Better Than a B-Cycle
Drill Powered Vehicle Project
Final Report

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MCEN 3025 Component Design
Derek Reamon

I. Introduction/Background:

Project Purpose

The purpose of this project is to create a hand-drill powered tricycle. As the Better Than a B-Cycle team, our goal is to design a tricycle that leverages the power of a drill to complete an endurance race course. Our team must make the design light, strong, and nimble, such that it can tackle the challenges of the course. This project is also an excursion in engineering. This project teaches students to maintain an organized workflow process and stick to a schedule. This is the first time that students have free range in a large project with distinct responsibilities. Most importantly, the project teaches practicality. To succeed, students must leverage the wisdom and experience of peers, instructors, and machinists.

Project Objective

Our team is competing in the endurance race. This race consists of an 1100 foot circuit around Kitt Pond, involving two left turns, four right turns, and 24 feet of elevation gain. The duration of this race is 30 minutes, and the goal is to complete as many laps in the allotted time. There are constraints on the team's bicycle too, such as a maximum weight of 50 lbs, a budget of 200 dollars, and the front fork as our only pre-existing part. The objective of the team is to follow these guidelines, and use resources in the Idea Forge to design a tricycle that will excel. Individually the objective for each member of the team is to create a product that they are proud of.

Design Motivation

To achieve the objectives above, our team chose a tricycle design with a single front wheel, and two back wheels to keep a stable base for turning along the course. With each team being allowed one preexisting bike part, we chose to use the front fork, which keeps the smooth steering of a normal bicycle. This is crucial when the driver is racing the clock and constantly turning on the course. One of our design dogmas is to maintain simplicity. A simple tricycle means less opportunity for issues to arise. Our design draws inspiration from other bicycle designs with a vertical top and down tube connecting to our back wheels.

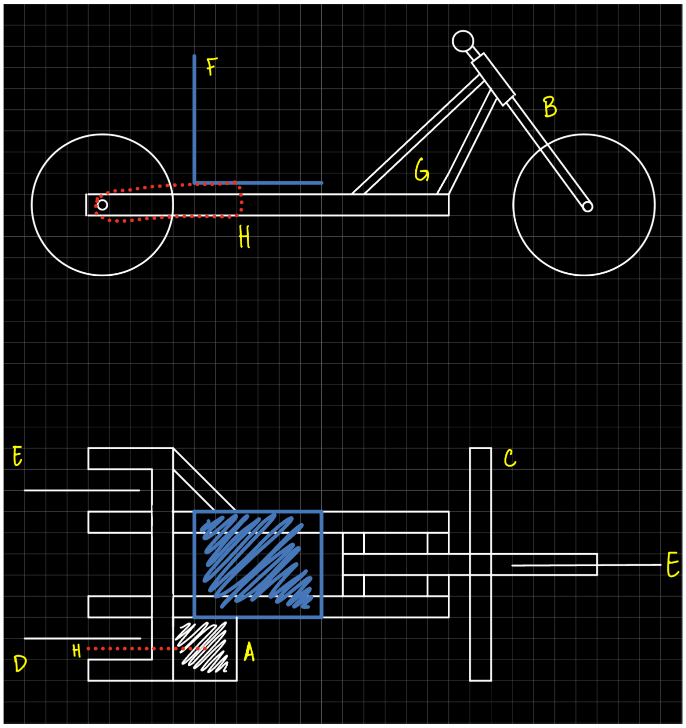
II. Design:

Conceptual Design

Every design process begins with a brainstorming session between team members. The Idea Forge kindly supplied us with many different supplies that will help us manufacture our vehicle so there were many items we did not have to consider buying when brainstorming.

For simplicity, only one of our back wheels will be driven by our drill, while the other will rotate freely. The most effective setup we were able to come up with was a two rear fork design, where each of the rear wheels would sit by themselves, and are not connected via an axle. Eliminating a design with an axle saves us from having to include any sort of differential for when

our bike goes around turns. Due to the design requirements, a tricycle construction also allows us to almost completely manufacture the
rear end of the bike while using borrowed, previously produced parts for our front end.



A. Drill plate mounted to the frame

B. Front fork - sourced from old bike

C. Handlebars for steering

D. Driven rear wheel

E. Front and rear freewheels

F. Beach chair for driver

G. Manufactured frame

H. Chain connecting drill to driven wheel

Figure 1: Initial Design Sketches of our drill powered vehicle.

We did stray away from this exact frame setup after our design review, however all other components remain in the same location.

Selected Design

Overview of Design and Operation

The functionality of our design is very similar to our concept design, with a few iterations that improved our overall functionality and safety from failure. We have a tricycle with one steering freewheel in the front, and two wheels in the back, one a driven wheel, and the other a freewheel. The drivetrain is to the back right of the driver and the front steering system and headtube is attached by two connection points.

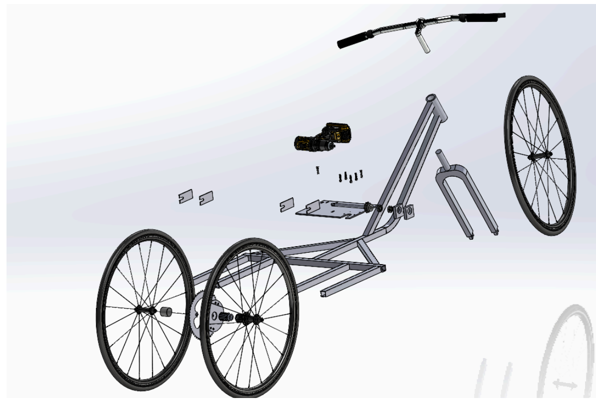


Figure 2: CAD model of full assembly of the selected design.

Our driver will sit between the drill and the down tubes on the two diagonal pegs outwardly attached on the main support bar that extend to the back fork. For steering, the front handlebars will have two brake levers, one running to a rim brake that will be attached to the front wheel, and one running to the triggering system (or throttle) on our drill. This will be the mechanism that turns the drivetrain on and off. The lower half of the drill, including the battery, will be free from connection to the drill plate, and therefore the frame. This will allow easy access to the battery, in case of a need to change the battery while testing.

Description of Materials and Components

We used materials that were either salvaged, given by the Idea Forge, or purchased. Our used materials are either parts from a project member that has spare parts, from Community Cycles's unwanted bikes (Community Cycles is a thrift store for bicycles), or other parts that we could salvage from previous group's projects. Included in our used materials is our back chain ring, the chain, the front rim brake, the brake line and levers for the throttling system, the front fork, and the wheels. The components made from materials given by the Idea Forge include; the drill plate, the pillow blocks, the drill, the headtube, the drill axle, steel coupons for drops, and a variety of fasteners. The materials we purchased include; the steel tubing, the front sprocket, the bearings, the chain ring adapter, and the throttling system (a spring, a door hinge, and a L bracket).

Design Iteration

Throughout our initial design process, we had several iterations for our frame and other components, with the largest change happening after the design review. We initially came up with the two rear fork design, a middle connection with two steel tubes running up to the down tubes that were meant to support a beach chair, and no bent steel members. However, we were given a suggestion during our design review that would help us save weight and simplify our frame.

The idea was to combine our two front running bars into only one that would run up the center. By doing this, we could reduce the amount of steel in the front section of our bike by almost half. This new design would also save on welding time. Tubes that are bent are more structurally sound in this case than those who are welded to each other. Looking at our previous load calculations on the frame, we also realized our safety factor was unnecessarily high, which left room for design optimization. See Figure 3 below for reference to frame and bike design iterations.

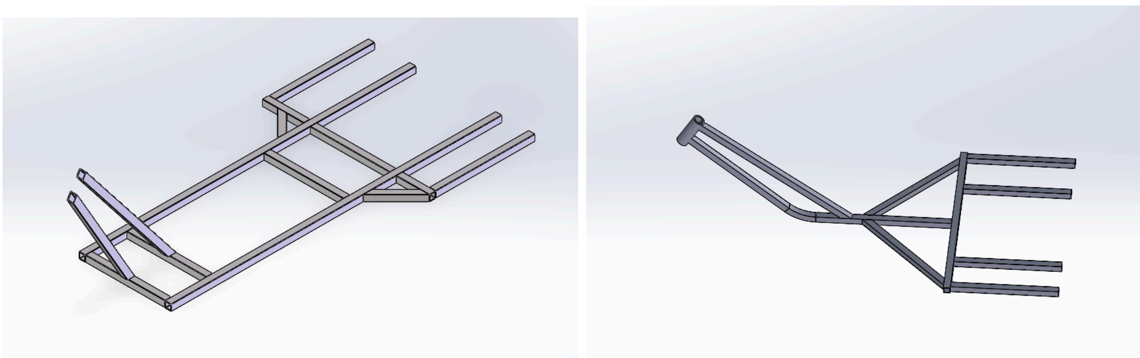


Figure 3: Design Iteration showing previous frame design (left) and current frame design (right).

Another component that experienced design iteration was our adapter plate. Previously it was thicker than necessary and had a spacer machined into it, so it would be one solid part. However, we changed this design to make it a flat, thinner plate where we would instead use a 3D printed spacer. This would make the manufacturing of the plate much easier, and cheaper. As shown in Figure 4 we have two orientations of holes to fit different chainring attachment styles, where we have a symmetrical and asymmetrical style.

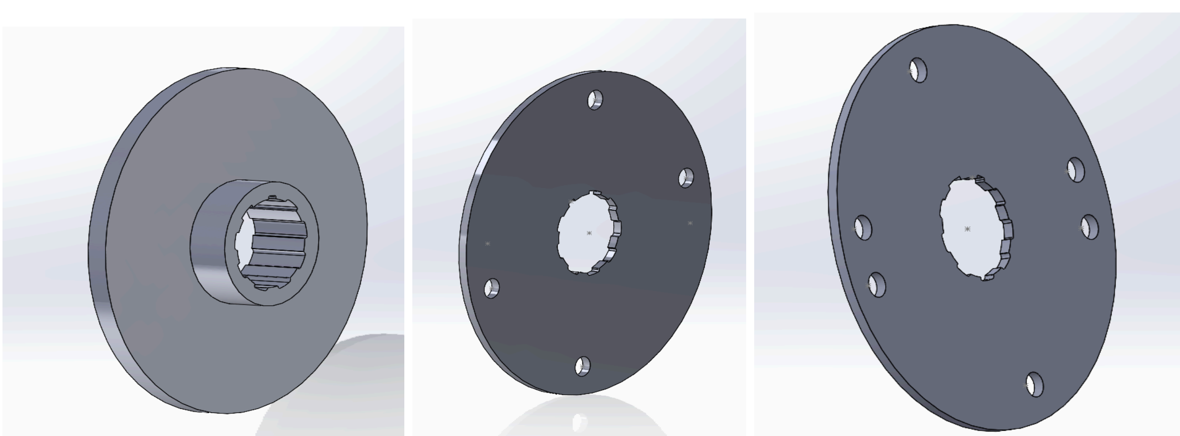


Figure 4: Models of the adapter plate showing the first design (left), a second iteration (middle) and the final design (right).

Finally, another component that experienced heavy design iteration was our drill plate. The drill plate went through many design iterations since it heavily depended on many other components of our design, such as the axel, pillows, frame and wheels. One of the changes was minimizing the amount of slots holding the drill to the plate. We were able to reduce the straps around the drill from two to just one around the handle of the drill, as the pillows and drill axle hold the drill down, so all we needed to do was keep the drill from rotating. We designed the plate to have three holes for bolts to connect the plate to the frame. Since the frame changed continuously, the arrangement of connection holes had to change with it. Finally, the most important change we made was the larger slot in the bottom right of the plate. Previously, we had the drill and pillows raised above the plate to avoid the chain hitting the plate. But the gap between the plate and the drill would create unnecessary challenges, so instead we opted to cut a slot for the chain to run through the plate. See Figure 4 for a visual example of the iterations of the drill plate.

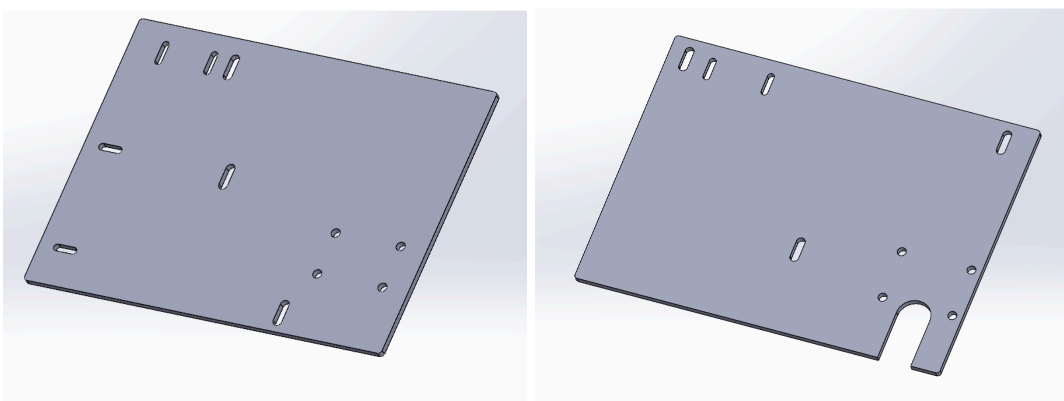


Figure 5: Design iteration of our drill plate showing our initial design (left) and our final design (right).

III. Component Analysis Critical Components

Frame

The frame is a critical component of our vehicle. We made the frame with AISI 1020 steel tubing. The frame consists of 8 1” x 1” 14 gauge steel bars welded together to the front fork of a salvaged bike. We made our frame strong and lightweight to complete as many laps as possible in the endurance challenge. It is the largest component on our vehicle and it needs to be made well to support the weight of the rider as well as other forces. The frame also must not deflect too much to ensure structural stability and ease of riding.

To test the strength of our frame we did hand calculations to find the points where it would most likely fail. We found that these spots were on the center bar at the furthest point from any support due to bending and the connection between one of our back forks and cross beam due to shear. For ease of calculating these stresses and deflections, we simplified the beams to simply supported beams with reaction forces on either end. This allowed the beam to not be statically indeterminate and therefore the team was able to find the stresses and deflections.

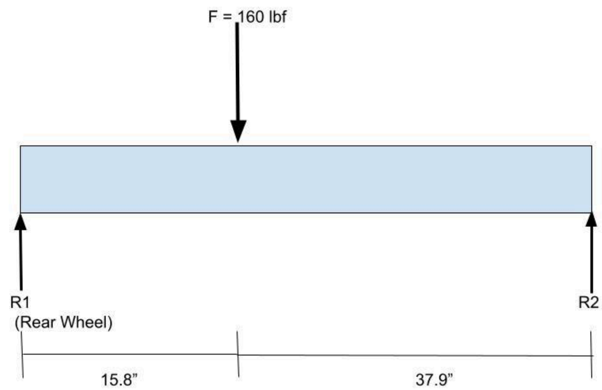


Figure 6: Diagram showing the forces acting on a sample frame piece.

Calculation for Deflection of Frame(See Appendix A part i for full calculations)

- Overall Deflection

$$I = \frac{1}{12}bh^3$$

$$y = \frac{Pb(3L^2 - 4b^2)}{48EI}$$

- Middle long beam

$$M = F*d$$

$$\sigma = \frac{M*y}{I}$$

$$N = \frac{Sy}{\sigma} = 1.79$$

- Back Cross beam

$$M = F*d$$

$$\sigma = \frac{M*y}{I}$$

$$y = \frac{PL^3}{48EI}$$

$$N = \frac{Sy}{\sigma} = 2.105$$

From our calculations the factor of safety is at an acceptable level above 1, and the amount of deflection is not a cause for concern. The overall deflection of -0.55 inches may seem like an issue; however, comparing this with the overall length of our vehicle, it is small enough to not be an issue. We were instructed to buy tubing at a constant 1 inch by 1 inch, but the gauge we decided on could have been changed. The team deliberated the thickness of the frame tubing but the safety factor and displacements found showed it was not necessary to change.

Drive Shaft

Our drive shaft is another critical component. The drive shaft is manufactured out of a steel rotary shaft. We milled down one side to have a hexagonal cross section. In doing this, the shaft will be able to smoothly fit into the mouth of the drill without slipping. The shaft has a circular diameter of 0.5 inches and is 5.5 inches long. This shaft will be pressed into the sprocket bore hole and in between 2 pillows with bearings. The shaft and sprocket will fit together with a dog point set screw. This will allow the drill to turn the shaft and therefore then turn the sprocket.

To test the strength and angular deflection of our shaft we first had to test the output torque of the drill. The output torque was measured to be around 298 in-lbs, and in order to calculate torsion and angular deflection on the shaft, we simplified it to a cantilever beam with fixed support at one end and a free end on the other.

Calculation for Drive Shaft (See Appendix A part ii for full calculations)

$$J = \frac{\pi}{32} * d^4$$

$$\tau = \frac{Tr}{J}$$

$$\theta = \frac{32LT}{G\pi D^4} = 0.175\,°$$

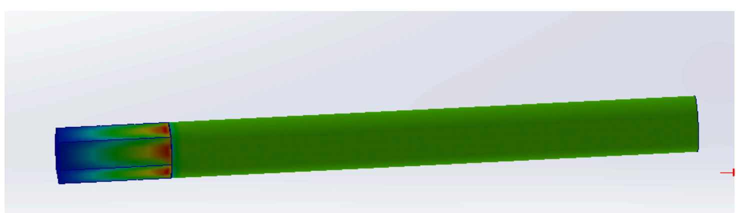


Figure 7: Finite element analysis of the drive shaft.

From the calculations the amount of deflection the shaft would face is an acceptable amount. .175 ° will not cause any structural damage. The torsion that the shaft faces is also not an issue, only being 12141.6 psi. Even with a stress concentration shown in the FEA analysis above, the factor of safety is high enough to compensate for the higher stress. Based on this analysis no changes to the shaft diameter or material were needed to improve design.

IV. Fabrication:

Our product was fabricated by five main manufacturing processes. Our team used a lathe to turn down cylindrical parts, a mill to mill out certain geometries (most typically holes and taps), a waterjet, a saw, a welding torch, and a 3D printer.

Look at appendix B for engineering Drawings

1) **Frame**
    - Made from: 14 gauge rectangular 1020 AISI steel tubing 1” x 1”.
    - Machines used: Roll in band saw, sandblasting machine, tube bender, tube notching machine, weld torch.
    - Fabrication process:Our team cut the steel to the desired length using the band saw, including cuts at angles for correct geometry. Then sandblasted the ends of each tube to prepare for welding. We bent the two necessary pieces with the tube bender,we also coped those same pieces with the tube notching machine. Finally, pieces were welded together with the welding torch.
2) **Head tube**
    - Made from: Easily weldable steel stock, 1.5” OD.
    - Machines used: Roll in band saw, lathe, weld torch.
    - Fabrication process: Our team cut the steel to the desired length using the band saw, then faced the piece using the lathe. Finally we welded the head tube to the rest of the frame.
3) **Adapter plate**
    - Made from: A36 Steel ⅛” thickness.
    - Machines used: CNC waterjet cutter.
    - Fabrication process: We used the CNC waterjet to the necessary shape and holes out of the drill plate according to the provided drawing and .DXF file.
4) **Adapter spacer**
    - Made from: PLA Plastic
    - Machines used: Prusa MK4 3D printer.
    - Fabrication process: Our team used the 3D printer to build the necessary shape given the .STL file of the part.
5) **Drill Plate**
    - Made from aluminum 6061
    - Machines used: CNC waterjet cutter, 3 axis CNC milling machine.
    - Fabrication Process: CNC waterjet cut the necessary slots and holes according to the engineering drawing and .DXF file. After testing and iterations, the team made adjustments on the plate using a simple milling machine.
6) **Pillow Blocks**
    - Made from 2” x ½ “ aluminum bar stock.
    - Machined used:Roll in band saw, 3 axis CNC machine, press machine.

- Fabrication Process: Our team used the band saw to cut the stock to appropriate rough sizing.Then we used a milling machine to drill the holes for the fasteners that connect the pillows to the drill plate. We also used the milling machine to tap the same holes. Next, we used a 3 axis CNC machine to mill out the holes for the pillow blocks to press fit tolerance. Finally, we used a press machine to press the bearings into the pillows.

7) **Drive shaft**
    - Made from 1566 TG&P steel shaft ½ " diameter, 12" length.
    - Machines used: Roll in band saw, lathe, 3 axis CNC milling machine.
    - Fabrication Process: Our team used the band saw to cut the material to rough length. Then we used the lathe to face the material. Finally, we used the mill to mill down the hex on the end of the shaft to fit into the drill.
8) **Driving sprocket**
    - Made from: Machinable ANSI Steel.
    - Machines used: Lathe, 3 axis CNC milling machine.
    - Fabrication process: Our team used the lathe to turn down the thickness of teeth from .284" down to .090"
    - down teeth.

Standard Components

Part name	Quantity	Modifications Needed	Machines used
Salvaged steel bike frame	1	Remove unnecessary material and prepare surfaces for welding	Bandsaw
Bike chain	1	Clean and grease to ensure smooth operation	Chain breaker
Front wheel	2	Add footpegs to front wheel	N/A
Rear wheel	1	Add freehub adapter/custom spacer	N/A
Brake Cables	2	None	N/A
Hinge and spring for trigger system	1	None	N/A
Handlebars	1	None	N/A
Back Gear	1	None	N/A

V. Testing and Results:

Our testing will be conducted to verify our analytical predictions and to evaluate the accuracy of our previous results, as well as the overall performance of the bike. Our key tests will focus on the forces and stresses on key components, as well as the performance of the bike due to the battery life and the power output of the back wheel. Testing will play a crucial role throughout the design and manufacturing process, confirming theoretical analysis and identifying potential areas for improvement. By testing individual components as well as the fully assembled vehicle, we aim to ensure the trike will perform reliably and effectively under real-world conditions.

Frame Deflection

To validate our analytical predictions for frame performance, we will measure the maximum deflection of the frame with a rider seated. This deflection is expected to occur near the loads center of mass and will be compared to the theoretical predictions from finite element analysis (FEA) and hand calculations. Any discrepancies may result from complexities such as support bars, the full frame structure, and welds, which are challenging to replicate accurately in theoretical models.

Speed and Power Trials

To assess the vehicle's power output and endurance, we will conduct speed trials at three throttle levels: low, medium, and high. During each trial, we will adjust the throttle to achieve distinct speed settings, although exact speeds will not be measured directly at this stage.

In subsequent tests, we will measure the wheel's revolutions per minute (RPM) directly, allowing us to calculate precise power output. Currently, we anticipate the torque applied to the rear wheel after gearing to be approximately 1580 in-lb. Using this torque value, we will estimate power output across different throttle settings by applying the equation:

$$Power(HP) = \frac{Torque\ (in\text{-}lb) * Speed\ (RPM)}{63025}$$

where the RPM will be substituted with measured values for each throttle level.
This symbolic approach will provide an initial understanding of the relative power demands across low, medium, and high speeds. It will allow us to approximate the energy requirements for each throttle setting and inform initial endurance estimates. Once we gather actual RPM measurements, we will refine these values to provide more accurate predictions of runtime and overall endurance.

We had our rider do many laps around the pond on the vehicle trying different speeds and coasting to try and decide what the best way to conserve the battery would be. During this testing, we learned that our bike cannot take corners at speed and will top over very easily. Our rider had to practice leaning into corners so we could maintain a higher speed around the course. We decided that our strategy during the race would be to coast as much as possible and go slowly with minimal throttle on the uphill to conserve o

Battery Life Estimation

To estimate battery life, we will calculate the battery's watt-hour capacity using the equation:

$$Wh = Voltage * Ah$$

With a 20V battery rated at 2 amp-hours, we anticipate a capacity of 40 Wh, or roughly 0.0536 HP·h. By comparing this battery capacity to the estimated power output for each speed, we will approximate that the trike can operate at low, medium, and high speed.

Through testing, we aim to gain valuable insights into the trike's capabilities and to confirm several aspects of the initial design analysis:

- **Component Validation**: We anticipate that frame deflection will be measurable but not significantly impactful to performance or stability, aligning with our theoretical expectations for structural integrity.
- **Operational Endurance**: Testing will provide an estimate of runtime at various speeds on a single battery charge. This information will help us gauge endurance, though factors like variable speeds, track curves, and elevation changes (testing will occur on a flat, straight course) may influence real-world performance.

Overall, testing is expected to reinforce the reliability of our design while also revealing areas for possible improvement, such as enhancing component stability and optimizing power usage to maximize the trike's endurance.

Testing overview and results

One of the biggest issues that we came across in assembly was that the chainring mounted on our drive wheel was on the wrong side. We designed it initially to be on the inside, however, this meant that the wheel was freewheeling when the drill was running. To power the wheel in the correct direction, we needed to flip the wheel around.

This was not an easy fix because other parts of our bike were designed to align the gears in this way. Luckily, we were able to drill new holes to move the plate over towards the outside of the bike.We also needed to allow our drive sprocket to move more towards the outside of the bike, so we widened the chain slot on the drill plate to allow the chain to align straight. Other pieces like welds on our frame had to be filed down so our wheel could spin freely in this new orientation.

Overall, this fix was time consuming and menial. It was a problem that could have been resolved if we had done more prototyping.

VI. Design Iteration after Testing

The main components of our bike that were necessary to test were our frame, drivetrain, throttle assembly, and our brakes. Unfortunately, most of these components couldn't go through thorough rigorous testing previous to our entire bike being assembled, so our testing was both brute and efficient.

Our plan to test our machine's frame was by applying a load exceeding the amount of our rider on the position of the seat. Once assembled, the largest person in our group stood on the bike and jumped. This effectively tested our welded connections and strength of our steel tubes, which should have held up within a decent factor of safety according to our calculations.

After testing we noticed that our bike's chain would pop off the back sprocket because of two reasons, the alignment for the chain was off, and the chain itself had two stiff links. We fixed the alignment of the chain by widening the slot on the drill plate that the chain will run through, and changing the location of the drive sprocket so it aligned with the back wheel better. Next, we replaced the chain since the two stiff links were unfixable. These iterations prevented the chain from popping off.

VII. Bill of Materials/Cost:

For our tricycle we kept costs low by leveraging used bike shops as well as parts from our groupmates. Many of our parts were sourced, free of charge, from local bike shop, Community Cycles. One of our group members, Cole, is a bike enthusiast. He had collections of parts which he donated to the group. Our other major saving was in our steel. We bought the steel from Den-Col, a Denver based steel company. Their steel was cheap and we saved shipping costs by picking it up ourselves.

The total cost of our project was $127.46, well below the project cost requirement of $200.00. Below is the itemized bill of materials, with names, amounts, costs, and sources listed.

PART	AMOUNT	PRICE	SOURCE
Pillow Bearings	2	$26.26	Mcmastercarr, the sealed ones
Front Sprocket	1	$16.98	McMasterCarr (679K141)
Head Tube Inners	1	$0.00	Community Cycles
Drill Axel	1	$0.00	Idea Forge
Drops	2	$0.00	Idea Forge
Frame Tubing	20 ft	$61.00	Den Col Supply
Back Gear (53t)	1	$0.00	Cole
Brakes	1	$0.00	Cole
Pillows	2	$0.00	Idea Forge
Drill Plate	1	$0.00	Idea Forge
Freehub Spacer	1	$9.23	McMaster
Spring for Throttle	1	$5.00	mcmaster
Foot Pegs	2	$8.99	Amazon
Wheels	3	$0.00	Cole
Brake Line	1	$10.00	Community Cycles
Total		$127.46	

VIII. Appendix:

A) Calculations for Analysis

i)

T_drill = 298 in-lbs

G = 79.3 MPsi

Sy = 63000 psi

J = $\frac{\pi}{32} * d^4 = \frac{\pi}{32} *.5^4 = .006136in^4$

$\tau = \frac{Tr}{J} = \frac{298*.25}{.006136} = 12141.61psi$

N = $\frac{63000}{12141.61}$ =5.19

$\theta = \frac{32LT}{G\pi D^4} = \frac{32*5*298}{79300000*\pi*.5^4} * \frac{180}{\pi} = 0.175\,°$

ii)

Sy = 50800 psi

E = 29700000 Psi

L = 53.8in

$I = \frac{1}{12}bh^3 = \frac{1}{12}1 * 1^3 - \frac{1}{12}.917 * 917^3 = .0244088\ in^4$

R2 = $\frac{160*15.85}{37.95} = 66.825lb$

R1 = R3 = $\frac{160-66.825}{2} = 46.587lb$

$y = \frac{Pb(3L^2-4b^2)}{48EI} = \frac{160*15.85(3*53.8^2-4*15.85^2)}{38*29700000*.0244088} = -.5596in$

Middle long beam

M = 160*9 = 1440 lb-in

$\sigma = \frac{1440*.5}{.0244088} = 29497.56\ psi$

$N = \frac{Sy}{\sigma} = \frac{50800}{29497.56} = 1.79$

Back Cross beam

M = 93.174*13.125 = 1222.911 lb-in

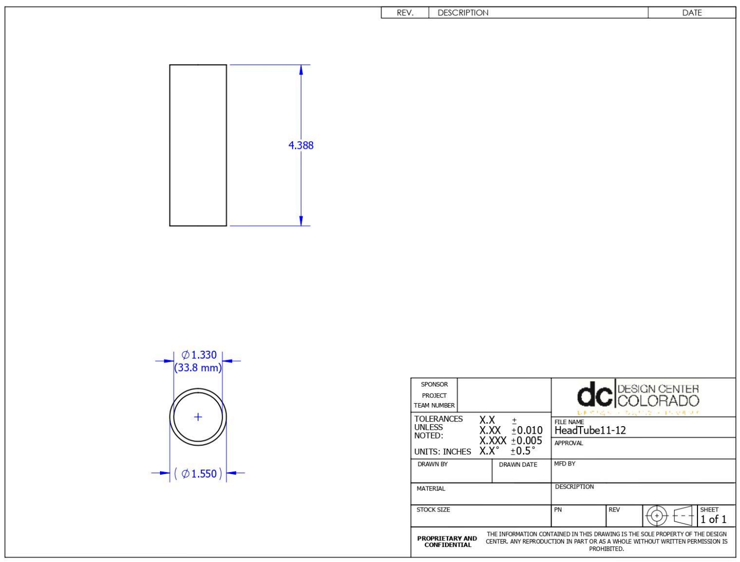
$\sigma = \frac{1222.91*.5}{.0244088} = 25050.9psi$

$$y = \frac{PL^3}{48EI} = \frac{93.175*26.25^3}{48*29700000*.0244088} = -.0484in$$

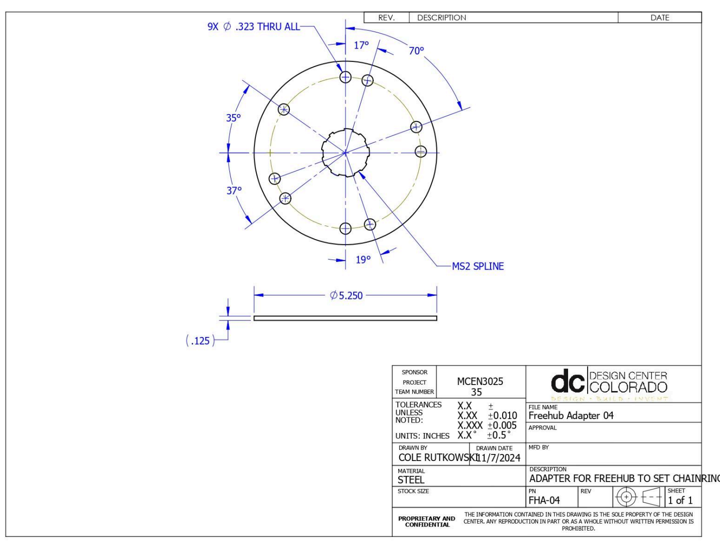
$$N = \frac{50800}{25050.9} = 2.105$$

B) Engineering Drawings for Manufactured Parts:

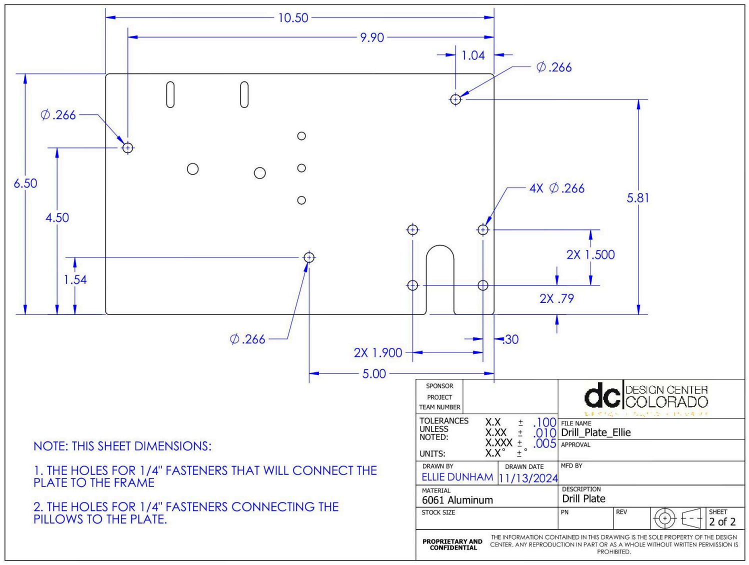
- Head tube

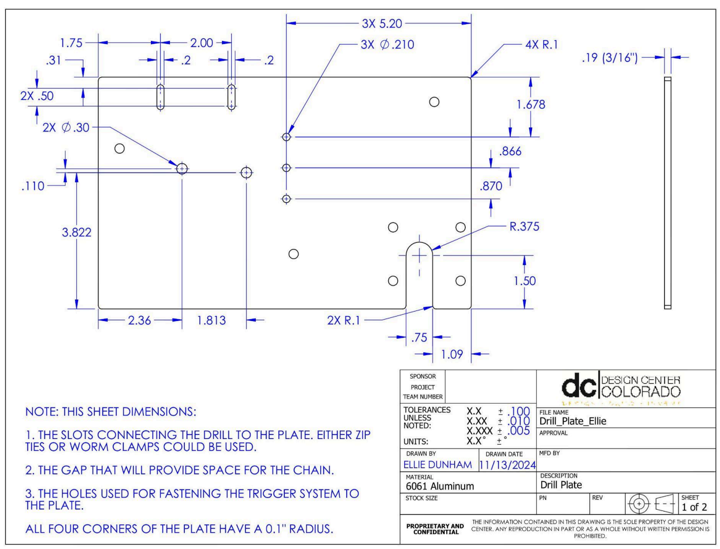


- Adapter plate

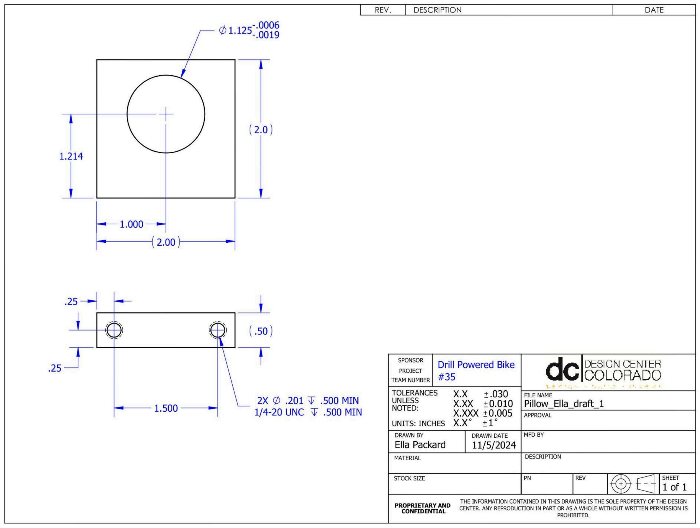


- Drill Plate

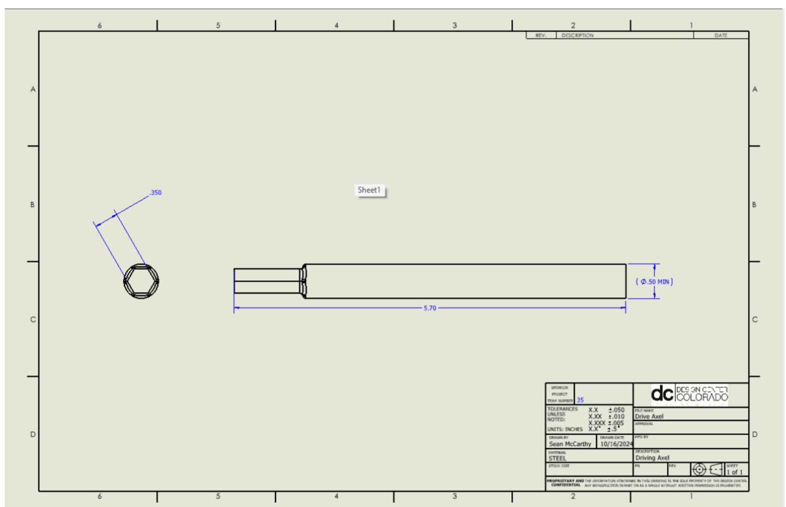




- Pillow Blocks



- Drive shaft



- Driving sprocket