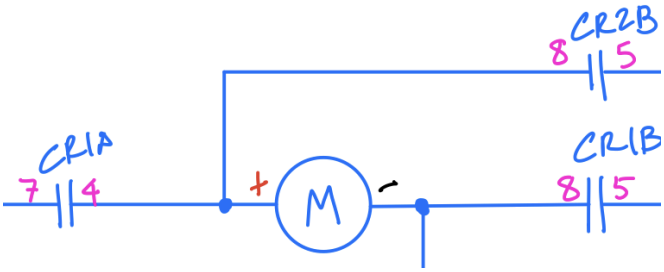
DC Motor Rotation

The direction of rotation of a DC motor is determined by the polarity of the current. If the motor spins clockwise when positive voltage is applied to its positive terminal, it will spin counterclockwise if the positive voltage is moved to its negative terminal. To learn more about how DC motors work, refer to the Scenic Automation Handbook, pages 114-117.

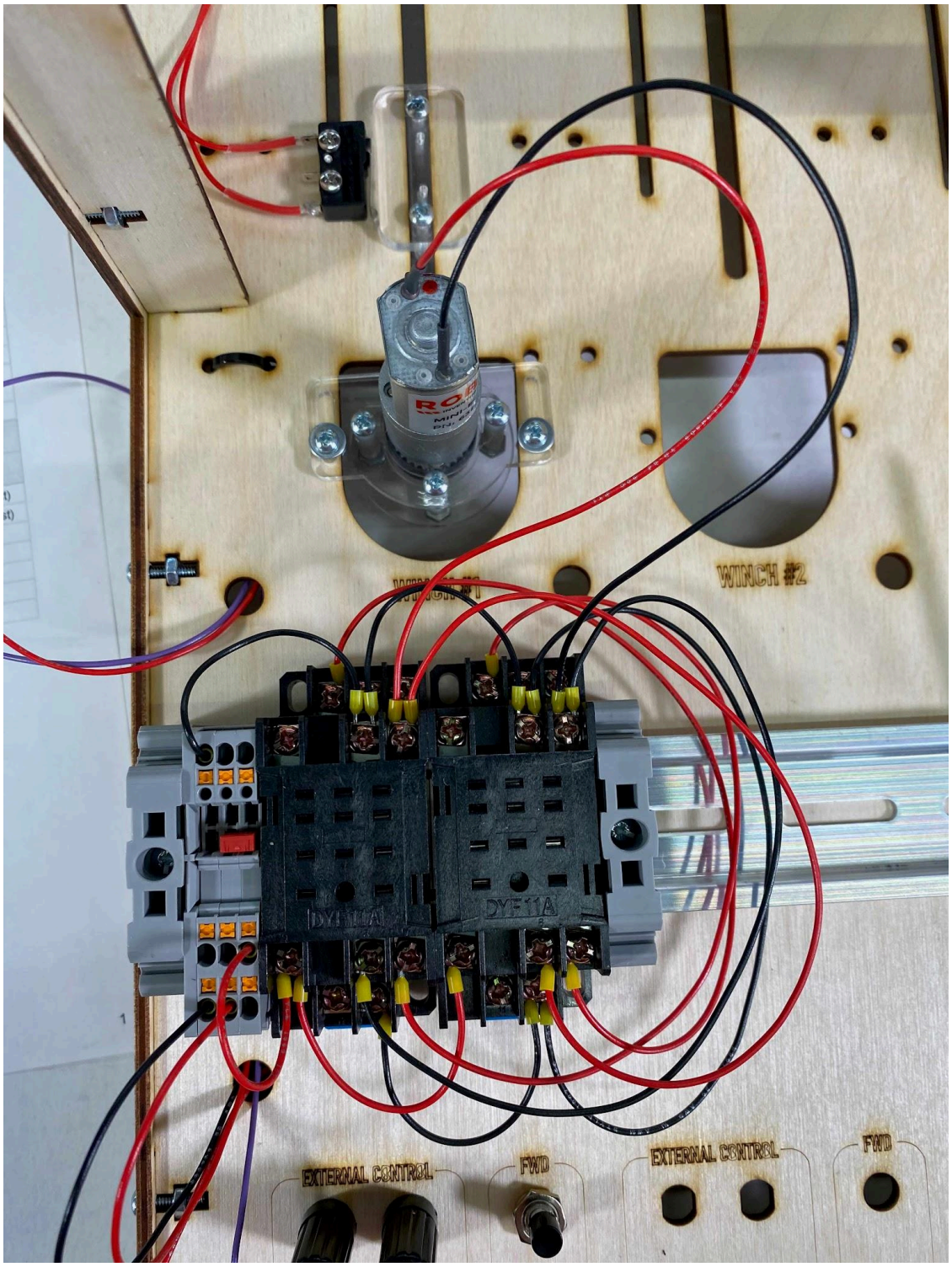


14. Connect an 8” red wire from CR2-#8 to CR1-#4. Tighten down CR2-#8, but leave CR1-#4 loose to accept the red wire from the motor.

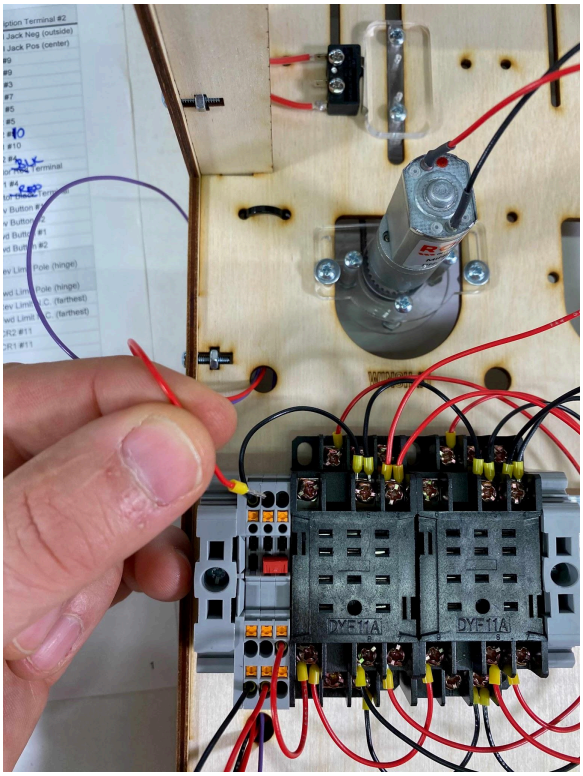


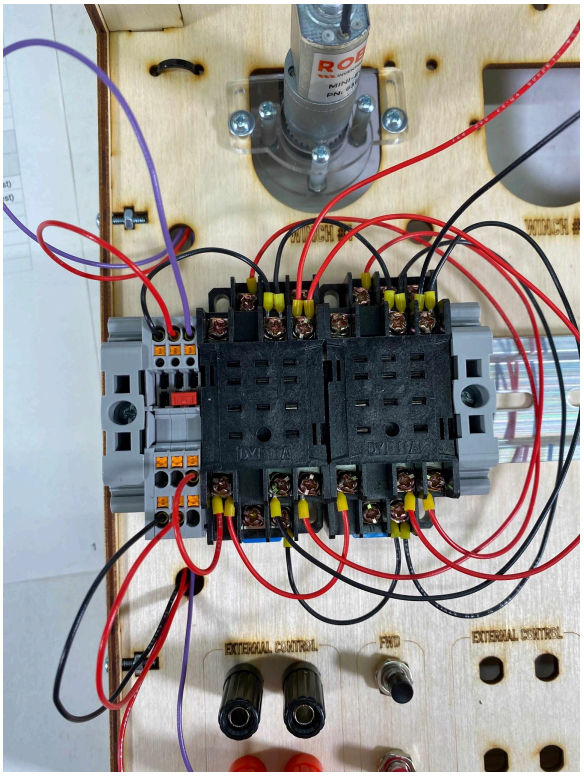


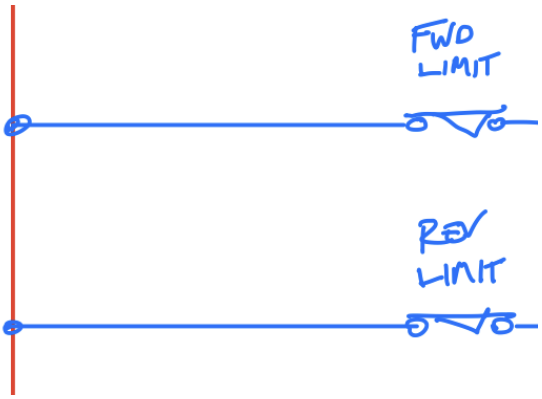
15. Connect the red wire of the motor to terminal CR1-#4. Tighten down the terminal with two wires installed. We've now given two potential paths for the positive terminal of the motor: it can either connect to COMMON through relay CR2, or it can connect to +12VDC through relay CR1.



16. At this point, your wiring should look roughly like the image above. This is a good stopping point to double-check your work. Trace your wires and make sure they match the schematic (or photos).



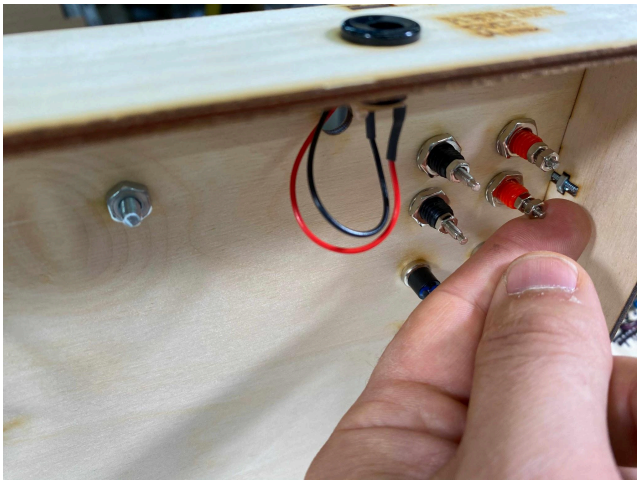


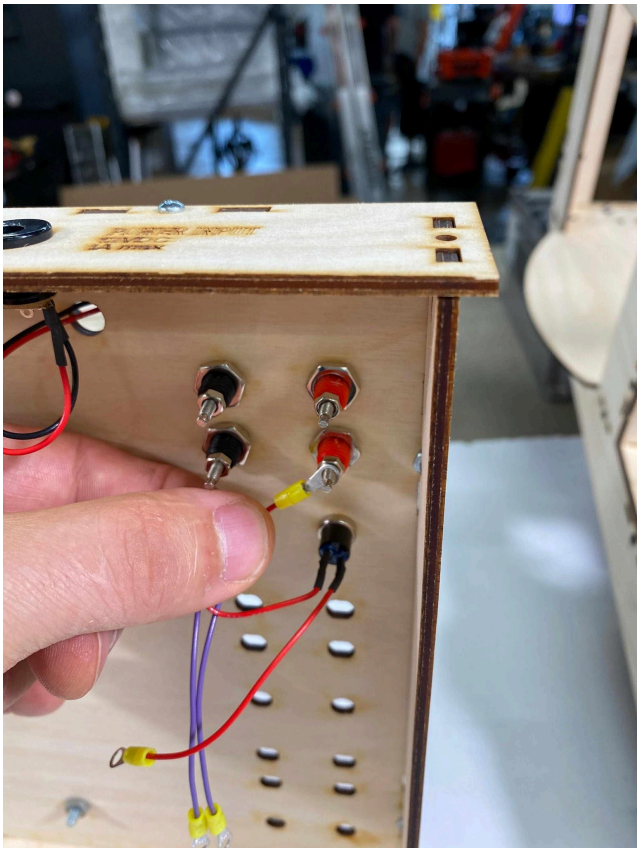


17. Take the red wire from the **reverse limit** that is poking up through the Stage Floor and insert it into the +12VDC terminal block. Do the same with the purple wire from the **forward limit**.

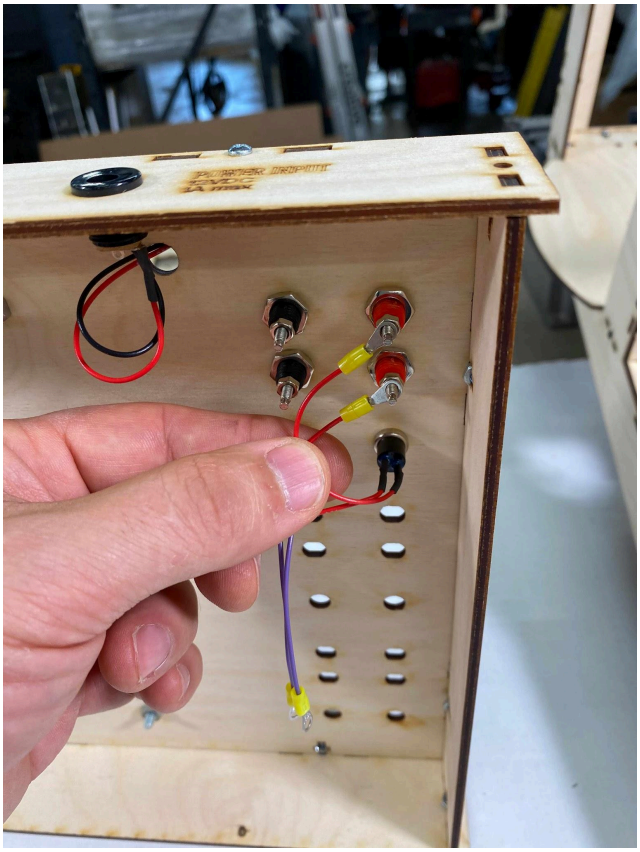
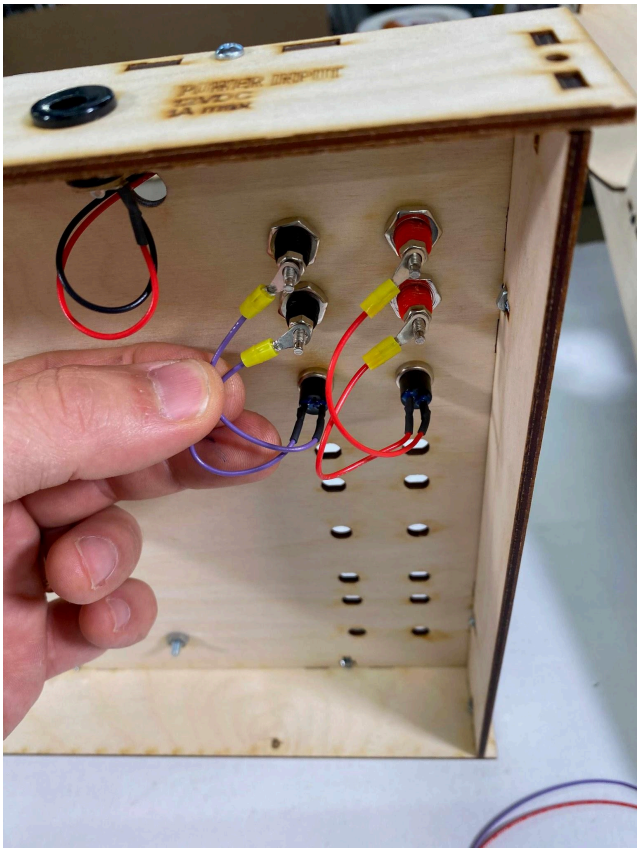
Failsafe Limit Switch Circuitry

These limit switches are SPDT switches, meaning they have a Normally Open contact and a Normally Closed contact. When we are wiring switches meant to limit travel on a machine, we wire them Normally Closed. Why? This is failsafe. If the wire is cut, the lack of current will stop the motion just the same as if the Normally Closed switch was activated and opened the circuit. By contrast, if we wired them Normally Open, the control circuit could not distinguish between a triggered switch with a cut wire and a functioning switch that hasn't been triggered (eek!). The Normally Closed circuit is more skeptical, it has to know *that the circuit is conducting electricity otherwise it assumes the motor should stop. Failsafe design, and switch types, are interesting topics — see Chapter 6 in the Scenic Automation Handbook for more detail.*

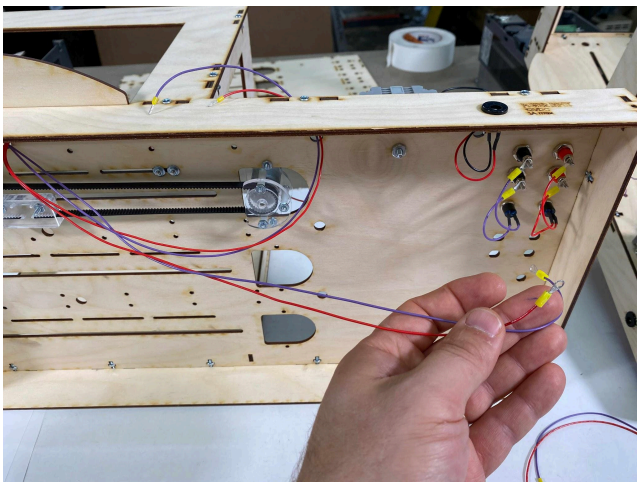
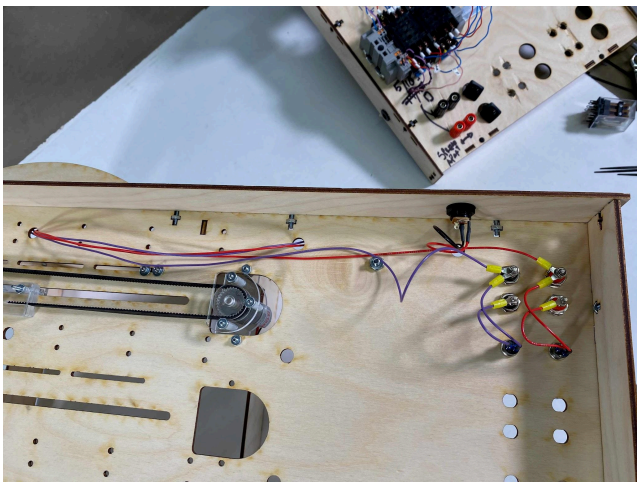




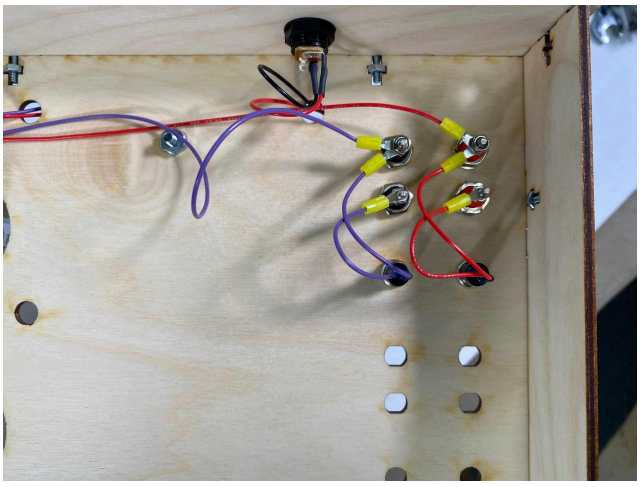
18. Tip the stage onto its back so you can do some wiring below. Loosen the small nut on the upstage red banana jack. Slip on one of the red wires from the reverse push button (it doesn't matter which one).

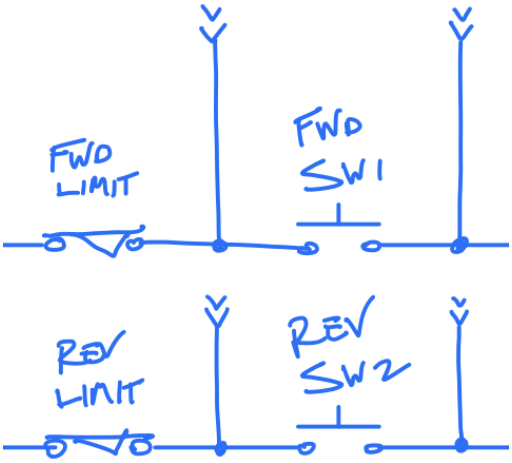



19. Repeat the process to connect the rest of the pushbutton wires. **Red wires** go to **red jacks**, **purple wires** go to **black jacks**.

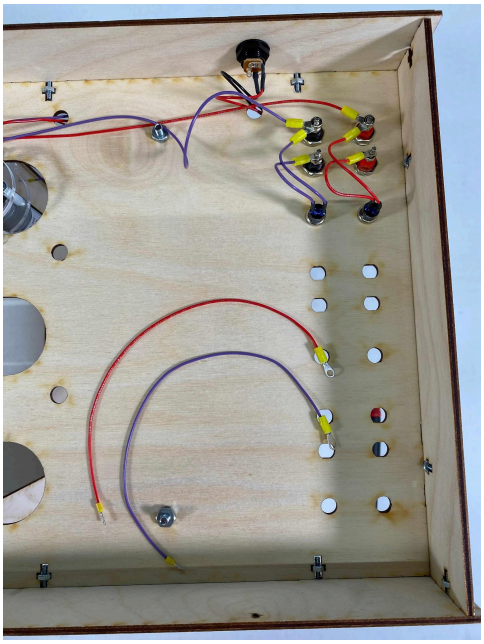



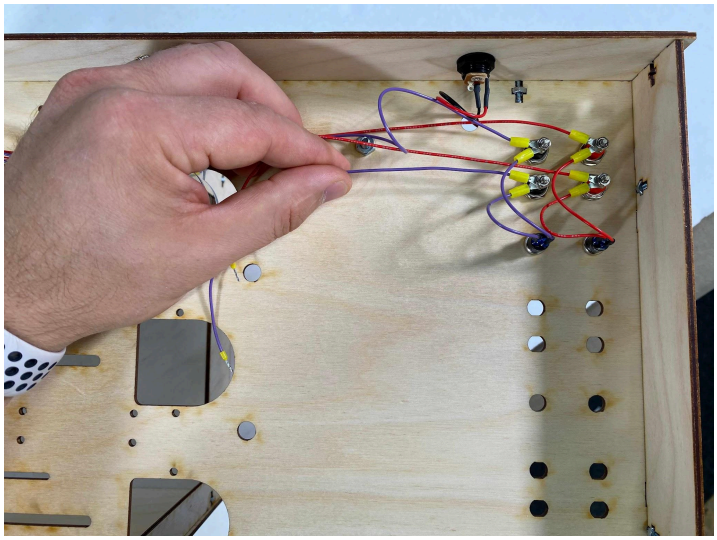
20. Take the long purple and red wires from the forward and reverse limit switches that we left underneath the stage. Connect the **purple wire** to the downstage **black banana jack**. Connect the **red wire** to the downstage **red banana jack**. Now fasten the small nuts back onto the downstage **banana jacks**.





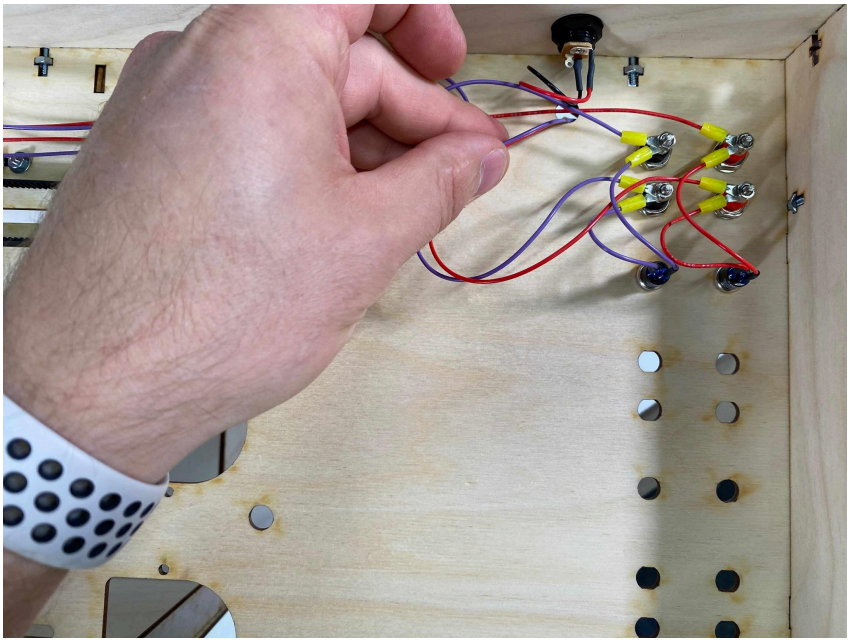
21. We've provided a path from +12VDC through the **forward limit switch** to the **forward pushbutton** *and* the downstage **black banana jack**. Pressing the button, or connecting the two **black banana jacks**, will send voltage onward in the circuit. Similarly we've provided a path from +12VDC through the **reverse limit** to the **reverse pushbutton**. But, as you can see in the schematic, the **limit switches** can interrupt current to their respective buttons. So if the **forward limit switch** is activated, no current will flow to the **forward pushbutton**, making it inert.



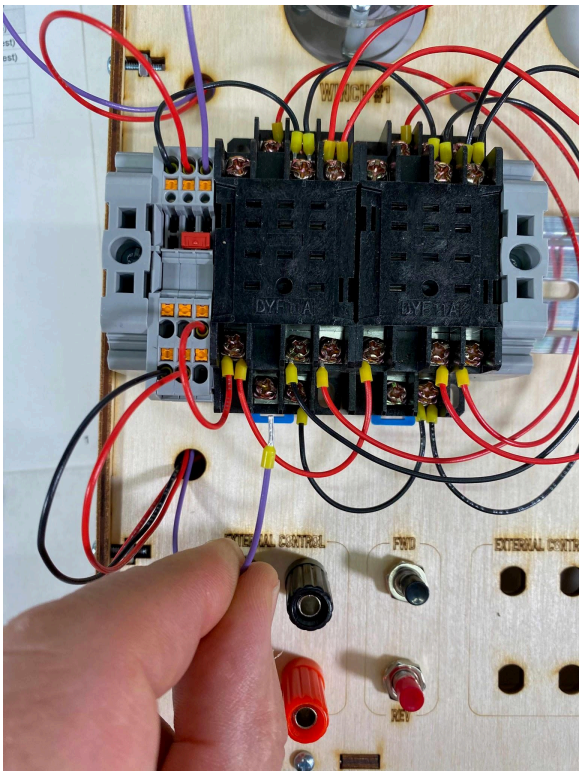


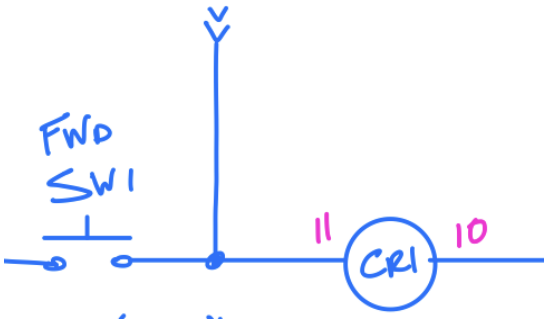
22. Find the 8" red wire with a ring terminal on one end, and the 8" purple wire with a ring terminal on one end. Place the **red wire** on the upstage **red banana jack**. Place the **purple**

wire on the upstage **black banana jack**. Tighten the small nuts onto the **banana jacks** to secure the wires. Each **banana jack** should have two wires on the terminal.



23. Fish the free ends of the two 8” wires up through the 5/16” chase hole in the Stage Floor.





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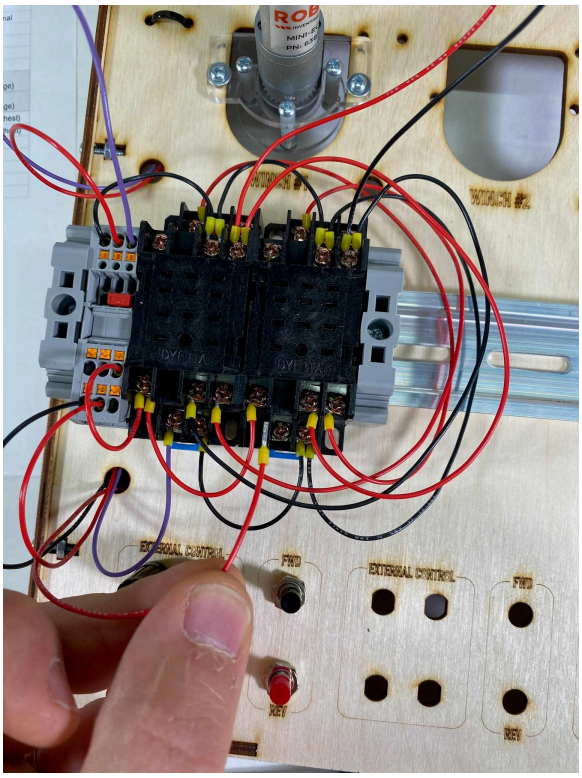
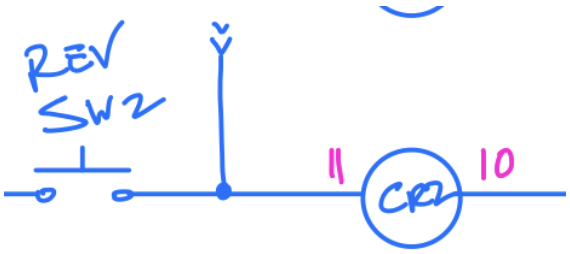
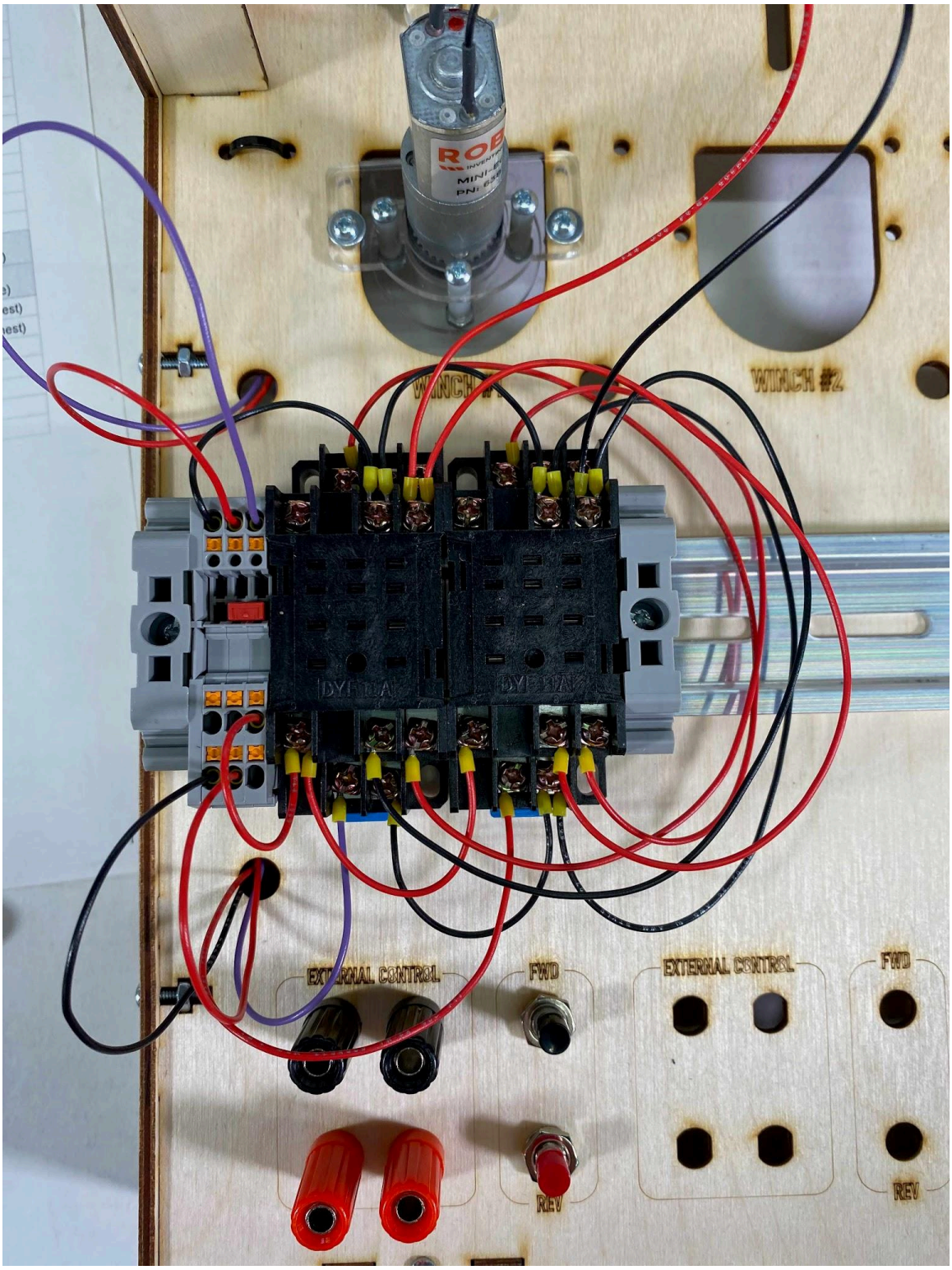
24. Flip the stage right side up. Connect the free end of the purple wire to CR1-#11. Now we've connected the output from the **forward pushbutton** to the **forward relay** coil. When the button is pressed, if the **forward limit** is not engaged, the CR1 coil will energize, activating the **relay** switch to spin the **motor** forward.





25. Connect the free end of the red wire from the **banana jack** to CR2-#11. This finishes the path from the **reverse pushbutton** to the **reverse relay** coil. When the **reverse button** is pressed, if the **reverse limit** is not engaged, the CR2 coil will energize, activating the **relay switch** to spin the motor in reverse.



26. Whew! You did it! The wiring is functionally complete.

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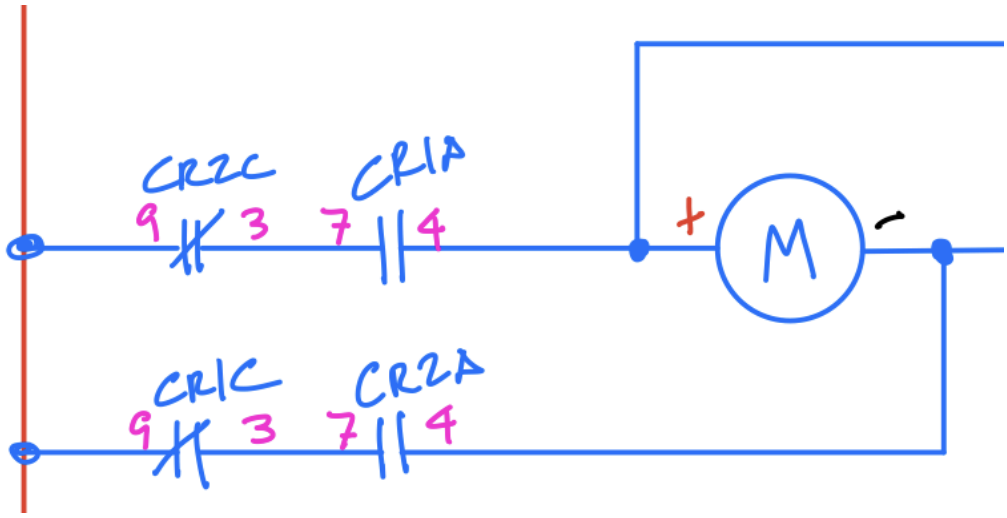


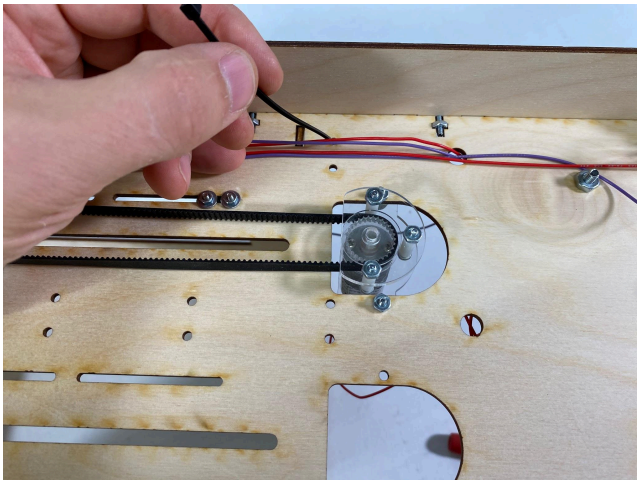
One thing I never explained was the seemingly overly-complex circuit that feeds +12VDC into the motor. Why do we route the voltage through CR2 on a normally-closed contact just to pass it onto a normally-open contact on CR1?

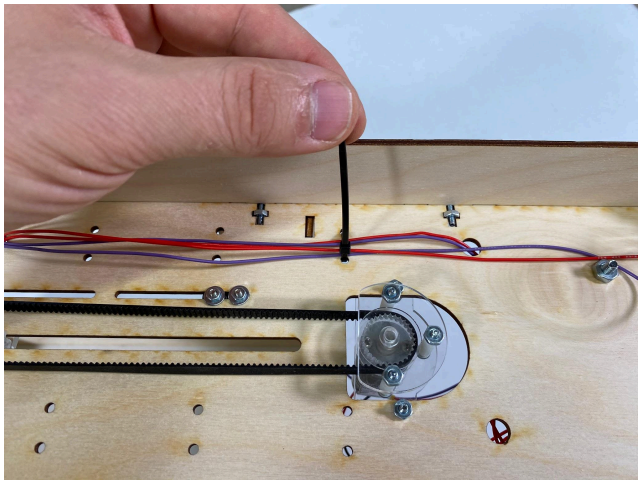
We do this to ensure that we never send +12VDC to both terminals on the motor, or worse create a dead short between +12VDC and COMMON. Looking at the top rung of the schematic snippet, if CR1 is energized it will close CR1A and allow positive voltage to the motor positive terminal. At the same time, CR1C opens and breaks any potential connection from +12VDC to the negative terminal of the motor.

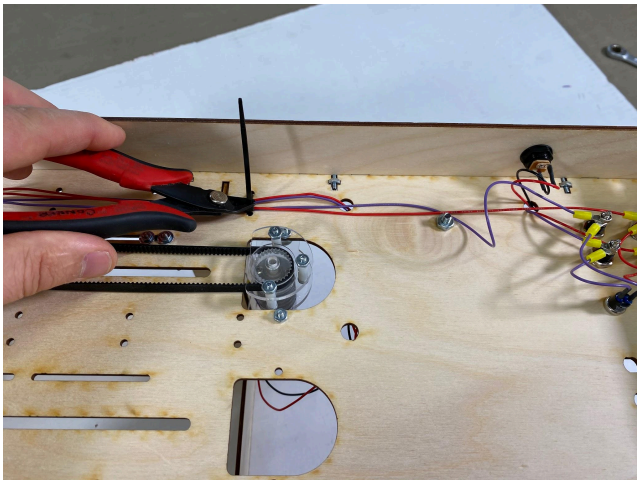
What if you press both buttons at the same time? Then CR2C & CR1C both open and the motor is completely disconnected from power. Nice, right? You will find this type of circuit commonly deployed in motor control circuits. If we were being fastidious, we'd use a relay with force-guided contacts so that a welded contact inside a malfunctioning relay couldn't defeat our intention – but that's an exercise left for the reader.

Wire Cleanup

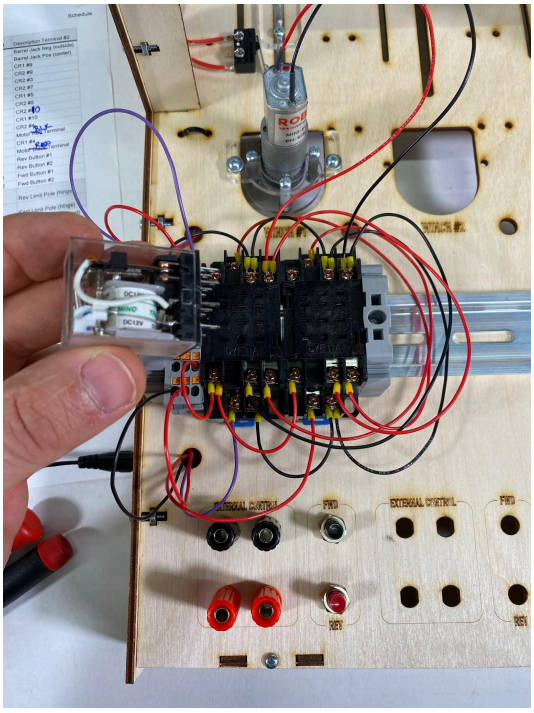
Now that the wiring is finished, take a minute and install some zip ties to bundle your wires and keep everything neat. In particular, make sure to dress the wires under the stage so they don't get snagged in the winch belt. There are small holes that run along the winch track that you can use for zip ties.



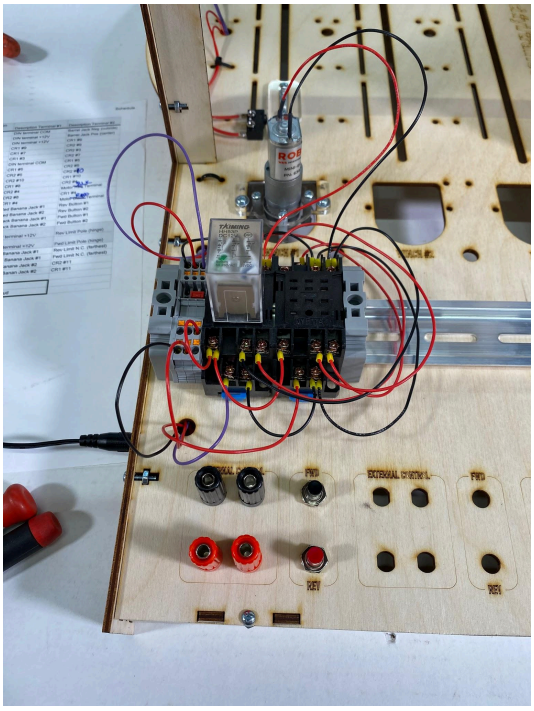




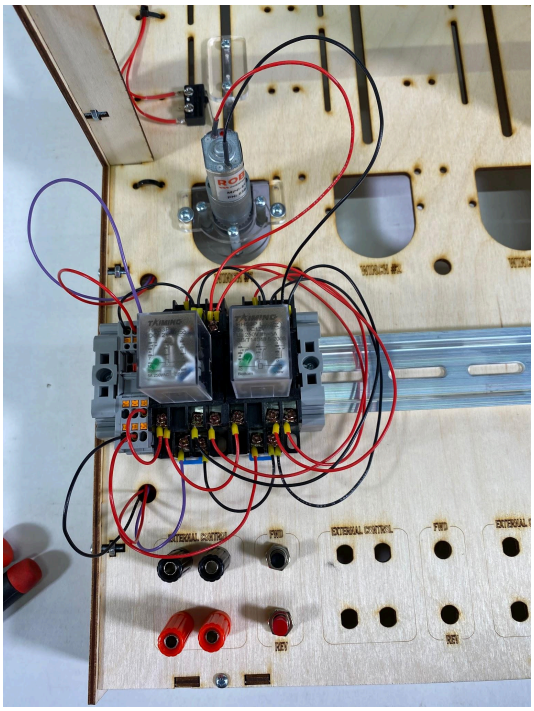
Install the Relays



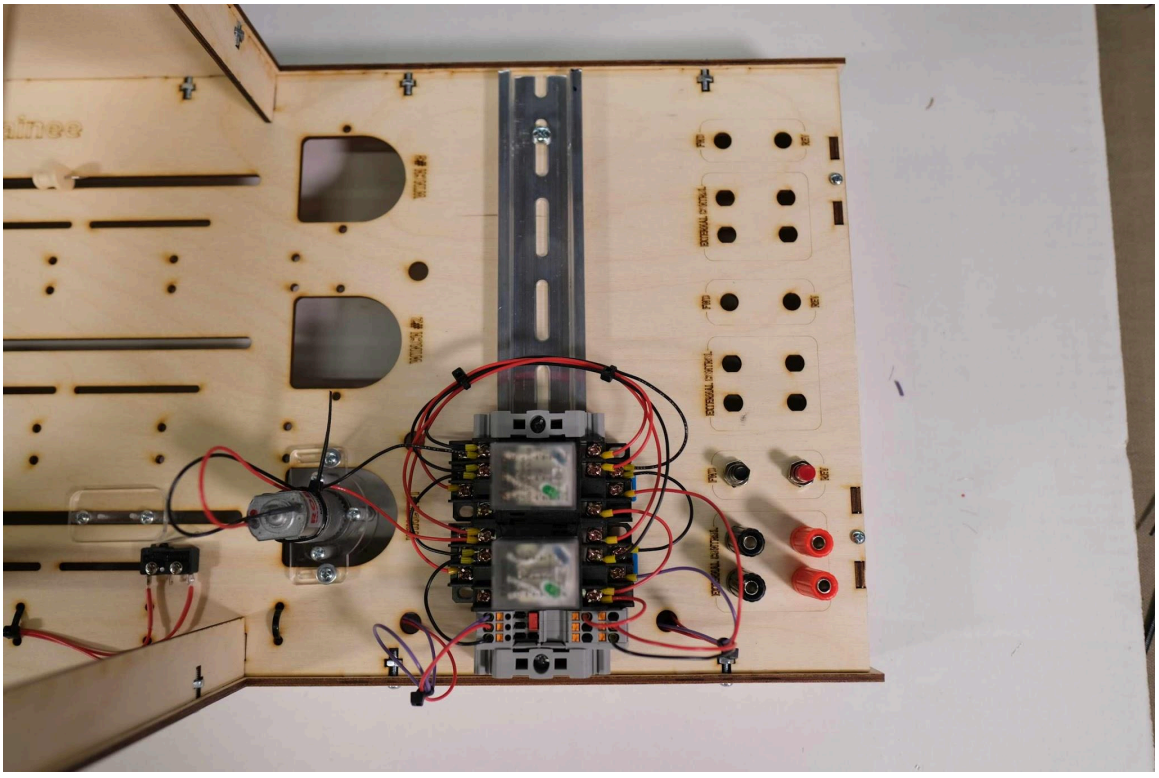
1. There are two (2) identical relays. Take one and align it with the CR1 socket. The pins are not symmetrical so you have to get the orientation correct.



2. Press the relay into the socket.



3. Install the second relay in the CR2 socket.



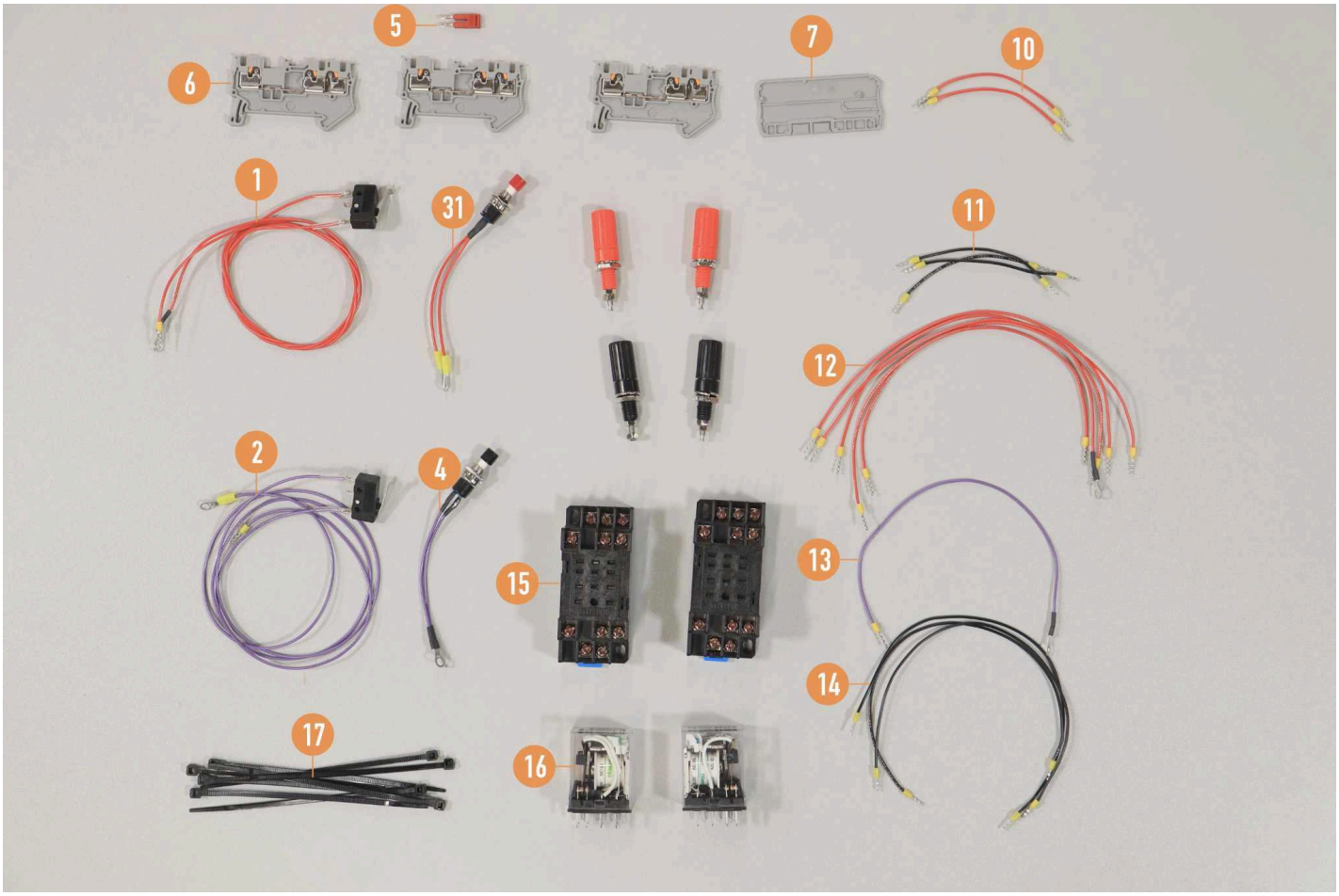
4. With both relays installed, and your zip ties zipped, your Trainee should look like the image above. Now we're ready to power up and move!

Add-On Kit

In this section, we will walk you through the steps necessary to get your Add On Kit installed. Many of these steps will be a repeat of what you have already learned while assembling your first winch, but there are small tweaks for the system to function properly.

What's Included

You should have received (1) Winch Kit with the Trainee Base and (1) Winch Kit for each Add-On Kit you have purchased. In addition, you will receive an Add-On Electrical Kit that is a little different than the Base Electrical Kit.



Item	Qty	Item
1	1	Reverse limit switch (red wires)
2	1	Forward limit switch (purple wires)
3	1	Reverse push-button switch (red wires)

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4	1	Forward push-button switch (purple wires)
5	1	DIN terminal jumper 3.5mm
6	3	DIN terminal blocks
7	1	DIN terminal block cover
8	2	Banana jack (red)
9	2	Banana jack (black)
10	2	Red wire - 3” long
11	3	Black wire - 3” long
12	5	Red wire - 8” long (1 with ring terminal)
13	1	Purple wire - 8” long
14	3	Black wire - 8” long
15	2	3PDT relay socket
16	2	3PDT 12V coil relay switch
17	8	Zip tie - 4” long

Add On Winch

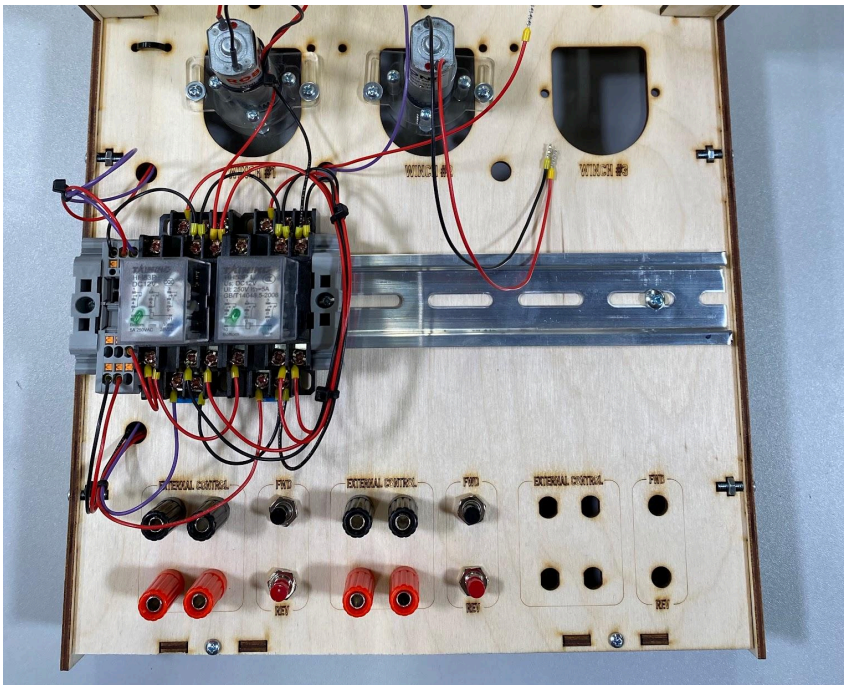
Assembling, installing and rigging your Add-On Deck Winch is exactly the same as the steps you’ve already completed! How exciting. Use the previous sections to complete those steps and come back here when you’re ready to wire. Here are the steps that should be completed before returning:

- Assemble Motor & Mount to Stage
- Turnaround Pulley
- Rig Track

Note: If you turned on the power to test your first winch, ***power off to install and wire the Add-On Kit!!***

Add On Wiring

Next, we'll wire in the Add-On Winches. Our step-by-step instructions will be reduced to notate the difference between the first winch wiring you did - if you need a refresher in more detail, refer to the "Wiring" Section for the Base Model.



1. Each winch section on the base stage has its own "External Control" and "FWD/REV" controls. Install and secure the **red and black banana jacks** and the **push button switches** in the **External Control** section that correlates to your Add On Winch. Remember, we'll want to keep our wiring consistent across our system, so continue to use red as reverse.

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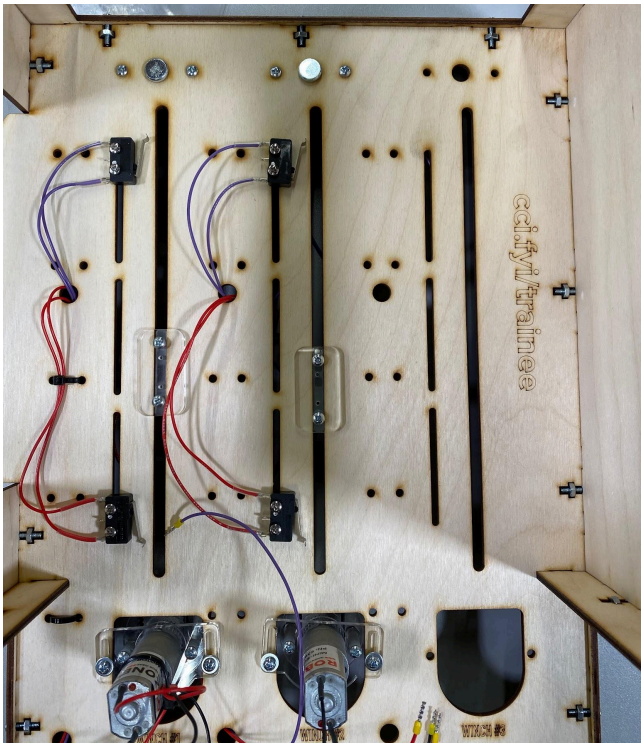
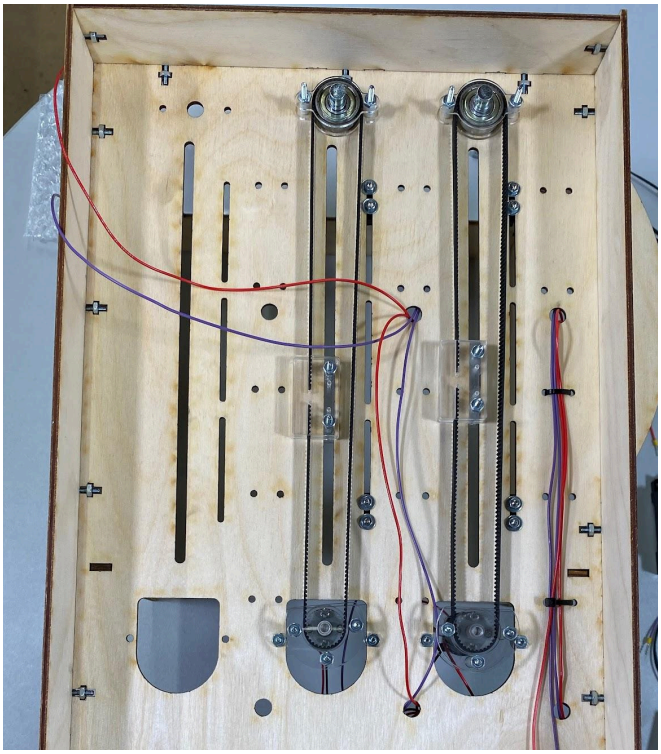
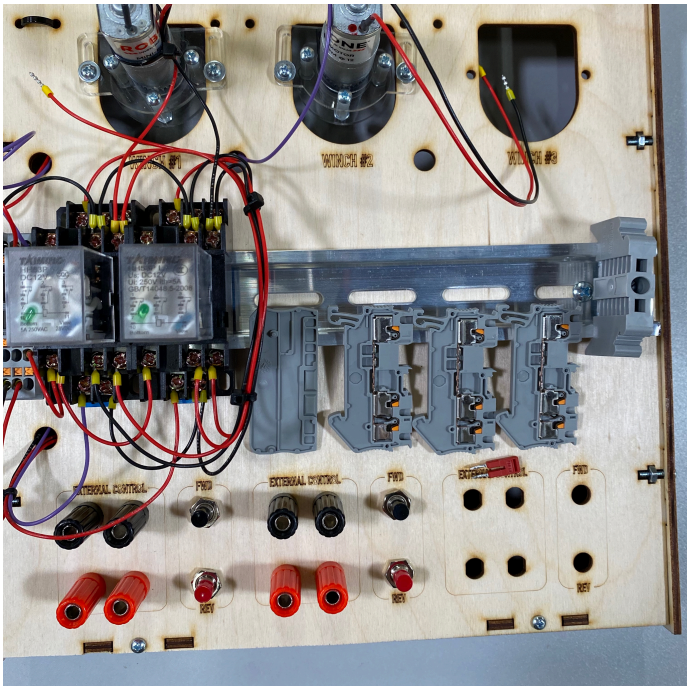




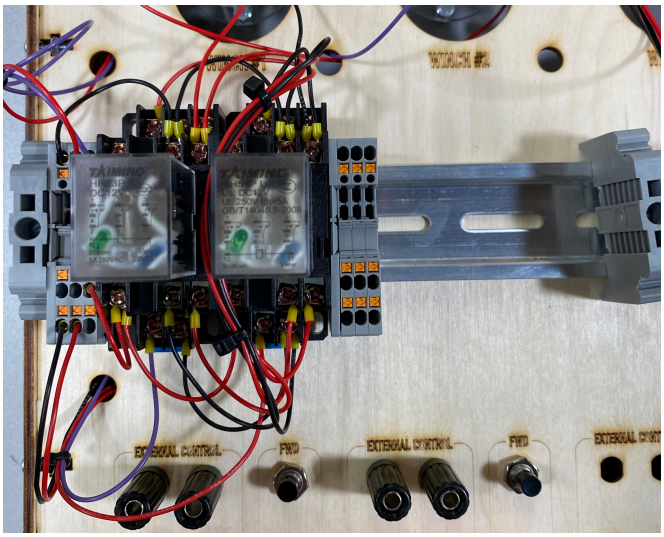
2. Collect the parts and mount the limit switches for this Winch Track. Your wiring should look like the above photos once completed.

3. Loosen the upstage DIN clamp and move it upstage so you have room to work.

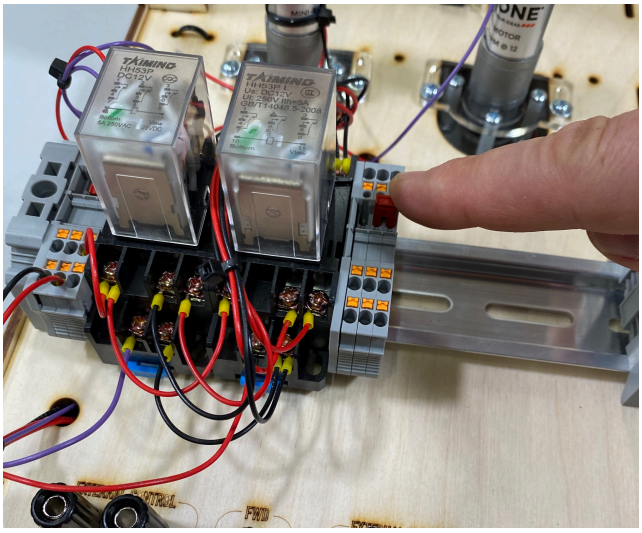


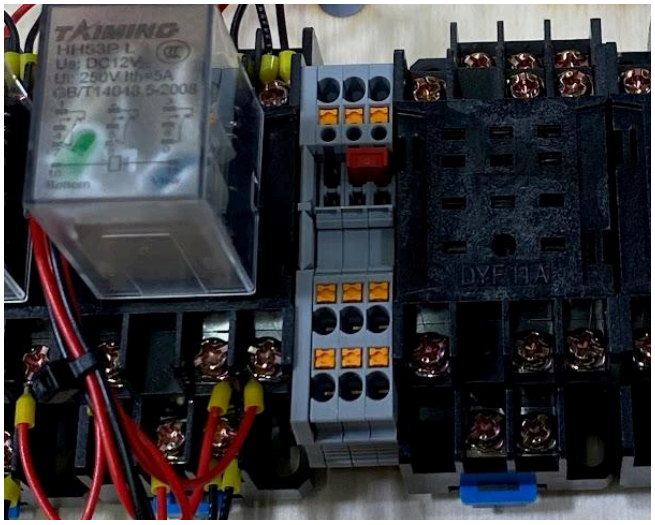
4. Arrange your DIN components from downstage to upstage. **Note:** You won't have additional end clamps, as you're adding onto the system you already assembled.

a. **DIN terminal cover**
b. Three (3) **DIN terminal blocks**
c. **DIN terminal jumper**

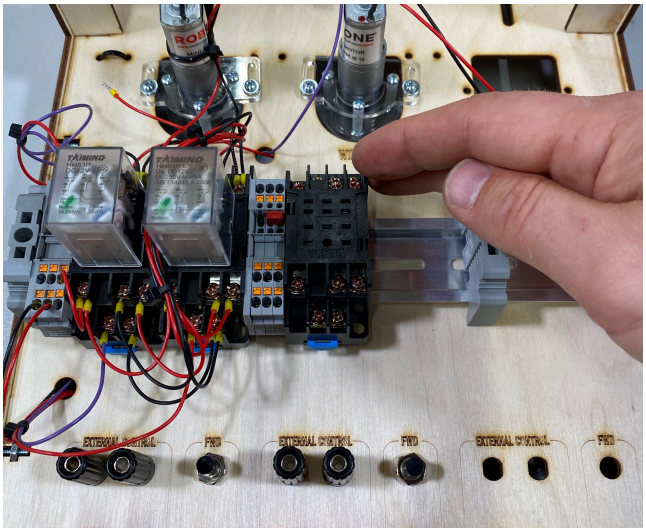


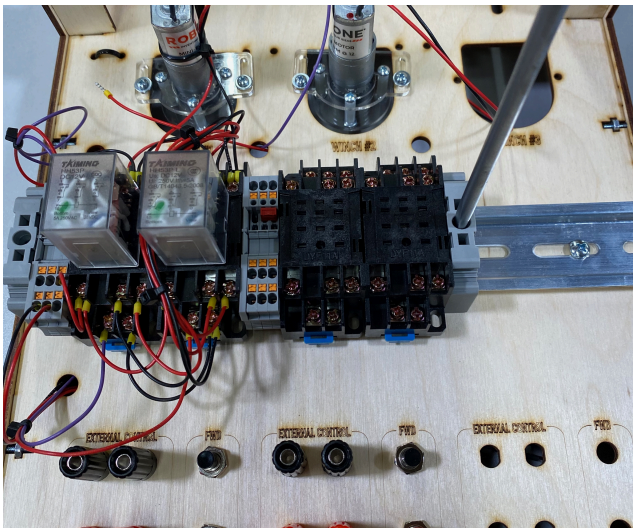
5. Install the **DIN terminal block cover** onto the downstage **DIN terminal block** and install all 3 **DIN terminal blocks**. Align them closely to the first winch's relays - just like in a real theatre, backstage space is at a premium!



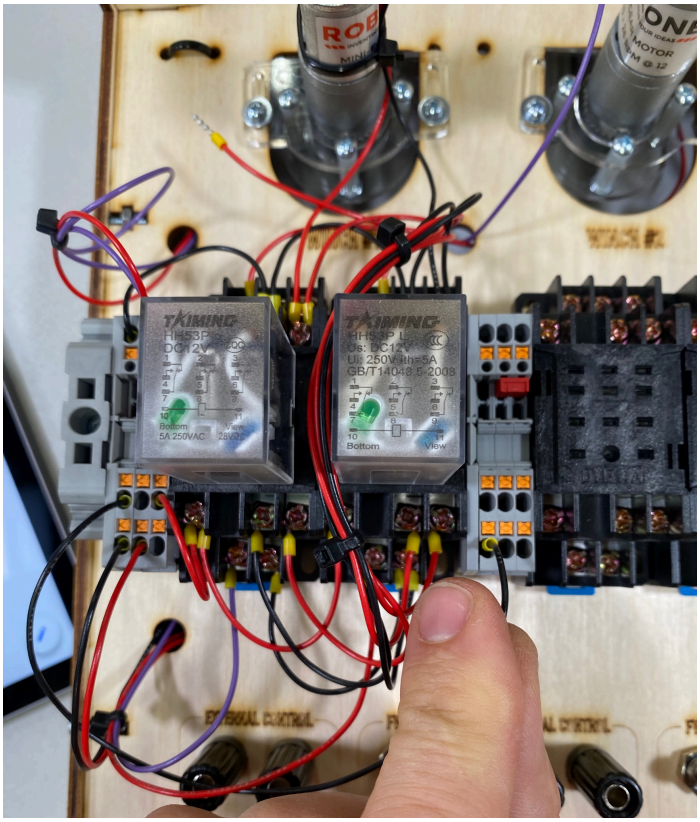


6. Install the **DIN terminal jumper** in the upper row of the two most-upstage terminal blocks, as shown.

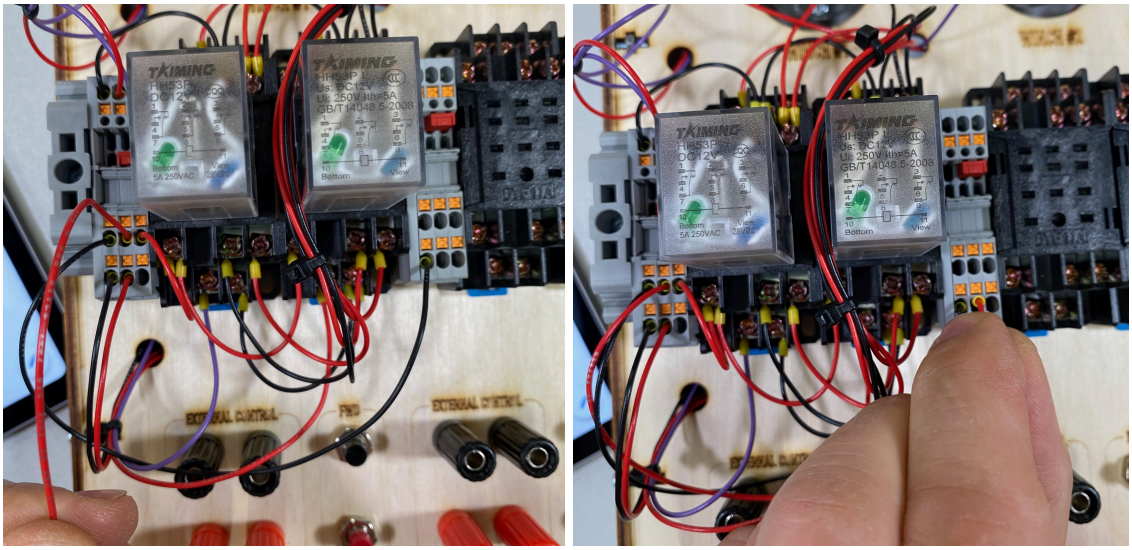




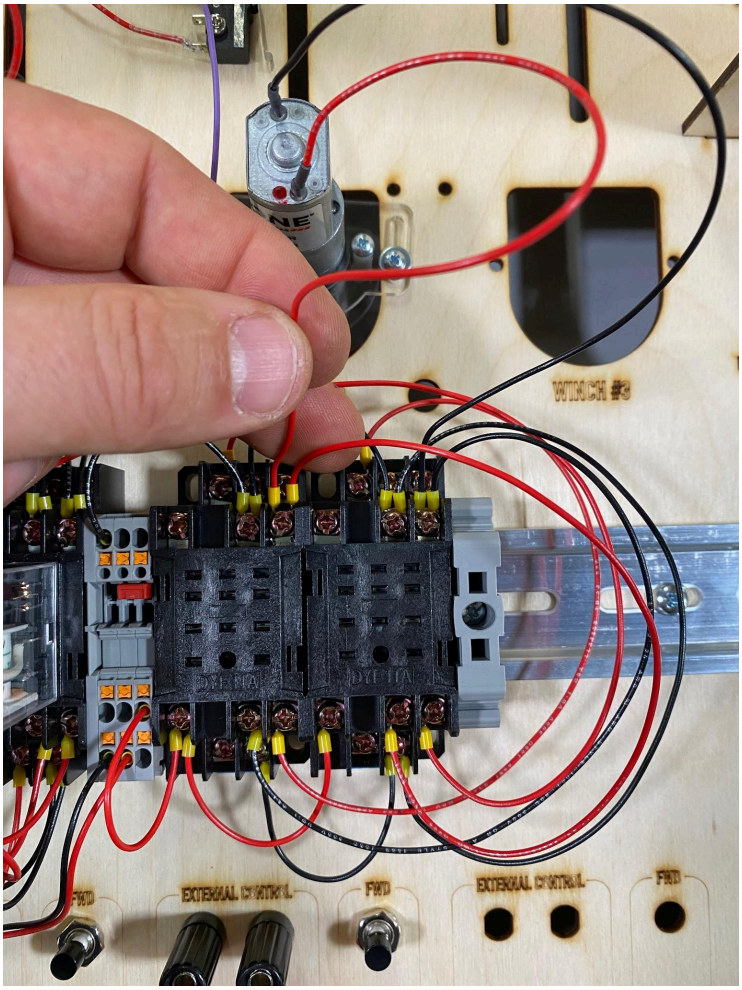
7. Next install the **3PDT relay sockets** onto the **DIN rail**. Pay attention to the orientation the blue release tab should face offstage, just like the ones you installed earlier. Now, move the DIN end clamp flush to the end of the assembly and tighten down.



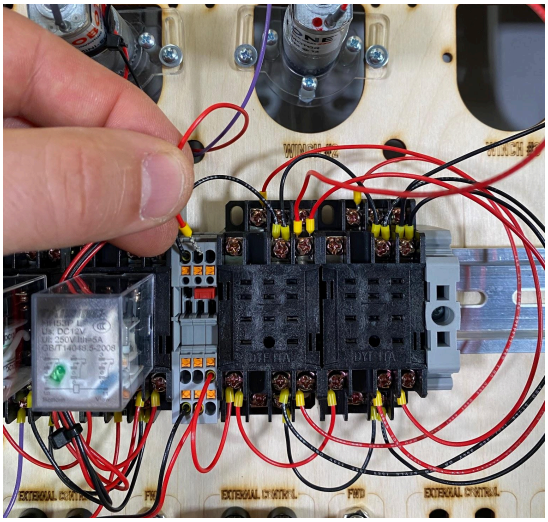
8. You might have already noticed that you didn't install a power jack for this winch. You will daisy chain the power off the previously installed terminal! Take one of your **8" black wires** and insert it in the first terminal, above where the power jack black wire terminates.

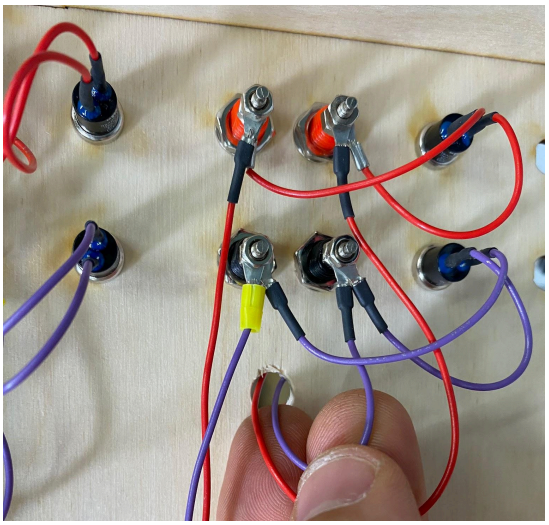


9. Similarly, take a **8” red wire** and connect to the terminal above the power jack red wire, and install it on the new set of terminal blocks.

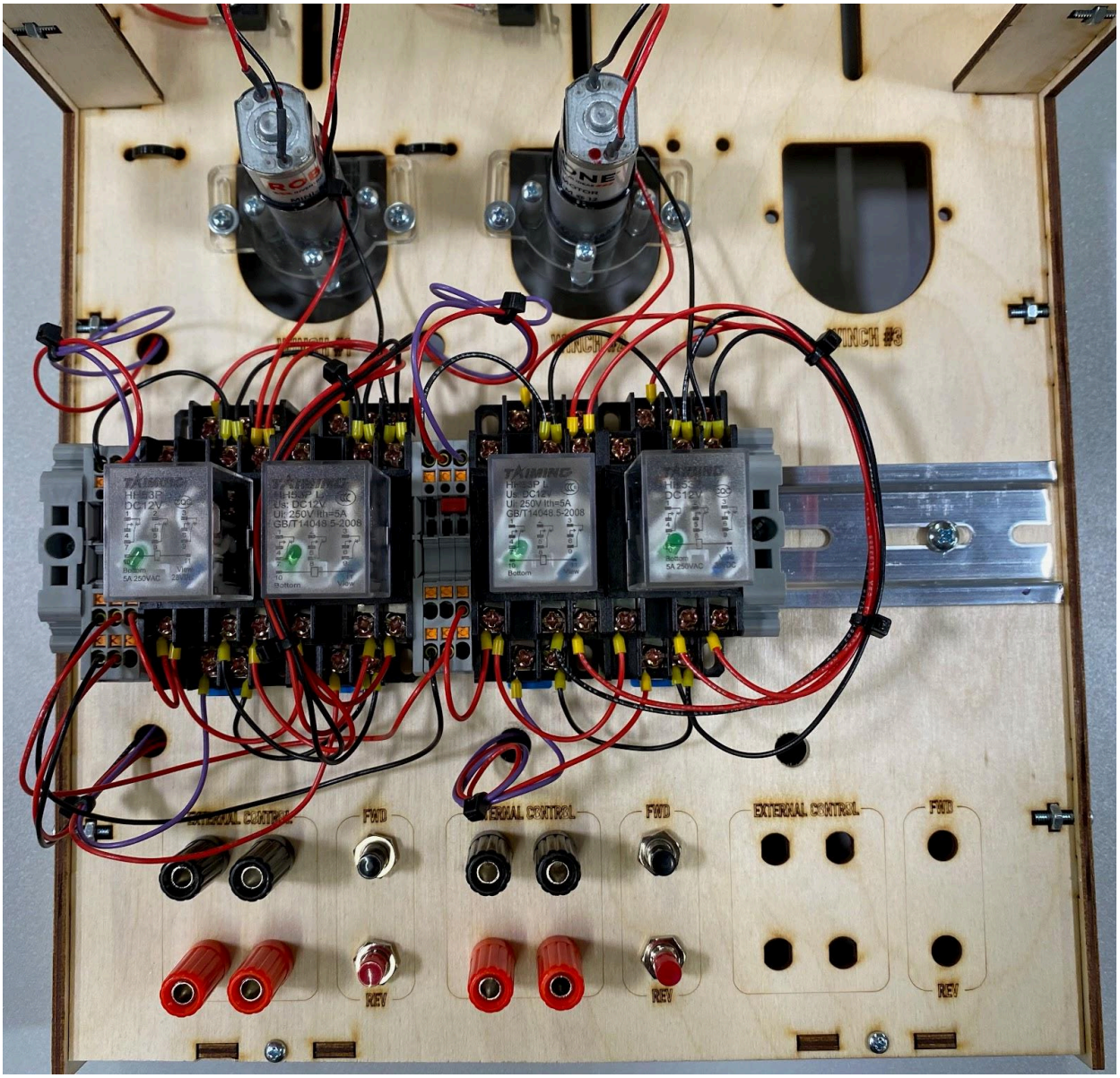


10. Pickup the wiring steps from the previous section, Motion Control Circuit. Once you have connected the motor, your wiring should look like the above photo. Trace your wires and make sure they match the schematic.





11. Now, use the passthrough holes to attach the limit wiring, and connect the banana jacks. Remember consistency matters, **Red wires** go to **red jacks**, **purple wires** go to **black jacks**. Install the **relays** into the sockets.



12. Wahoo! You did it! Use the **zipties** to clean up the wiring underneath the stage before powering on.

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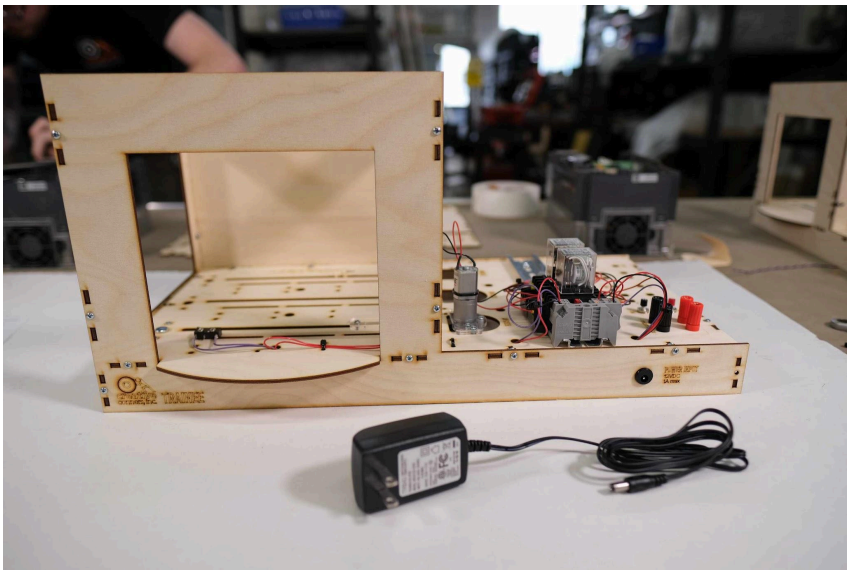
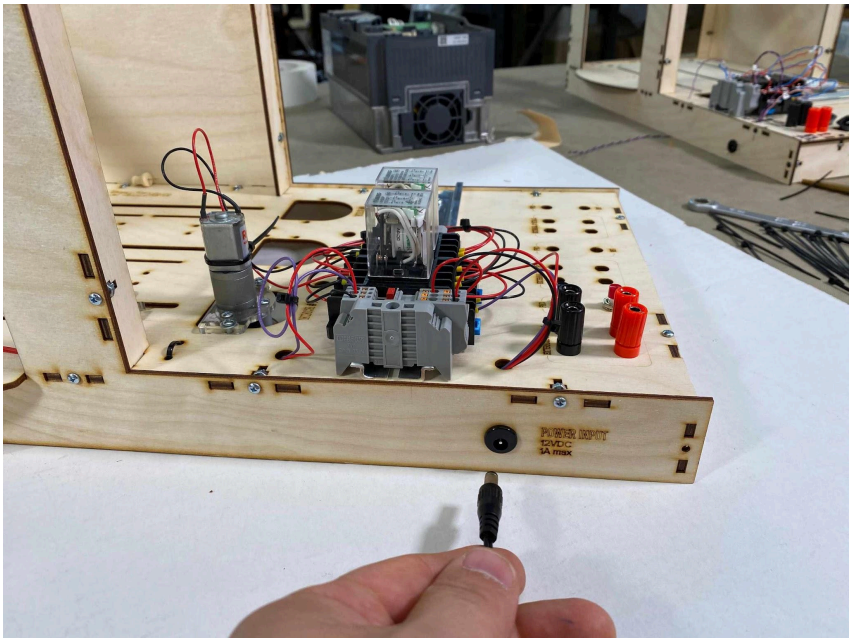
Operation

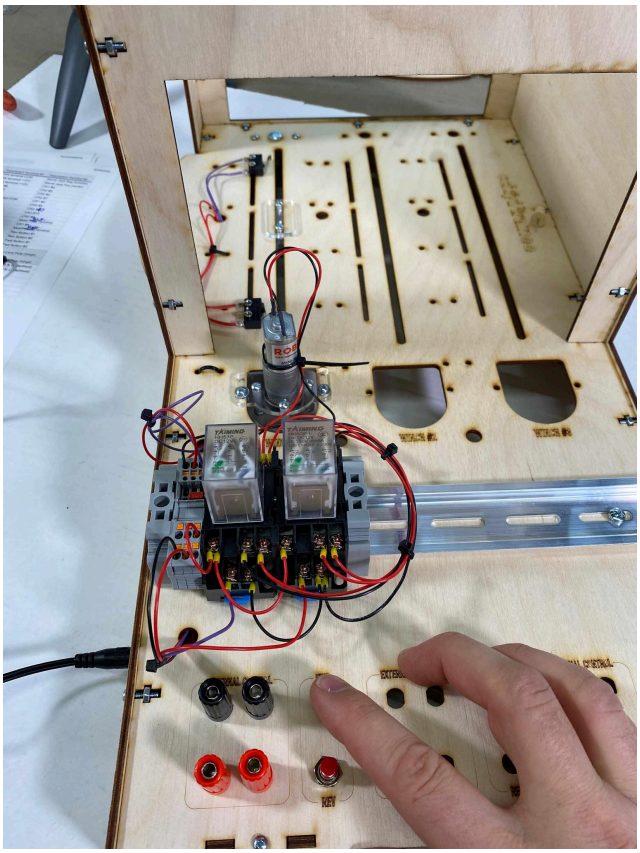
Push-button Control



1. Dig out your power supply and plug it into a wall outlet.



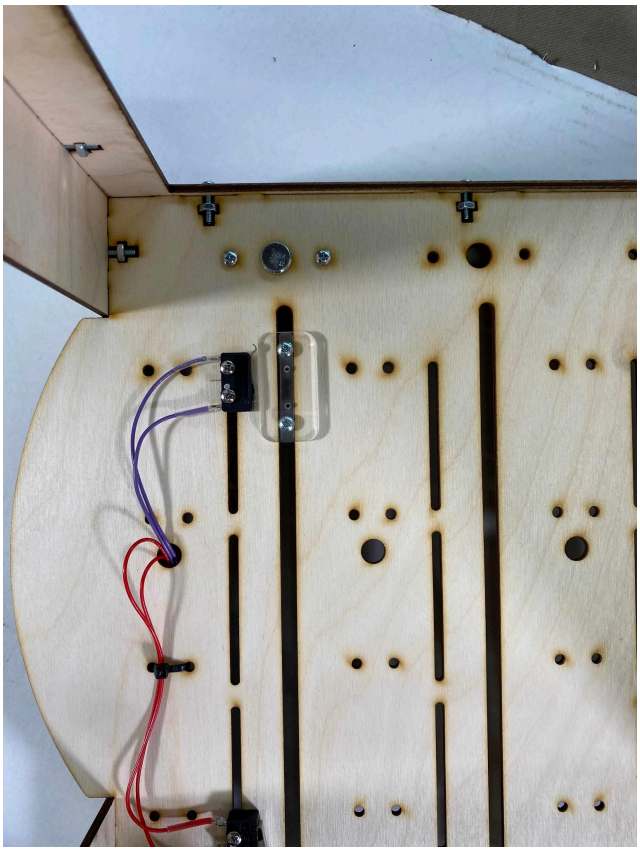
2. Insert the barrel tip of the power supply into the barrel jack on your Trainee.



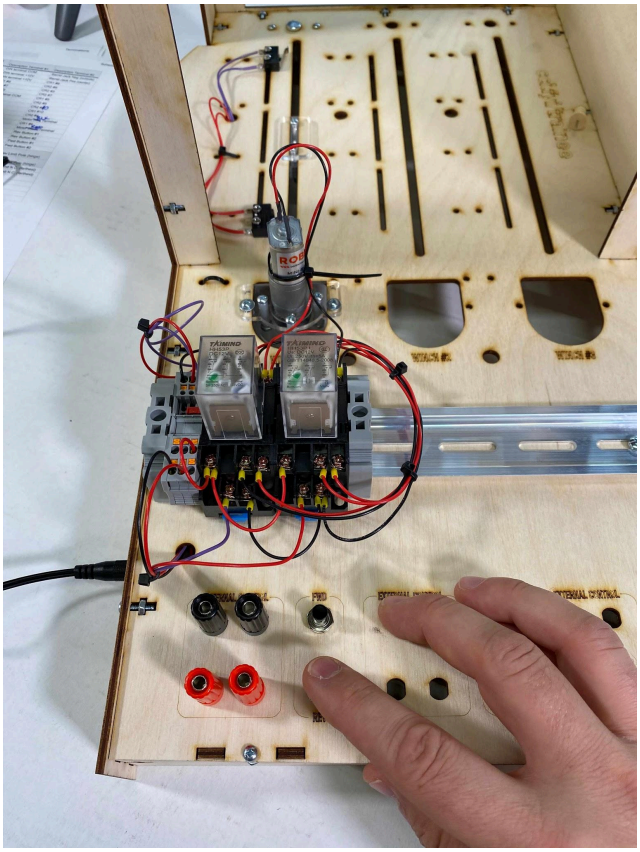
3. Press the **black forward button**. The motor should move the **dog** Stage Right. Notice also that an indicator light inside the relay CR1 lights up! If you release the button, the motor stops and CR1 turns off. Take a look at the innards of the relay switch as you are running the motor. You can see how the relay switch works. It's simple, but useful.

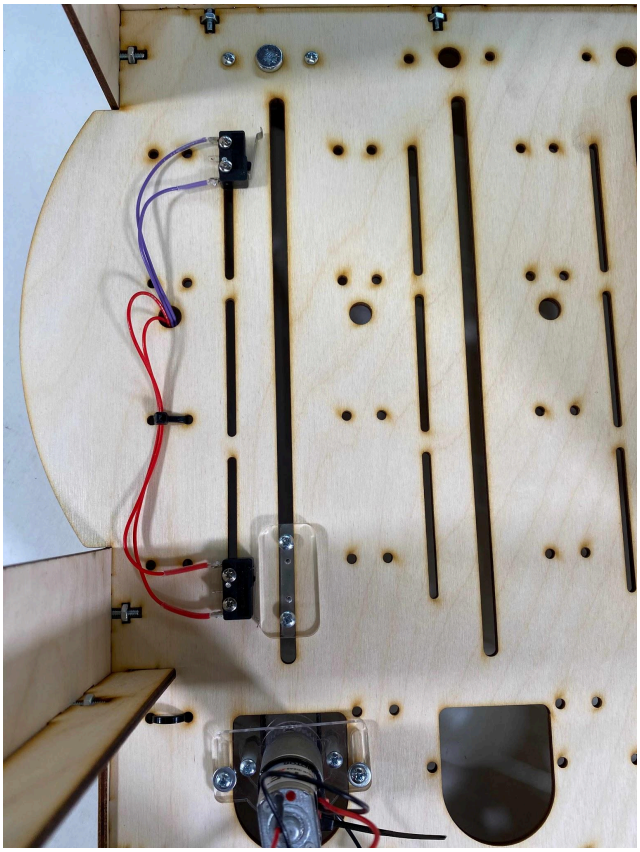
Changing motor polarity

If the motor runs the wrong direction, swap the black and red motor wires between CR1 & CR2. This will change which direction the motor rotates when commanded to move "forward."



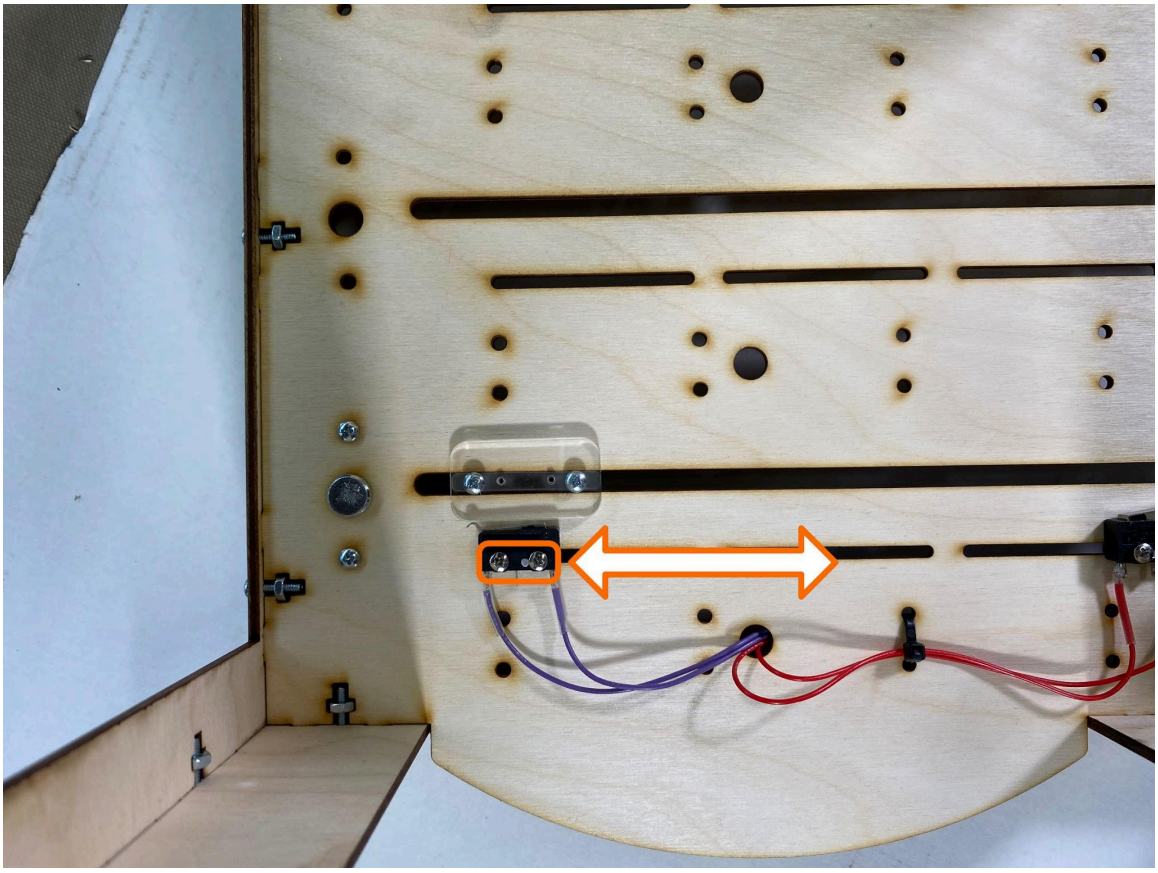
4. When the dog strikes the **forward limit switch**, it should stop. If it doesn't check your limit switch wiring (and make sure to release the pushbutton to avoid a crash).





5. Now, try the same steps in the reverse direction to verify your **reverse limit switch** is working.

Adjusting Limits



To change the spot that your winch stops, you need to move the limit switches. Loosen the mounting screws and slide the limit switch to the spot you want and tighten it back down. Notice that the dog travels slightly beyond the limit switch. This is the same issue you will encounter when setting limit switches on a big machine. There's a bit of drift and that drift will vary with the speed of the machine. In a fixed speed system, it's easy to allow for the drift. In a variable speed system it's more difficult to account for varying amounts of overtravel and maintain accuracy.

Variable Speed Positioning
In a variable speed system, we typically wouldn't use limit switches for positioning because it's hard to get repeatable accuracy as the speed changes. Instead, we'd use an encoder to get more precise positioning and couple it with a much more sophisticated motion controller. That's a topic for another day, but if you're curious check out Chapter 9 in the Scenic Automation Handbook.

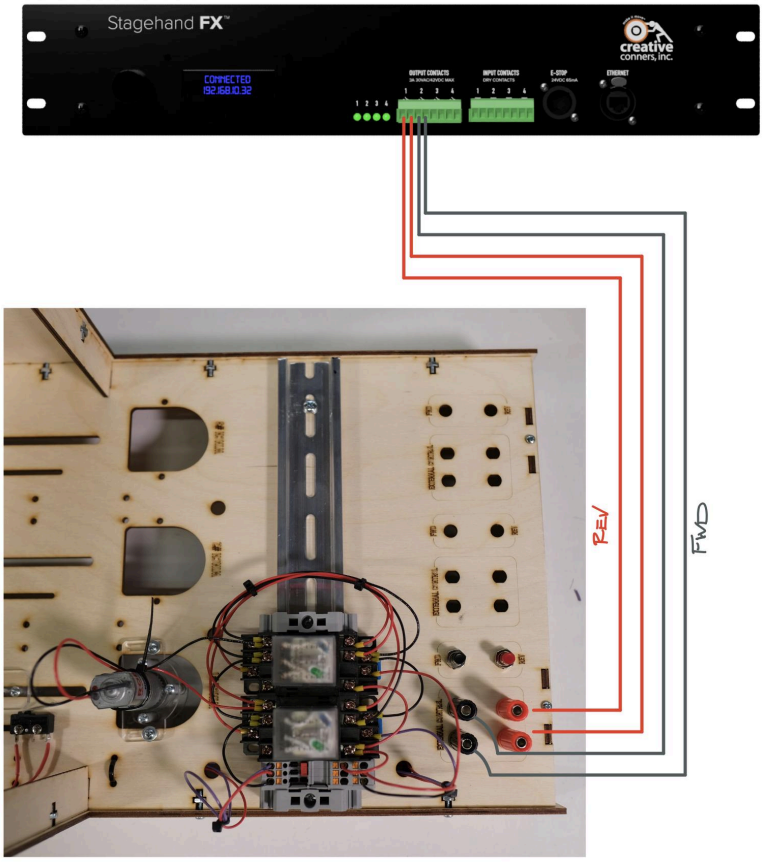
External Control

As great as our pushbutton system is at the moment, if you install more winches on your stage, getting the motion of all the winches choreographed relies on your button-pushing precision. **Trainees** are equipped to work with external controllers to manipulate the motors and give you repeatable motion that you can program. The **banana jacks** that you wired into the control circuit

replicate the functionality of the pushbuttons. If you make an electrical connection across the **black banana jacks**, the motor will move forward. Make a connection between the **red banana jacks** and the motor will move in reverse. Experiment with a bit of wire to see how it works. Poke one end of the wire into the top of the downstage black (or red) banana jack, poke the other end into the top of the upstage black (or red) banana jack. When you make contact the motor will move. Break the contact and the motor will stop.

Any programmable controller that can close a switch (aka dry-contact) can be used to control the motors. Some possibilities are:

- Stagehand FX with Spikemark
- PLC with your custom code
- An Arduino, Raspberry PI, or mbed microcontroller



When you use an external controller, you needn't drive the motors full distance and stop on the limit switches. You can instead use timers to control how long the motor runs and thus how far it travels. You can make some pretty fun scene changes with a little creativity!

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Timing based positioning
Would we write timing-based motion sequences on a real stage to control the position of a big motor? No, not really. It's too imprecise and could create serious hazards. But, it's harmless at this scale and gives you the chance to explore some basic cue programming with various controllers. Also, for simple prop automation, we might use timing loops for position control. The key factors are: the relationship between time and position has to be predictable, and inaccurate positioning cannot create a hazard for people or scenery.

Conclusion

Huzzah! You did it, nice work! You've got a fully functioning fixed-speed motor control circuit. Though this is a simple system, it's useful and used in the real world all the time. Fixed speed control with limit switch positioning is a fast, economical, practical way to control simple effects that don't require more sophistication. Along the way you've learned about relay switches, DC motors, limit switches, timing belts, and wiring. That information never gets stale; you'll use that knowledge even in more sophisticated control circuits. Having a good foundation is critical to your training in scenic automation and you have made great progress laying that foundation. I hope you're excited to learn more!

Disassembly

Trainee can be disassembled and reassembled multiple times. In a classroom setting we hope that it can be reused for years to come. To break it down, carefully clip the zip ties (you'll need to grab some more for next time), and roughly follow the instructions in reverse. For best results, keep all the original hardware bags and packaging so you can keep track of all the little parts.

TECHNICAL SUPPORT

If you have trouble getting your Trainee working, we're here to help. Send an email to support@creativeconners.com and one of our support team experts will get you up and running.

SPECIFICATIONS

Trainee measures 19.75" X 11" X 9.625" and weighs a mere 2.6 lb when fully assembled.

Device	Specification
Power supply	Input: 100-240VAC 50/60Hz Output: 12VDC 700mA 2.1mm barrel tip, center positive
Winch motor	12VDC

	0.1A no-load current 0.35A full-load current 1.5A stall current 26rpm output speed 651 oz-in stall torque 488:1 gear reduction (spur gears)
Timing belt	GT2 profile
Limit switches	SPDT snap acting 250VAC 5A max
Pushbutton switches	SPST momentary 250VAC 3A max
Relay switches	3PDT Coil: 12VDC Contact rating: 5A @ 250VAC/28VDC