Component Design
Final Report

Steminists
SID's: 478-368, 025-652, 050-495, 735-123, 020-290

Contents

1 Introduction

1.1 Purpose

Being able to tie together the fundamentals of core mechanical engineering courses and successfully bring an idea to its fruition is the motivation behind building a drill-powered vehicle. In accordance with the 2019 curriculum of Component Design with Dr. Janet Tsai, the Steminists have been tasked with the drill-powered vehicle project as a means of building upon core concepts of mechanics of materials, statics, and dynamics. The design ultimately boils down to important concepts such as safety, reliability, manufacturability, and timeliness. Team members must implement the theoretical skills learned in class in their design and have a profound understanding of the material in order to plan and refine their vehicle.

1.2 Project Objectives

The maneuverability course has been chosen as the challenge for this vehicle. The project objectives are closely tied to the needs of the course. Objectives include successfully navigating a slalom course without upsetting any cones, driving through a tunnel without touching the top or sides, and completing two U-turns in a 10 ft. by 20 ft. box. All component design teams have a set of basic limitations in which to work with the bike. These constraints lead to the bike needing to be less than 50 lb. and costing less than $250. Finally, the ability to work as a team proves to be an invaluable trait in industry. The project allows for each team member to gain a new skill set by allocating team roles prior to beginning the project.

1.3 Design Motivation

The Game of Thrones powered vehicle is representative of all the guts and glory of Khaleesi. It is the mother of dragons—or wagons, in this case—and is designed to be swift, powerful, agile, and a moving force. For swiftness, a small and sleek chassis will be ideal. For agility, a smaller turning radius and a smaller front wheel will allow for greater and better maneuverability. For power, the driver will be positioned more towards the rear wheel, as this will give more efficient power output. As for the moving force, this will be the force embodied by the Steminists to design, manufacture, and drive to victory.

2 Vehicle Design

2.1 Conceptual Design

The conceptual design preceded the official design review and any formal feedback. It was created with the minimum requirements of the maneuverability challenge in mind, as shown in Fig. 1. A bike design with two wheels was chosen to minimize the width of the frame, making it easier to maneuver. A small front tire was selected to create a more reactive steering system and lower the overall bike height, as any contact with the tunnel would result in an automatic penalty. The driver weight is primarily on the rear wheel, increasing the driving wheel traction for more efficient power output, at the cost of initial traction. Wide tires were selected to maintain stability. The steering, as shown in Fig. 2, will consist of two separate wheel shafts and a shorter tube to connect the steering with the main body of the bike, allowing the bike to complete a 70 degree turn without interference of the chassis. In Fig. **??**, the drill can be seen attached to the rear wheel, making the vehicle rear-wheel driven. An entirely mechanical throttle system will allow the driver full control with the incorporation of a foot pedal that will be placed on the bottom right tube of the chassis, as shown in Fig. 4. The brake system is adapted from a standard v-brake design, as shown in Fig. 5. The maneuverability challenge offers diversity in the challenges that will be confronted, such as loading, fatigue analysis, steering and braking system design, and throttle system design.

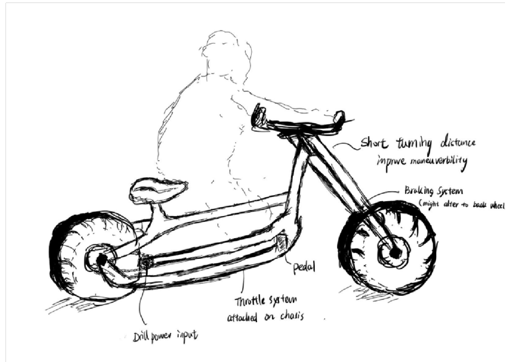

Figure 1: Initial Sketch of Desired Vehicle Design

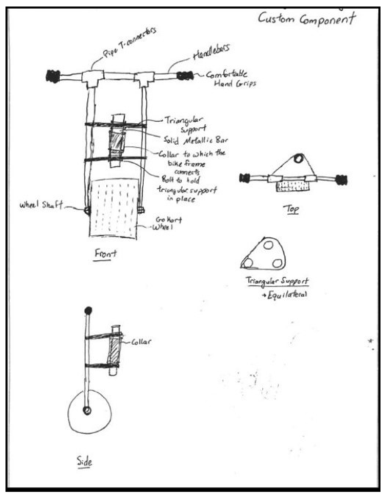

Figure 2: Initial Steering System Sketch with Custom Triangular Connector to Head Tube

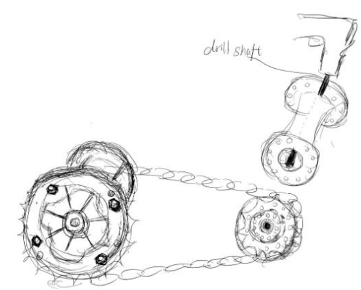

Figure 3: Initial Sketch of Drive Train

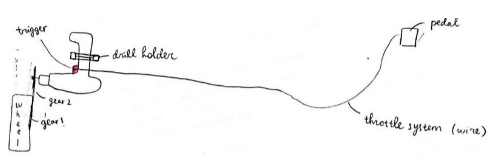

Figure 4: Initial Sketch of Throttle System Previewing Drill Interface with drive train

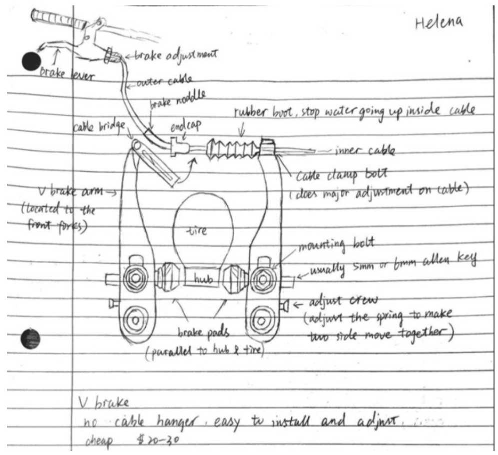

Figure 5: Initial Sketch of the V-Brake System Design

2.2 Selected Design

The selected design section denotes the preliminary design material and component choices that were made before the design review commenced. The main components of the vehicle are the steering system, drive train, chassis, braking system, and the throttle system. Team was excited to compete in the maneuverability challenge. As such the selected design is two wheels to reduce turning radius. Further the team is designing a lightweight bike to increase ease of turning as cones are moved through. The steering system will be assembled with mount steel tubing of two different diameters. Mount steel tubing of 0.75 in. diameter will be used for the connections to the front wheel and tubing of 1 in. diameter will be used for the collar. For the chassis, the same mount steel tubing will be 16 gauge and 1 in. in diameter, as shown in Fig. 6. This gauge was chosen because of the preference for easily welded steel and flexibility, as many bends will need to be made for the desired chassis design. Additionally, the machine shop in the IdeaForge had the most bending options for a 1 in. diameter tube. The customized steel triangular pivot unit for connection of the steering to the frame will be made of 4130 alloy steel, as this has a slightly thicker wall that will not distort when being welded to the steel frame. The drive train will use two sprockets that have been selected for a desired gear ratio of 2.45:1 and an acrylic board. Miscellaneous parts include connectors, such as screws, washers, lug nuts, bolts, and pillows blocks. A refurbished bike seat has been claimed from the DIDL, and rims will be scavenged from existing tires. The braking system will use a V Brake with a cable and lever, as shown in Fig. 5. The throttle system will incorporate plywood for the pedal, a 24-gauge, 100-foot galvanized wire, and a wall mounting bracket.

Figure 6: Exploded view shows the preliminary designs

3 Design Iterations

3.1 Design Alterations

Upon completion of the design review with attendees Dr. Janet Tsai, Greg Potts, and Katherine O'Dell, critical feedback and concerns were incorporated to refine and improve the original vehicle design. The five categories in which several adaptations were enacted are the drive train, steering system, throttle system, chassis, and drill plate. The design which resulted from design review can be seen in Fig. 7.

3.1.1 Drive Train

The main concern with the previous drive train centered around the acquisition of parts and their stability within the drive train to ensure proper usage. The selected sprocket for the desired gear ratio was unobtainable in the marketplace. Thus, the gear ratio was re-calculated to match available sprocket sizes. The new gear ratio is 2.36 based on desired torque output of the drill at 60% of the stall torque and the relative shaft and wheel diameters. It was also recommended that the team acquire a free wheel spinning capability. As this will be necessary for the maneuverability course, it has been incorporated into the new design. Pillow bearings have been added to ensure consistent alignment of the sprockets as well.

3.1.2 Steering System

The steering system had similarly significant alterations. Originally, the design featured a wheel frame in which the forks did not merge onto the handlebars. This meant that a triangular device was used to facilitate the turning of the steering system and its attachment to the frame. Upon discussion during the design review about the difficulty in completing this, the design was altered to include a steering system from a children's bike. The head tube was removed, and the new design includes a replacement head tube onto which frame attachments could be mounted. This will increase manufacturability to ease of steering for the team.

3.1.3 Throttle System

The throttling system was more complicated than it strictly needed to be in the initial design. A more simplistic design that does not include many custom parts has replaced the old design. This will allow for easier manufacturing and equivalent performance. Now the throttle system is activated by a spring loaded pedal on the base of the vehicle. The pedal itself is made from plywood and attached to a plywood base using a door hinge. A torsion spring was then added to the assembly such that when the pedal is depressed the spring is tightened. The wire, which allows the throttling system to reach from the drill to the pedal, is now enclosed for safety purposes. A small plate for the pedal to rest on has been added to the design. This plate will also act as a foot rest for the rider. A standard V brake will be added to the standard width front tire. This has been acquired from Boulder Community cycle. Previously, the braking was undefined.

3.1.4 Chassis

There were several changes to the chassis design, the largest of the changes being the number of pieces used to create it. Every connection point is a potential point of failure, particularly in context of team welding skill. Therefore, the team has reduced the number of individual pieces. As opposed to 45-degree cuts, more standard fish-mouth and welding practices have been incorporated into the new design. This tube has a more appropriate wall thickness of 1/16 in. instead of the previously designed 0.5 in.

3.1.5 Drill Plate

The drill shaft was not held into a precise location in the original design, and it has been altered to lay flat on the drill plate with a more explicit drawing set. Since the design review, every connector has been added to the CAD assembly. CAD assembly also include an exploded view, a zoomed-out view, and a more obvious visual indication that the sprockets line up.

The final assembly view is shown in Fig. 7. Before and after views of the designs can be seen in Fig. 8, Fig. 9, and Fig. 10. Overall, the drawings needed more detail to be acceptable in a machine shop. This detail has since been added at a significantly higher level of detail.

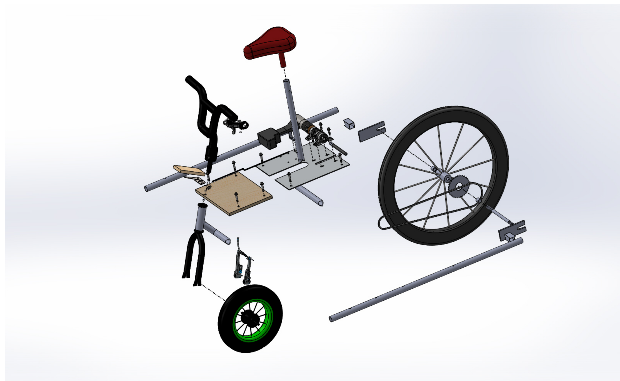

Figure 7: Exploded view shows the new design, after feedback from the design review and formal iteration was incorporated.

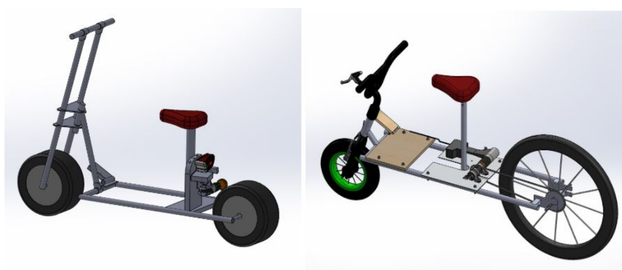

Figure 8: Isometric views of old and new design

Figure 9: Side views of old and new design

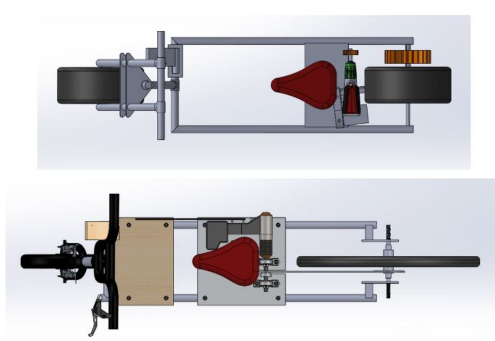

Figure 10: Top views of old and new design

4 Vehicle Analysis

4.1 Critical Components

4.1.1 Frame

The frame is critical to the design. Not only must it ensure safety for the rider, but it is the base on which all other components are connected. If the frame deflects too much, alignment of the other components will be altered. If, for example, the frame is bent, it might alter the tensioning in the chain along the driveshaft. Depending on the severity, it could cause the chain to fall off or for the drive train to stop running all together. The maneuverability course, in particular, necessitates a light vehicle that can turn easily and with a short turning radius. The frame itself, being the component that encompasses the most volume, needs to be designed with mainly the weight in mind, such that the bike can be maneuvered. With this concern, a SolidWorks simulation of displacement was necessary as seen in Fig.11. FEA results for deformation, stress and strain can be seen in the Appendix as Fig. 32, Fig. 33, and Fig. 34.

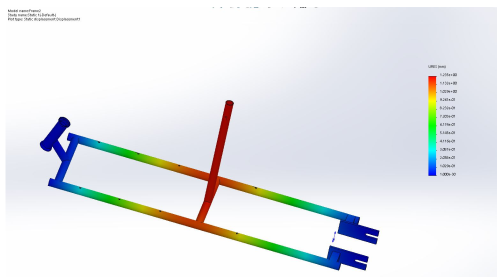

Figure 11: Finite Element Analysis was performed on the frame with SolidWorks 2018, revealing the largest displacement occurs on the horizontal bar and the point load of the seat.

There is a concentrated point load 20 inches from the radius of the front wheel where the driver sits. For the process of the FEA, a point load was placed in the downward normal direction on the top rim of the seat base. Additionally, fixed geometry was specified to be inside of the back fork cut-outs–specifically at the top–and inside the bottom part of the head tube–at the flat surface against which a bearing would press. The results confirmed the Steminists' confidence in the design decision, with the largest magnitude of displacement being 0.049 in. In comparison to the length of the frame components, this displacement can be neglected.

4.1.2 Drive Train Sprocket Connection

Without a working drive train, the project cannot be successful. Should the drive train have a fault, it is possible that the vehicle will not move at all, the drill would stall, or the chain would fall off, causing a potentially hazardous situation for the driver and/or viewers. The connection between the sprocket and the drive shaft is one of the most important locations along the drive train. The sprocket is held on with set screws that have been set into holes drilled into the drive shaft. If these set screws failed the sprocket could spin independent of the drive shaft making it impossible to move the vehicle. Further it would allow the sprocket to move side to side which would cause the chain to fall of the drive train.

4.2 Failure Analysis

4.2.1 Force and Moment Analysis

Based on the free body diagram featured in Fig.12, shear force in Fig.13 and moment in Fig.14 were calculated with a MATLAB program.

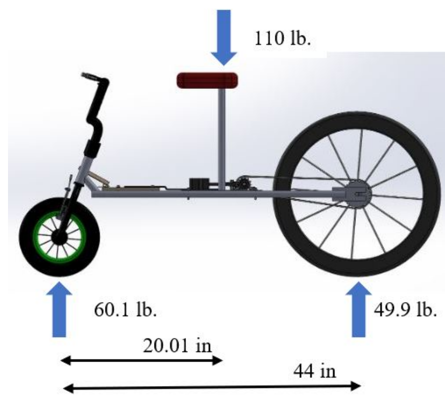

Figure 12: Free Body Diagram of Bike used in frame analysis. Frame is simply supported.

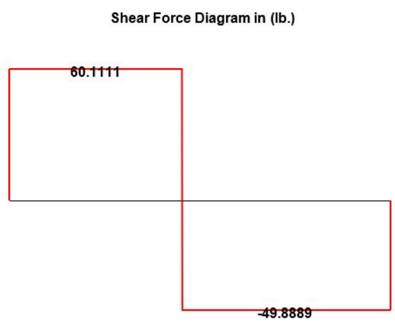

Figure 13: Shear force diagram shows the magnitudes of the maximum and minimum shear force to be 60.11 lb. and 49.89 lb., respectively. The maximum occurs in the region between the front wheel and the seat position, and the minimum occurs in the region between the seat and the rear wheel.

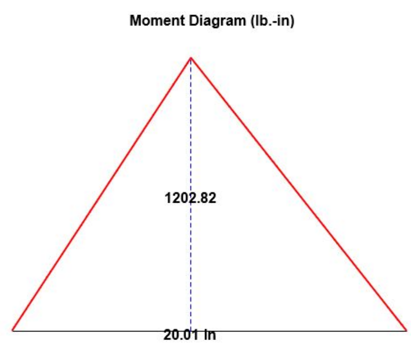

Figure 14: Moment diagram shows the maximum moment of 1202.82 lb-in. occurring at the position of the point load, 20.01 in. from the center of the front wheel. This confirms the FEA study that was done with SolidWorks and is why the largest deflection will occur at the position of the bike seat.

Calculations were performed for the bending moment and shear force on the chassis using equations for a hollow, round tube. The maximum bending stress is denoted by Eqn. 1.

$$\sigma = \frac{Mc}{I} \tag{1}$$

where σ is the maximum shear stress, M is the maximum moment, c is the radius, and I is the area moment of inertia. I is calculated using Eqn. 2.

$$I = \frac{\pi(r_o^4 - r_i^4)}{4} \tag{2}$$

where r_o is outer radius and r_i is the inner radius. The maximum bending stress was calculated to be 29.6 ksi. The total displacement of the frame at the location of the highest moment was calculated using the yield strength of mount steel tubing and the Norton Beam Tables in Eqn 3.

$$y_{max} = \frac{F_{load}}{3EI} * (2a^3 - \frac{a^4}{L} - La^2) \tag{3}$$

Where F is 110 lbs., a is 20.01 in, L is 44 inches, and E is 30 Mpsi. The maximum displacement is $2.16 * 10^-7$ in, which is even smaller than that which was calculated with the FEA simulation. The team is confident that the deflection in the frame will not be an issue.

4.2.2 Set Screw Direct Shear Failure

The small sprocket on the drive shaft contains two set screws composed of 1020 cold rolled steel each with a 0.5in diameter. The set screws have an S_y of 57 ksi as listed in the Norton text. To increase the holding power of the set screws the team drilled two small holes in the drill shaft to place the set screws into. Each hole was 0.05in deep which is sufficient to keep the screws in place. With the set screws embedded into the drill shaft, the most likely mode of failure is a failure in direct shear along the shaft-sprocket interface. The desired operational torque of the drill is 60% of the stall torque which results in $230lb * in$. These values were used to calculate the factor of safety of the sprocket connection to ensure that this critical component will not fail in Equation 4.

$$P = \frac{T}{r_{shaft}}$$

$$A_{shear} = 2 * \pi * (r_{screw})^2$$

$$\tau = \frac{P}{A_{shear}}$$

$$N = \frac{0.577 * S_y}{\tau} \tag{4}$$

P is 920 lbs., and A_{shear} is $0.098in^2$, leading to τ at 9371 psi. S_y is 57 ksi, as previously discussed, making the factor of safety of 3.51. This level of safety makes the team confident in the ability of the set screws to hold the sprocket in place and maintain the integrity of the drive train.

4.3 Race Course Discussion

The race course has a number of inherent constraints. There are three portions to the course: a slalom, tunnel, and U-turn box. The slalom requires that the vehicle be easy to steer and that it can change directions quickly. These constraints altered the frame of the vehicle, a critical component. It necessitated that the vehicle be lightweight but with little deflection, which ultimately affected the material choices. Furthermore, it required that the handlebars be easily reached and maneuvered, which altered the shape of the vehicle. The tunnel portion of the course puts a height restriction on the vehicle. The wheels, steering, and frame heights were all limited by this. The vehicle was designed so that the rider would need only minimal crouching motion to pass through the tunnel while on the vehicle. This ensures a faster motion through the tunnel, placing constraints on height. Finally, the U-turn zone dictated the distance that could be between the wheels, which, in turn, altered the design for the frame. It also required a drive train that could respond quickly to alterations in throttling, as small adjustments are made during the turning process. The critical component of the set screws which hold the sprocket in place on the drive shaft, therefore, needed to be secure with the varied needs of power transfer across the course. The race course is exciting, and the final design reflects the requirements of the course.

5 Fabrication

5.1 Description of Fabrication

The STEMinists vehicle was primarily manufactured in the IdeaForge. The excellent staff inside of the Ideaforge assisted with design for manufacturability and manufacturing skills throughout the process. The broad skills of milling, lathing, facing, coping, drilling, cutting, and welding were utilized during the creation of the vehicle.

5.2 Detailed Part Fabrication

5.2.1 Custom Parts

The manufacturing process of the vehicle involved becoming well-acquainted with the Idea Forge machine shop. As seen in Fig. 15 the frame of the vehicle is composed of 1" mount steel tubing. The tubing was cut using a vertical roll-in band saw, lathed at both ends to ensure parallelism for preciseness, coped using a coping machine, and sandblasted to prepare for welding. Once all of the tubing for the frame had been prepared, it was MIG welded in the Idea Forge shop.

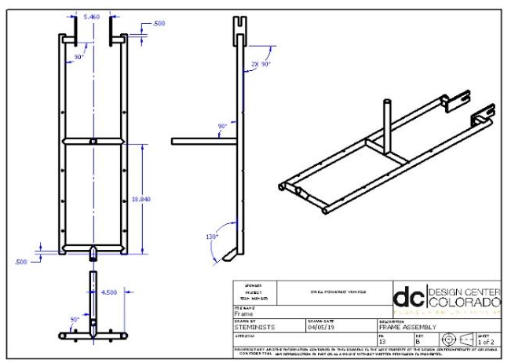

Figure 15: Frame Drawing

The rear axle is composed of ground steel 0.5in diameter shaft. This was cut using the vertical roll-in band saw. Once the piece was cut to an acceptable length, 2in on either end was threaded using a lathe. This can be seen in Fig. 16.

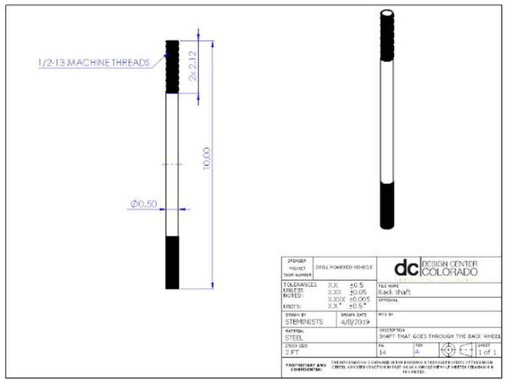

Figure 16: Back Axle Drawing

Forks which connect the rear axle to the frame are composed of one low carbon steel bar, which was cut using the vertical roll-in band saw. Individual passes at the fork cut-out were done manually with a CNC mill using two different drill bits–a thinner drill bit was used to make an initial rectangular cut-out with a higher tolerance for error, and a thicker drill bit was used to make the radius of the circular slot. The drawing can be seen in Fig. 17

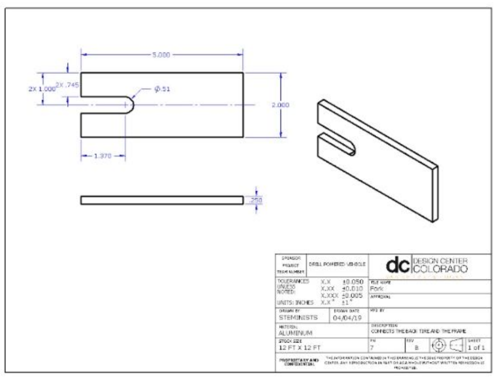

Figure 17: Fork Drawing

The drill plate was created primarily with a CNC milling machine using the design seen in Fig. 18. First, the edges were deburred with a metal hand file to ensure that the sides were perfectly square and smooth. Then, a drill bit of a quarter-inch radius was used to make the fastener holes for both the plate to the frame and the drill to the plate. For wider slots and more complex geometry, such as the chain slot, the seat slot, and the pillow block slots for chain tensioning, the SolidWorks part file was used to create a custom lay-out that would indicate the drilling path to the CNC milling machine. The Z-axis was set every 30 thousandths of an inch, and the slot creations consisted of multiple passes at different depths and one final pass at the full part depth upon completion of all slots.

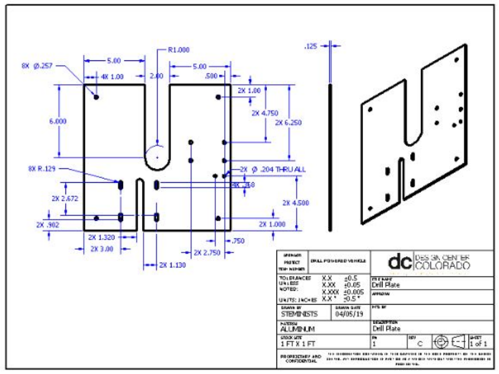

Figure 18: Drill Plate Drawing

The drill shaft was also manufactured as seen in Fig. 19. This was cut from a ground steel rod with a vertical roll-in band saw. The ends were lathed for parallelism. A CNC milling machine was used to create a hexagonal pattern along one end of the shaft that would fit without slip or interference inside of the drill chuck.

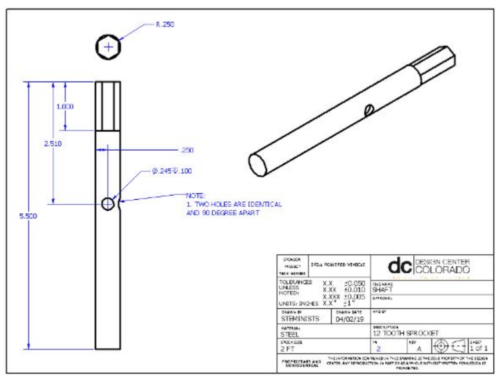

Figure 19: Shaft Drawing

Other custom parts included a small sprocket bore for the drive train assembly, for which the face width was reduced to 0.125in using the lathe, and can be seen in the Appendix Fig. 21. Aluminum spacers were also created to fill the space from the outer surface of the rear wheel gear to the forks. For these, a lathe was used to ensure parallelism among either end and to hollow out an inner diameter that was substantial for a slip fit onto the rear axle. The spacers can be seen in Appendix Fig.29. The head tube was made from recycled tube obtained from the Machine Shop in the Idea Forge using the vertical roll-in band saw and a metal hand file. The pedal was created out of plywood scrap from the ITLL and was the most unique feature of the vehicle, as the Steminists were the only ones to feature a pedal in their final design. This drawing can be seen in the Appendix as Fig. 22.

5.2.2 Standard Parts

The vehicle also includes a number of commercially available parts. The parts and their vendors have been listed in Table 1 for easy viewing.

The portions of the children's bike used include the steering column and the bike seat. This steering column consists of the front wheel, forks, and handlebars. Although the head tube was replaced and a caliper brake was added, this column remains without major modification.

Part	Quantity	Vendor
Children's Bike	1	Walmart
25" Wheel	1	Boulder Community Cycle
TRITAN 40B12H X 1/2 MPB Plain Bore B-Hub Sprocket, 12 Teeth, 1/2" Pitch, 1/2" Plain Bore	1	Tritan
1/2" A Rd 1045 Turned, Ground, Polished (+000/-.001)-24"	1	Speedy Metals Online Industrial Metal Supply
6061 Aluminum Sheet 1/8" thick, 12" x 12"	1	DenCol Supply
Low-Profile Mounted Sealed Steel Ball Bearing for 1/2" Shaft Diameter	2	McMaster Carr
Galvanized Steel Strap "Plumbers Tape"	1	Home Depot
30" Mount Steel Tubing	1	DenCol Supply
Low-Carbon Steel Bar, 1/4" thickness, 2" wide, 1 ft long	1	McMaster-Carr
Caliper Brake	1	Boulder Community cycle
Corner Brace 1.5" Zinc 4pck	1	Home Depot
1/16 Wire Rope Clamp Zinc	2	Home Depot
# 40 Chain	1	The Fix
Cordless Driver Drill XFD11	1	Makita from Class

Table 1: Standard Parts

5.3 Fabrication Issues

The movement between theory and reality is often one of the more challenging portions of mechanical engineering projects. This project was no exception. Since time was a critical constraint, the Steminists had chosen to begin welding the frame without having the back forks made, and this resulted in a frame that was splayed upwards in the back. Thus, a Dremel tool was used to remove the existing welds so that new welds could be done to be within the tolerances of the original design. Significant time was spent in the second iteration to ensure correct alignment and stability in all pieces prior to welding. Tacks were placed on critical joints so that the system could be checked and measured again to ensure that nothing had moved in the process of setting up. Once the manufacturing engineer was confident in the alignment, each joint was fully MIG welded. After correction, the frame was well under the 0.5in of allowable displacement at the location of maximum deflection.

6 Vehicle Testing

6.1 Test Plan

After reviewing the analytical calculations for the frame strength, gear ratios, and power input and output, testing the reliability of the vehicle before run-off becomes a very significant task. The vehicle and its components will be expected to work in conjunction with one another when assembled and perform as an entity to complete the desired task.

Test 1 Deflection: To make sure the vehicle runs safely, deflection in the vertical direction will be measured with the driver sitting on the vehicle. If the deflection is less than 0.5 inch the frame shall be deemed within a safe level of bending stress. Once the deflection value is obtained, shear force and moment can be calculated more accurately. The strength of the weld between the bike's frame and the head tube will be inspected by a staff member of the IdeaForge prior to use and observed through other testing process to ensure the weld is secure. The FEA analysis predicts a deflection of significantly lower than 0.5 inch as do the hand calculations.

Test 2 Linear Speed: The vehicle speed will also be tested. During the test, the vehicle will be brought up to speed on flat ground far enough away from the starting location to ensure that all acceleration has taken place prior to timing. The rate of the vehicle will be measured based on distance traversed and time to traverse. The maneuverability course requires more control than speed so a speed of 7.5ft/s would be considered a pass for the vehicle on this requirement. If the measured velocity is greater than or equal to to the desired velocity, thus allowing for a successful slalom test, it will be concluded that the gear ratio is correct.

Test 3 Turning Radius: In order to successfully complete the U-turn at the end of the course the vehicle needs to have a turning radius of less than five feet. To ensure there is space for driver error the vehicle will be considered to pass this test if it has a turning radius of four feet or less. For this test the vehicle will be place on the ground, perform a 180 degree rotation and the turning diameter will be measured. The calculated turning radius is 3.9 ft.

Test 4 Braking Capacity: Finally, the ability to brake is an important safety feature. Both the braking speed and the braking distance are important to the team. The braking distance will be measured from the location of brake initiation to the location of a complete stop. Braking time is also important as obstacles can sometimes appear rather suddenly by the driver. To pass this test the vehicle will need to stop less than 10 feet from the initiation of the brake and within 5 seconds.

6.2 Test Results

Test 1 Deflection: The deflection of the frame should be greatest underneath the seat which bears the majority of the rider's weight. At this location, displacement was measured when the rider put their full weight on the vehicle. The change was smaller than the instruments available to the team (calipers and tape measures) were able to accurately measure. Although the team is not confident in measured values of deflection, it is certain that the deflection is less than 0.5 inch, as the FEA and hand calculation derived from bending stress predicted. The vehicle passed this test easily.

Test 2 Linear Speed: Three tests were done over 25 foot distances for linear speed. The average speed of four tests was 9.0 ft/s with a range of $\pm$ 1.2 ft/s. The team is satisfied with this speed for the maneuverability challenge. This led to a successful test as the vehicle could surpass 7.5ft/s.

Test 3 Turning Radius: The measured turning radius was 3.54 feet. The test requirement stated that the turning radius was under four feet for the u-turn portion of the course. This measurement passed the test. It was also close to the turning radius calculation made which predicted a turning radius of 3.9 feet.

Test 4 Braking Capacity: Braking is important in any vehicle for safety of the driver. Upon testing, the vehicle was able to come to a complete stop 6 feet after initiation of the brake. This was accomplished in an average of 1.2 seconds after brake initiation with a range of $\pm$ 0.1 seconds. The team is comfortable in the ability of the braking system to keep both the driver and those around the vehicle safe should something unexpected happen. The brakes passed the test which required stopping in less than 5 seconds over no more than 10 feet.

7 Design Iteration After Testing

An issue that the STEMinsts ran into during testing was a difficulty in getting the drill and the shaft to line up perfectly. When this alignment was at all askew the drill hit its stall torque sooner than expected which resulted in a "skipping" of the power being delivered to the shaft. During the testing process it was possible for the drill to move slightly on the drill plate. As even a few millimeters was enough to cause problems, this was a significant problem. It made the vehicle highly unreliable. The team worked to fix this by adding fasteners to the vehicle surrounding the drive train. The first area of interest was the area containing the shaft. It was important to first ensure that this section did not move. Not only would it help to keep the drill/drill shaft connection stable but if this section moved it would cause the chain to fall off the sprockets. The team had made slots in the drill plate so that the chain could be tensioned from the drill plate and the pillow bearings. To ensure that the pillow blocks did not move in these slots, which could result in a misalignment of the shaft, washers were added to the bolts holding down the pillow blocks. Further, small bolts were added in the opening between the end of the pillow block and the slot end. Though this space was small any comprising of the space would have been undesirable. The small bolts filled the space and prevented any movement. Once the team was certain the drill shaft was stable and straight, the next step was to address alteration in the location of the drill. Further, the throttling system must wrap around the drill trigger. The way in which the throttle system was originally configured, it was possible it was adding a horizontal force on the drill. This could have been responsible for the twisting of the drill. Therefore the team added a small tube on to the wire to keep placement of the wire more consistent and secured in its location on the drill. Unfortunately, as will be discussed in the run-off results, these alterations did not end up remedying the problem completely, despite the team's efforts. To the best of the team's analysis a combination of difficulty in machining the hexagonal faces of the shaft that go into the drill chuck and the problem discussed above lead to complications during the actual race.

8 Runoff Results and Lessons Learned

8.1 Runoff Results

During Runoff, there were several problems which led to a difficulty in completing the challenge without using the driver's foot to support. However, between the first and second attempts adjustment were made to realign the drive shaft and the drill which had become misaligned. These adjustments led to a more successful run subsequently. Further, the drill setting was put in second gear which has medium speed/torques for drilling purpose. Unfortunately, this was not enough to turn the whole drive train and caused the drive shaft to slip inside of drill chuck. For the later run the drill was switched back into first gear. Although the first run was complicated, the later run showed a much more successful attempt. The Runoff experience was fun and the team enjoyed watching all the teams race the vehicle that have been in creation all semester.

8.2 Lessons Learned

The main lessons learned from this project was the significance of designing and testing early in the process. No matter how perfect the 3D CAD model is, it does not translate exactly in reality. The team should finish all the detailed design before manufacturing. Even a very small design change would lead to wasted time redoing manufacturing for the same part. Three iterations on the drill plate caused the positions of the holes to be less precise than expected since the error in setting the xyz axis could not be fixed. These errors caused the two sprockets not aligned perfectly and it took hours to figure out and fix that small angle.

Another lesson of this project was the team should double check the functionality of the vehicle just before the team's race at Runoff. All the details should be confirmed in normally operation before they are needed. The main cause for the failure in the first run is the functionality of the drill. The drill shaft was not fully pushed in and the speed model was not set up right. As the drill is critical to success, its gear setting and clutch setting are also essential and cause problems if set wrong. For the gear setting, setting 1 is mainly for driving screws with low speed and high torque, and setting 2 will give a higher speed but medium torque mostly for drilling, so the team should have keep the drill on setting 1 instead of 2. For similar reasons, the clutch setting should kept on hammer, to prohibit the drill from "slipping" during operation. The mistake made in runoff may have been caused by an accidental touch in the process of moving the vehicle outside the building. However, if the team had double checked it before runoff, the first runoff would have succeeded.

9 Budget and Bill of Materials

An important portion of every engineering project is cost management. From industry to entrepreneurship this is an important design factor which the team understood and considered during the design process. The vehicle project requirements document gave a maximum budget constraint of $250. The team is happy to report that a total of $215.50. This is only 86% of the allocated budget based upon the design requirements. A full breakdown of the expenses can be seen in Table 2. Per instructions given in the FAQ section of the #designproject slack channel the children's bike is only reported at half of its retail cost. As only the steering and the bike seat were taken from the bike this is a reasonable estimate of what purchasing only the steering column and seat would have been.

Items Purchased	**Location of Purchase**	**Quantity**	**Total Price**
Torsional Springs	McGuckin's Hardware	1	$1.29
Children's Bike	Walmart	1	$27.03
TRITAN 40B12H X 1/2 MPB Plain Bore B-Hub Sprocket, 12 Teeth, 1/2" Pitch, 1/2" Plain Bore	Triton via Amazon	1	$10.92
1/2" A Rd 1045 Turned, Ground, Polished (+000/-.001)-24"	Speedy Metals Online Industrial Metal Supply	1	$23.30
6061 Aluminum Sheet 1/8" thick, 12" x 12"	McMaster-Carr	1	$38.68
Low-Profile Mounted Sealed Steel Ball Bearing for 1/2" Shaft Diameter	McMaster-Carr	2	$30.48
Galvanized Steel Strap "Plumbers Tape"	Home Depot	1	$3.53
Mount Steel Tubing by foot	Dencol Supply	15	$13.66
Low-Carbon Steel Bar, 1/4" thickness, 2" wide, 1 ft long	McMaster-Carr	1	$19.35
Caliper Brake	Boulder Community Cycle	1	$10.34
L Bracket 1.5" Zinc 4pck	Home Depot	1	$2.67
1/16in Wire Rope Clamp Set Zinc	Home Depot	1	$1.52
Ferrule and Stop Set 1/16" Aluminum	Home Depot	1	$1.24
Elastic Band	McGuckins	1	$4.40
#1 Compression Spring	McGuckins	1	$0.85
3/16in x 1/40D Tube Vinyl	McGuckins	1	$0.19
# 40 Chain	The Fix	1	$13.06
Spray Paint	McGuckins	2	$13.00
Door hinge	Shirley	1	$0.00
Cordless Driver Drill XFD11	Makita from Class	1	$0.00
Back Tire	DIDL Supply	1	$0.00
Plywood	ITLL scrap	1	$0.00
#40 Chain	DIDL Supply	1	$0.00
Misc Connectors (Screws, Bolts, Washers, LugNuts, wire, torsional spring)	Shirley	Various	$0.00
			$215.50

Table 2: Bill of Materials

10 Appendix

10.1 Additional Assembly Pictures

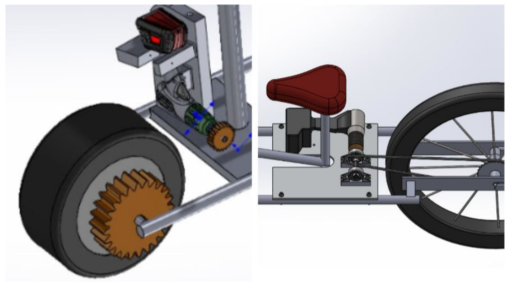

Figure 20: Assembly View of the Initial Drill Position and Assembly of the Final Drill Position with Pillow Blocks. Previous concerns with the drive train included the misalignment of the gear and sprocket, the positioning of the drill, and the number of teeth chosen for the gear on the rear wheel being non-existent.

10.2 Additional Part Drawings

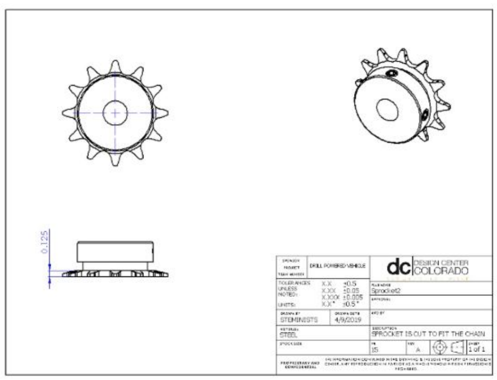

Figure 21: Sprocket Drawing

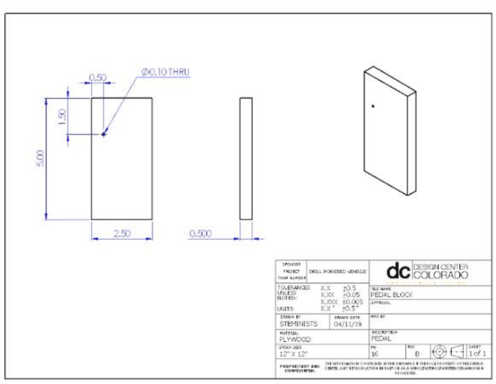

Figure 22: Pedal Drawing

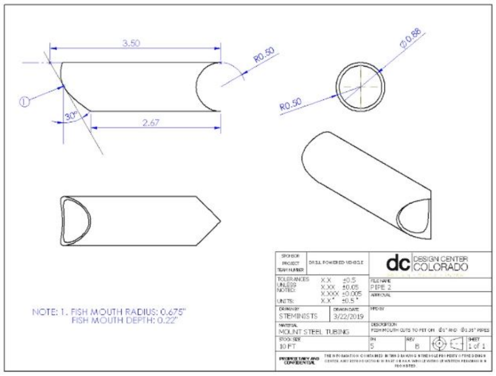

Figure 23: Small Connecting Tube Drawing

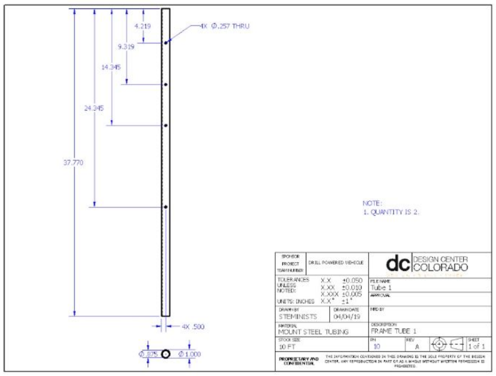

Figure 24: Frame Pipe 1 Drawing

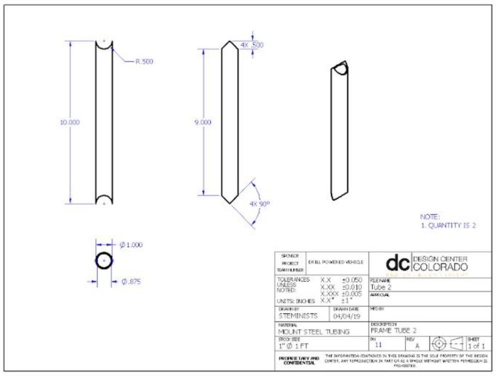

Figure 25: Frame Pipe 2 Drawing Drawing

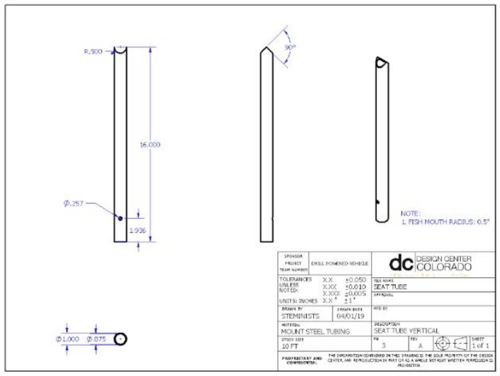

Figure 26: Seat Pipe Drawing

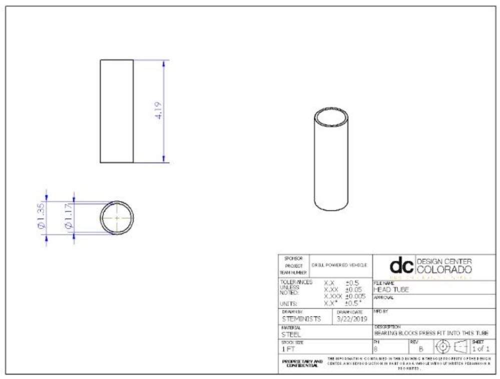

Figure 27: Head Tube Drawing Drawing

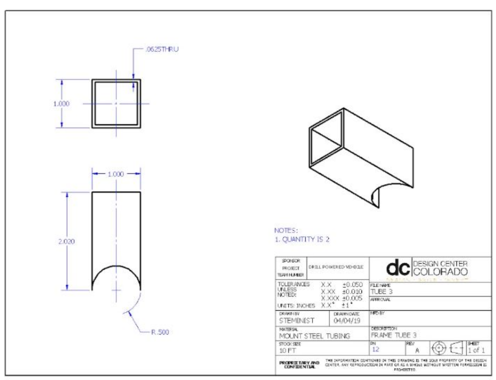

Figure 28: Square Tube Drawing

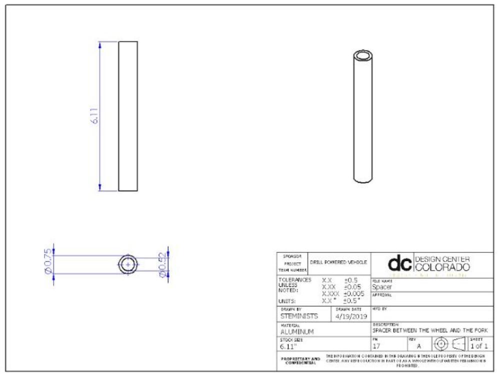

Figure 29: Back Axle Spacer Drawing

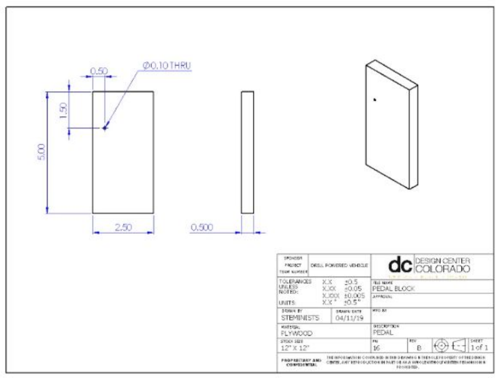

Figure 30: Pedal Drawing

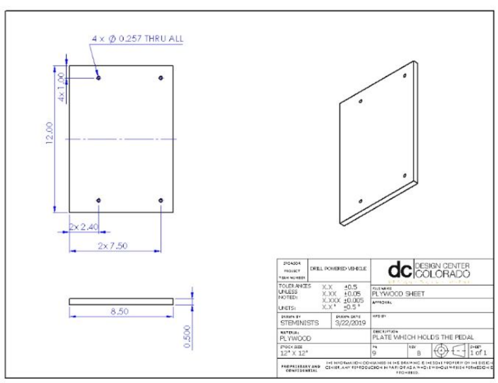

Figure 31: Plywood Floor Drawing

10.3 Additional FEA Analysis

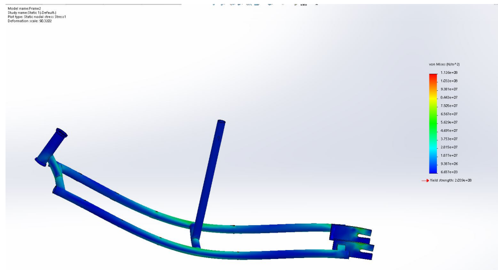

Figure 32: Frame Deformation FEA Analysis

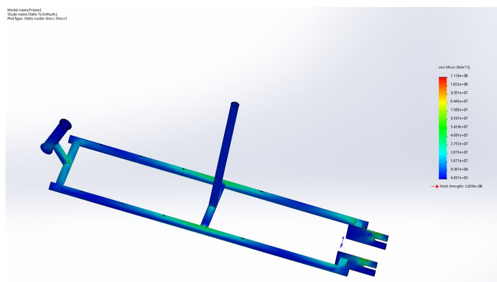

Figure 33: Frame Stress FEA Analysis

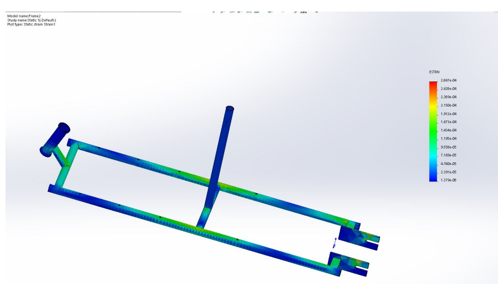

Figure 34: Frame Strain FEA Analysis