OPEN SOURCE EBIKE BATTERY MOUNT

How-to video: https://youtu.be/FgjxSFlo72g
Github repository: https://github.com/pittxprojects/ebike

AUTHORS & CONTRIBUTORS:

Maya Román - *Junior ME Student*

Peter DeNicola - *Junior ME Student*

John Rozzo - *Sophomore EE Student*

Nick Bohn - *Senior ME Student*

Brandon Barber - *Project Coordinator*

Daniel Yates - *Project Coordinator*

William Clark - *Project Coordinator*

Stephen Spencer - *Project Sponsor*

Thick Bikes (Pittsburgh, PA) - *Bike Donor*

Project & General Design Overview

The main objective of this engineering project was to design a mount that allows a DIY E-bike to receive power from a commercial power tool battery. More specifically, we designed the mount to accept the RYOBI 40-Volt lithium-ion high-capacity battery. The intentions for this scope of design are as follows:

- Employ the economies of scale that are soon to come for lithium-ion batteries
- Take advantage of the safety features already incorporated in the battery
- Provide a battery solution for an E-bike that is easy to source and replace

Table of Contents

The purpose of this documentation is to display what we have designed and explain why we have designed it that way. This documentation also serves to provide context towards how we expect this bike to be used, inform of necessities and recommendations when sourcing components and approaching the build process, outline proper safety precautions, and give insight into the success of the project.

(click titles to go to sections)

Approach

- Our goal was to create an affordable e-bike conversion tutorial for commuters and bike hobbyists that can be done within a weekend
- We needed to design a battery mount that can attach a multitude of bikes
- We also needed to create simple wiring to connect the battery to a motor

Background Information on EBikes

The following section details relevant background information to guide you while choosing a bike and motor for your DIY ebike.

Critical Bike Features

Choosing a proper bike as the foundation for this design build is the first and most important step.

We recommend that your bike be equipped with disc brakes both in the front and rear, as rim brakes are not reliable and often not powerful enough to stop the added force of a motor.

Know where you will place the batteries and accommodate room for the mounting assembly on the bike (i.e. inside frame triangle, front rack, back rack, etc.)

Each set of water bottle bosses will allow for 1 battery to be mounted to the bike frame. If two batteries are desired for operation, water bottle bosses located on both the down tube and seat tube are preferred.

Note: Check if bottom bracket is compatible with motor if using a mid-drive kit

EBike Questionnaire

- We created a Google Survey to gather potential customer data (view here)
- From this, we found:
  - The overwhelming majority of ebike users will use the motor only when biking up hills
  - Most people that commute using an (e)bike have a commute distance of four to seven miles which takes under thirty minutes
  - This allows us to calculate battery recommendations accordingly

Motor Selection

Motor Power Rating

If the use case of the motor is in a hilly area like Pittsburgh, a motor smaller than 500 W should not be considered. A 250 W motor would usually work for a rider less than 200 lbs if the use case is flat terrain. For very heavy riders, very steep and hilly terrain, or use cases where fast and very powerful performance is desired, 750-1000 W motors should be considered.

Motor Selection

Peak Power

Additionally, one should consider the peak power (wattage) they will be able to receive with their combined motor and battery setup. This can be calculated by multiplying the Amperage rating of the motor controller (which determines the maximum current that can instantaneously be supplied to the motor) by the voltage of your battery setup. Usually, the peak power will be greater than the wattage that the motor is rated for. For example, a 500 W motor with a 25 Amp controller attached to a 40 V battery setup will experience a peak power of 1000 W. This will be an accurate representation of the power you can expect when you twist the throttle.

$$[Peak\ power] = [max.\ motor\ controller\ amp\ rating] * [battery\ voltage]$$

Motor Selection

Motor Type

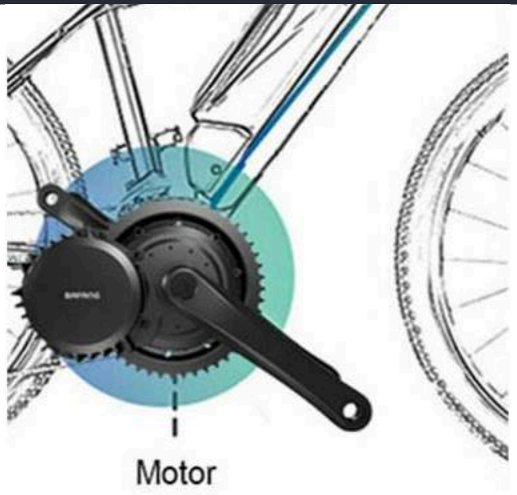
There are two main types of motor styles used for powering ebikes:

Mid-drive

Mid-drive motors attach at the bike's bottom bracket, driving the rear wheel in the same way the pedals drive the bike. Mid-drive motors allow you to shift through the bikes gears and provides high power.

Hub drive

Hub drive motors involve replacing one (or sometimes both) of your bike's wheels with a wheel with a motor at the hub.



Motor Selection

Mid-Drive Motor	Hub Motor
Higher torque/power since motor directly drives the crank	Decreased torque/performance due to more losses since motor drives rear or front wheel
Maintenance and service is very easy	Service can be complicated for even changing a flat tire
Improved handling by positioning close to the bikes center of gravity creating the feel of riding a traditional bike	Weight is distributed unevenly across the bike either towards the front or rear tire, creating an unnatural ride
Expensive	Cost-effective

Battery Selection

The problem presented to us by our sponsor related to battery selection for DIY ebikes. People converting bikes to ebikes on their own face the decision to spend a lot of money on proprietary batteries that are large and expensive, or spend less money on less safe batteries. The power tool battery chosen for this project was a RYOBI 40V 4Ah due to the brands popularity and reputation, and battery availability.

Battery Selection

Battery Overview	Price per Kilowatt hour Comparison (based on large home improvement retailer pricing)	
Our sponsor had us use two RYOBI 40V 4Ah batteries to power the bike. (Battery Manual)	RYOBI 40V 7.5Ah	$763.33/kWh
	RYOBI 40V 6Ah	$745.82/kWh
	RYOBI 40V 5Ah	$795.00/kWh
	RYOBI 40V 4Ah	$900.00/kWh
	RYOBI 40V 2Ah	$1237.50/kWh

Range Calculations

You can estimate your range based on your battery combination's total energy capacity and your ebike's efficiency based on your riding conditions.

Energy Capacity:

The power your battery selection can provide your ebike is based on the batteries' voltage, their Ah capacity, and how many batteries you use.

$$[power] = [voltage] * [capacity] * [\#\ of\ batteries]$$

In our case, with two 40V, 4Ah batteries, our battery system would be capable of providing 320 Wh of energy in one charge:

$$(40\ V) * (4\ Ah) * (2\ batteries) = 320\ Wh$$

Efficiency:

On average, going 20mph on flat terrain, an ebike has an efficiency of about 25Wh/mi using just the throttle, with no pedal contribution. The efficiency while using pedal assist, but still assuming a speed of 20mph on flat terrain is closer to 15Wh/mi.

Many factors affect the actual efficiency, including total load (weight of rider, bike, and cargo), wind speed and direction, road conditions (paved, gravel, dirt, etc), aerodynamics of your bike, hill grades, etc.

Check out this page for a more in depth efficiency estimation.

Range Calculations

Total Range:

To find your battery combination's total range on one charge, simply divide the energy capacity by the efficiency.

$$[estimated\ range] = \frac{[energy\ capacity]}{[estimated\ efficiency]}$$

This means that in our case, with two 4Ah 40V batteries, we would have a range of about 12.8 miles using just the throttle, and about 21.3 miles if we use pedal assist – assuming we're going 20mph on flat terrain.

$$\frac{320\ Wh}{25\ Wh/mi} = 12.8\ \ miles \qquad (throttle\ only)$$

$$\frac{320\ Wh}{15\ Wh/mi} = 21.3\ miles \quad (with\ pedal\ assist)$$

Use these calculations as guidelines rather than hard rules to help you decide which battery or battery combination to use. Remember to give yourself a margin between the range you need and the range your battery system can provide.

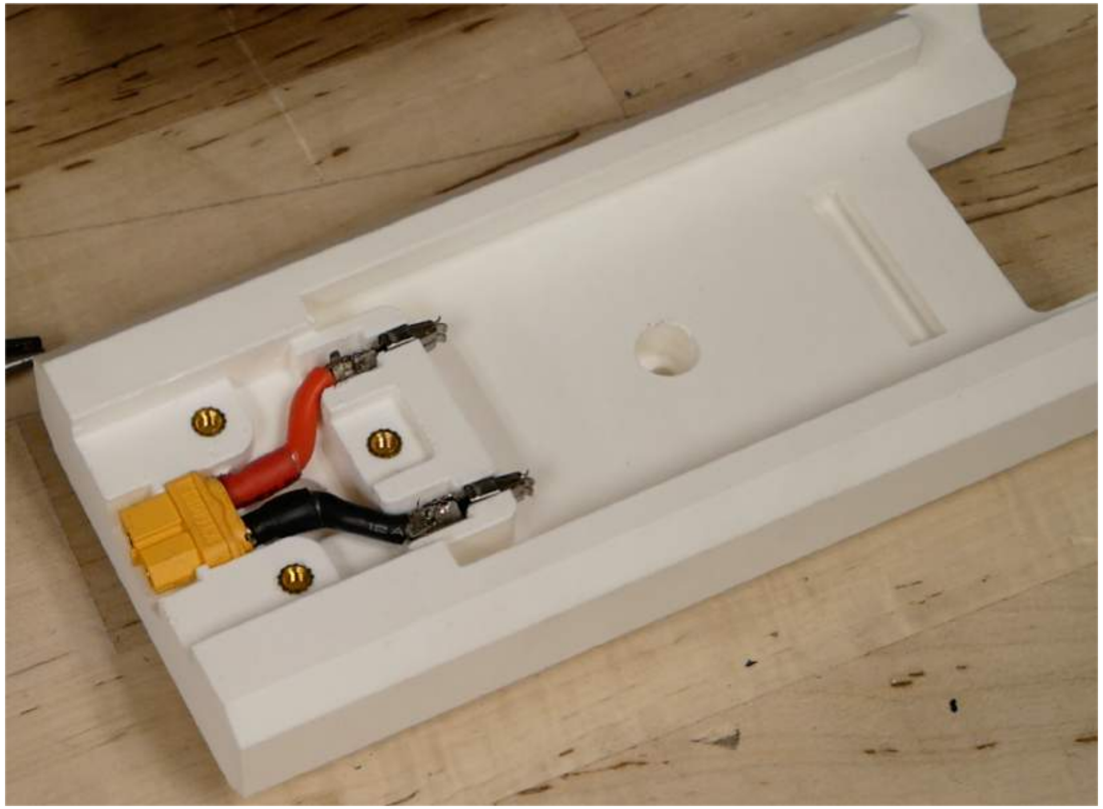
Our Solution

The following section details the specifics of how to make our DIY Battery System. This section supplements our how-to video.

Our Battery System

Our system consists of two RYOBI 40V 4Ah lithium ion batteries attached to the ebike via mounts we designed that connects in parallel to the motor via a Y-harness.

Our Battery System

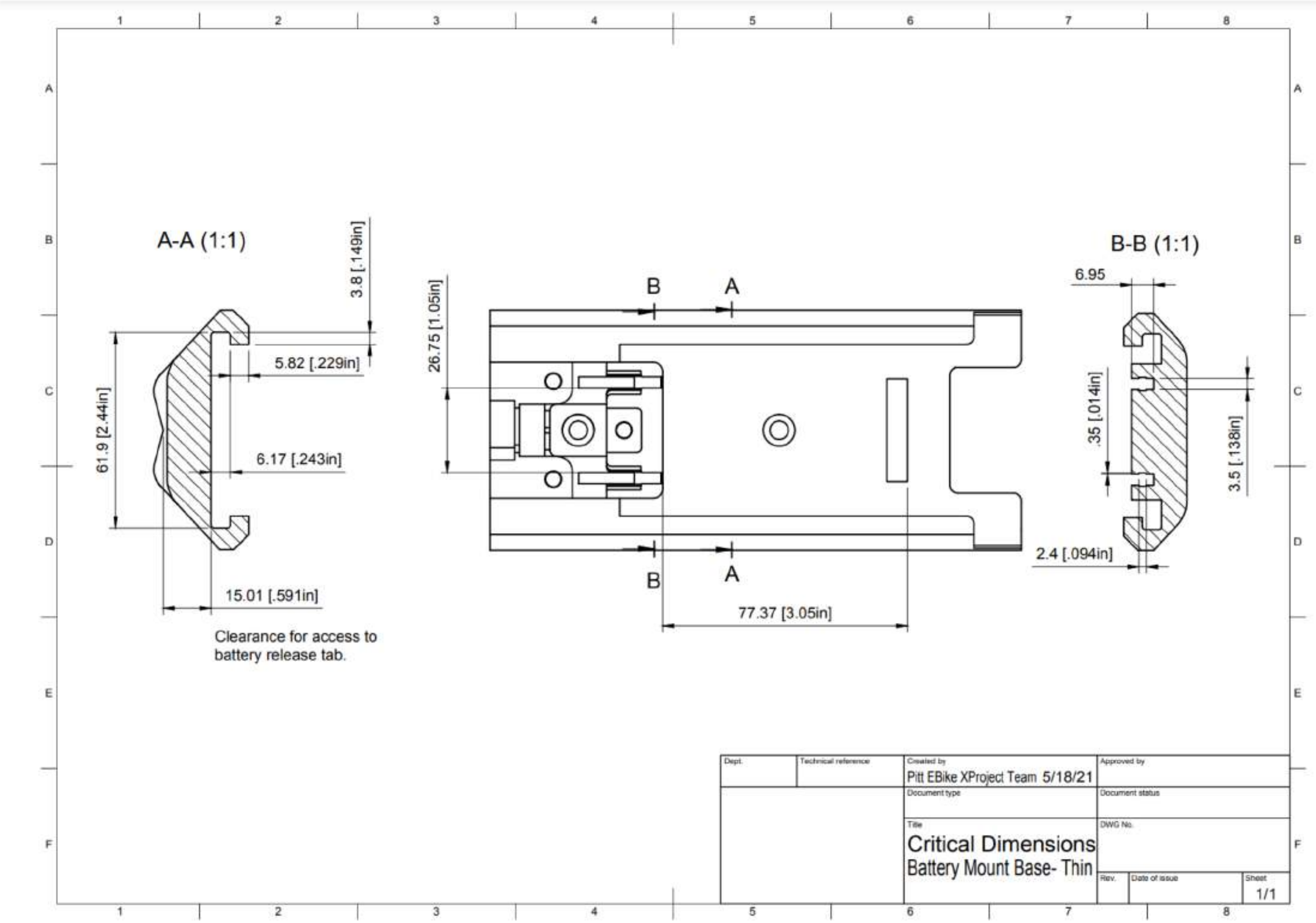


The mount features rails for the battery to slide into, a slot for the battery's latch to lock into, two mounting holes to attach the mount to the bike, geometry to hold the internal harness in place and mounting points for a wire cover.

Critical Dimensions

The critical dimensions of the battery mount are ones we caution against changing if you adjust the CAD model or design your own based on ours. These dimensions are detailed in the next slide, and the critical dimension drawing on our Github repository. The key dimensions are the battery mating profile, the size and position of notches for power timer tabs, the position of power timer timer slots in relation to each other and the locking tab, and the height between the top face that touches the battery and the mounting point on bike (for hand access to battery release tab)

Critical Dimensions



Bill of Materials

Item	Qty	Vendor	Link	Unit Price	Total Price
M5x0.8 12mm bolts	4	McMaster-Carr	https://www.mcmaster.com/92095A210/	$8.66/50	$8.66
6-32 ½" bolts	6	McMaster-Carr	https://www.mcmaster.com/91251A148/	$9.59/100	$9.59
Heat set threaded inserts for 6-32 bolts	6	McMaster-Carr	https://www.mcmaster.com/94459A280/	$10.12/50	$10.12
24-12 AWG stranded wire (more on wire sizing later)	~1ft black, ~1ft red	Amazon	https://www.amazon.com/BNTECHGO-Silicone-Flexible-Strands-Stranded/dp/B01ABOPMEI	$12.98/20ft	$12.98
XT60 connector pair, male and female	3 pairs	Amazon	https://www.amazon.com/Upgrade-Female-Bullet-Connectors-Battery/dp/B07VRZR5TL	$8.99/12 pairs	$8.99
Standard power timer contacts	4	Digi-Key	(10-11 AWG) (11-13 AWG) (13-17AWG)	$00.74 $00.40 $00.30	$2.96
3D printer filament (Village Plastics PLA)	~59m	-	-	-	-
Heat shrink (we used 3/8" and ¼" 3:1)	~16 pieces	Amazon	https://www.amazon.com/Wirefy-275-Heat-Shrink-Tubing/dp/B084GWYX42	$13.95/275 pcs	$13.95
Solder	-	-	-	-	-
RYOBI 40V 4Ah batteries	2	Home Depot	https://www.homedepot.com/p/RYOBI-40-Volt-Lithium-Ion-4-Ah-High-Capacity-Battery-OP4040A1/307973316	$144	$288
BAFANG 500W mid-drive motor kit	1	Amazon	https://www.amazon.com/gp/product/B07PQM7167/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1	$404	$404
Donor bike	1	-	-	-	-
				TOTAL	$759.25

Bill of Materials

- Note on the BOM: the only item we recommend being exactly the same as what we used are the power timer contacts which interface with the battery terminals. All other materials can be what you have on hand or find at a hobby store or website. We provided the material links more as a helpful reference than as the exact places you must buy parts.

How-to Overview

- Order parts
- Modify mount if you wish
- Print mounts
- Install threaded inserts
- Make internal harness
  - Cut wire
  - Strip wire
  - Solder XT60
  - Apply heat shrink
  - Solder power timer contacts
- Make y-harness (if using multiple batteries)
  - Cut wire
  - Cut insulation on one wire
  - Strip wire
  - Solder
  - Heat shrink
  - Solder power timer contacts x3
  - Heat shrink
- Install on bike
  - Bolt into water bottle mounts
  - Install internal harness
  - Bolt wire cover on
  - Plug in y-harness
  - Insert battery/ies
  - Turn bike on!

Order Parts

- You can use our Bill of Materials as a reference for your project, however you don't have to use all of the same exact parts as we did.
- It's probably a good idea to get a few extra of the components like the threaded inserts, the power timer contacts, and the XT60 connectors if possible just in case something goes wrong while putting it all together
- Make sure the get heat shrink and power timer contacts that are compatible with your chosen wire gauge
- The next slide details how to choose your wire gauge

Electrical Safety

Loose connections, power overloads (excessive current), and short circuiting can all melt your wire and cause electrical safety hazards!

To prevent excessive current draw, you must use wires properly rated for current that you expect to put through them.

Ideally, your battery system should be the current-limiting factor in your ebike system, meaning the total amerage capacity of your battery(ies) should be greater than the max current your motor controller is rated for.

That was not the case for our setup, and our motor controller was rated for a maximum of 25 Amps, so we used 12 AWG wire to incorporate a margin of safety in the worst case scenario of maximum current draw.

Use the chart on the right (from here) to help you determine which wire gauge is appropriate for the current that will go through your system.

AWG	Diameter (mm)	Diameter (in)	Square (mm^2)	Resistance Copper (ohm/1000m) (ohm/1000ft)	Resistance Aluminum (ohm/1000m) (ohm/1000ft)	Typical Max. Current Load Ratings - Copper (am				
						Single Core	Multicore			
							up to 3 cores	4 - 6 cores	7 - 24 cores	25 - 42 cores
40	0.08	.	0.0050	3448	5300					
39	0.09	.	0.0064	2693	4141					
38	0.10	0.0040	0.0078	2210	3397					
37	0.11	0.0045	0.0095	1810	2789					
36	0.13	0.0050	0.013	1326	2038					
35	0.14	0.0056	0.015	1120	1767					
34	0.16	0.0063	0.020	862	1325					
33	0.18	0.0071	0.026	663	1019					
32	0.20	0.0080	0.031	556	855					
30	0.25	0.010	0.049	352	541					
28	0.33	0.013	0.080	216	331					
27	0.36	0.014	0.096	180	276					
26	0.41	0.016	0.13	133	204					
25	0.45	0.018	0.16	108	166					
24	0.51	0.020	0.20	88	133	3.5	2	1.6	1.4	1.2
22	0.64	0.025	0.33	52	80	5.0	3	2.4	2.1	1.8
20	0.81	0.032	0.50	34	53	6.0	5	4.0	3.5	3.0
18	1.0	0.040	0.82	21	32	9.5	7	5.6	4.9	4.2
16	1.3	0.051	1.3	13	20	15	10	8.0	7.0	6.0
14	1.6	0.064	2.1	8.2	13	24	15	12	10	9.0
13	1.8	0.072	2.6	6.6	10					
12	2.1	0.081	3.3	5.2	8.0	34	20	16	14	12
10	2.6	0.10	5.3	3.3	5.0	52	30	24	21	18
8	3.3	0.13	8.3	2.1	3.2	75	40	32	28	24
6	4.1	0.17	13.3	1.3	2.0	95	55	44	38	33
4	5.2	0.20	21.2	0.81	1.3	120	70	56	49	42
3			26.7	0.65	0.99	154	80	64	56	48
2	6.5	0.26	33.6	0.51	0.79	170	95	76	66	57
1	7.4	0.29	42.4	0.41	0.63	180	110	88	77	66

Max. Current Load (amps)

Modify the Model

- The default model allows you to mount two 40V 4Ah RYOBI batteries on both sets of water bottle mounting points, however you can edit the model to function as you need. You can download the Fusion 360 models from our Github repository.
- To move the mounting hole position in the model, edit Sketch 11
- To remove the v-notch geometry, suppress Extrude 13
  - You'll have to edit the counterbore in Hole 1 so that there’s enough thickness for the two mounting bolts to clamp on to
- To adjust the battery mating geometry, edit Sketch 2, renamed “battery mating geometry”

Print Mounts

- You can download the stl files for the mount on our Github
- We printed two mounts and two lids out of PLA with 20% infill and a 0.2mm profile on Ender 3 3D printers, but you can adjust the settings as you like
- We printed the mounts in a vertical orientation to minimize supports needed, but we've seen it print fine in this orientation without supports at all

Install Threaded Inserts

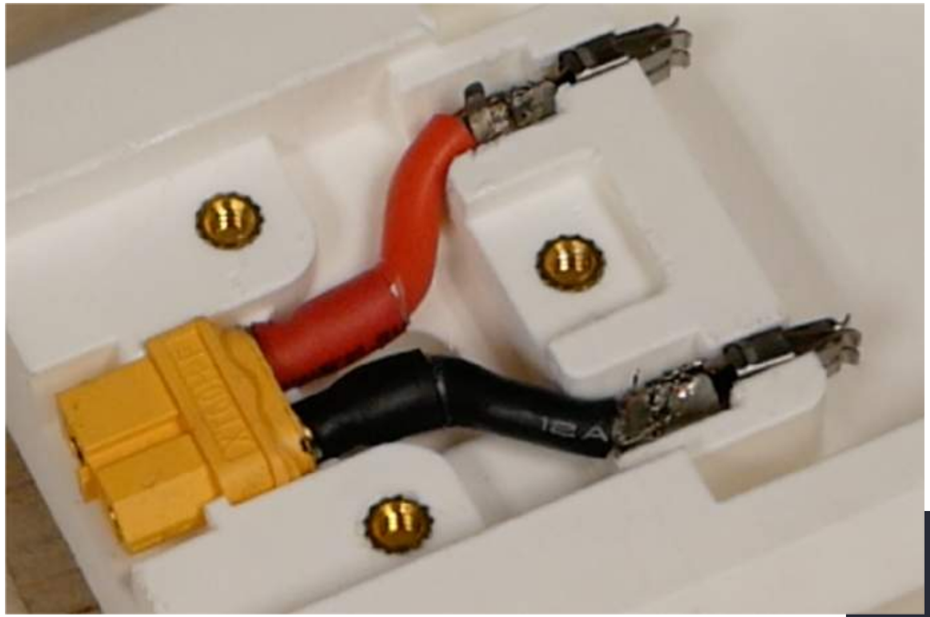
- To bolt the lid to the mount, you'll need to install threaded inserts into the mount
- You can use a soldering iron (since the holes for the inserts go all the way through the part you can use a regular soldering iron tip) to heat the insert while it's sitting in the hole, gently pressing down until the insert is 90% of the way down
- Then remove the soldering iron, and use something flat and heat resistant to press down on the threaded insert, so it's flush with the top face
- Press down for about 10 seconds, by which the plastic surrounding the insert should have cooled enough
- Repeat for the other two holes
- Watch us perform the technique in our video, or read more about it here

Make Internal Harness

- To make the internal harness you'll need two pieces of wire, one 1 ¼ in length, and one 1 5/8 in length. It doesn't matter which is which, but it will make installation into the mount easier.
- Strip about a quarter of an inch of insulation off both ends of both wires.
- Solder the wires to a female XT60 connector. Make sure the wires are soldered onto the correct side of the connector, each side should be labeled as + or -.
- Use up to ½ in of heat shrink on each wire where its soldered to the connector. The heat shrink mitigates possible shorting, but use too much and the small wires will be difficult to bend.
- Solder the power timer contacts to the other ends of the wires. While soldering, make sure not to clamp onto the tabs that come out of the wider sides of the contact, otherwise they won't snap into place in the mount properly.

Make Internal Harness

- You can crimp the contacts if you have the right kind of crimping tool. Otherwise it helps to use pliers to pinch the contact around the wire before you solder.
- Additionally, before you solder, make sure to orient the contact as shown below so that it's easy to install into the mount. Notice the orientation of the power timer contact slot in relation to the XT60
- We don't recommend adding heat shrink to wire's connection to the power timer contact because when installed the contacts can't short to each other, and the heat shrink makes it too stiff to install easily.



Make Internal Harness

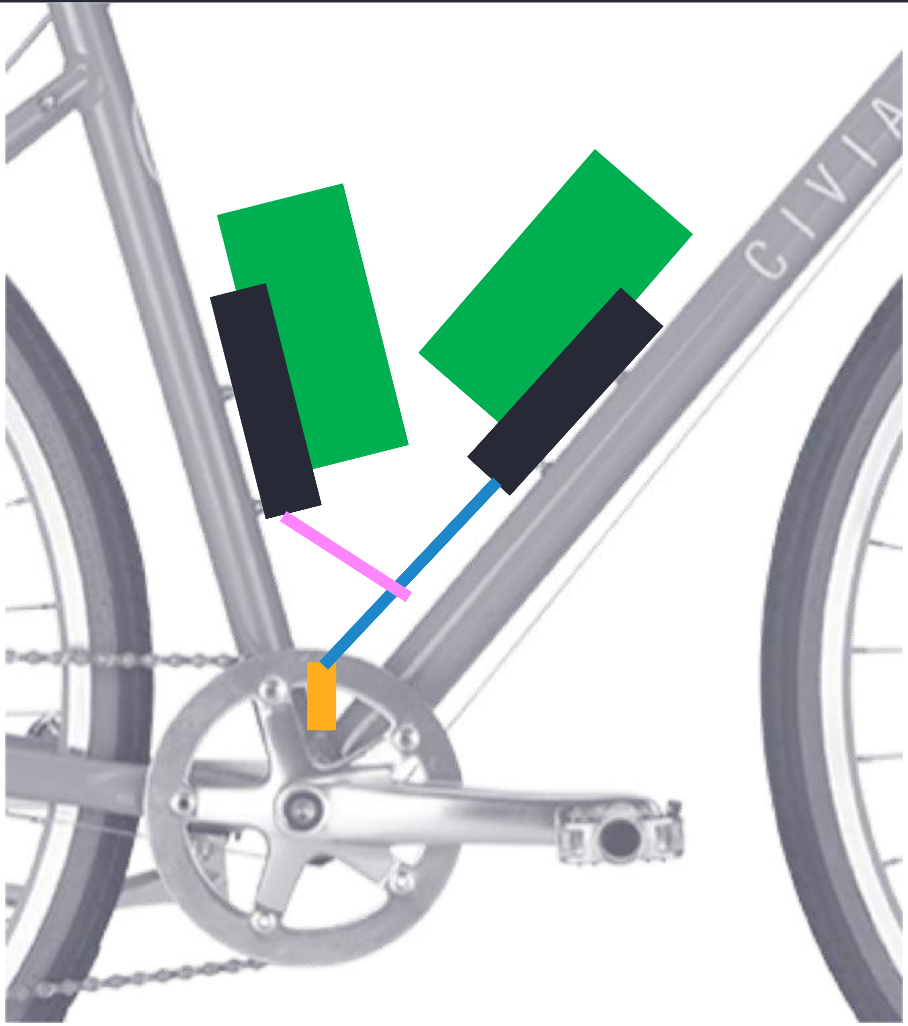
Use this slide as reference for which connector is which type, and which side is positive or negative.

Make Y-Harness

- If you use two batteries, you'll need a Y-harness to connect them in parallel. If you want to wire more than two batteries to your system, you could make other parallel connectors like this or this.
- To make the Y-harness, you'll need to measure how much wire you need based off of where your motor/motor controller power cable ends in relation to your batteries. See the next slide for more details.

Make Y-Harness

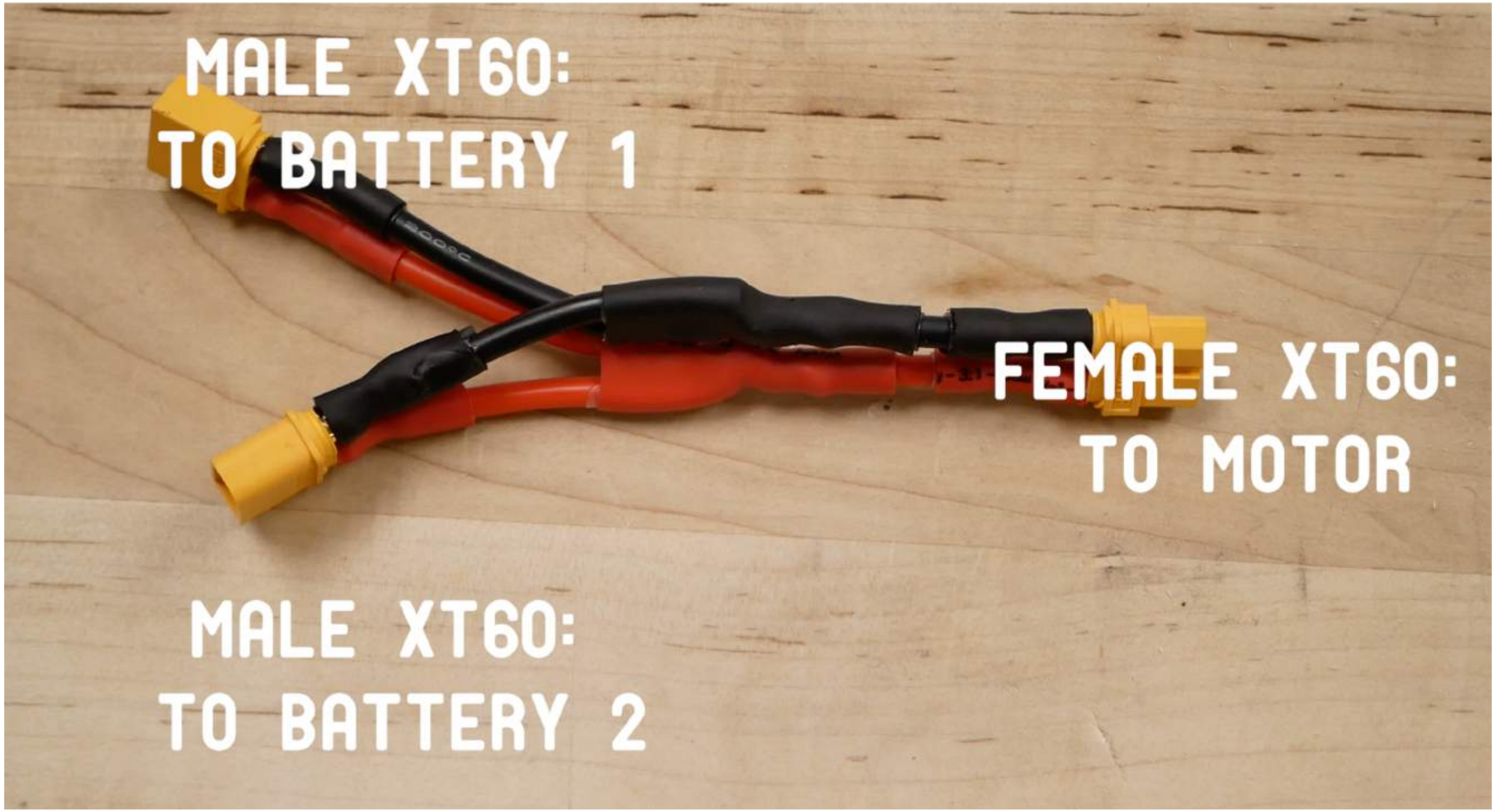
- You'll need two sets of wires for the Y-harness, each set needs one ground and one positive wire of the same length.
- Approximate how long the blue wire would need to be on your bike – from the connector to one battery - add some length for slack, and cut one set to that length
- Then approximate how long the pink wire would need to be – from any point on the first wire to the second battery. Add some length to that value for slack, and cut the second set to length



Make Y-Harness

- Now, using a knife, cut out a section of the insulation on the longer wires at the location where you want the second wire to connect (where the pink and blue wire intersect in the previous diagram). The cut out only needs to be 1-2 inches wide.
- Strip the wire at both ends of all wires.
- Solder one end of the shorter wire to the exposed section of the longer wire. We found this method to be easier than soldering the ends of three wires together given the larger wire gauge size we used. Repeat with the second set of wires.
- Use heat shrink to cover the solder joints.
- Solder the end of the wires going to the motor to a female XT60 connector, and solder the two ends going to the batteries to male XT60 connectors. See the next slide for reference. Make sure the polarity of the XT60 connectors is correct.
- Use heat shrink to cover the solder joints on all of the XT60 connectors.

Make Y-Harness



Install on Bike

- First, bolt the 3D printed mounts onto the water bottle mounts using the M5 bolts. Make sure the opening to slide the battery in is at the top of the mount.
- Next, install the internal harness into each mount. The contact going to the ground wire should go in the right and the contact on the positive wire should go in the left.
- Start with whichever wire is longer, and slide the contact into its groove until you hear a click. The tabs on either side of the contact should have snapped into place in the mount. Repeat with the other contact.
- Snap the XT60 connector into its slot, then install the wire cover by bolting it down with the three 6-32 bolts into the threaded inserts.
- After installing both internal harnesses and wire covers, use the Y-harness to connect the mounts in parallel to the motor.
- Insert the batteries, turn the bike on, and enjoy your new ebike!

Design Studies

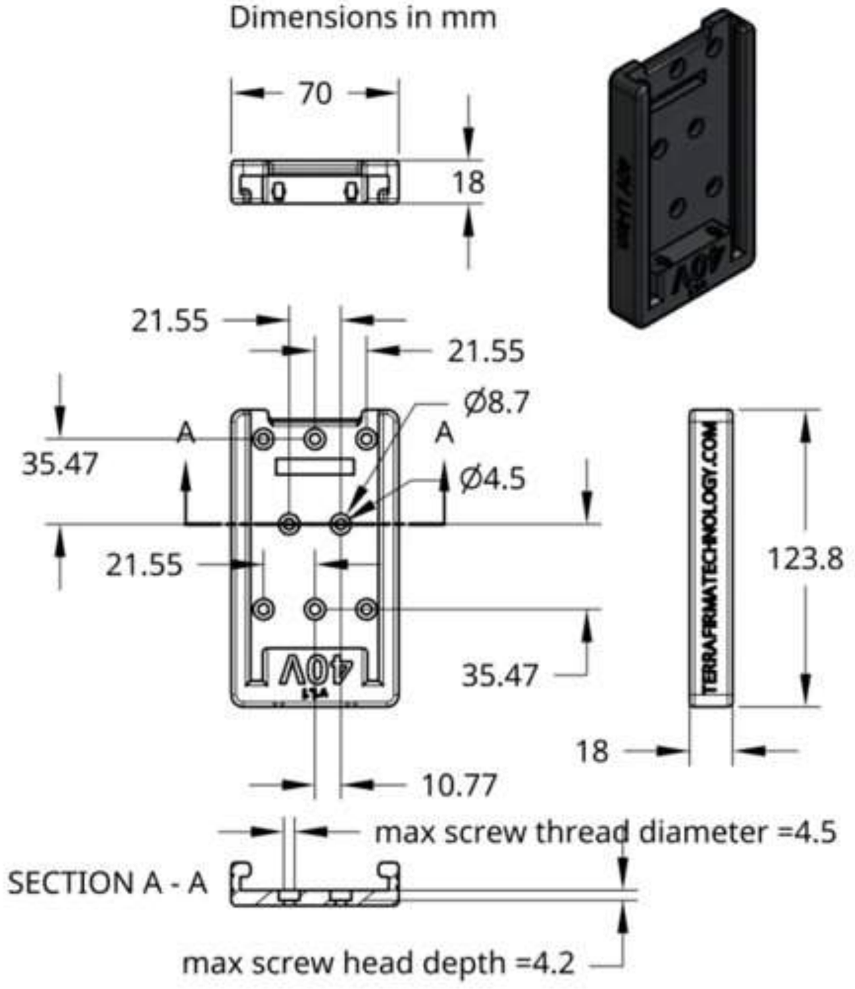
We identified the four most critical aspects of the design, and conducted design studies to investigate each aspect

Design Study: Battery-Mount Mating

- The initial inspiration was found on thingiverse (https://www.thingiverse.com/thing:4213959)
- From here, we adjusted the geometry to achieve our specific design goals

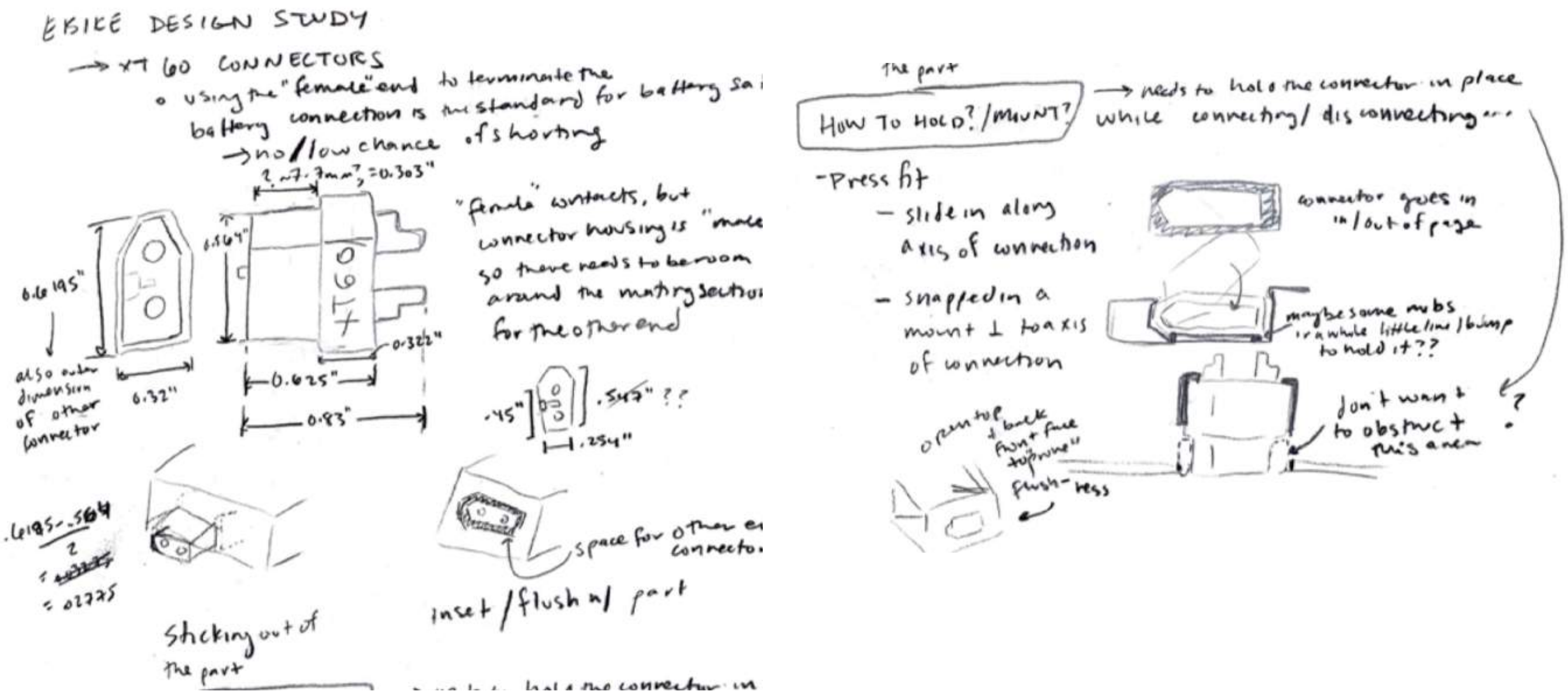
Design Study: Battery-Mount Mating

- Dimensions we adopted and modified for our design

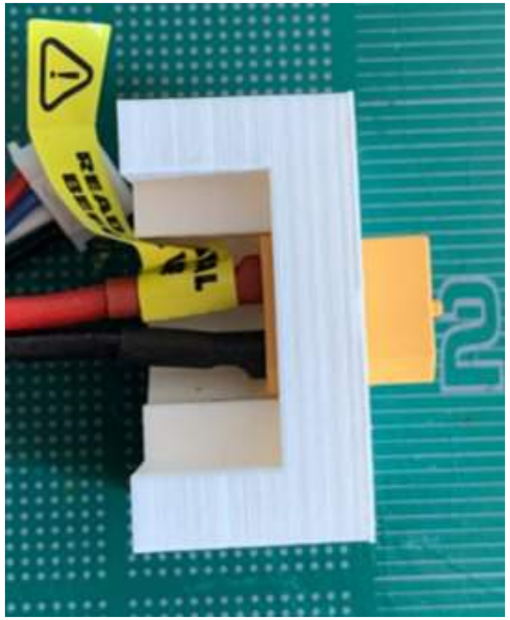


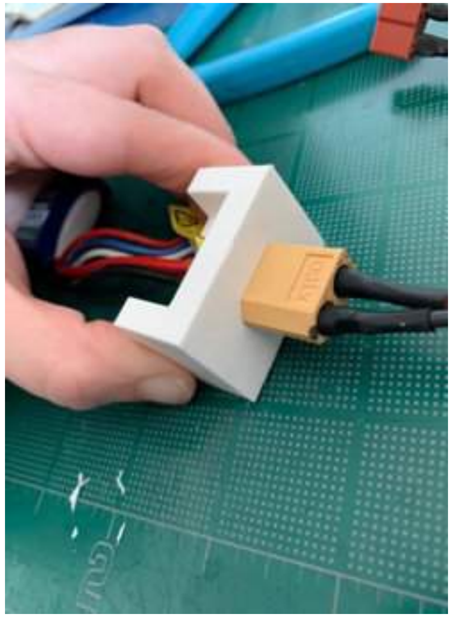
Design Study: XT60 Connectors

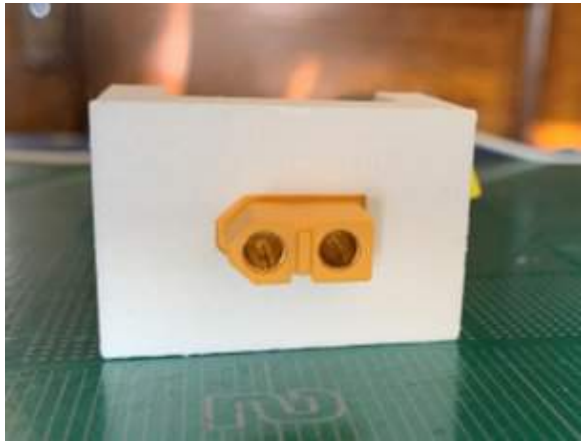
- XT-60 connector needed to attach to the battery mount in a secure fashion
- XT-60 connector dimensions <u>here</u>



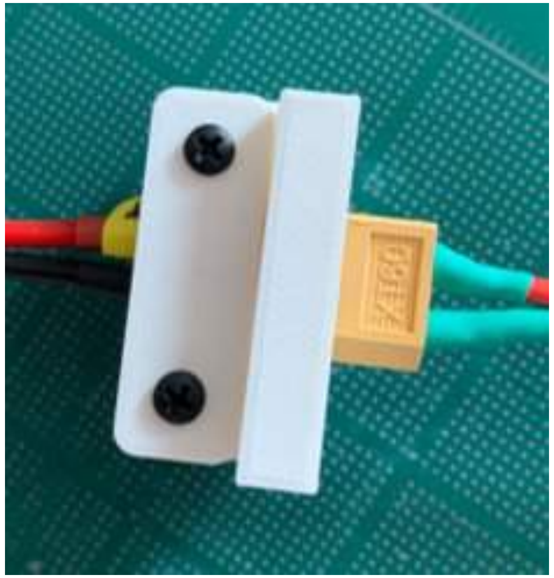
1st iteration

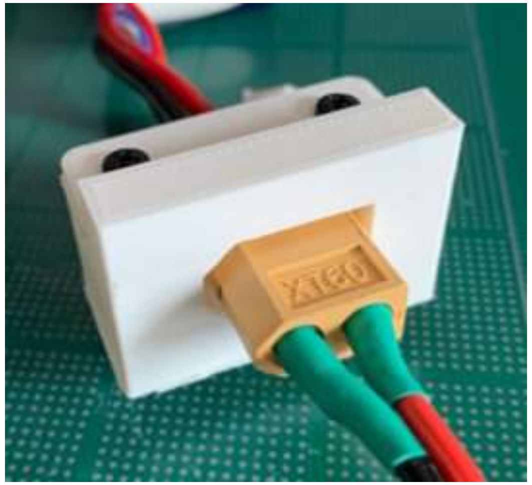


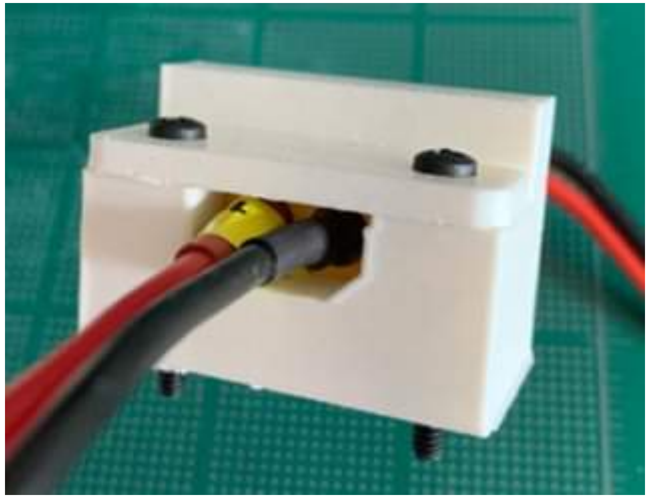




2nd iteration

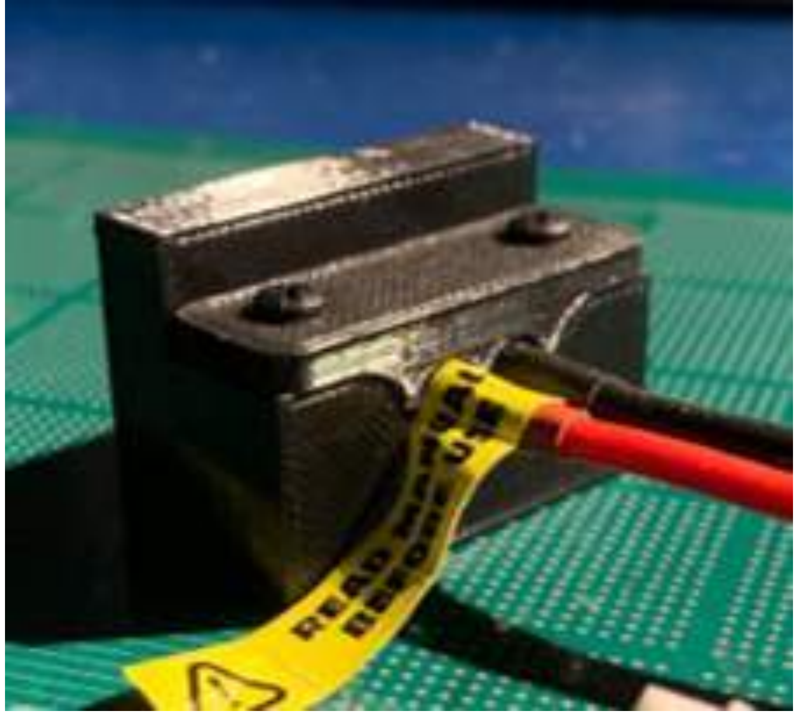


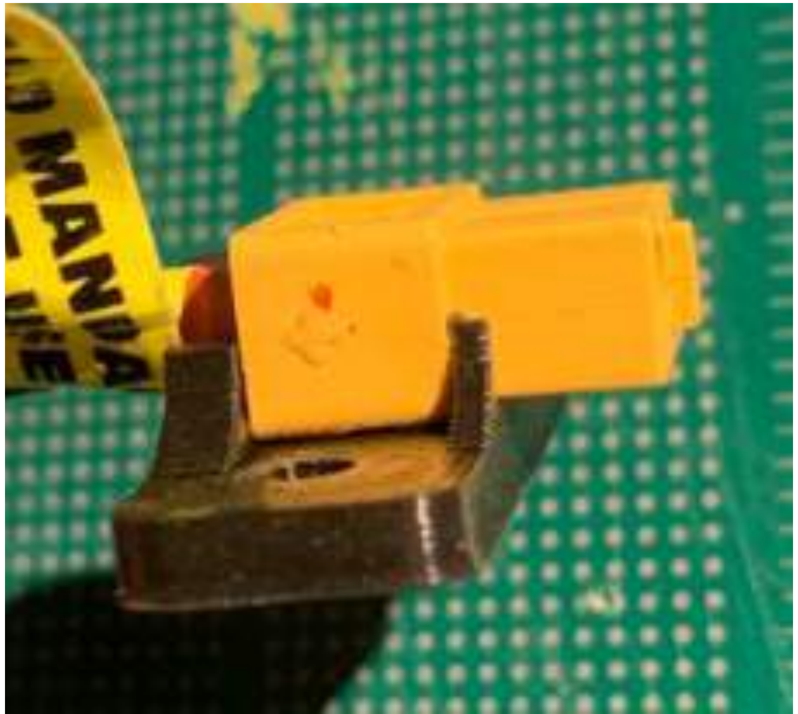


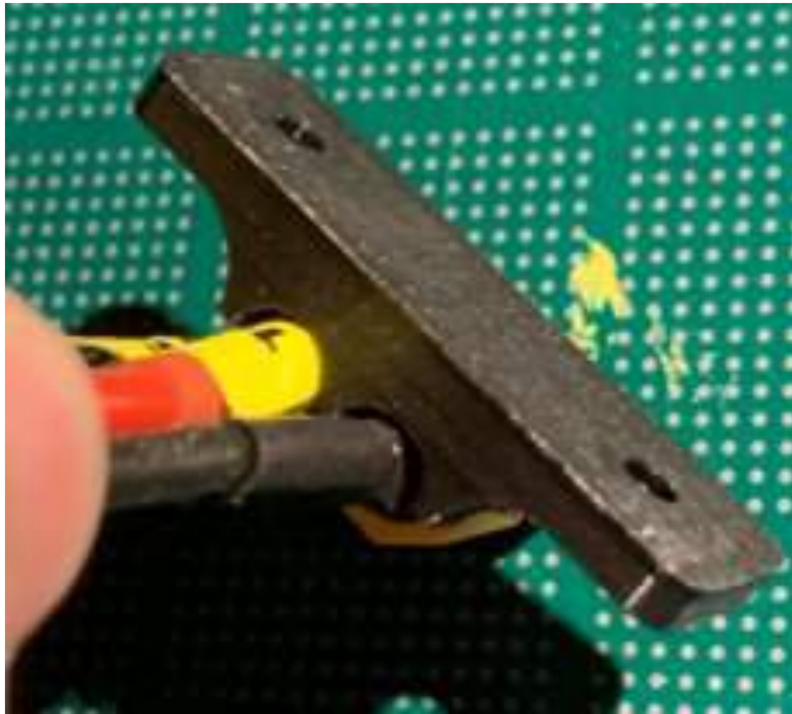


3rd (final) iteration

- Includes notches to hold in XT connector well
- Two parts to design
  - Main block that represents the battery mount
  - Screw on lid with notches

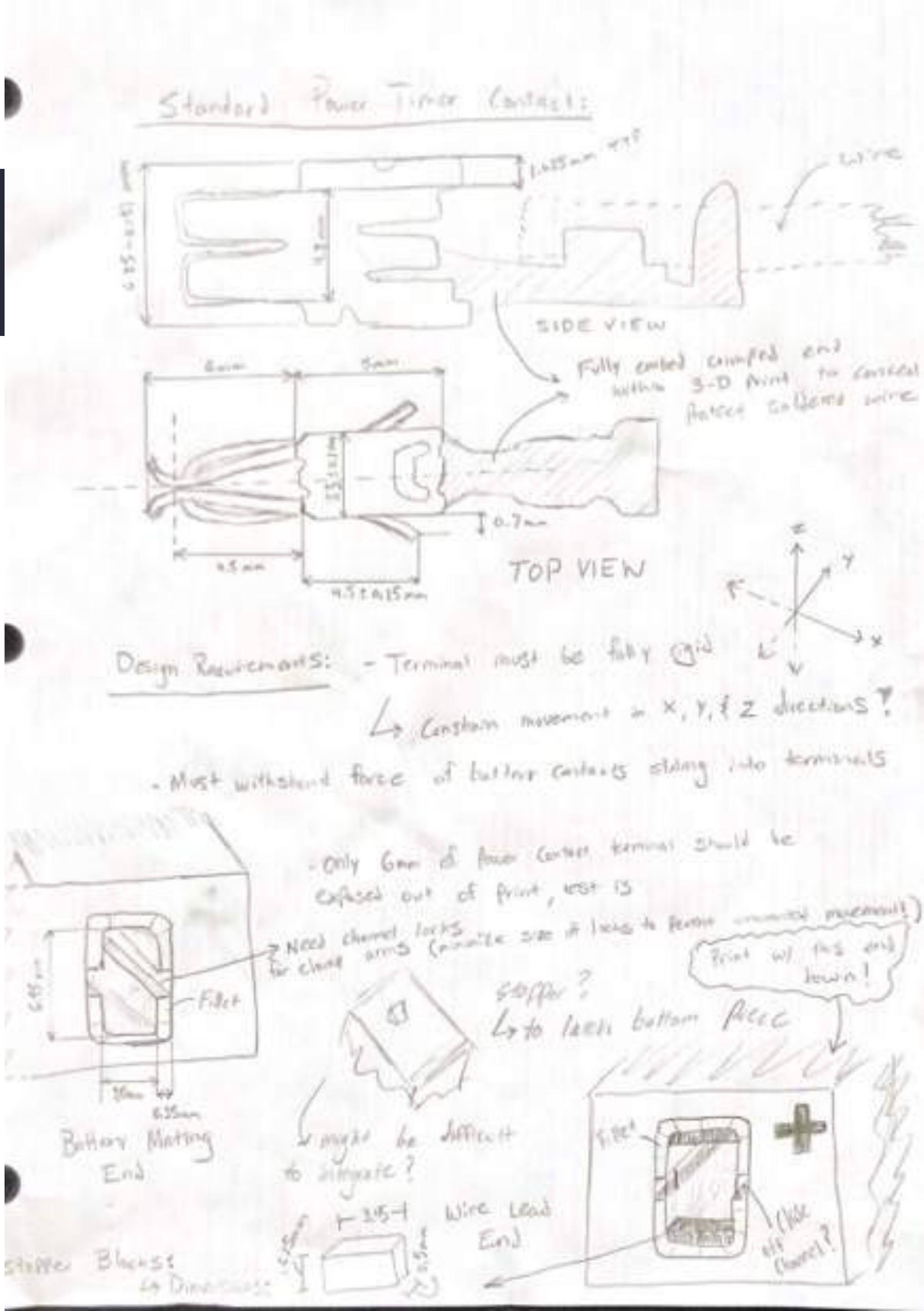




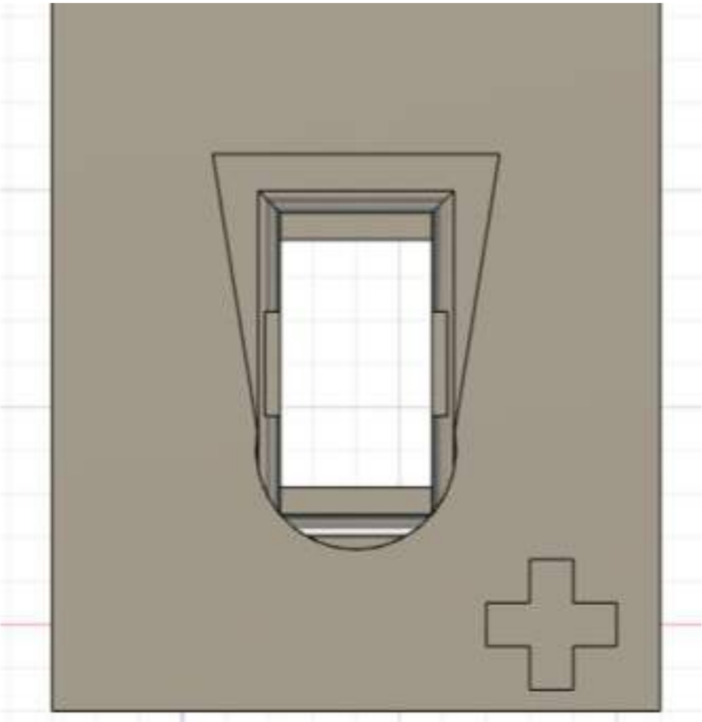


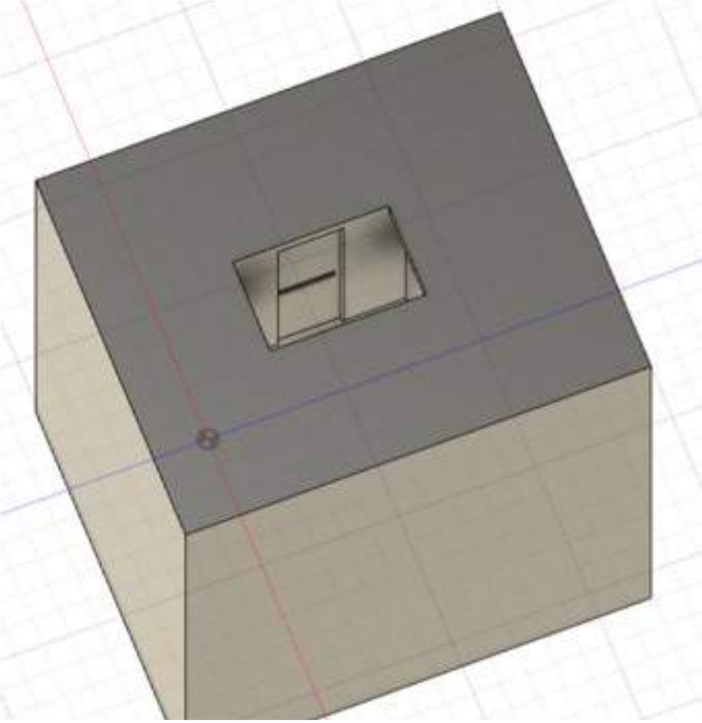
Design Study: Power Timer Contacts

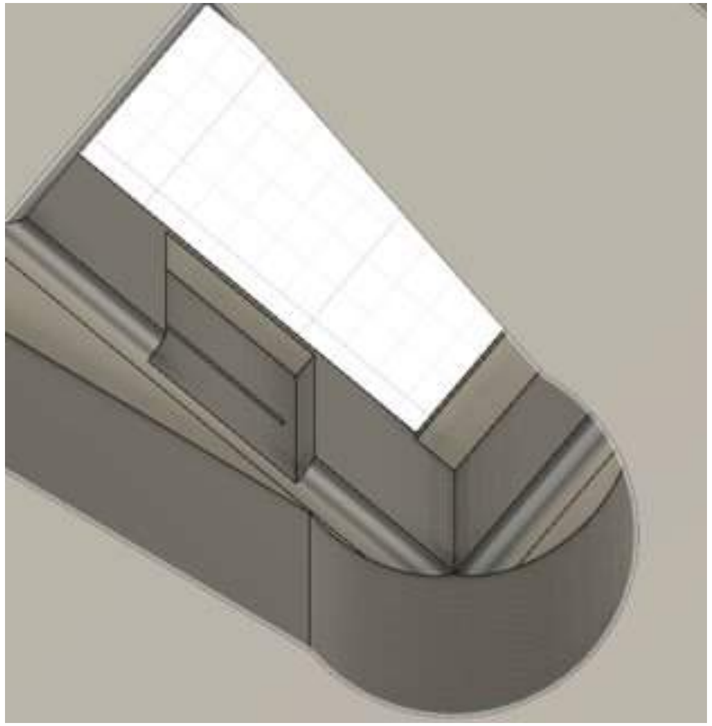
- Standard design sketch:
  - Needed a power timer contact capable of being snug into the confine space of the battery mount
  - The interior of the battery mount geometry needed to be altered to easily allow for this snug fit
- Link to the power timer contact we used here



Design Study: Power Timer Contacts



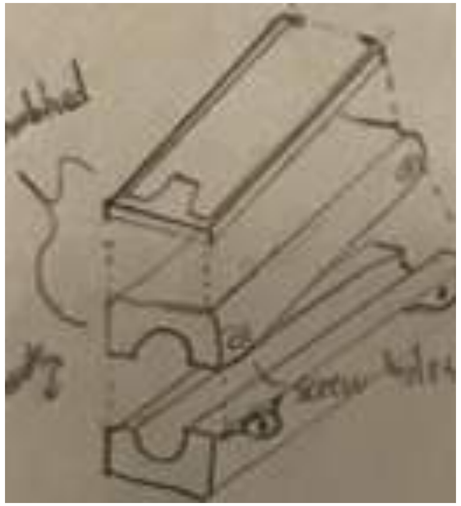


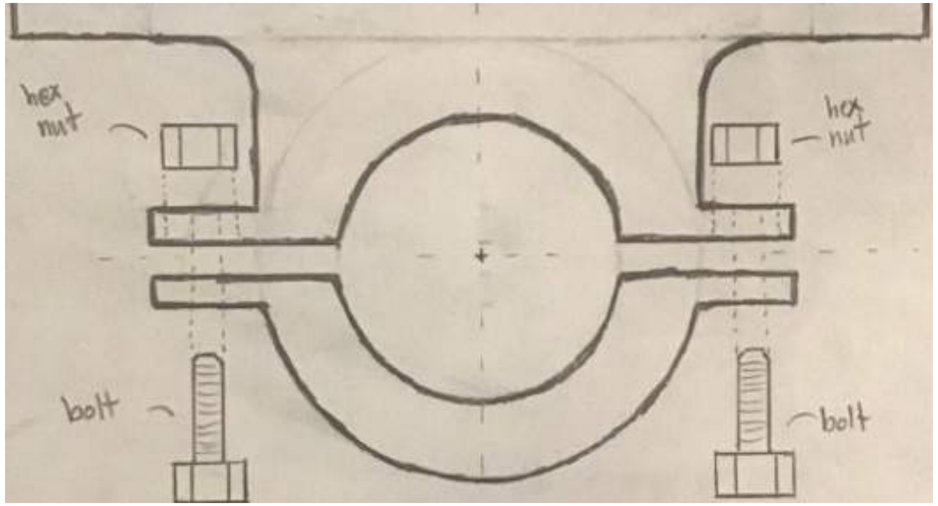


- This piece was to be integrated into the battery mount
- The slots and mini-divots allow for the aforementioned snug fit

Design Study: Mount-Bike Tube Mating

- We needed a sound way to attach a rectangle to a cylinder
- We initially wanted to attach a flat platform to the down tube of the bike for the battery mount to be screwed onto
- We concluded a v-notch grip (top right) would be best. This would allow the design to fit all down tube dimensions while being secure





Design Study: Integration

- Multiple designs incorporating all design studies were created and tested
- The final design comes with a lid that is meant to further protect the wiring and XT connector

Project Conclusions

Final thoughts and points to wrap up the project.

Success Metrics

These are the features we defined and set out to tackle at the beginning of this project:

Customer Preferences:

- Robust for ease of mind
- Cost effective to make
- Weather resistant
- Complies with local, state, & federal law
- Theft protection (battery cannot be easily stolen)

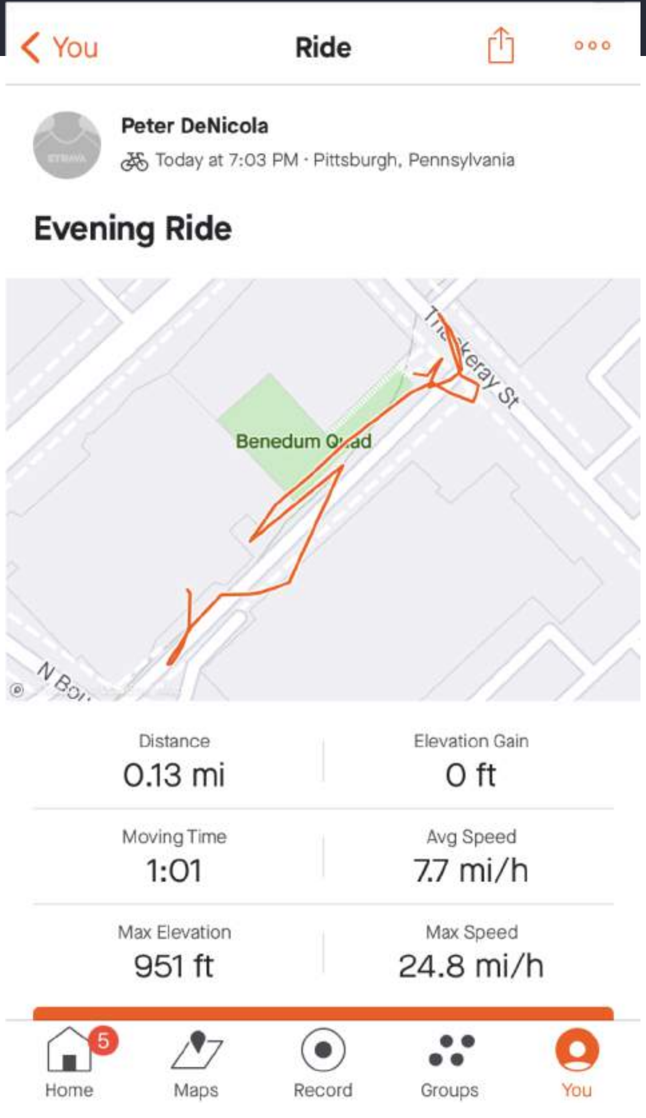
Functional Requirements:

- ✓ Battery securely mates and easily detaches from mounting point
- ✓ Battery properly provides power to motor controller
- ✓ Mount is easy to replicate and build with common tools
- ✓ Universal functionality across all bicycles

Test Ride on Flat Ground Using Only Motor Assistance

- Using the Strava app, we were able to record a maximum speed of 24.8 mph traveling on flat ground using only motor power, with two RYOBI 40V 4Ah batteries, verifying our goal of powering an ebike with our mount and commercial batteries!

- Note: Please check your local, state, and federal laws to ensure that you are in compliance when operating a self-made ebike



Project Outlook

Future Features: Additional features we encourage others to incorporate into the mount design.

- Hook latch
- Roofing shelter for batteries
- Snap in wire lid
- Zip tie channels
- Down tube mount extender / attachment plate
- Versions for other battery brands

Future Project Ideas: Additional related project ideas that would be interesting to combine with our project

- DIY 3D printed motor

Thank You to All Involved!

Project sponsor and mentor: Stephen Spencer

Bike donation: Thick Bikes (Pittsburgh PA)

Project coordinators: William Clark, Brandon Barber, & Daniel Yates

Student contributors: Maya Román, Peter DeNicola, John Rozzo, Nick Bohn