

Tab 1

Final Report

Drill Sergeants (12)

Endurance Event

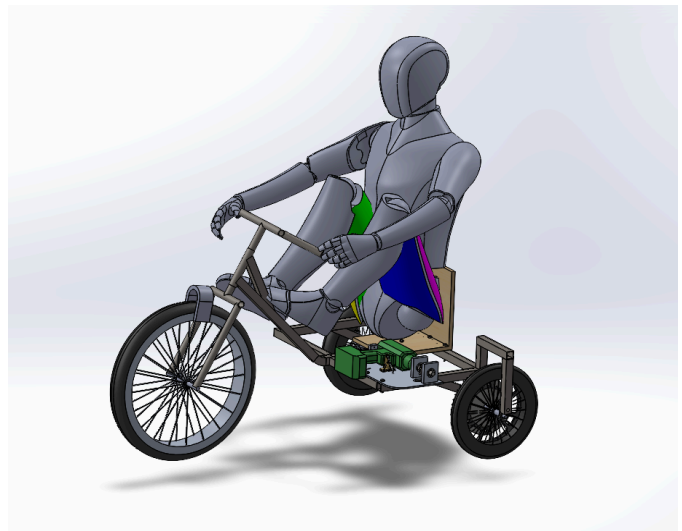
Project Manager: Mark
Prasertjing

CAD Engineer 1: Amanda
Stevens

CAD Engineer 2: Ailin Chinn

Manufacturing Engineer: Tinius
Klaveness

Testing Engineer: Trent Stodden



1. Introduction

The purpose of this project, at its core, is to design and manufacture a drill-powered vehicle. This vehicle will be entered into one of the five competitive events at the end of the semester. If it survives said competition, it will participate in an all-out tug-of-war competition. The event we chose as a group was endurance. This entails that we need to design a vehicle with the purpose of getting the most laps it can in thirty minutes, whilst maintaining its structural integrity and function.

While as a group we are working to complete this goal, we are learning valuable experiences that we will apply to our senior projects and to what we do in the engineering industry. This includes designing the vehicle based on calculations that we have made using the concepts we have learned in class related to stress, failure, material science, mechanics, and dynamics.

This also includes learning how to collaborate as a group, prioritize our time, make a timeline, build off each other and our ideas, and organize ourselves in an orderly manner that is beneficial to ourselves, our project, and our team members.

The objective of this project is also to get manufacturing experience—to learn in a hands-on environment about what it takes to get these engineering projects done, why things with tighter tolerances are more expensive, and how much time, equipment, material, and manpower are required for each aspect of the part we are making.

Since we decided on the endurance challenge, we wanted something lightweight, efficient, but durable, and we had to make a design that accounted for this while staying under budget. Overall, this project has taught us what it really takes to bring an engineering idea to life. From the first sketches to the final welds, we've learned how design, analysis, and teamwork all come together to make something that actually works.

2. Design

2a Conceptual Design

In initial conversations about high-level design choices, we went to previous students to gather opinions on what types of designs tend to work out the best in their experience. Some of the feedback we heard was that a tricycle with two wheels in the back is a really popular choice, and a lot of people vouched for its success. We also discussed which wheel we wanted to power, or whether to power both the back wheels, and we quickly ruled out powering both back wheels due to not wanting to deal with differentials. The choice was really between the front and a back wheel, which is where we needed to talk about the components we wanted to take from a bike to assist in guiding this choice. We thought it would be the simplest option for us to take the front fork and handlebars from a bike as our acquired component, due to specifically selecting a bike with brakes on the front wheel. After making this choice, we thought it might be easier to

incorporate the drill plate on the back wheel since there is more room for customization, as it can be designed and welded with this in mind.

From here, we wanted to get a general shape of the frame made, which we first drew out by hand, then put into a SolidWorks model. We thought the triangular nature of it would make it strong, but at this point, it was mostly guesswork. This design had several major flaws that we quickly realized. First, the way the tubing would come together at joints would be unrealistic to weld, with intricate angles and over 3 segments coming together at some joints. Next, once we learned more about bike wheels, unless we found wheels made for a trike, we would need double shear support, so both sides of the bike axle are connected and supported. The frame design did not allow for this to be easily accounted for. These issues essentially forced us to go back to the drawing board and come up with a new design.

For the next design, we looked toward existing trike designs to get a general idea for the shape of the neck and seat. We found that a low seat, with a bend in the neck, is common and decided to incorporate it in our design. The major modification that would need to be made is a double shear support for the wheels. Also, in the design, we intended to make it as small as possible so that it would be within weight requirements and to keep material costs low. We then used SolidWorks to create the initial model. At this point, we also needed to decide which wheel to power and where to put the drill plate. We wanted to power the outside wheel on the endurance course, which was the back left wheel, and to do this, we must have the chainring facing the inside of the bike, and we decided to hand our drill plate slightly off the side to make it be in alignment with where this would be. This model had issues, but it cleared up the major issues of our first design, so we decided to use this as our starting point for the current version.

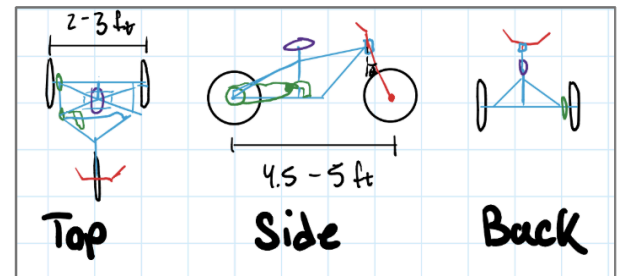


Figure 1: Hand drawings of concept of first idea for bike

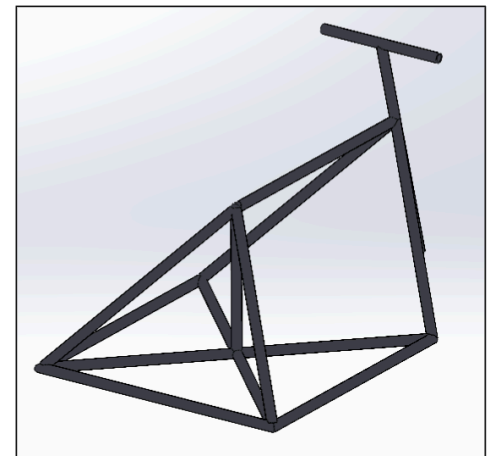


Figure 2: CAD rendering of initial bike design

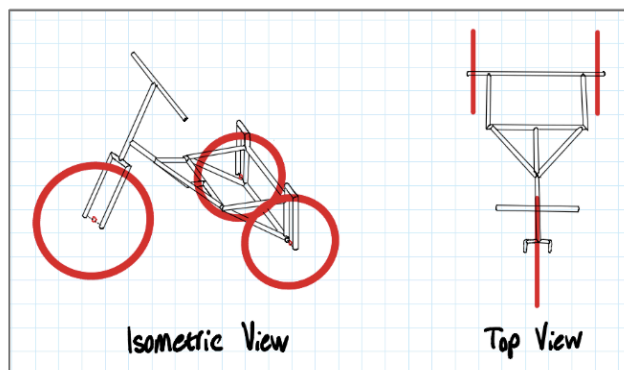


Figure 3: Hand drawn concept of improved bike design, second main design

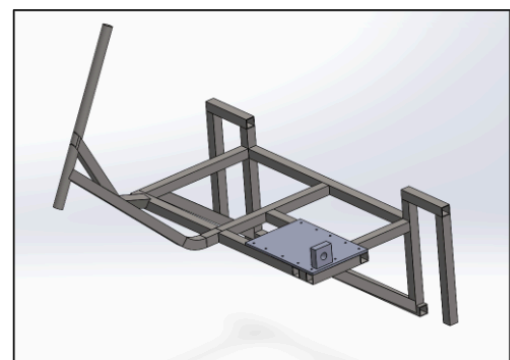


Figure 4: CAD rendering of improved bike design

2b Selected Design

For our selected design, we decided to stick with the latter of the two concepts due to it having significantly fewer issues than the first. We decided to keep the seat on level with the bike wheel axle, and we chose to have 12" wheels in the back, and a 20" wheel in the front, taken from a children's mountain bike with the fork included. We wanted to simplify the design, so this change, as well as getting rid of an unnecessary cross piece on the neck and hanging support for the drill plate. We made sure to measure the axles on the wheels we got and adjusted the width on the wheel supports to make sure they would fit correctly, and also used these measurements to determine how far to overhang the drill plate and where to drill holes so that the driven sprocket and chainring would be aligned. We decided that it would be easy to weld dropouts at an angle on the ends of the wheel supports so that they could be used to tension the chain instead of having to build that into the drill plate.

For the drill plate itself, we needed to have a way to control the drill trigger, so we built a hinge system with a spring so that a cord or wire could be attached and pulled on to activate the drill. We are going to use the brake wire off our bike for this, and this will be fed through a custom block and through to a hinge, which, when pulled on, will compress the drill trigger. A spring will be connected to the hinge on the other side to pull the hinge off the trigger when tension is released, so the bike will slow down.

Another custom component is the sprocket adapter. At the time of design, we did not have the chainring we were going to use, so we decided to include both 110mm and 130mm bolt patterns to account for either type. We found the wheel at this point, so we had the machine shop help us with finding the internal spline pattern we would need, and found it would be their "large 3-bump spline".

The overall design would have the left back wheel powered, with the chainring facing inside so that it would still be oriented correctly, and we would not have to hang the drill plate as far off to achieve alignment between the chainring and sprocket. Keeping everything as small as possible will also ensure we are under the weight requirement, even though its size might present trouble with fitting onto it comfortably. Also, it is so small that reaching the handlebars shouldn't be an issue.

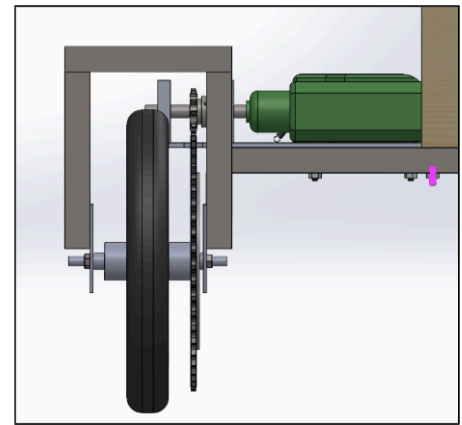


Figure 5: CAD rendering of driven wheel system showing chain alignment

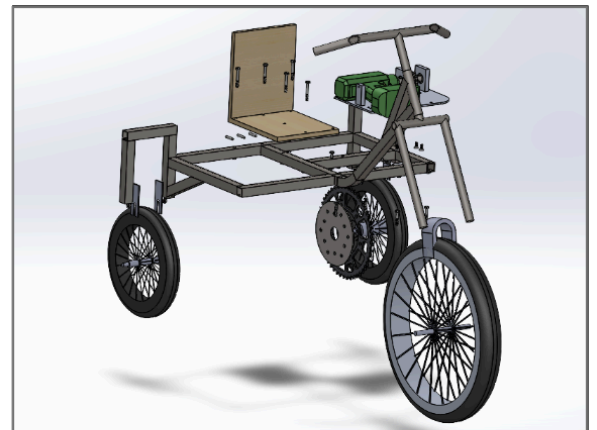


Figure 6: CAD rendering of finalized full bike assembly

3. Component Analysis

3a Critical Components

Drill Plate

The drill plate is one of the most critical components in our design because it houses the drill, pillow blocks, and throttle system—the core of our drivetrain. It is the interface that allows power from the drill to be transferred to the wheel through the shaft and sprocket system.

A significant portion of our design effort went into accurately modeling this part. We modeled the drill in detail to ensure proper fit, rounded all internal corners since the water jet cannot produce perfectly sharp 90° edges, and precisely located the holes for the throttle cable and pillow block mounting. The holes for both the throttle and pillow blocks were designed to be countersunk, ensuring a flush and secure assembly that maintains alignment under load.

From an engineering perspective, the drill plate functions as a load-carrying structural member subjected to torsion and bending from the drill's output torque (up to 240 in·lb). Using class principles of shear and bending stress, we sized the 3/16" aluminum plate to provide sufficient stiffness while minimizing mass. We also analyzed potential deflection between the pillow-block supports to prevent chain misalignment and uneven bearing loads.

To mount the plate, we added multiple bolted connections to the frame to ensure it could resist the drivetrain reaction torque without shifting. The bolt pattern was optimized to distribute loads evenly and prevent local stress concentrations around holes. We also removed unnecessary material from low-stress regions to reduce weight, improving the overall efficiency of the vehicle—critical for maximizing laps in the endurance challenge.

Overall, the drill plate was designed to be both lightweight and durable, striking a balance between stiffness, manufacturability, and performance. Its success directly determines how efficiently our power system delivers torque to the wheels throughout the competition.

Main Crossmember

The main crossmember of the frame is another crucial component, as it carries the combined load of the rider, drill system, and drivetrain while maintaining the overall rigidity of the vehicle. It experiences the highest bending stresses in the frame and is therefore the most likely member to fail if not properly designed.

We modeled the main crossmember using beam bending theory to ensure it could safely support the expected 240 lb combined load of the rider and vehicle. By treating the crossmember as a simply supported beam under a concentrated mid-span load, we applied the bending moment stress equations and stress deformation equations to determine the required section modulus and stiffness for an acceptable factor of safety and deflection limit. We performed the hand calculations for these bending and deflection analyses to confirm that our chosen tubing—1" × 1" × 1/16" 6061-T6 aluminum—provided sufficient strength while keeping weight low.

We designed the crossmember geometry to accommodate the large front wheel by introducing a controlled bend that maintains clearance without compromising structural integrity. The crossmember is split into two welded parts, distributing loads more evenly and reducing the bending moment experienced by any single section.

Because the endurance competition emphasizes efficiency and fatigue resistance, we aimed for a lightweight but durable design. Aluminum's high stiffness-to-weight ratio made it ideal, though its welds are weaker in the heat-affected zones. We accounted for this by applying a 20% reduction in yield strength near welded joints in our calculations and ensuring proper weld bead orientation along the load paths.

Lastly, we minimized fatigue risk by rounding internal corners, avoiding abrupt geometry changes, and ensuring welds are placed along neutral axes where possible—reducing stress concentrations. These considerations improve the crossmember's fatigue life, allowing it to endure repeated load cycles throughout the 30-minute endurance run.

In short, the main crossmember combines structural theory, material science, and manufacturing awareness. Its design reflects a balance between strength, stiffness, and weight, optimized for both performance and reliability under real-world endurance conditions.

3b Failure Analysis

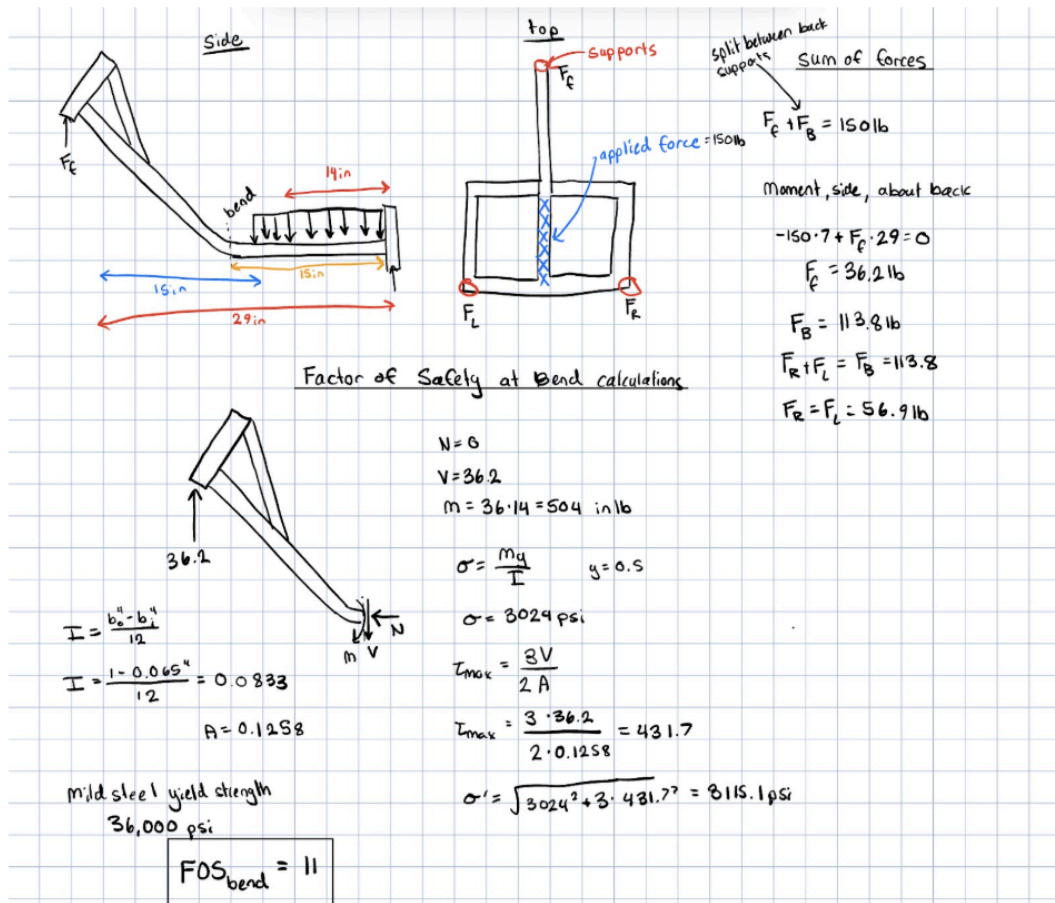


Figure 7: Hand calculations for frame failure and factor of safety

The piece that would be responsible for most of the load would be the bend piece, so we took the worst-case scenario of all of the load being concentrated on this piece, which is the most critical and likely to fail, since it would have the maximum bending moment and be farthest away from the wheels. We think 150 lbs is a good estimate for the driver's weight, so we put this distributed load across the seat of the bend. We used the bending and shear equations to calculate the von Mises stress and compare it to the yield strength of mild carbon steel. We calculated the FOS to be 11 after this analysis, which we feel extremely comfortable with, as the vehicle won't break. We tried to do FEA analysis, spent hours in office hours with Daniel, Alexis, and others, and no one could get it to work for our bike. But we feel really good with the hand calculations and had those looked over to make sure we did it right.

4. Fabrication

When designing our bike, we wanted to achieve something that would excel in the endurance challenge that we will be participating in. To do this, we had to design and manufacture several custom parts to fit our frame and wheelbase. These custom parts include a custom drill plate, two pillow blocks to support the drill shaft, four dropouts to mount our wheels to the frame, and more. We decided to choose plain carbon steel for the material of our frame, picking the 14-gauge square tubing with 1" thickness, as this met our strength needs. Performing hand calculations and SolidWorks FEA's, we ensured that this size of tubing will support the weight of the rider without failing. Manufacturing the frame required cutting and bending certain frame members before welding them together. After cutting the individual members to length using the band saw, we laid them out on a flat surface to ensure that our measurements were correct. Before welding the members together, we drilled holes in certain members using a mill, allowing us to mount our drill plate to the frame later. Confirming the member lengths and hole locations, we were ready to tack the members together. After tacking all members together, we again confirmed that we had achieved the correct measurements before finishing welding the members together, resulting in our finished base frame.

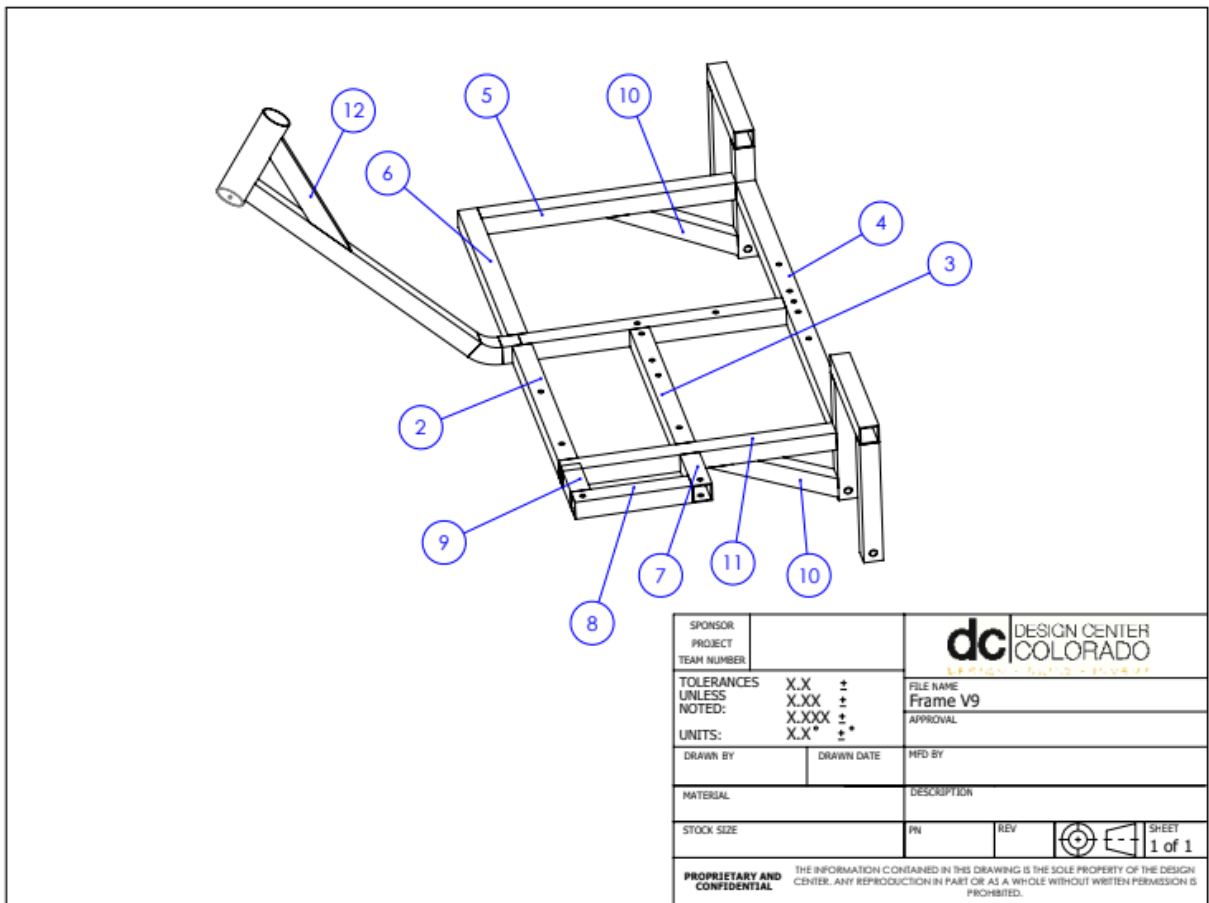


Figure 8: Full Frame Drawing

As shown in the figure above, we opted for a square base for our frame. This base has a cross member in the middle for strength and stability, and another cross member on one side, so we could mount our drill plate. The cross member in the middle of the square base extends past the base and bends up towards the collar, securing the steering column. This member of the frame was initially cut to length and then bent to a 45-degree angle using the 4.5" die. The frame also includes the two wheel brackets on the backside of the frame base. We designed our wheel brackets in this manner to achieve a double shear on the wheels, resulting in a stronger connection and easier mounting. Our custom dropouts were mounted onto the bottom of each of these wheel bracket members (four in total), welding them directly to the frame to prevent the dropouts from rotating. The two dropouts securing the driven wheel were welded in place at an angle (not directly vertical), allowing us to tension the chain after mounting the wheel.

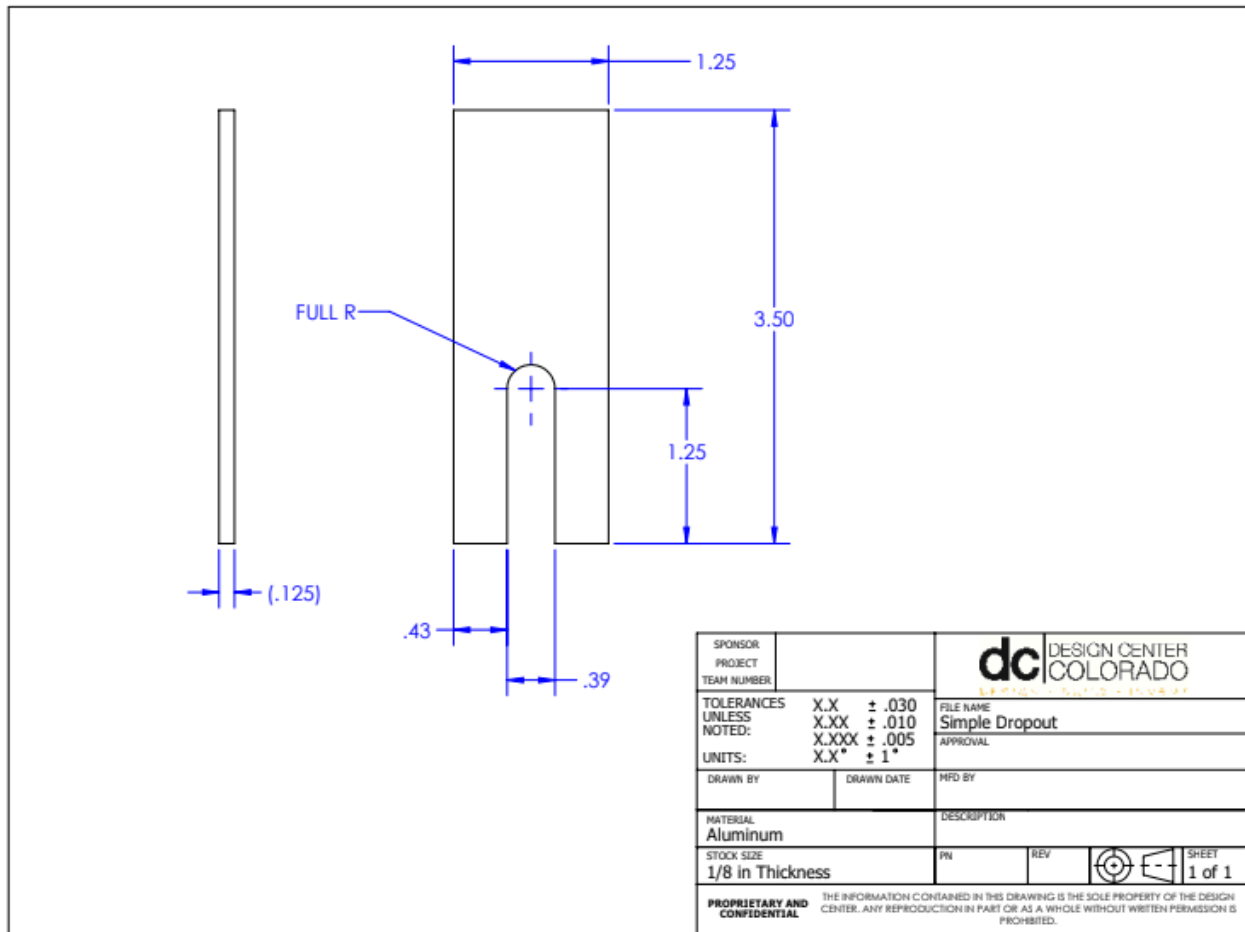


Figure 9: Wheel Dropout Drawing

Our dropouts are manufactured out of 6061 aluminum alloy and have a very simple yet effective shape to ease the manufacturing process. Due to its simple and flat design, we could easily manufacture this custom piece with the water jet. The dropout is made out of a small piece of 0.125" aluminum with a round slot at the bottom where the dropout will rest onto the wheel axle. The dropout was then secured to the wheel by a nut on each side of the wheel axle, preventing the wheel from sliding side to side.

Another of our custom-manufactured parts was the pillow blocks. We were given 2" x 2.25" x 0.5" 6061 aluminum alloy blocks by the machine shop, which we had to alter to fit our bike design. After receiving these blocks, we started by drilling and tapping the mounting holes on the bottom of the pillow blocks. These were drilled out using a 1/4" milling bit, and then hand tapped using the 1/4" 20 UNC drill tap. After successfully milling the mounting holes, we moved on to machining the holes where we would press-fit a bearing. This cut had to be extremely precise, as a hole too big would result in a loose fit and a hole too small would put too much pressure on the bearing, resulting in it not spinning properly. Luckily, regardless of the very slim tolerance we had to achieve, we managed to get a perfectly cut hole on the first attempt. We decided the height of this hole relative to the bottom of the pillow block by measuring the height of the drill shaft when placing the drill on a flat surface with the battery hanging off the side (so we can change batteries throughout the race).

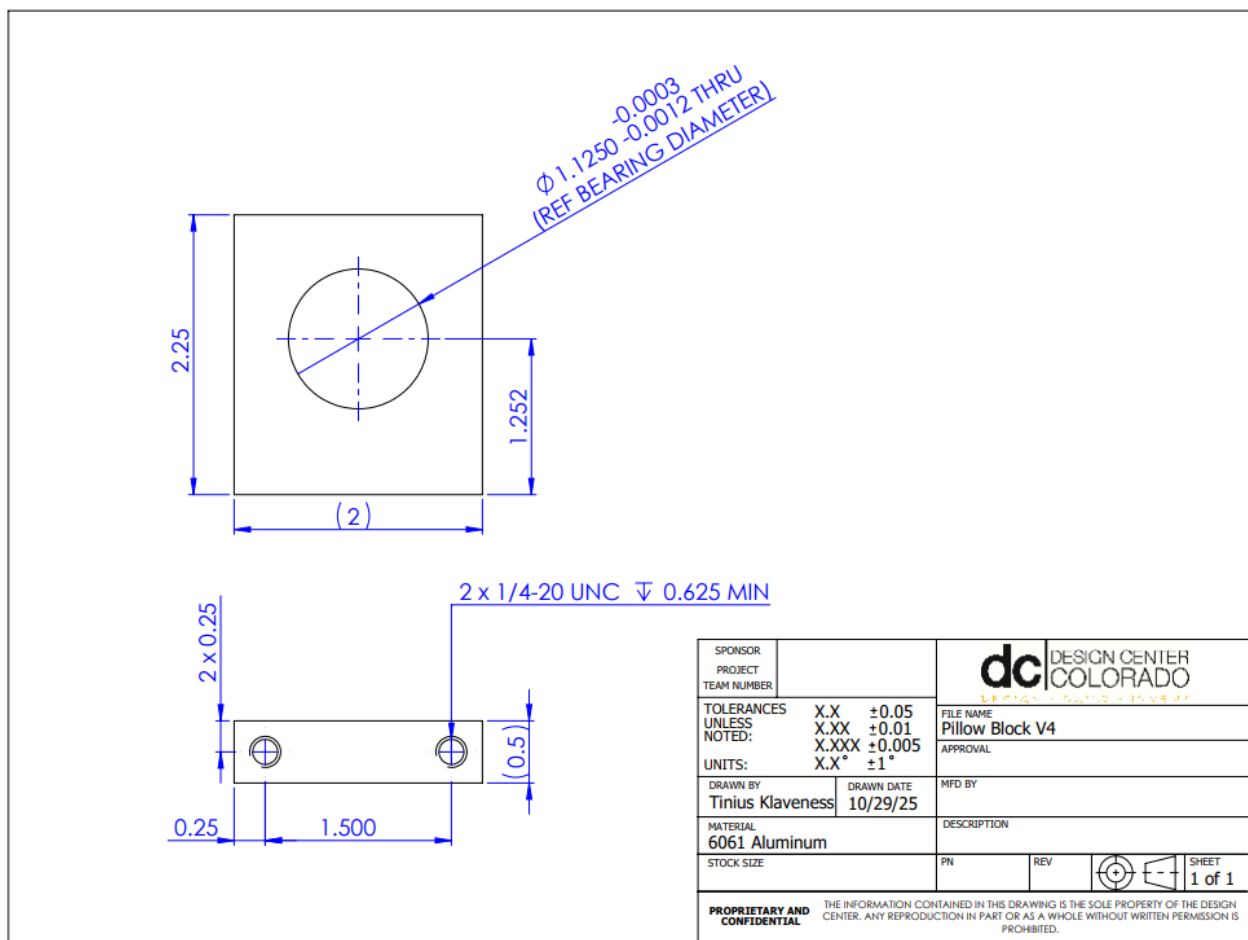


Figure 10: Pillow Block Drawing

Once we finished manufacturing the pillow blocks, we could press-fit our bearings into them and mount our drill assembly. This drill assembly consists of our two pillow blocks, the two bearings, the drill shaft, a 10-tooth machinable sprocket, and the drill. The drill shaft is a piece of 6061 aluminum with a 1/2" diameter. This piece was given to us by the machine shop, and all we had to do was machine out one side of the shaft to be in a hexagonal shape. This would allow us to attach the shaft to the drill chuck securely. We machined this side of the shaft using the mill.

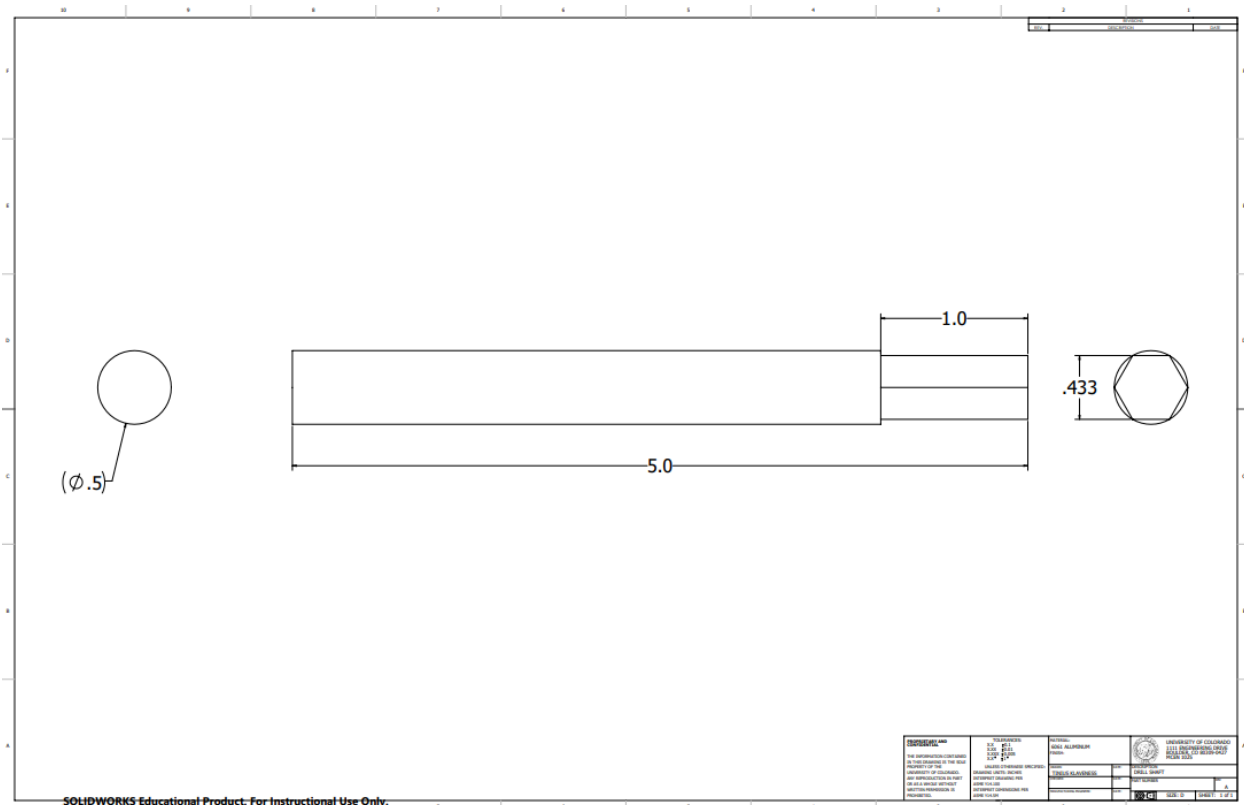


Figure 11: Drill Shaft Drawing

The only part that we were missing from completing our drill assembly was the machinable sprocket that we ordered from McMaster-Carr. This piece had to be altered slightly so we could secure it properly to our drill shaft. We drilled a hole in the sprocket and hand-tapped it so we could use a setscrew to mount it to the shaft. In addition to this set screw, we made a slight dimple in the shaft where we wanted to secure the sprocket, ultimately preventing the setscrew from slipping.

Now that we were finished with our full drill assembly, we were ready to mount it to the drill plate. The drill plate was machined out of 6061 aluminum alloy using the water jet. This piece is relatively complicated due to all the mounting holes (to the frame and to the pillow blocks) that have to be very precisely located. The drill plate also included a round 1" slot that allows the bike chain to pass through without any interference. The mounting holes for the pillow blocks had to be far-side countersunk, so our screws would not interfere with the frame. We chose to use 1/4" flat head countersink screws for mounting these blocks, meaning the screws would lie flush with the frame. Two of the mounting holes in the drill plate also had to be near-side countersunk to prevent interference with the drill on the top of the plate. Similarly, we used 1/4" flat head screws here as well to mount the drill plate to the frame. The drill plate also had some other clearance holes of different sizes, allowing us to mount our throttle assembly using nuts and bolts. Finally, the drill plate features two small parallel slots. These slots were to allow for the use of zip-ties to secure the drill to the drill plate.

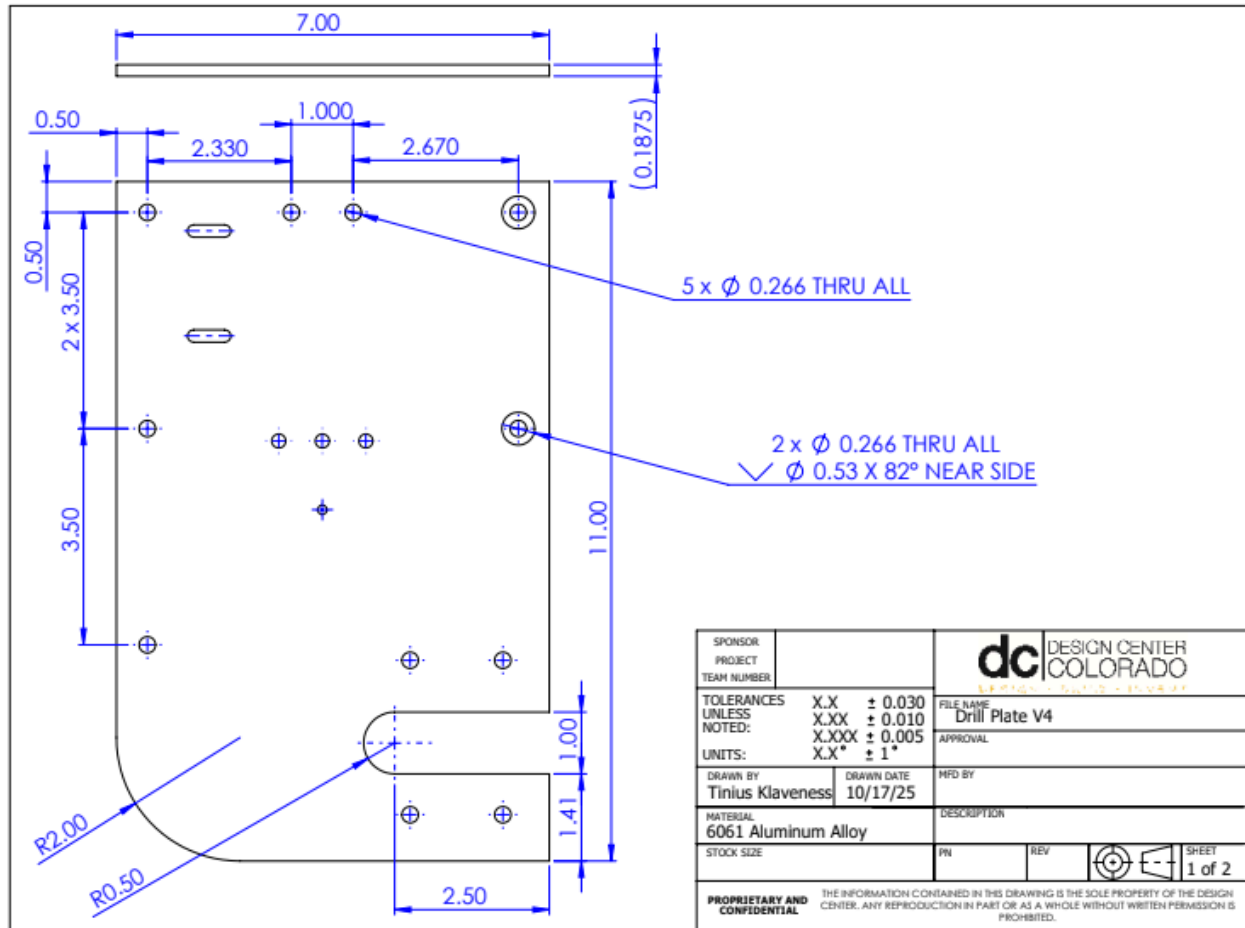


Figure 12.1: Drill Plate Sheet 1

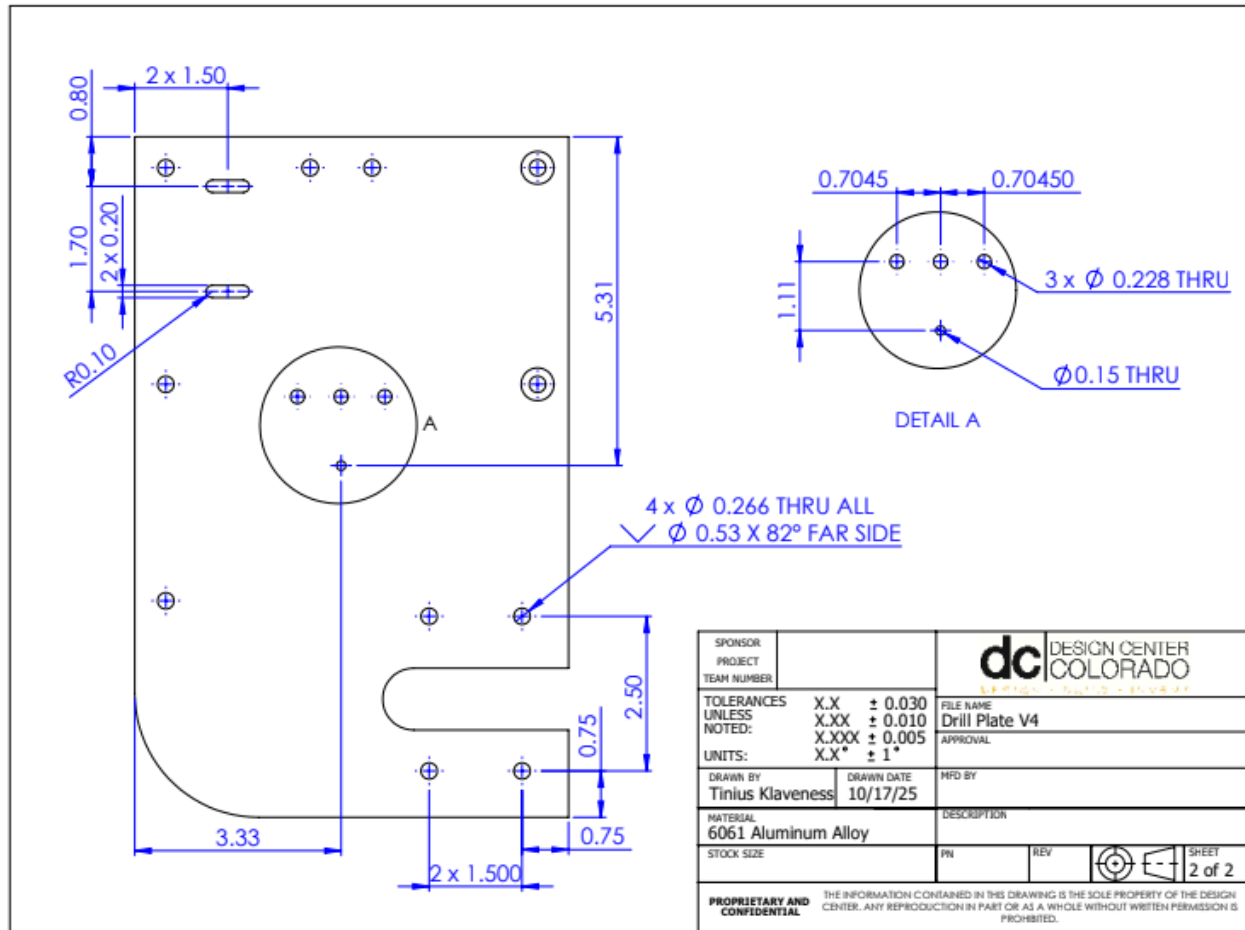
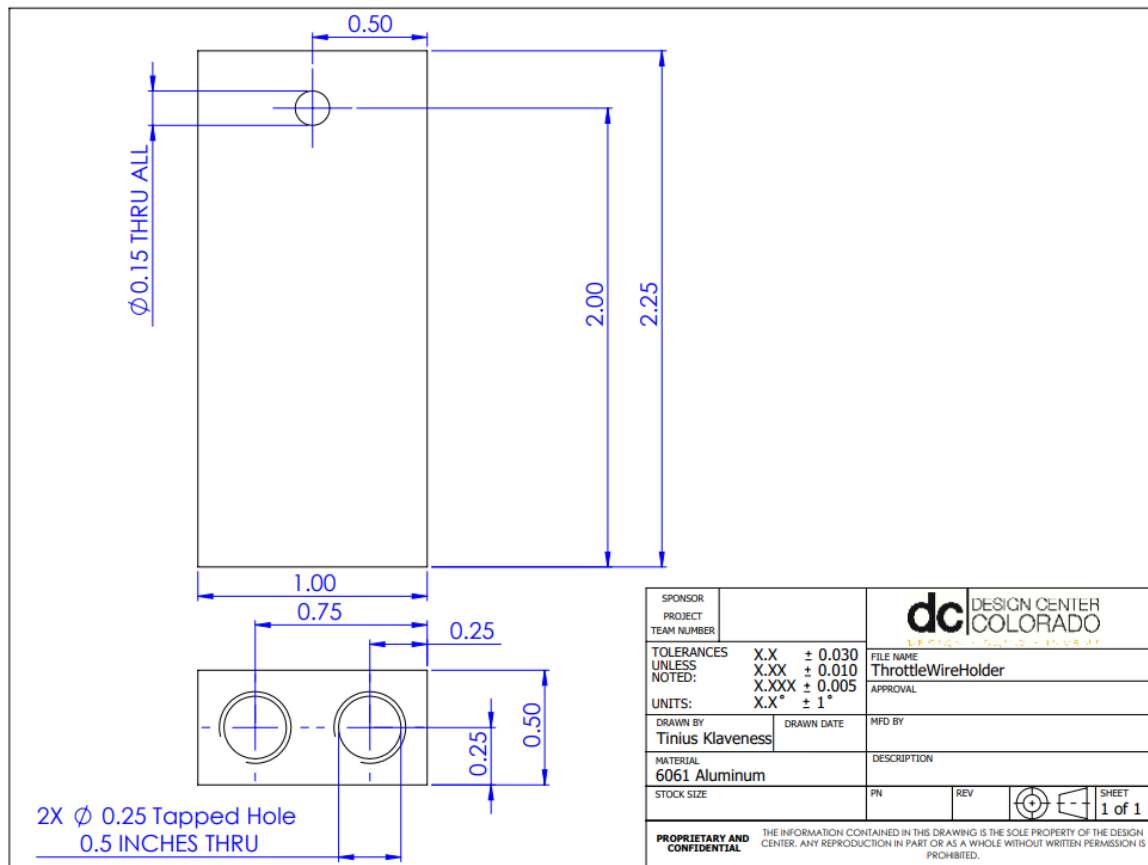


Figure 12.2: Drill Plate Sheet 2

Mounted to the drill plate is another custom piece that we manufactured out of 6061 aluminum alloy using the lathe. This was a relatively simple piece to manufacture, as all it required was a hole in the top to allow for a brake wire to pass through, and two mounting holes at the bottom. We used a 1/4" drill bit to drill the mounting holes and then hand-tapped the holes using the 1/4" 20 UNC drill tap. For the little hole on the top, we used the mill with a #7 drill bit.



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Figure 13: Throttle Wire Holder Drawing

Other than the custom parts discussed above, we used a lot of standard parts that we acquired from McGuckins and other hardware stores. This includes all the nuts and bolts used for mounting the drill plate, pillow blocks, dropouts, and throttle assembly. Below is a table of each of the standard parts we used for our bike.

Table 1:

Part	Source
Drill Shaft Sprocket	Another Team (McMaster-Carr)
Pillow Block Bearings	Another Team
Chain	Idea Forge
¼" 20 UNC, 1.5" Hex Bolt screws	McGuckins
¼" 20 UNC, 2" Hex Bolt screws	McGuckins

1/4" 20 UNC, 0.75" Flat Head (Countersink) Screws	McGuckins
1/4" 20 UNC, 0.1.5" Flat Head (Countersink) Screws	McGuckins
1/4" Hex Nuts	McGuckins

5. Iterations to our Design and Fabrication

Our project evolved quite a bit from the initial concept to the final product. Early in the semester, we spent a few weeks brainstorming ideas for our design. We went through many rough hand sketches and frame iterations on SolidWorks, but ultimately decided on a tricycle design that has two smaller rear wheels and 1 large wheel in the front. A larger front wheel makes steering smoother and more stable. Smaller rear wheels allowed us to keep the frame compact, reducing the weight of our tricycle while also allowing us to mount the drill assembly lower on the tricycle, thus keeping our tricycle's center of gravity low. While we realized after fabrication that the frame ended up a bit smaller than ideal for our rider, it still functioned well. Earlier consideration of rider fit and ergonomics could have made the frame design even better.

One of the biggest challenges throughout the design process was figuring out how to mount the drill to the drill plate. Once we assembled the drill, pillow blocks, and shaft in SolidWorks, we noticed that the drill didn't sit flat on the plate. The pillow block height created a small vertical gap. To correct this, we went to the machine shop, measured the actual drill height with the battery attached, and adjusted the pillow block height accordingly in SolidWorks. We also initially planned to secure the drill using hose clamps, but after our design review with Greg and Chase, we switched to zip ties and adjusted the slots on the drill plate accordingly. This change simplified our assembly, lessened our material budget, and made it easier to remove/replace the drill for maintenance during the race. Greg and Chase also suggested shortening the drill plate so that the battery could hang off the back to make it easier to swap batteries during pit stops. This change was crucial for the endurance event.

Greg and Chase also recommended finding a machinable-bore sprocket with a #40 pitch from McMaster, widening the chain slot, and avoiding sharp 90-degree internal corners on the drill plate. They also pointed out missing tolerances and dimensioning issues, asking us to think about the manufacturability and precision of our dimensions. So, we adjusted the number of significant figures of our parts in order to make the fabrication process smoother. After making necessary revisions to our design, we printed our updated drawings and brought them to the machine shop for review. The machinist there went over each drawing with us, marking them up with notes and suggestions, giving us a clear understanding of what information was actually needed for fabrication. After a few rounds of edits and final approvals, we could finally start fabricating.

Machining the parts themselves was pretty straightforward. With the help and guidance of Greg, Chase, and the rest of the machine shop crew, the process went smoothly. First, we started by

cutting our steel square tubing beams to form the base frame of our tricycle. We used the bandsaw for all of the cuts and a belt sander to smooth out rough edges. Throughout the process, we also made sure to measure our cuts with a measuring tape after passing them through the bandsaw and a leveler after using the belt sander. We wanted to make sure we weren't drifting too far from the tolerances on the drawings. Out of all the components we machined, the pillow blocks were easily the most satisfying to make. They were one of the more detailed and difficult parts in the entire design. We faced and milled the blocks to dimension, drilled and tapped the mounting holes, and bored out the bearings to match our diameter. Welding was straightforward, but by far the most time-consuming. It might have given us more for testing and assembly if we had designed a base frame that needed less welding. But luckily, we didn't run into too many issues during testing or assembly.

Assembling everything was where we started to notice some mistakes and ponder whether or not we had the time and resources to make any tweaks to our initial design. We had to change things about our drill trigger system—like adding a spring to the drill plate and reboring the drill shaft sprocket to adjust for the housing we put on the wires that connect to the left hand brake. We also ran into some issues with how the back-driven wheel fit onto the dropouts we designed, so we ended up having to reweld a new set of dropouts to adjust for this. We had to move the wheel forward and make the chain shorter so that there would be enough tension. Finally, we added some zip ties to further secure the drill to the drill plate and organize the wires to the front fork. For fun, we added a bell from a kid's bike we got from a junkyard.

At the runoff, we completed 4 laps, almost 5. Though most of us agree that we could've easily done 6 or even 7 laps if we managed our time and energy expense of the drill batteries more efficiently. We played it a bit too safe by going relatively slow for the first 2 laps with the intention of conserving energy and maintaining the stability of the vehicle. We thought that the drill battery would die much quicker than it did, thus leading to us having an extra fully charged battery by our fourth lap. Unfortunately, by then, we had run out of time. At the very least, our trike, though not incredibly fast, remained stable.

6. Timeline

Initial Planned Timeline Below:

(Dates with Asterisks are Given Milestones/Deadlines)

*September 25: Project Planning Document and Concept Sketches Submitted (All Teammates)

- Work on concept sketches and CAD drawings, and complete the project planning document with an outline of the schedule for the rest of the semester.

*October 6 - 15: Design Reviews (All Teammates)

- Present our design for review; already signed up for October 8 at 3:10 PM - 3:50 PM.

October 19: Finalize CAD Design (Amanda and Ailin)

- Finish improving our CAD design based on the feedback received during the design review. We will all have to meet together between October 8 and 19 to talk about changes that need to be made.

October 22: Purchase All Materials (Any Available Teammate)

- Ideally purchase all the necessary materials before this date to have it ready for manufacturing immediately.

*October 30: Report Draft (All Teammates)

- Complete and submit a report of our final design, writing in detail about the materials we plan to use, what sections will most likely fail, etc...

November 5: Parts Ready to be Assembled (Tinius and Any Teammate)

- All parts need to be cut and ready to assemble via welding and/or other methods.

November 10: Assembly Completed (Trent, Amanda, and Tinius)

- All parts need to be assembled to match the CAD design. Any teammate who has been to the weldments workshop can work on the welding of the bike.
- Prioritize the assembly on mechanisms for the hardware demonstration in case we cannot complete the entire assembly by November 12.

*November 12: Hardware Demonstration (All Teammates)

- Demonstrate a functioning assembly of the bike

November 14-17: Fix Issues from Hardware Demonstration (Tinius and Any Teammate)

- There may be issues that arise from feedback during the hardware demonstration that we may want to fix. Spend this time making adjustments to improve the mechanism.
- Also spend this time to finish assembly if not already completed.

November 17: Light Testing Before Demonstration (Trent and Mark)

- We will try to test the bike under minimal to normal stress conditions to not overwork the bike. This should help us prepare for the Final Vehicle Testing Demonstration and Run-Off early.
- If something fails, we will need to fix the problems by November 21.

*November 21: Final Vehicle Testing Demonstration (All Teammates)

November 22 - December 3: Work on Final Design Report (All Teammates)

- We will use this time to work on the final design report to submit it in time.

*December 4: Run-off (All Teammates)

*December 5: Final Design Reports (All Teammates)

Drill Powered Bike

Mark P. Project Manager

Project start: **Sat, 9/20/2025**

Display week: **1**

SIMPLE GANTT CHART by Vertex42.com
<https://www.vertex42.com/ExcelTemplates/sample-gantt-chart.html>

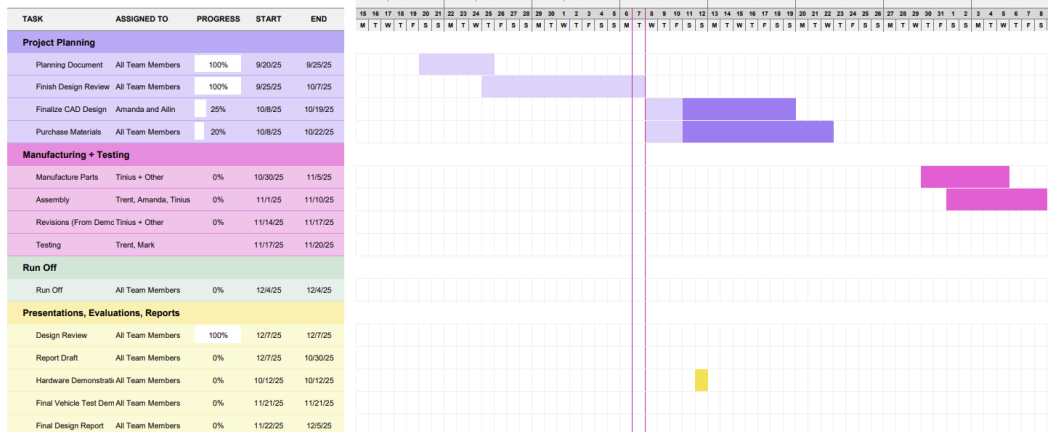


Figure 14: Gantt Chart

We have done a fairly good job of meeting the given major deadlines. The deadlines to submit the project planning document, present our design review, submit a final vehicle testing demonstration video, and turn in this final draft (which is now due a week later than planned) have been successfully completed on time. There are also other minor deadlines that were met, such as for October 19th, where we were actually able to complete the final design by October 17th in conjunction with our final design review submission.

However, with the remaining minor deadlines that we had set for ourselves, these were more challenging for us to meet without delay. For example, the October 22nd deadline on purchasing all our materials was not met. This is mainly because of certain budget and quantity issues that arise from buying small amounts of materials. Specifically, with our hex bolts and nuts, we initially created a bill of materials that cited Amazon as a source to purchase from, but the quantity of bolts received would be so large (by a factor of 10) that it would not be wise to spend more money than the number of bolts we actually need. Therefore, we wanted to consider alternatives before rushing to meet the deadline and spend unnecessary amounts of money. This worked in our favor because we were able to spend much less on these fasteners by buying individual parts at McGuckin Hardware.

Another example was the deadline on November 5th, where we initially planned to have all parts ready for assembly and welding. By this date, we already had most parts manufactured as seen on our drawings in the Appendix, with the exception of the drill shaft and a block for our trigger mechanism. Even though we may have been slightly behind schedule relative to our own timeline, we found out that the hardware demonstration major deadline set for November 12th wasn't going to happen because this would be combined with the final vehicle testing demonstration that was due on November 21st. This simply meant that we didn't have to rush as much to meet the November 12th deadline, and used the remaining time to carefully assemble everything and make sure the vehicle functions properly. In fact, even though we had some minor issues that needed to be fixed quickly (such as welding new drop outs since the current

ones could not tension the chain properly), we were able to assemble and drive a functioning vehicle a day before the vehicle demonstration deadline (so November 20th). November 20th was also when we did some testing to make sure no other issues arose before submitting a video, which was later than planned but still done regardless. The testing involved changing drill settings to find a good driving speed, as well as simply seeing how it holds up when being driven. Due to how well our vehicle functioned, we didn't have to make any adjustments leading up to the run off.

Finally, for the minor deadline of completing the final report between November 22 - December 3, since the final report wasn't officially due until December 12th and final exams were taking up a lot of our time, we just ended up finalizing our draft report whenever we had time. Overall, while we were just a few days behind with some of the minor deadlines that we set for ourselves, this didn't affect our ability to submit or complete what was necessary for the major deadlines given.

7. Bill of Materials and Cost

Table 2: Initial Bill of Materials

Item	Location on Vehicle	Source	No. of Parts	Price (\$) / part	Total Price (\$)	Link
Pillow Block Bearings	Pillow blocks	Amazon	10	1.025	10.25	link
1/4" 20, 1.5 inch hex bolt screws	Drill plate	Amazon	1 box (25)	0.6264	15.66	link
1/4" 20, 2 inch hex bolt screws	Seat	Amazon	1 box (25)	0.77	19.25	link
1/4" 20, 0.75 inch Flat Head (Countersink) Screws	Pillow blocks	Amazon	20	0.4195	8.39	link
1/4" 20, 1.5 inch Flat Head (Countersink) Screws	Drill Plate	Amazon	20	0.4745	9.49	link
Drill Shaft Sprocket	Drill Shaft	McMaster	1	20.48	20.48	link
1/4 inch Hex Nuts	Drill Plate, Seat	Amazon	1 box (50)	0.1198	5.99	link
Zip Ties	Drill Plate, Drill	Amazon	1 pack (100)	0.0399	3.99	link
Components Related to Trigger Mechanism (Screws, Hex Bolts, etc...)	Drill Plate	Borrow from Idea Forge	multiple	0	0.00	no link
Bike	Front Fork, Wheels	Marketplace	2	30	30.00	no link
14 Gauge 1 inch Steel Tubing	Frame	DenCol	3 10 ft pieces	4	70.00	link
				Total:	193.5	

Table 3: Final Bill of Materials

Item	Location on Vehicle	Source	Quantity	Total Price (\$)
1 in Steel Square Tubing	Frame	DenCol	4 (Long Tubes)	60
Drill Shaft Sprocket	Drill Shaft	Another Team (McMaster-Carr)	1	21.81
Pillow Block Bearings	Pillow Blocks	Another Team	2	4
Bike	Front Fork, Wheels, Brake	Marketplace	2	35
Fasteners (including Hex Bolts, Nuts, Screws), Springs, Hinges (Check Table 1 for more detail on some of the fasteners we bought)	Drill Plate/Frame, Rear Wheels	McGuckin Hardware	Unspecified Amount	31.58
Chain, Drill	Drill Plate, Left Rear Wheel	Idea Forge	1	0
				Total: 152.39

Note: the total cost listed above has some uncertainty (around $\pm \$5$).

When comparing the initial bill of materials (Table 2) to the final bill of materials (Table 3), it is clear that we have been able to reduce our budget significantly. To keep the purchases as inexpensive as possible, we have employed strategies to reduce costs, which include working with other teams to buy parts like sprockets and bearings as they have bought them in bulk. This is most noticeable with the bearing costs, where we saved around \$6 because we bought the exact amount we needed from another team instead. It also turned out that the cost of the steel tubing was less than \$70, which lowers our budget a decent amount. In terms of the fasteners and other small components like springs, this was where we saved the most money because instead of purchasing in bulk on Amazon which would have cost upwards of \$40-\$50, we only bought what we needed from a McGuckin Hardware store.

Note that the only amount listed on the initial BOM that ended up appearing more expensive was the drill shaft sprocket. On technicality, however, the \$21.81 is inclusive of tax and shipping fees that the team we bought this from had to pay, whereas the cost on the BOM excluded tax and shipping fees, which means that the actual price we would have needed to pay would be much greater than \$21.81. Overall, we have improved on our initial BOM immensely and saved around \$40 in costs by finding cheaper alternatives that still got the job done well.

8. Advice

We realized that the planning process of this project is likely the most important, as it sets up for a smoother and more efficient process moving forward into the manufacturing and testing phases. This is because in our experience, we noticed that our biggest challenges occurred during the early stages of this project, where we needed to come up with good vehicle designs and create detailed CAD parts and drawings. But after the planning portion of the project was completed, the other processes, like manufacturing the parts, felt easier to do in comparison due to the fact that we were simply following a detailed plan that has already been carefully thought out.

We also noticed that during the design stage, when creating our CAD parts, drawings, and assembly, it was really important to have good communication with the TAs and professors because they have the most experience and insight in this project and will be able to guide any team in the right direction. They can help avoid teams that may spend hours creating a design, only to discover errors in things like their gear ratios or factors of safety, which would waste lots of time to redesign.

In addition, even though each person in a group has their own designated role, each team member should have relatively equal participation in all given tasks wherever and whenever possible. This advice is particularly useful for the CAD design portion of this project. Our experience with CAD was very challenging, where most of the work to design and model the vehicle was given to our CAD engineers. This caused an imbalance in the workload for a period of time that would have been more efficient in hindsight to have each person work on a separate portion of the vehicle design at the same time. This definitely helps meet deadlines with better results in terms of quality of CAD design since distributing the workload well provides more time for everyone to make meaningful improvements. That said, each team member should still do more work than the rest of the team if the task targets their role specifically.

Furthermore, in the manufacturing stages, it is important to understand that there will be unexpected issues that come up, meaning you should not procrastinate. We were fortunate enough to not have many issues that were difficult to fix as we were very careful with the entire manufacturing process. However, there were issues we could not foresee, such as parts of our frame melting due to welding too quickly. While we knew welding one part of the steel tubing would heat up a large area around the weld, we didn't realize that the hollow frame was so thin that if we didn't wait for the large area to cool, the following weld on the same steel tubing could melt into a small hole. Because of this revelation, it severely delayed our welding process since we were forced to wait around 15 mins for each weld. We expected to finish the welds in around 2 days, but it ended up taking around 5 days for our frame design. Therefore, it is necessary to start the manufacturing process early in order to have plenty of time to deal with unexpected problems such as this.

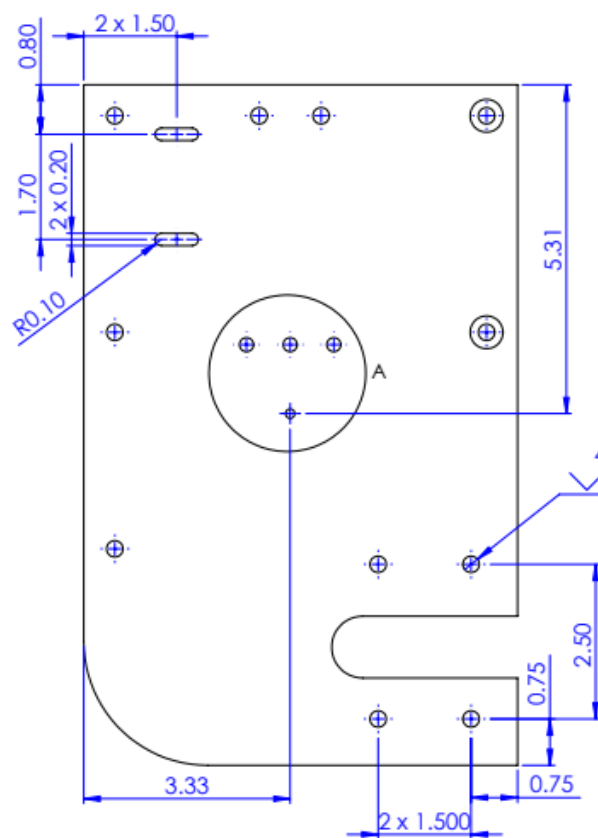
Technical drawing of a rectangular drill plate with dimensions and features:

- Overall dimensions: 7.00 (width) x 11.00 (height).
- Top edge features: 0.50 (width of top flange), 2.330 (distance from left edge to first hole), 1.000 (distance between first two holes), 2.670 (distance from second hole to right edge), and (0.1875) (thickness of top flange).
- Left edge features: 0.50 (width of left flange), 2 x 3.50 (distance from top edge to first hole), 3.50 (distance from first hole to bottom edge), and R2.00 (radius of bottom-left corner).
- Right edge features: 1.00 (distance from top edge to first hole), 1.41 (distance from first hole to bottom edge), and 2.50 (distance from bottom edge to right edge).
- Holes: 5 x $\varnothing$ 0.266 THRU ALL (5 holes along the top edge), 2 x $\varnothing$ 0.266 THRU ALL (2 holes along the right edge), and $\varnothing$ 0.53 X 82° NEAR SIDE (1 hole near the bottom-right corner).
- Material: 6061 Aluminum Alloy.
- Stock size: 1.41 x 1.00.

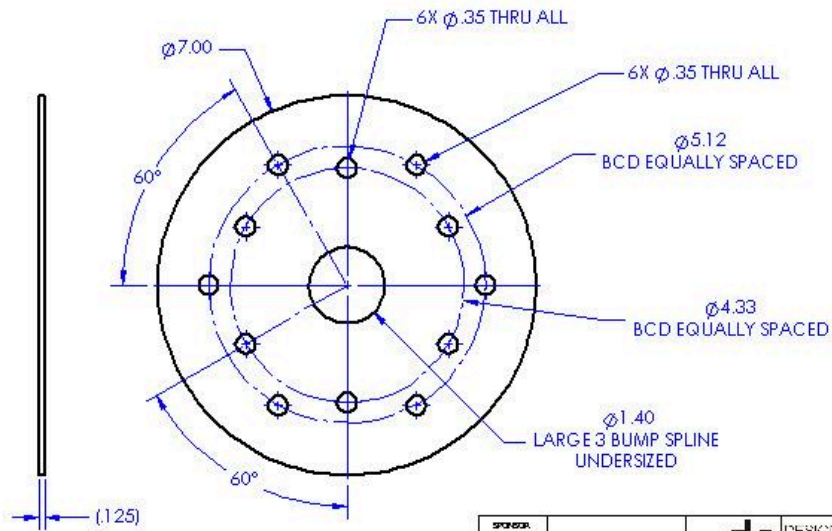
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DRAWN BY Tinilus Klavness		DRAWN DATE 10/17/25 MFD BY 	
MATERIAL 6061 Aluminum Alloy		DESCRIPTION	
STOCK SIZE		PN	REV
		SHEET 1 of 2	

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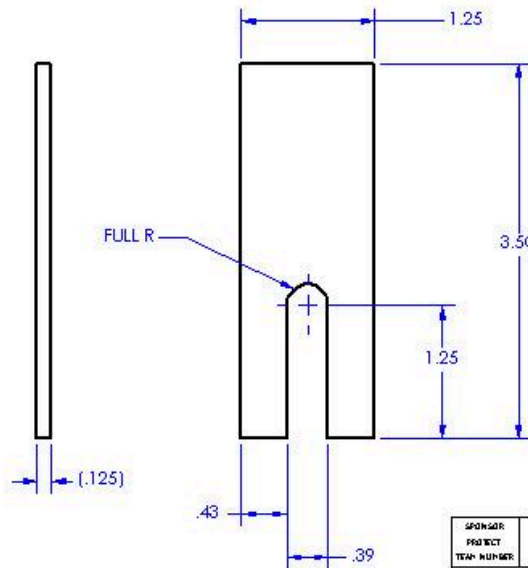
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DRAWN BY Tinius Klaveness		HFD BY	
DATE 10/17/25			
MATERIAL 6061 Aluminum Alloy		DESCRIPTION	
STOCK SIZE		PN	REV
			
PROPRIETARY AND CONFIDENTIAL		SHEET 1 of 2	
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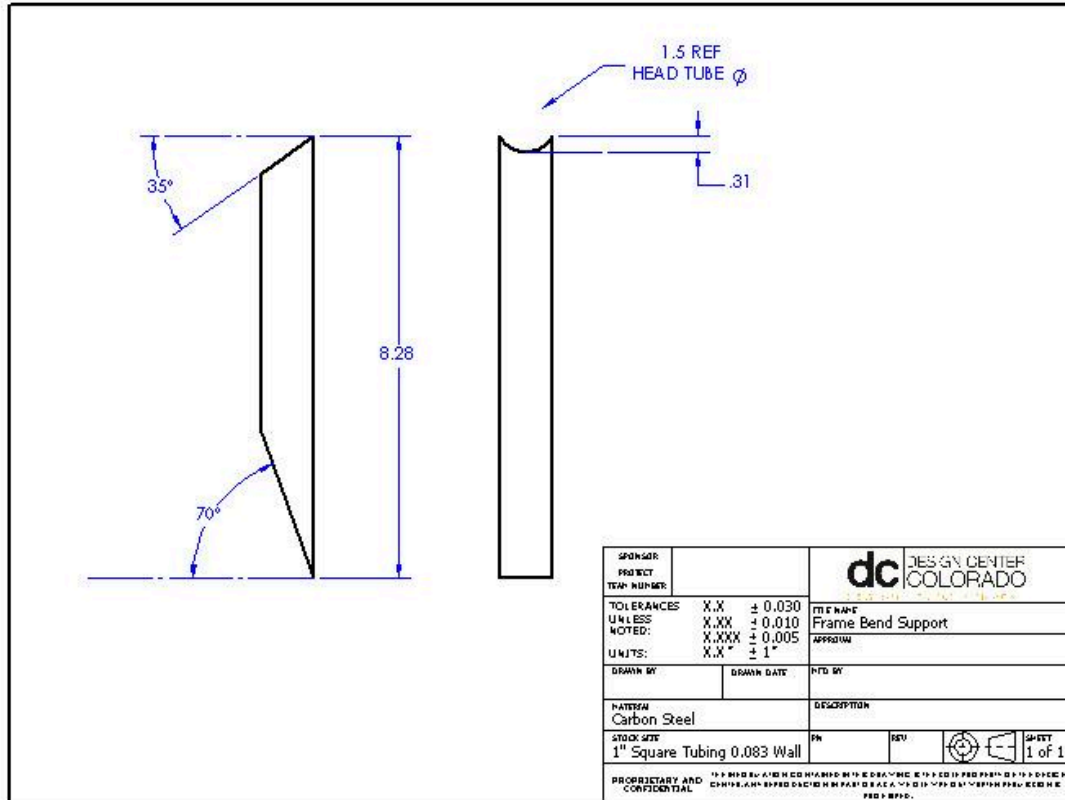
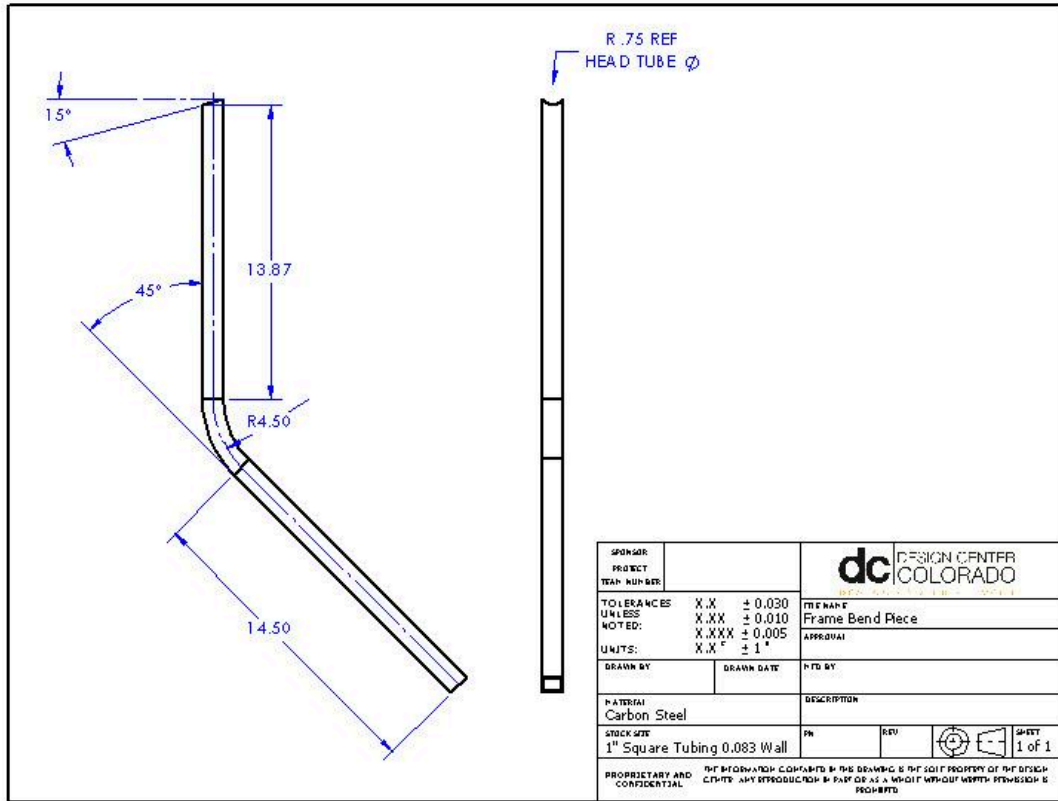
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STOCK SIZE		PN	REV
			
PROPRIETARY AND CONFIDENTIAL		SHEET 2 of 2	
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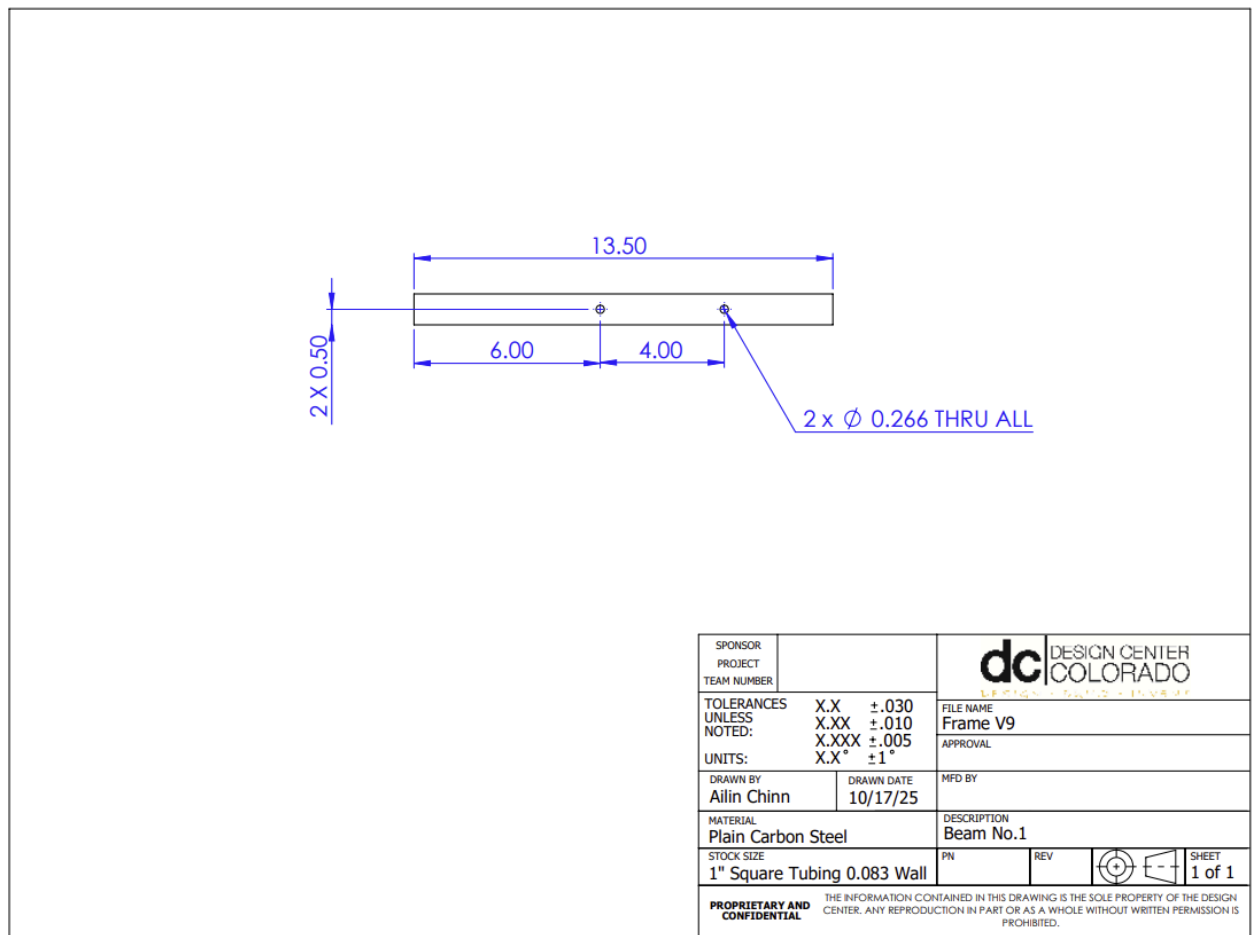


SPONSOR		dc	DESIGN CENTER
PROJECT		COLORADO	
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UNLESS	X.XX ± .010		
NOTED:	X.XXX ± .005		
UNITS:	X.X" ± 1"		
DRAWN BY		DATE	
MATERIAL	Aluminum	DESCRIPTION	
STOCK SIZE	1/8 in Thickness	PN	REV
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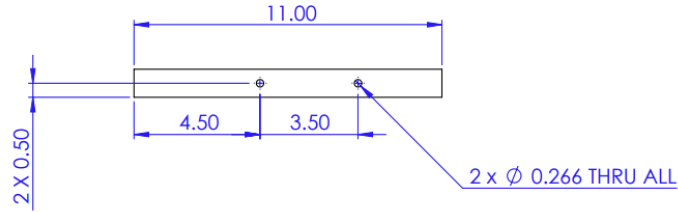


SPONSOR		dc	DESIGN CENTER
PROJECT		COLORADO	
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UNLESS	X.XX ± .010		
NOTED:	X.XXX ± .005		
UNITS:	X.X" ± 1"		
DRAWN BY		DATE	
MATERIAL	Aluminum	DESCRIPTION	
STOCK SIZE	1/8 in Thickness	PN	REV
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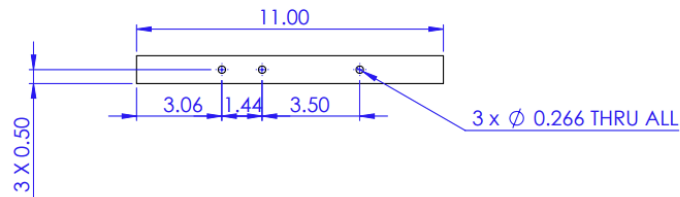




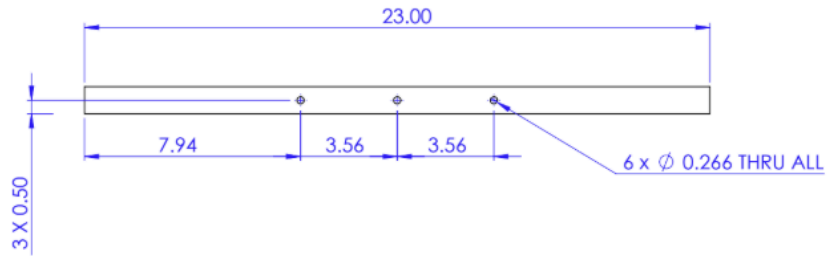
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TOLERANCES UNLESS NOTED:		X.X ±.030 X.XX ±.010 X.XXX ±.005 UNITS: X.X° ±1°	
DRAWN BY Ailin Chinn		DATE 10/17/25 MFD BY	
MATERIAL Plain Carbon Steel		DESCRIPTION Beam No.1	
STOCK SIZE 1" Square Tubing 0.083 Wall		PN	REV
		SHEET 1 of 1	
PROPRIETARY AND CONFIDENTIAL			
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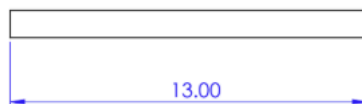
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PROJECT		FILE NAME
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UNITS:	X.X° ±1°	
DRAWN BY	AINLIN CHINN	MFD BY
DRAWN DATE	10/17/25	
MATERIAL	PLAIN CARBON STEEL	DESCRIPTION
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PN		REV
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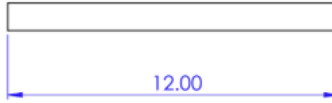
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PROJECT		FILE NAME
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DRAWN BY	AINLIN CHINN	MFD BY
DRAWN DATE	10/17/25	
MATERIAL	PLAIN CARBON STEEL	DESCRIPTION
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PN		REV
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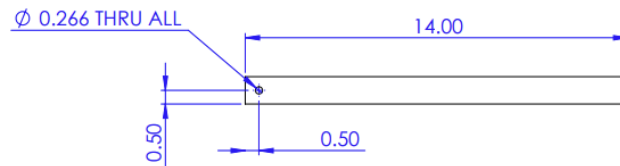
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PROJECT		COLORADO	
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MATERIAL	Plain Carbon Steel	DESCRIPTION	Beam No.4
STOCK SIZE	1" Square Tubing 0.083 Wall	PN	REV
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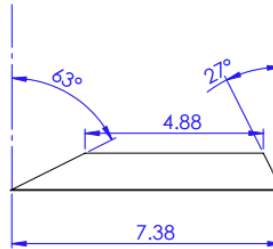
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PROJECT		COLORADO	
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NOTED:	X.XXX ±.005		
UNITS:	X.X" ±1"		
DRAWN BY	Ailin Chinn	DRAWN DATE	10/17/25
MATERIAL	Plain Carbon Steel	DESCRIPTION	Beam No.5
STOCK SIZE	1" Square Tubing 0.083 Wall	PN	REV
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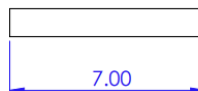
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DRAWN BY	Ailin Chinn	MFD BY	
DRAWN DATE	10/17/25	DESCRIPTION	Beam No.6
MATERIAL	Plain Carbon Steel	PN	
STOCK SIZE	1" Square Tubing 0.083 Wall	REV	
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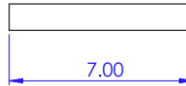
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DRAWN BY	Ailin Chinn	MFD BY	
DRAWN DATE	10/17/25	DESCRIPTION	Beam No.7
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STOCK SIZE	1" Square Tubing 0.083 Wall	REV	
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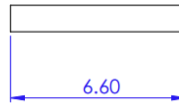
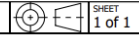
SPONSOR		dc DESIGN CENTER COLORADO Engineering • Planning • Environment	
PROJECT		FILE NAME	Frame V9
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UNLESS	X.XX ±.010		
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MATERIAL	Plain Carbon Steel	DESCRIPTION	Beam No.8
STOCK SIZE	1" Square Tubing 0.083 Wall	PN	REV
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PROJECT		FILE NAME	Frame V9
TEAM NUMBER		APPROVAL	
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UNLESS	X.XX ±.010		
NOTED:	X.XXX ±.005		
UNITS:	X.X" ±1"		
DRAWN BY	Ailin Chinn	DRAWN DATE	10/17/25
MATERIAL	Plain Carbon Steel	DESCRIPTION	Beam No.9
STOCK SIZE	1" Square Tubing 0.083 Wall	PN	REV
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TOLERANCES UNLESS NOTED: UNITS:		X.X ±.030 X.XX ±.010 X.XXX ±.005 X.X" ±1"	
DRAWN BY Ailin Chinn		DRAWN DATE 10/17/25	
MATERIAL Plain Carbon Steel		DESCRIPTION Beam No.10	
STOCK SIZE 1" Square Tubing 0.083 Wall		PN	REV
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TOLERANCES UNLESS NOTED: UNITS:		X.X ±.030 X.XX ±.010 X.XXX ±.005 X.X" ±1"	
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MATERIAL Plain Carbon Steel		DESCRIPTION Beam No.11	
STOCK SIZE 1" Square Tubing 0.083 Wall		PN	REV
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More Pictures of Our Finalized Vehicle







Tab 2

