Adaptive Adjustable Tricycle

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Executive Summary

As a part of the Cal Poly Mechanical Engineering curriculum, all students must take part in a three quarter long senior design project. Students are presented with existing problems, select a project, and then apply the knowledge they have gained throughout their academic career to design and build a solution. The intent behind this project is to create an experience that is similar to an engineering project in industry, by applying engineering and teamwork skills to solve a problem.

Team Trikeceratops' mission was to develop an adaptive adjustable tricycle to be used in the Special Education Department of the Buena Park School District for recreational use and physical therapy. The design team was comprised of four Cal Poly mechanical engineering students and a kinesiology student-consultant who worked through three primary design phases over the course of nine months to develop a functional prototype. These phases included ideation and conception, detailed design, and manufacturing, all of which have different requirements that call for a variety of skill sets.

During ideation and conception, Team Trikeceratops developed lists of requirements from sponsor input, divided the project into components, generated ideas, and refined the options to reach an overall conceptual design. This initial phase was also essential in developing a team mentality and establishing the basic rules and guidelines by which the team would operate. At the end of ideation and conception, the team had developed a full theoretical design that would meet the customer requirements.

Detailed design was the second phase wherein the students took the conceptual design and applied engineering knowledge to clearly define the solution. In this phase, most of the more stereotypical engineering occurred. Students sized tubing for the frame, performed calculations and analysis on components, created manufacturing drawings, identified part numbers for acquisition, and began contacting companies for parts and services. At the end of detailed design, the team had a bill of materials, manufacturing plan, contact information for suppliers, and fully dimensioned drawings for manufacturing custom parts.

The third phase of product development was manufacturing and testing. Students cut, notched, welded, and machined various custom components while simultaneously overcoming problems of improper sizing and extended lead times on ordered materials. Following this process, the students tested the tricycle to ensure that it met the customer requirements set forth in the Design Verification Plan and Report (DVPR). At the end of this phase a functioning prototype was completed and staged for delivery and the final report was compiled.

This remainder of this report details Team Trikeceratops' progress from initial concept generation to prototype realization and explores each part of the aforementioned engineering design process in depth.

CHAPTER 1: INTRODUCTION

The goal of this project was to design and build an adaptive adjustable tricycle that will be used by students with disabilities within the Buena Park School District for physical therapy and recreational purposes. The project was proposed to the Cal Poly Mechanical Engineering Department by Dr. Kevin Taylor on behalf of the Buena Park School District and Lisa Colburn, an occupational therapist for the Buena Park School District. This project was funded by Cal Poly's Research to Aid Persons with Disability (RAPD) grant from the National Science Foundation.

The team assigned to the adaptive adjustable tricycle project consists of four mechanical engineering students, Jasper Bolton, Kemely Chow, Ryan Hirahara, and Heather Instasi, and one kinesiology student consultant, Sierra Dunbar. All mechanical engineering students at Cal Poly engage in a three quarter long senior project where they are presented with a problem in which they must apply knowledge gained throughout their academic career to design and then build a solution.

Lisa Colburn and the students with disabilities within the Buena Park School District are the adaptive adjustable tricycle project clients. These clients would like Team Trikeceratops to design and build a tricycle that will be used for recreation and physical therapy. Additionally the tricycle will need to adjust for the students' varying sizes and ability levels.

Currently, the Buena Park School District is in possession of a tricycle used for the stated recreational and physical therapy purposes; however, the tricycle is too small for most of the students in the program and fails to provide back, neck, or trunk support to those in need. The pedals are standard plastic-cast flat-pedals that have no effective have no method of securing the user's feet, decreasing the tricycle's usefulness in teaching the motions for physical therapy purposes. Additionally, the tricycle is not adjustable and contains none of the additional features commonly found on cycles built for adaptive purposes. Overall, these factors make the current tricycle unsuitable for the special education department.

Objectives

The goal of the project is to design and build an adaptive tricycle that will be used by students varying in size, age, and disability. The customer and engineering requirements for the project can be seen in Table 1-1 and Table 1-2 respectively. The customer requirements were gathered during a conference call with Lisa discussing the project and from the team's site visit to the Carl E. Gilbert Elementary school. Lisa presented the team with basic requirements and the team asked additional questions - developed from the background research - to propose additional desirable features.

Table 1-1 Customer Requirements

Customer Requirements
- Familiarize children with the motions of riding a bike - Include foot straps - Incorporate a push handle - Fit through a door - Accommodate weight up to 150 lbs - Accommodate heights from 4'-0" to 5'-10" - Provide full trunk support - Perform on asphalt - Provide varying resistances - Provide rear steering - Provide upright sitting for rider - Perform at low speeds - Require low maintenance - Be stored in a classroom - Provide a brake for supervisor - Provide a parking brake - Keep legs aligned properly for pedaling

The engineering specifications were developed using the "Quality Function Deployment" (QFD) method, part of which involves converting customer requirements into quantifiable values and comparing them against both engineering requirements and existing products. The QFD lists out all customer requirements and engineering requirements and allows comparison between the two (the Adaptive Adjustable Tricycle QFD can be found in Appendix A). A numbering system was used to show the relationship between a specific engineering requirement and a given customer requirement, ensuring that every customer requirement had at least one corresponding engineering specification. The maximum speed and braking specifications were determined after the team observed the students with disabilities riding an adaptive tricycle at Carl E. Gilbert Elementary. The maximum size specifications were determined by the space where the tricycle will be stored. The 10 mph maximum speed was chosen for the purposes of ensuring that the design will have acceptable dynamic performance, i.e. not tip over, at any speed that the students achieve. The 10 mph does not mean that the students will achieve a 10 mph traveling speed; it is a safe estimate of the highest speed likely to be reached on open asphalt if they are highly proficient on the tricycle.

Table 1-2 Engineering Requirements

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Tricycle Weight	75 lb	Max	M	A,I
2	Rider Weight	150 lb	Max	L	A,T,I
3	Tricycle Length	5 ft.	Max	L	A,I
4	Tricycle Width	30 in.	Max	L	A,I
5	Tricycle Height	4.5ft	Max	L	A,I
6	Rider Height	4 ft.	Min	H	I
7	Rider Height	5 ft.-10 in.	Max	H	I
8	Seat Back Angle	90 degrees	+5 degrees	L	A,I
9	Basic Maintenance(Lubrication)	5 years	Min	M	A,S
10	Hand Brake Squeeze Force	5 lb	Max	L	A,T,S,I
11	Turning Radius	10 ft.	Max	M	A,T,S,I
12	Speed	10 mph	Max	L	A,T
13	Cost of Materials	$1500	± $500	M	I
14	Full stop on paved ground from 5 mph within	10 ft.	Max	L	A,T
15	Pedal Force required for motion	5 lb	Min	L	A,T
16	Various ratios for pedaling	5	Max	M	I
17	Foot attachment at pedals	2	N/A	L	T,I
18	Trunk support through shoulders	-	N/A	L	A,T
19	Steerable from rear	-	N/A	L	T
20	Capable of being pushed from behind	-	N/A	L	T
21	Hand brake in the rear	-	N/A	L	T,I
22	Align legs for proper pedaling technique	-	N/A	L	T,I

L=Low Risk, M=Medium Risk, H=High Risk
A=Engineering Analysis, I=Inspection, S=Similarity to Existing Designs, T= Physical Testing

Table 1-2 contains the formal engineering requirements along with their units, tolerances, risk for non-compliance, and how compliance will be gauged. The tolerance defines how much the final value can differ from what is specified. The “max” states that the value listed is the highest acceptable value, while the “min” is the lowest acceptable value. In the risk column, the requirements are assigned letters that correspond to the team’s perceived ability to meet those requirements. “H” designates a high risk for compliance, “M” represents a medium risk and “L” represents a low risk. The high risk compliance requirements in this project correspond to the desire for this tricycle to accommodate a large user size range. Companies currently produce adaptive tricycles in multiple sizes to account for a large size range. These companies are developing designs for mass production, a circumstance where it is more economically viable to make several sizes of the same design rather than a single design that will function for many sizes. The team is confident that they will be able to meet this challenge because our design constraints do not include a profit margin; the only concern is that the tricycle performs its designated function. The compliance column describes how the team will test for that specific requirement. “A” means engineering analysis will be performed, “T” means that physical testing will done, “S” means that it is assumed that the design will work due to its similarity to existing designs, and “I” means that compliance will be verified through inspection.

CHAPTER 2: BACKGROUND

The students who will be using the tricycle have varying levels of cognitive and physical disabilities. Due to the nature of their disabilities, many of the students' physical, social, or cognitive skills may be affected. Some of the students may have difficulty learning things at the same rate as their peers. Additionally, some of the students may have difficulty controlling their behaviors, controlling their body movements, focusing, or communicating.

Though each of the students has various needs, they can all benefit from having access to a tricycle that can be adjusted to fit each of them. This tricycle will be used for physical therapy to help strengthen and improve muscular control. Riding the tricycle may also aid in the improvement of the rider's spatial awareness while teaching the basic motions of riding a bicycle. It is also important for the students to have fun while riding the tricycle. The tricycle will not only be a form of therapy, but a way of allowing them to accomplish a childhood milestone of riding a bicycle. One of the students the team met during the site visit has the specific goal of learning to ride a bicycle and having an adaptive tricycle will help him move towards that goal.

The two most popular products on the market that attempt to meet similar objectives include the Rifton Adaptive Tricycle and the Freedom Concepts Discovery Tricycle. These tricycles include features such as rear steering and braking, trunk support, foot straps, a self-aligning front wheel, tires that do not need air, and a direct drive gear system. The cost for one of these tricycles currently ranges between approximately $2000 and $4000 depending on size and added features. The largest sized Rifton tricycle can be seen in Figure 2-1. The one pictured does not feature rear steering nor trunk support, although both are optional add-ons. Although the Rifton models feature a parking brake, they are not ergonomic; the supervising aid standing behind the tricycle is required to bend forward to engage the brake bar at an awkward angle.

Figure 2-1 Rifton Adaptive Tricycle

The Freedom Concepts Discovery is pictured in Figure 2-2. It features rear steering and braking as well as slightly more back support than the Rifton pictured in Figure 2-1. Examination of the figures reveals many similarities between the two designs. Foot straps are used to keep the riders feet on the pedals. However, a physical observation of students riding the Rifton during a site visit to Carl E. Gilbert Elementary School highlighted problems in the strap design. The rider's feet often slide around the pedal while riding and their feet do not remain pointing forward. It was also observed that some of the riders' legs bowed out while pedaling and concern was voiced for a student whose legs tend to angle inward. A mechanism that helps keep riders' legs in proper alignment would aid some riders and could be removed so that it does not interfere with riders who do not need alignment assistance.

Figure 2-2 Freedom Concepts Discovery Tricycle

Common features in both existing models include a loop handlebar, non-pressurized tires, a direct drive pedal system, a removable hand braking system, and a pedal positioning cord. The loop handle bar is covered in a thick, durable foam padding and provides a comfortable and versatile gripping platform for riders with various hand and arm dexterity levels and also provides some protection should the rider's head come into contact with the handle bar. Tires that do not require air pressurization lower the need for constant maintenance. A direct drive system featured in the models allows the rider to be pushed while having their legs go through the pedaling motions. Direct drive also helps maintain safe speeds as continuous pedaling is required to keep the tricycle in motion. The drive systems found in these designs only offer one level of resistance, which does not account for students with varying degrees of ability. A removable hand braking system allows the brake to be moved to any position on the handlebar that best suits the rider or removed entirely if it is not needed. The braking system utilized by both tricycles is the standard caliper braking system found on most bicycles. Additionally, the rear steering and braking features allow the supervisor to give aid to the rider when necessary without impeding the rider's experience and sense of independence while on the tricycle. The models feature a cord, as seen below in Figure 2-3, which runs through the frame and connects both pedals together. This cord keeps the pedals from spinning around when not in use, making it easier and quicker to get the rider's feet strapped in.

Figure 2-3 Pedal support cord on Rifton Adaptive Tricycle

On the Discovery tricycle, the pedal positioning cord also helps position the rider's feet for better leverage during the power phase of the pedal stroke. The Discovery also incorporates a spring mechanism that realigns the front wheel of the tricycle when the rider releases the handlebar.

Although both designs come in various sizes to accommodate a range of users, purchasing multiple tricycles is not ideal for the Buena Park school District due to monetary and storage space constraints. As there are currently no applicable codes or standards that must be met, the Rifton Adaptive Tricycle and the Freedom Concepts Discovery Tricycle will serve as baselines to compare the team's design to.

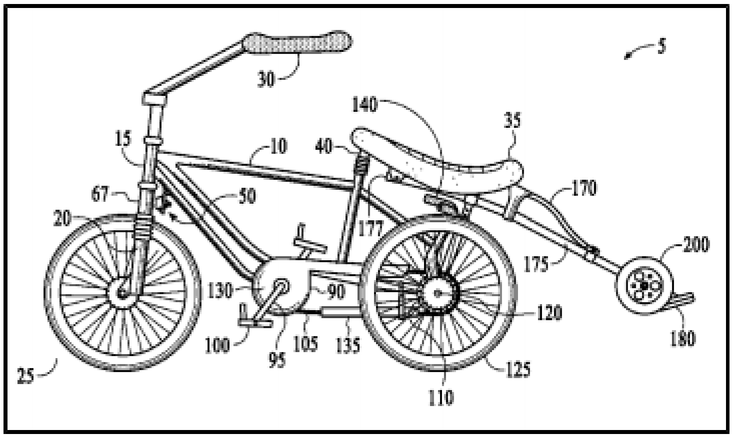


Figure 2-4 Special needs adaptive tricycle (U.S. Patent 7819414)

An existing patented device seen, in Figure 2-4, is a tricycle with both therapeutic and recreational uses. The patent includes systems for shock absorption and enhanced stability, a specialized lever system that positions the rider at the tricycle's optimal center of mass, and a wheelie bar (U.S. Patent 7819414). Another patent found includes a device, seen in Figure 2-5, for automatic tightening pedal straps. This device uses a front basket area on the pedal for the rider to place their foot and a strap that tightens around the foot automatically (U.S. Patent 6510764). The team also encountered a patent for a stepping bicycle where the rider propels the bike with a walking motion rather than pedaling (U.S. Patent 8220814). The systems and features incorporated into the patented designs will be considered during the conceptual design and planning stages of the project.

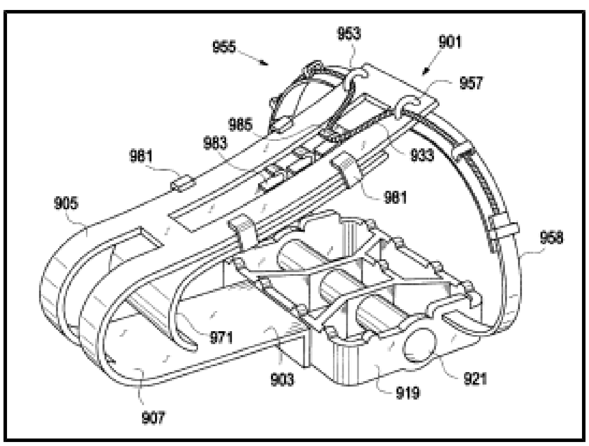


Figure 2-5 Automatically tightening pedal strap (U.S. Patent 6510764)

Other completed research includes finding information on different pedals on the market. As previously mentioned, the Rifton pedal securements are not adequate for keeping the rider's feet in place. The rider's feet often shift, especially if they are not accustomed to pedaling. The existing pedal straps are made of long Velcro ® pieces that wrap both over the foot and around the ankle. These straps are approximately 1 inch wide and allow for quite a bit of foot movement. Because the Rifton tricycle comes in multiple sizes, they are able to accommodate a different range of foot sizes on each sized tricycle. Based on anthropomorphic data found in Appendix F, foot size for the children in the target age range will vary by 3.65 inches, meaning the team's pedal length design will require adjustment. Also, the existing straps are very long and when not in use, they drag on the ground or get in the way. Other improvements that have been considered include front and/or back "stops" for the feet, for example a front basket shape for the toe or a cup to prevent the heel from slipping off the back. Another adjustment will be to make any Velcro ® straps wider and sturdier in addition to incorporating a method of adjusting the length of the pedal.

Currently, exercise equipment and existing adaptive tricycles incorporate a variety of methods for seat adjustment. The Rifton uses angled telescoping seat posts that change both the seat's height and its horizontal distance from the pedals. The telescoping mechanism found on the Rifton has a restricted range of adjustability because it is dependent on the lengths of both the inner and outer telescoping seat posts. Exercise equipment currently on the market often uses two separate mechanisms to adjust the seat's height and horizontal distance from the pedals. Based on anthropomorphic data (Appendix F), for the children in the target age range, the seat's horizontal distance from the pedals will need to vary by 9.57 inches and the seat height will need to vary by 9.17 inches.

Current adaptive tricycle frames are typically made out of high carbon steel. Common materials used in bicycle frames include various alloys of high carbon steel, 4130 chromoly steel, aluminum alloys such as 6061 and 7005, stainless steel, titanium and various composites. Titanium and composites are the most expensive and are utilized in highly specialized bicycles, while carbon steel and aluminum are the most widely used materials. Carbon steel has the advantage of being less expensive and easier to work with, but it has a higher density and must be coated to prevent corrosion. Aluminum has a lower density and does not need to be coated to prevent corrosion, however, more skill is required to weld it and it requires post-weld heat treatment. Chromoly steel is a type of high carbon steel that contains chrome and molybdenum, making it stronger and harder (increasing the strength to weight ratio) when compared to standard carbon steels, such as 1020. Some drawbacks aluminum alloys have are that they must be Gas Tungsten Arc (TIG) welded, which requires more skill than the Gas Metal Arc (MIG) welding used with carbon steel. Although TIG welding is also recommended for chromoly steel, MIG welding is an acceptable alternative. Also, brazing is a low heat process, it should not damage any heat treatments already performed on a material. Cal Poly possesses the facilities to braze, TIG, and MIG weld.

CHAPTER 3: DESIGN DEVELOPMENT

Idea Generation and Selection

The next step in the design process required the generation of concepts that can be used to meet the project requirements. Concepts were generated through several processes including brainstorming, inspiration from existing products, morphological matrices, sketching, and modeling. After a sufficient number of concepts had been generated, the next step involved selecting a specific idea for each main subsystem of the tricycle. To aid in the narrowing and final selection of each idea, several methods were used.

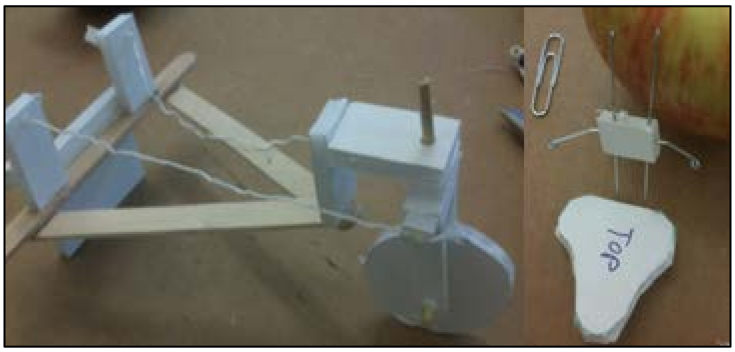


Figure 3-1 Solid Modeling During the Concept Generation Phase

One method that was used to evaluate and learn more about each subsystem was the physical modeling of individual components. To do this, the team used a variety of materials including foam board, wood, and old bicycle parts to fabricate conceptual models. The conceptual models were then used to validate the functionality of the concepts.

Another method included creating a Pugh Matrix for each of the major subsystems. A Pugh Matrix is a way of evaluating how effectively new and existing concepts satisfy a given criteria. To create a Pugh Matrix, first a datum is chosen and each different concept is given a "+", "-", or "S" for each criteria. The "+" means that the concept is better than the datum, the "-" means that the concept is worse than the datum, and the "S" means that the concept performs as well as the datum. The four Pugh Matrices that were created are shown in Figures 3-2, 3-4, 3-7, and 3-11.

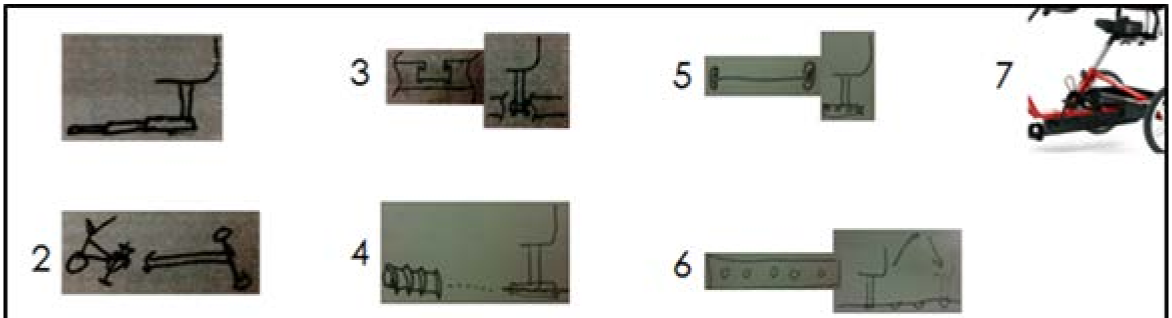
One of the most useful aspects of the Pugh Matrices was that during their creation, more ideas were generated. For example, with the seat and pedals, the final concepts that were chosen were not shown on the Pugh Matrix, but were developed from a combination of the best ideas present in the matrix. The team also weighted various criteria on which the concepts were judged.

The subsystems into which the tricycle was divided into included a seat adjustment assembly, pedal assembly, drivetrain, and frame material. They were addressed individually and the independent solutions were combined to form the final concept. This final concept meets all the customer and engineering requirements and should effectively solve the school district’s current problem.

Some of the features present on most adaptive tricycles did not require the team to improve upon their functions. These features include handlebar height and angle adjustment, a self-aligning front wheel, a moveable rider brake lever, a front wheel caliper brake, and an oversized bicycle seat. These concepts were considered, but their final design will be very similar to existing products on the market.

Adjustable Seating

To determine the best method of adjusting the tricycle's seat, the design team considered concepts that allow movement in two planes (seat height and horizontal distance from the pedals). These concepts, seen in Figure 3-2, included telescoping seat posts, rolling carriages in tracks - akin to automobile seats, sliding carriages along rails, power screws for both vertical and horizontal adjustment, standard bicycle seat-post clamp mechanisms, and a split-frame design.



	Concepts to Evaluate						
	1	2	3	4	5	6	7
Tolerance	+	+	+	+	+	-	D
Durability	-	S	-	S	-	+	
Safety	-	-	-	-	-	S	A
Ease of Adjustment	+	-	+	S	+	+	
Stability	-	S	-	S	+	S	T
Ease of Cleaning	S	+	-	S	-	+	
Likelihood of Failure	-	S	-	S	-	S	U
Robustness	-	+	S	S	S	+	
Ease of Manufacturing	S	S	+	S	S	S	M

Σ +	2	3	3	1	3	4
Σ -	5	2	5	1	4	1
Σ S	2	4	1	7	2	4

Figure 3-2 Seat Adjustment Pugh Matrix

Of the initial ideas surveyed, none of them provided the proper combination of simple, easy adjustability, reliability, and user stability. The design team elected to incorporate the key features from several different concepts to create the best possible seat. This final seat concept took advantage of the simple fixed-angle adjustment found on the Rifton tricycles and combined it with a rail-and-locking-carriage system (a linear bushing on a guide rail). Features of the final seat concept can be seen below in Figure 3-3. An angled rail allows movement along the two desired planes in one motion, saving the user time. Additionally, the use of a guide rail-and-carriage system allows the seat to accommodate a wider range of riders compared to a telescoping mechanism.

Figure 3-3 Seat Adjustment Concepts

Anthropomorphic data for children between the ages of 6 and 12 years old, found in Appendix F, was used to determine if a single angle would provide a sufficient range of adjustability to accommodate most riders. The data was used to find the relationship between knee to hip (upper leg) length and foot to knee (lower leg) length and determine if the relationship could be used to designate a rail angle suitable for all riders. The analysis revealed a linear relationship between upper and lower leg lengths, verifying the angled rail's ability to maintain the same geometry between the user's hips and the pedals regardless of age. The rail angle was determined using the average ratio of upper and lower leg length and calculated to be 42 degrees from horizontal. Additionally, the minimum seat adjustment distance along the rail was calculated to be 13.25 inches.

Pedals

To determine the best design for the tricycle's adjustable pedals, the team took inspiration from existing pedal and shoe designs of products ranging from current children's tricycles to ice climbing equipment. Many of these concepts are shown in the Pugh Matrix in Figure 3-4. The products considered addressed a variety of needs, but individually, each product was unable to fulfill all of the customer requirements. By selecting specific features from each product, the team designed a pedal that accommodates many foot sizes while ensuring the rider's feet are properly secured to the pedals.

Concept								
Criteria	Crampon (slide out & straps)	Exercise bike (straps & rubber basket)	large (~2in) velcro	hinged with basket	Rifton velcro straps	snowboard binding (heel support & snaps)	Telescoping (w/ basket)	Elastic Basket Area
Secure (keeps foot in place)	+	+	+	+		+	+	+
Ease of Adjustment	-	+	S	+	D	-	+	+
Durable	+	S	S	-		+	-	-
Safe/non abrasive	S	S	S	-	A	S	-	S
Extent of Adjustment	+	S	S	+		S	+	S
Ease of Access to Adjustment	S	S	S	S	T	S	S	S
Supportive	+	S	+	-		+	-	S
Complexity	-	S	S	-	U	-	-	S
Σ+	4	2	2	3		3	3	2
Σ-	2	0	0	4	M	2	4	1
ΣS	2	6	6	1		2	1	5

Figure 3-4 Pedal Pugh Matrix

The Rifton pedals consist of a small plastic base with long, thin Velcro ® straps that are used to secure the rider's feet to the pedals. The pedals are fixed in size, which prevents them from being used effectively by a wide size range of riders. Furthermore, the length of the straps which hold the feet in place is cumbersome and the positioning of them is ineffective. Changes to these existing pedals needed to include a more adjustable size of pedal and a more reliable, secure method of holding the feet.

The final pedal concept involves two separate pedal components bridged by a single bar that serves to change the distance between the two pieces.

- The pedals' front component spans the length from the ball of the foot to the tip of the longest toe. Borrowing from the basket concept of an exercise bicycle, the final concept incorporates a toe loop that captures the toe, and a Velcro ® band (fabric with a buckle is seen below in Figure 3-5) that wraps around the foot to prevent side-to-side movement.
- Beneath the heel, the pedals' back component incorporates the heel support of a snowboard binding (seen below in green in Figure 3-5) with a Velcro ® strap around the ankle to hold the rider's heel in place. The Velcro ® straps are two inches wide to hold additional torsional load on the foot.
- The adjustment mechanism seen at the base of the Crampon is the method by which the pedal will be lengthened and shortened. This metal bar is fixed to the heel component and slides into or out of the front component where it is held in place by a set of actuated pins.

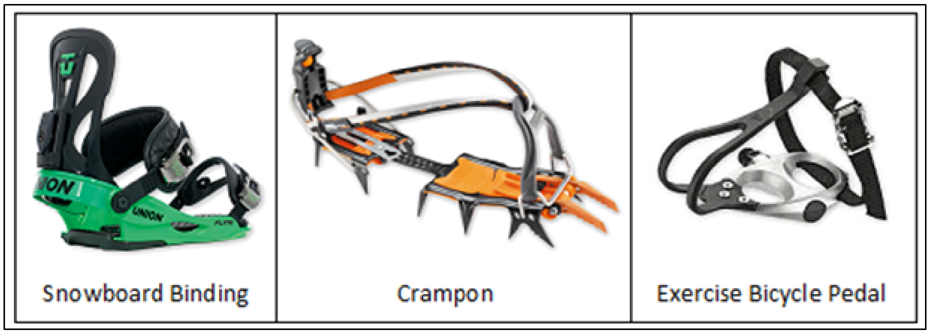


Figure 3-5 Pedal Concepts

Additionally, the heel and adjustable base are removable in the final concept, leaving the rider with only the front pedal component, allowing the rider to perform to the best of their abilities and improve their skill level. A sketch of the conceptual pedal design can be seen in Figure 3-6. Anthropomorphic data seen in Appendix D was used to determine the range of foot sizes expected in the specified age range.

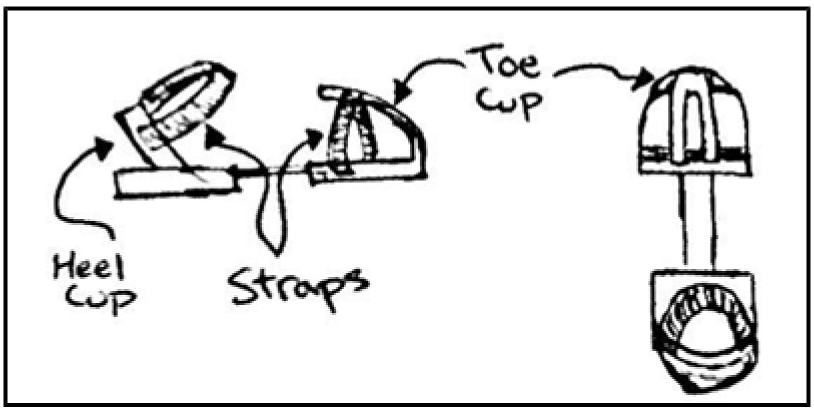


Figure 3-6 Final Pedal Design Sketch

Drivetrain

To determine the best design for the tricycle's drivetrain a single fixed gear was considered with different resistance mechanisms, including magnets resisting motion at the crank, friction pads on the drive shaft, and a compressor on the drive shaft that would relate resistance to pedaling speed. Additional drivetrain concepts considered included utilizing a belt drive system, similar to a continuously variable transmission (seen in some Subaru vehicles), two standard bicycle rear derailleurs acting as both tensioning and shifting mechanisms, a separate tensioning mechanism and a standard derailleur to shift, a gearbox driven by a shaft or chain, and a three-speed internal hub. See the drivetrain Pugh Matrix in Figure 3-7 for sketches of these designs. The team also considered creating a mechanism that would move the pedals to different positions along the frame, but the construction of a chain tensioning test rig revealed that moving the pedals would increase complexity and decrease reliability by adding more components to the system. Moving the pedals longitudinally would require a much longer chain with a highly adjustable tensioner, a track for the pedals to move along, and a locking mechanism to keep the pedals in place. Adding all these moving parts would create more opportunities for things to go wrong.

Concept / Criteria	1	2	3	4	5	6	7	8
	FIXED GEAR INTERNAL HUB	BELT DRIVE W/ CVT TYPE SYSTEM	SINGLE FIXED GEAR W/ MAGNETS	SINGLE FIXED GEAR W/ FRICTION ON DRIVE AXLE	MULTIPLE FIXED GEARS W/ TENSIONER + BASIC DERAILLEUR	MULTIPLE FIXED GEARS W/ [illegible] DERAILLEURS	SINGLE FIXED GEAR W/ COMPRESSOR ON DRIVE AXLE	GEAR BOX
A	S	-	+	+	D	S	-	+
B	-	-	+	+		-	-	-
C	-	-	+	-		-	-	-
D	S	-	+	-	A	S	S	+
E	S	S	S	S		S	S	+
F	-	S	+	+		-	-	-
G	S	+	+	+	T	S	+	S
H	+	+	-	S		S	-	-
I	+	-	-	+		+	-	-
J	S	S	S	S	U	S	S	S
K	+	S	S	S		S	-	+
L	+	S	-	S		-	-	-
Σ+	4	2	6	5	M	1	1	4
Σ-	3	5	3	2		3	8	6
ΣS	5	5	3	5		7	3	2

Figure 3-7 Drivetrain Pugh Matrix

The top concepts for the tricycle drivetrain included a chain driven gearbox, a 3-speed fixed gear internal hub, and a configuration similar to a standard bicycle with multiple sprockets on the crank, a single sprocket on the driveshaft, and a front derailleur to shift gears. All of the top concepts would relate the rider's pedaling motion directly to wheel rotation while providing multiple levels of mechanical advantage for various riders. Of the top concepts, the chain driven gear box and the 3-speed internal hub would allow the tricycle to shift gear ratios while not in motion and the absence of a chain across sprockets would reduce the amount of wear and eliminate the possibility of chain disengagement. Additionally, the absence of sprockets in the chain driven gear box and the 3-speed internal hub minimizes the number of pinch points around the moving drivetrain parts, increasing safety and simplifying the design of a casing for the drivetrain.

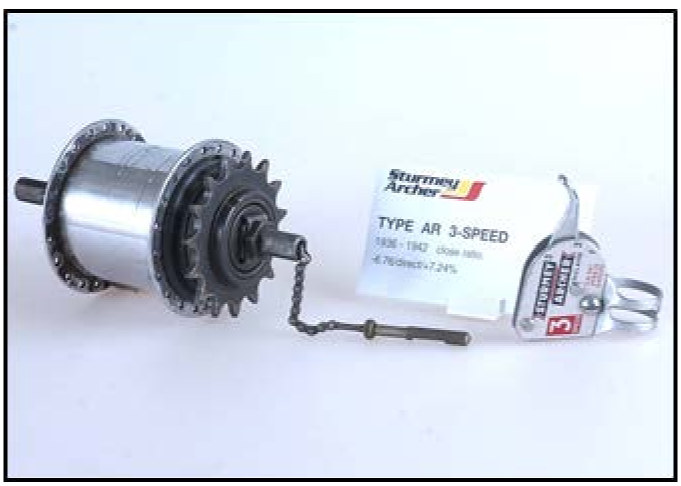


Figure 3-8 Sturmey-Archer 3-Speed Fixed Gear Internal Hub

The final drivetrain concept utilizes a Sturmey-Archer 3-speed fixed gear internal hub, seen above in Figure 3-8, to provide three levels of mechanical advantage. The 3-speed internal hub was chosen over the chain driven gear box because of its lighter weight and the overall reliability of the Sturmey-Archer's design. In the final concept the pedals will drive a chain that connects to the standard hub sprocket and another sprocket will be fixed to the hub body where the wheel would normally mount. A chain will run from the sprocket on the hub body back to the sprocket on the drive shaft. The hub will be mounted wherever space permits between the crank and the drivetrain. A casing will also be mounted that will help remove any pinch points and keep dirt and grime out of the drivetrain components. This drivetrain layout can be seen below in Figure 3-9.

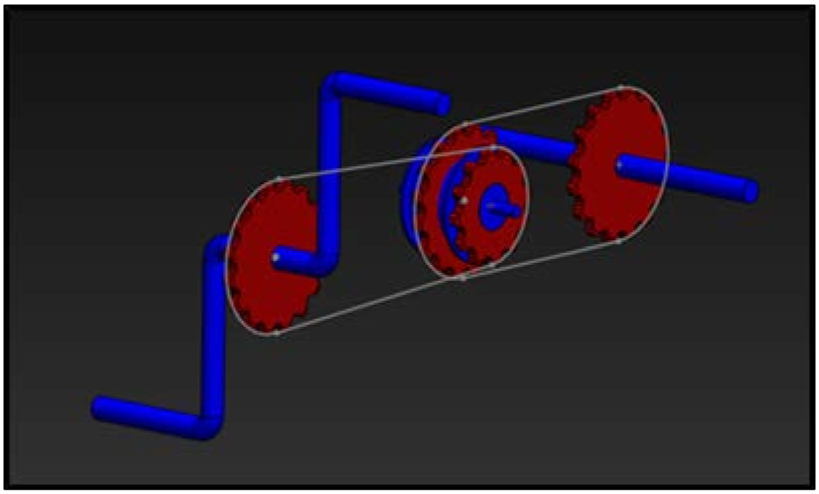


Figure 3-9 Solid Model of Drivetrain Assembly (not to scale)

The extra sprockets and chain are needed to utilize the gearing offered by the internal hub and drive both rear wheels at the same time. One obstacle the 3-speed internal hub presents is that it is designed to have a single wheel mounted to it; the final drivetrain application requires the internal hub to drive two wheels. Another possible solution considered was to have two 3-speed hubs, one in each wheel, but this would make changing gears more cumbersome, increase costs, and still require the use of two chains. Ultimately, the final drivetrain concept provides multiple levels of resistance in a simple, reliable package without negatively influencing vehicle dynamics.

Rear Steering and Braking

The rear steering mechanism currently available on adaptive tricycles is a solid bar that runs the full length of the tricycle and attaches to the front fork through a linkage. This method is rather conspicuous and blocks the rider in on one side. Several different ideas were considered to provide a less bulky and more inconspicuous rear steering method including steer-by-wire, brake-based steering, and solid bar linkages that were less obtrusive. The steer-by-wire concept was chosen for the final design because it was the most viable and least obtrusive solution. The steer-by-wire concept involves attaching wires to each side of the front fork such that either wire can be pulled to turn the wheel in that direction. Like brake cables, the wires are run to the back of the frame, connecting to a small steering bar the supervisor can use to turn the tricycle. The steer-by-wire method has the advantages of being lighter weight, less obtrusive, and more streamlined than the solid bar.

To satisfy the customer requirement that the supervisor be able to stop the tricycle, a brake cable will run from the front brake calipers back to the rear steering handle bar. The cable splits off to run both the supervisor brake and the rider's brake, allowing the supervisor to slow the tricycle down only when necessary. The parking brake will be a bar similar to the one found on the Rifton, however it will have a longer arm to actuate it so that it can easily be engaged by pushing it by foot.

Leg Aligner

The leg aligner is based on similar designs from current market products, but has been adapted to work easily with the team's final tricycle concept. It will consist of a round foam piece covered in PVC fabric with a bracket on the bottom to mount it to the same guide rail used to adjust the tricycle seat. The design concept can be seen below in Figure 3-10.

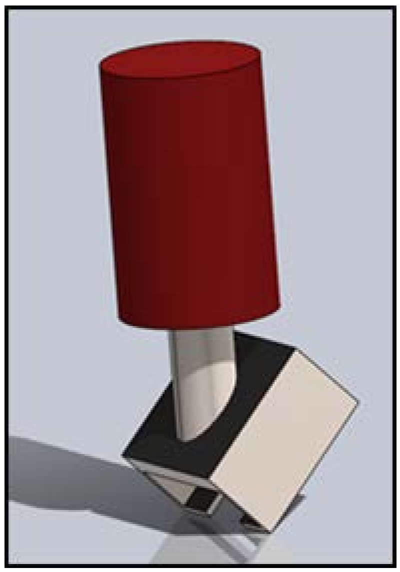


Figure 3-10 Leg Aligner Concept Model

Frame

Frame material selection relies on a final, dimensioned tricycle design because stress calculations are dependent upon frame geometry. A design tool based on stress calculations was created to output the minimum tubing diameter required to withstand the loads on the frame for each material considered. Once the tubing diameters were determined, they were combined with material properties to determine the weight and approximate cost of the different frames. Cost, weight, and method of material joining (rivets, welding, brazing, etc.) were the three primary criteria on which frame selection was evaluated. Cost and weight needed to satisfy both customer and engineering requirements, while method of material joining determined how much, if any, work would need to be outsourced. A comparison of how different materials accommodate these criteria can be seen in the Pugh Matrix in Figure 3-11.

Concept / Criteria	6061 Aluminum (T6)	7005 Aluminum (Not Heat Treated)	7005 Aluminum (Heat Treated)	4130 Steel (Chromoly)	1020 Carbon Steel	Carbon Fiber	Titanium	Aluminum MMC	
1	Datum	S	S	+	+	+	S	+	Outsource Welding
2	Datum	+	S	S	S	+	S	+	Outsource Post-Weld Heat Treatment
3	Datum	S	S	S	S	-	-	-	Outsource Frame Fabrication
4	Datum	S	S	-	-	S	-	-	Corrosivity
5	Datum	+	-	+	+	-	-	-	Cost *
6	Datum	-	+	-	-	S	S	S	Weight *
7	Datum	+	+	+	+	+	+	+	Yield Strength
8	Datum	+	+	+	+	+	+	+	Stiffness
9	Datum	S	S	+	+	-	+	-	Repairability / Longevity
10	Datum	+	S	+	+	-	+	-	Elongation / Ductility
Σ +	0	5	3	6	6	4	4	4	
Σ -	0	1	1	2	2	4	3	5	
Σ S	0	4	6	2	2	2	3	1	

Figure 3-11 Material Selection Pugh Matrix

Additionally, material selection also takes into account any post-weld heat treatment required by some materials and their joining methods. Welded joints can be the weakest points on the frame due to residual stresses caused by the high temperatures involved. To increase the strength of the material, specifically at the joints on the frame, a heat treating process is required to relieve the residual stresses from welding. One interesting material considered was air hardening steel because the welded joints become stronger as the steel is allowed to air cool because the high heat applied acts as a heat treating process. However, finding a supplier for the specific steel needed is difficult and the material would likely be more expensive than its counterparts. Due to the low impact nature of the tricycle design, the other varieties of carbon steel without heat treatment requirements will likely be more than sufficient for the application. Ultimately 4130 chromoly steel was chosen for the frame material.

CHAPTER 4: DESCRIPTION OF FINAL DESIGN

Overall Description

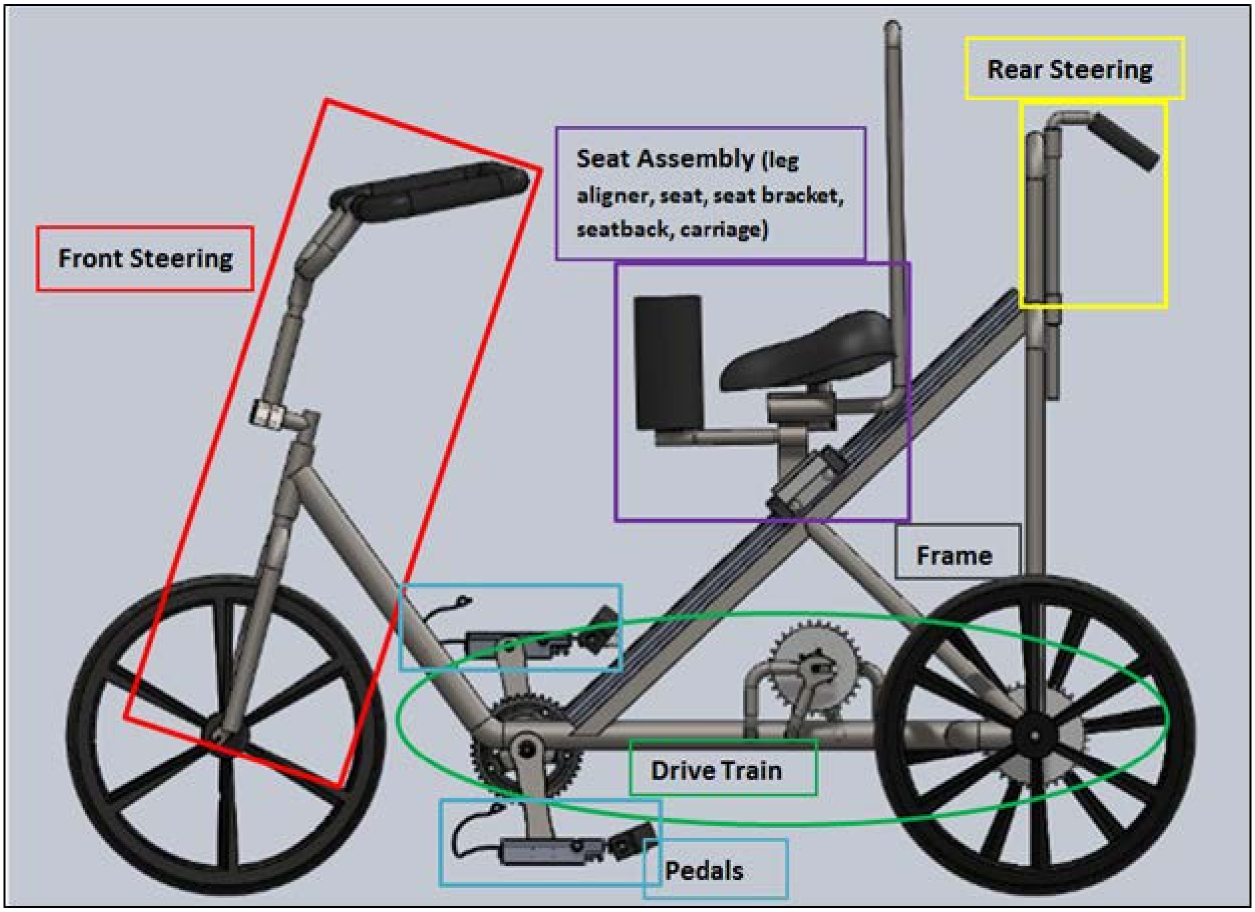


Figure 4-1 Labeled Model of Full Tricycle

The final design of the tricycle has been divided into six separate subsystems. These six systems are rear steering, front steering, seat assembly, frame, drive train, and adjustable pedal assembly. The rear steering is located on the back of the tricycle and allows for a monitor to push or steer the tricycle. The front steering mechanism is located in the front of the tricycle allows the rider to steer. The seat assembly includes the leg aligner, seat, seatback, seat bracket, and carriage. The frame includes all basic support for the tricycle components. The drive train includes the internal hub, sprockets, chains, and driveshaft that will be interconnected and used to drive the tricycle. The pedal assembly has been designed to easily and securely hold the rider's feet in place while being simple to adjust for different sized feet. The location of each of these subsystems is shown in Figure 4-1.

Detailed Design Description

Frame

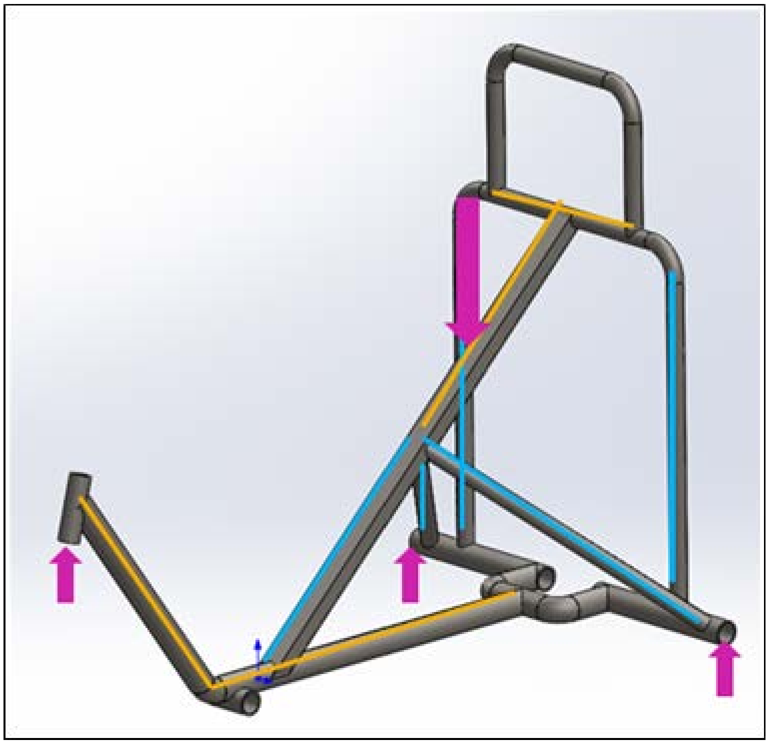


Figure 4-2 Frame loading conditions

The frame geometry was mainly dictated by the need to allow the seat to travel at a 42 degree angle to accommodate a large range of riders. The next factor that played into the geometry was the defined vehicle footprint. The triangle formed by the seat support tube and the bottom tube was determined by the height of the rider when the seat is in its top position and from the rider's position relative to the pedals. If the triangle's height was lowered too much, the rider's legs would have to extend out perpendicular to the body, similar to a recumbent, except the seat of the tricycle is at a 90 degree angle, these ergonomics would not be comfortable for the rider. The triangle defined in the final design with a height of 22.5 inches provides the rider with pedaling ergonomics that are very similar to most tricycles on the market today. It locates the pedals out in front of and below the rider so that the rider can utilize the seatback as support if necessary to help press their legs through the pedal strokes. The detail drawing of the frame can be found in Appendix B for exact dimensions.

The height of the head tube location was determined by the front fork and wheel size, ensuring that it was located in a position that would optimally allow for handlebar placement to fit a variety of rider positions. The head tube angle was determined so that the tricycle would have some trail, which creates a self-aligning moment about the front wheel when in motion and provides feedback to the rider through the handlebars.

The structural integrity was analyzed for a static loading condition assuming a 200 lb vertical downward force on the seat support tube. The 200 lb load was assumed to account for a rider slightly larger than the maximum specified weight of 150 lb and for the weight of the seat assembly. Given this loading condition, basic engineering principles were applied to the members of the frame to determine whether these members were in bending or could be approximated as a truss structure. Figure 4-2 illustrates the loading conditions for each member. Orange implies that the members are in bending and blue represents two force members.

For the bottom tube, the highest stress point is just in front of where the seat support tube connects to the bottom tube. This stress is caused by the moment produced by the supporting force at the front wheel and was used to size the bottom tube. The other member in bending is the seat support tube; this tube was sized based on a maximum acceptable deflection because if this member deflects too much it will cause a misalignment of the seat carriage and the carriage will bind on the track. The members that were approximated as a truss structure were analyzed to find the tensile or compressive forces in them and the corresponding stresses. All of these forces were plugged into the frame design tool that was created using Microsoft Excel. The results and governing equations for the analysis can be found in the Appendix E. This tool allowed the user to input the dimensions of the various members, the corresponding forces, various tube diameters, and wall thicknesses and would then output the factor of safety for each material and tube size as well as providing a weight estimate. The final material was chosen by comparing the tube size and weight for different materials at a given safety factor; because the tube size was known, cost could also be compared. The materials considered were 4130 chromoly steel, 6061 T-6 aluminum and 1018 steel. 1018 fell out of the running quickly because although it is cheaper than aluminum and chromoly, the amount of material needed to create the same factors of safety lead to space and weight problems. Aluminum offered a slightly lighter frame but was the most expensive option and would be the most difficult to weld. 4130 was chosen because it offered the smallest tubing diameters and the steel is known for its toughness, as it is used to make vehicle roll cages.

While Metal Inert Gas (MIG) welding had been chosen as the initial method of joining the frame and other components, Jasper Bolton proved to be more than capable at Tungsten Inert Gas (TIG) welding. TIG welding is the preferred method of joining for many bicycle frame builders because of the ability to control the heat and the amount filler. Additionally, TIG welds are more visually pleasing when compared to MIG welds.

To protect the frame from corrosion and other environmental factors, the team has opted to treat the surface with a powder coat. Powder coating will provide a more durable and consistent finish than if the frame was painted. Central Coast Powder Coating, a local company in San Luis Obispo, California was chosen as the company to complete this task.

Seat Bracket

The seating bracket needed to provide attachment points for the seat, seat back attachment, leg aligner and connection to the linear motion carriage and rail clamp. The final design can be seen in Figure 4-3. It allows the seat to be attached using a custom seat post that allows for removal and replacement of the seat if necessary. The seatback bars and leg aligner slide into tubes welded onto the sides of the bracket and are held in place by large knobbed set screws. Rectangular tubing was chosen for the base because it provides more surface area to weld the horizontal sleeves to. The rectangular tubing was sized slightly larger than the tubing used in the seat support bar to make it easier to weld and produce very little deflection. The rectangular tubing is cut at a 42 degree angle and welded to a plate to allow the bracket to be fastened to the linear carriage. Initially, machining the bracket out of a block of metal was considered, however while this would be very stable it would be complicated to machine and unreasonably heavy.

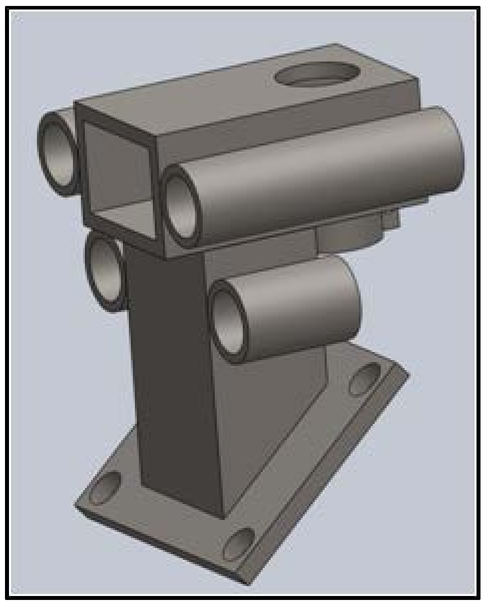


Figure 4-3 Seat Bracket Solid Model

Linear Motion Carriage

As per the design laid out in the Conceptual Design Report, a block and rail system forms the primary axis of movement for the seating component of the tricycle. The block and clamping system are responsible for changing the seat-to-pedal distance to accommodate different height riders. In selecting a particular linear motion system, the team focused on linear bearings and linear bushings. The first step in this process was to determine the various forces that could potentially be acting on the block. As a simple and immediate factor of safety, it was assumed the maximum rider weight to be 200 pounds instead of the required design load of 150 pounds. Initially, a linear bushing system distributed by McMaster Carr was selected to fill this need. After designing around that product for some time, an information panel from the manufacturer was found that stated the maximum moments that particular system could handle. On inspection, it was determined that this linear bushing could handle the forces, but not the moments that could potentially be applied through dynamic loading conditions (turns, eccentric weight position, etc.).

Figure 4-4 Chieftek Precision ARC 30 ML Block and Rail

The search for a new linear bushing was fruitless in turning up a system that could handle the moments the tricycle could experience, so the team ultimately turned to linear bearing systems. Two consequences of this action were an increase in price and an overall extreme increase in the factor of safety in terms of force capacity. These results were deemed necessary on account of the possibility of significant dynamic or eccentric loading.

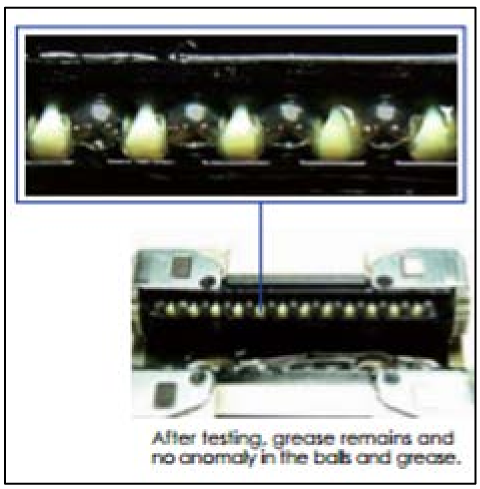


Figure 4-5 Bearings Self-Lubricate Through Small Pads and Internal Reservoirs

Most linear bearing systems fall into two ranges, high load and low load. The low load systems found were designed for small applications in robotics or machining, none of which were capable of supporting both the loads and the required moments. The high load systems are generally used for large industrial applications, on assembly lines, or in large pieces of equipment. One key design constraint was whether manufacturers would conduct business with the team – a relatively small customer. Ultimately, this led to the team completing the design with the ARC 30 ML block and rail system from Chieftek Precision Company. The ARC series will easily accommodate the loading constraints, as it has a directional limit of 8,900 pounds, yielding an almost absurd static factor of safety (44) for this application. Possible dynamic loading meant the limiting factor would be in the moments the block could handle. Given the most extreme potential loading condition, the team calculated that the selected block and rail system would have a minimum factor of safety of approximately 3.5.

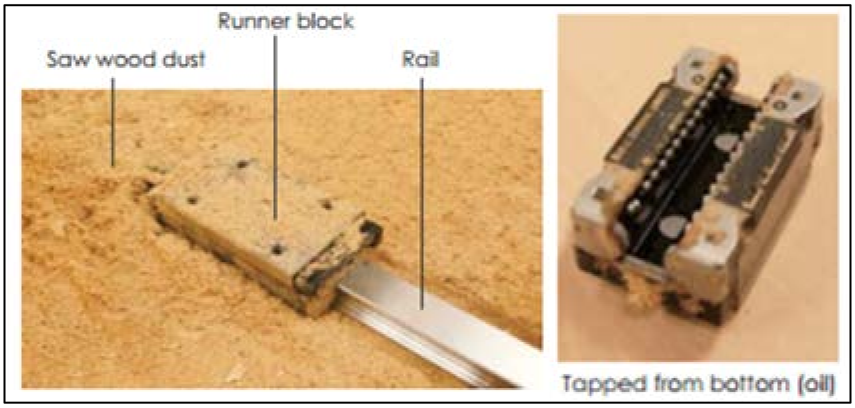


Figure 4-6 Chieftek Block After Sawdust Intrusion Test

The block and rail system was designed to attach via mechanical fasteners at frequent, regular intervals after the frame is powder coated. Chieftek's system employs various countermeasures against contamination and corrosion. The bearings self-lubricate from internal reservoirs and self-seal with brushes and scrapers to keep dust, dirt, and grime outside of the system. Additionally, the rails can be constructed of a stainless steel, black oxide, or nickel plating that provide varying levels of resistance to corrosion that may be present in the operating environment. Standard stainless steel rails are sufficient for this application.

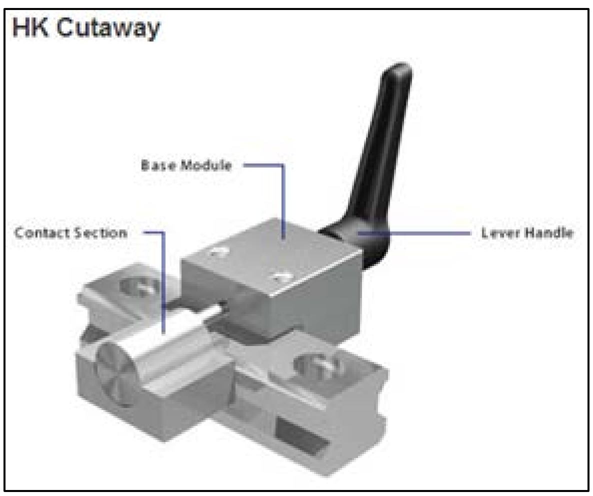


Figure 4-7 Zimmer HK Manual Locking Clamp Cutaway View

The second part to the rail/seating system is a clamping mechanism so the user can secure the seat in place. Currently, Chieftek does not produce a clamp that can be used with their rail systems. A German company called Zimmer manufactures a variety of clamps that are designed to function with the rails of several of the major rail and carriage manufacturers. The team selected the clamp seen in Figure 4-7 because it requires minimal force to actuate (11 foot-pounds), has a holding force ranging from 270-450 pounds, and it appears to be the only manually locking clamp to meet the minimum requirements, thus far.

Pedals

The pedals were designed to compensate for a large range of foot lengths based on of anthropomorphic data seen in Appendix D. To eliminate the necessity of constructing the complex interface between the pedal body and the crank arm, a standard bicycle flat pedal was purchased. A separate adaptive platform was designed to be placed around the flat-pedal body and can be seen in Figure 4-8. This adaptive platform consists of four different primary components with three supplementary components. The main pedal body is enclosed by an upper and a lower casing, which form the base where the ball of the foot will rest when the tricycle is in motion. A slot will be machined into the casing to allow the tongue-and-heel to adjust the length of the pedal.

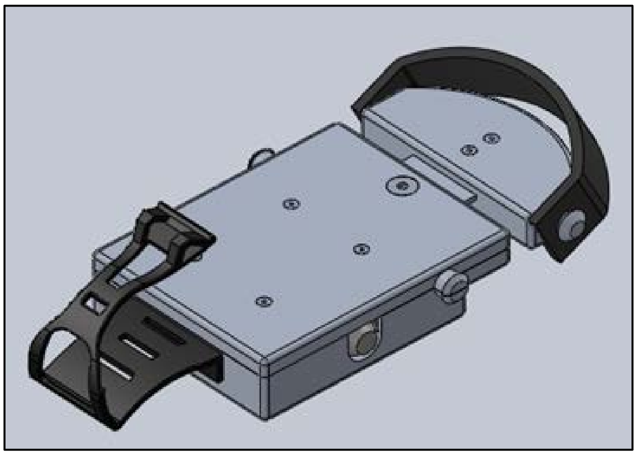


Figure 4-8 Pedal Solid Model

A heel plate and an aluminum tongue form the second major grouping in the pedal design. As seen in Figure 4-9, the pedal heel is attached to a slotted plate which functions as a sliding mechanism allowing the pedal heel to extend 4.3 inches. The sliding tongue is guided by the geometry of the pedal casing and is “set in place/clamped” by tightening a wingnut on the underside of the pedal.

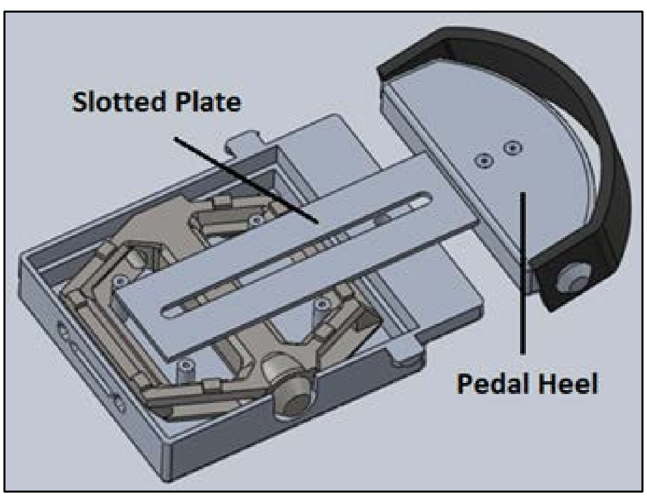


Figure 4-9 Pedal Sliding Mechanism

Two of the supplementary components to the adaptive platform pedal are toe clips and wide Velcro ® strapping. Standard bicycle toe clips on the front of the pedal casing enclose the front of riders' feet, preventing the rider's feet from sliding off the pedals. The toe clips link to 2-inch wide Velcro ® straps that attach back to the pedal casing to give further control over foot slide.

Pedal heel straps - the last supplementary feature - attach to knobs on the heel to secure the back of the rider's feet. Softride ® Super Straps were chosen for their ability to provide non-rigid support to the back of the foot and their adjustability. The straps can be relocated to attach to additional knobs found on the pedal casing to accommodate for smaller feet sizes allowing the pedals to adjust from 6.0 inches (with the straps attached to the knobs on the casing) to 12.5 inches (with the heel fully extended). The design utilizes standard bicycle toe clips to hold the front of the rider's foot. Additionally, Velcro ® straps will be used to secure the toe clip and pedal casing to the rider's foot.

Drivetrain

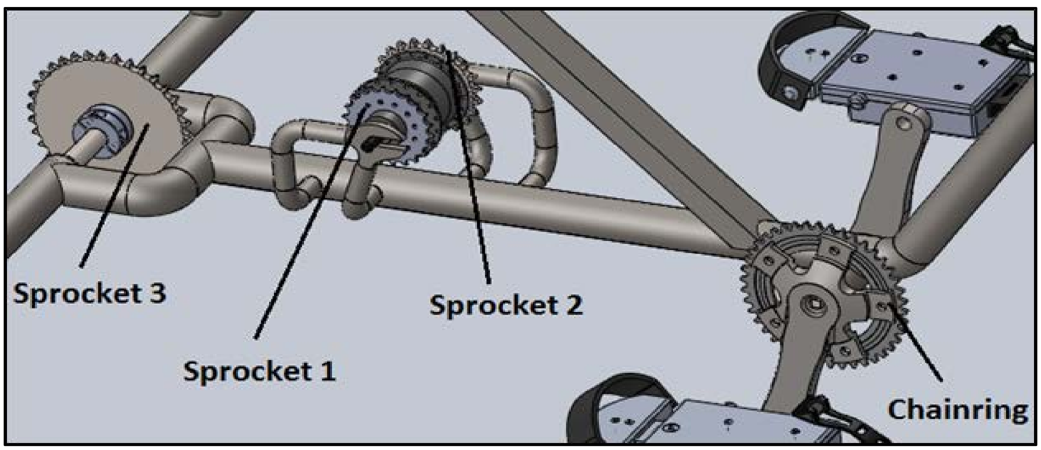


Figure 4-10 Drivetrain Layout

The design of the drivetrain was developed to accommodate size constraints of the tricycle, component machinability, and the customer requirements for mechanical advantage. The drivetrain's chainring and sprockets were chosen through an iterative process with a focus on minimizing the overall size of the drivetrain while providing a 1:1 rotation ratio between the pedals and drive wheel at the lowest setting for mechanical advantage (the highest level of resistance felt by the rider). The drivetrain design, seen in Figure 4-10, requires the chainring to drive a chain (chain 1) that rotates a sprocket (sprocket 1) mounted to the S3X. A second sprocket (sprocket 2) is mounted directly on the hub body of the S3X which is driven by sprocket 1 through the S3X internal gearing system. Sprocket 2 on the S3X drives a second chain (chain 2) that rotates a third sprocket (sprocket 3) located on the tricycle drive shaft.

The pedals and crank arm are where the rider directly interacts with the tricycle. To prevent the pedals from interfering with the ground and the front wheel, the Origin8 BMX Crank Arm set was chosen for its length of 5.51 inches, a shorter design than the average crankset. A Surly 35 tooth chainring was selected to place on the crankset based on availability, pricing, size, and the selection of other drivetrain sprockets.

Within the expected configuration of the S3X, sprocket 1 will mount to a part of the hub called the "driver." This sprocket will transmit the motive force into the hub itself, where gear reduction will be applied for mechanical advantage. A Sturmey Archer 22 Tooth ⅛" Flat Sprocket was chosen from the Sturmey Archer Catalog to ensure compatibility with the S3X driver. The number of teeth on the sprocket was chosen based on availability and the selection of other drivetrain sprockets.

For sprocket 2, a 22 Tooth Machinable Bore Flat Sprocket was chosen for its mechanical properties that allow it to accommodate a large central bore surrounded by smaller bores (required to mount the sprocket to the hub). Additionally, sprocket 2 played a critical role in determining the overall size and weight of the drivetrain because it was a reference.
This means setting the number of teeth on sprocket 2 helped define the number of teeth on other sprockets by limiting the options available to achieve the desired rotation ratio between the pedals and the drive wheel.

Sprocket 2 on the S3X drives a chain (chain 2) that rotates a third sprocket (sprocket 3) located on the tricycle drive shaft. A 35 Tooth Machinable Bore Flat Sprocket was chosen for three reasons: its machinability (required to mount the sprocket onto the selected shaft collar), to match the chain number needed to drive sprocket 2, to prevent contact with the tricycle frame and the ground, and minimize protrusion outside the frame geometry. Additionally, sprocket 3 played a critical role in determining the size of the chainring and sprocket 1.

The chainring and sprocket 1 are standard bicycle parts; therefore, a standard bicycle #41 roller chain will be used. Sprocket 2 and 3 are not standard bicycle parts and require chain 2 to be a #40 roller chain for optimal performance.

The drive shaft was designed as a stepped shaft that is keyed to mount the shaft collar and driving wheel. To prevent movement in the lateral direction, the shoulders of the stepped drive shaft were designed to sit against the bearings inside the frame tubing. Rubber sealed steel bearings were chosen for their dynamic load capability, low maintenance, pre-lubrication, and their ability to accommodate the drive shaft diameters. To mount the bearings to the frame, steel insert rings were designed to allow the bearings to be press-fit into the rings and the rings to be press-fit into the frame tubing. The Stafford Manufacturing Accu-Mount™ shaft collar was selected for its easy adjustability (repositioning on the shaft) and the simple clamping mechanism to mount sprocket 3.

To select a diameter for the drive shaft, the stress was calculated across the designed step shaft for a range of diameters, assuming a combined load of a 200 lb rider on the seat and a 200 lb force applied simultaneously on one of the pedals. The 200 lb load from the rider on the seat produced 80 lb normal loads at each of the rear wheels (refer to frame calculations) while the 200 lb load on one of the pedals was translated through the drivetrain as a torsional load into a maximum load of 384 pounds on the drive shaft. The partially keyed steel drive shaft was chosen for its ability to withstand the maximum anticipated stress on the shaft with a minimum factor of safety of 2.0. For calculations and additional information refer to Appendix E.

The S3X hub was designed to be mounted using a custom bracket welded to the bottom tube of the tricycle. The final design can be seen above in Figure 27. The bracket's horizontal dropout plates were inspired by horizontal rear dropouts, found on some bicycles. The plates were designed to allow the hub to slide back and forth to adjust chain tensions and negate the need for separate chain tensioners. Additionally, by facing the plate slots in opposite directions, the hub can be installed with chains already on the sprockets. The design allows the hub installation to be accomplished by rotating the hub to relieve tension on the chains, aligning the hub axles with the dropout slots before rotating it into its final position, and applying tension inside the dropouts.

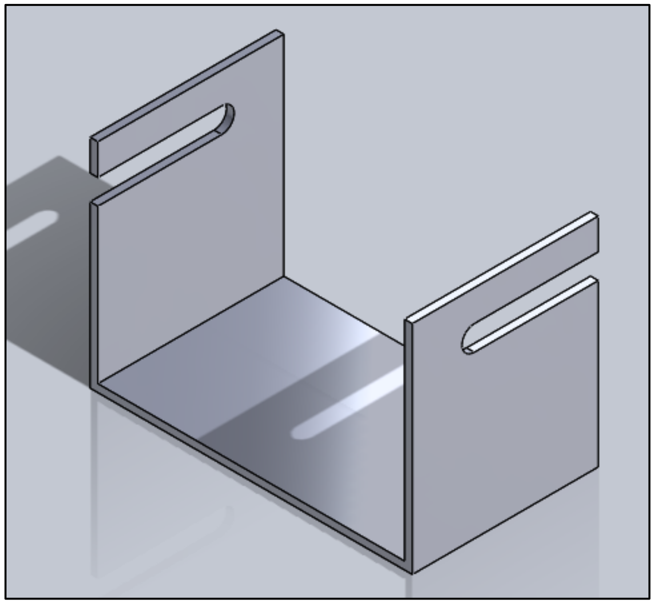


Figure 4-11 S3X Mount Model

Leg Aligner

The leg aligner was redesigned to attach to the seat bracket instead of attaching to the adjustment rail. Attaching the leg aligner to the seat bracket keeps it in the same relation to the seat, regardless of the seat's position on the rail. It also eliminates the need for a second carriage or an additional attachment mechanism to the rail, simplifying the overall tricycle design.

The main components of the leg aligner include two horizontal support tubes and a vertical tube that will sit between the rider's legs. The vertical tube is covered in foam for comfort and safety, and wrapped in PVC fabric for durability and to minimize the rider's discomfort due to friction. The leg aligner can be attached and detached by sliding the horizontal support tubes through the seat bracket attachment point, and it is held in place using set screws. Detailed design drawings of the leg aligner and the seat assembly can be found in Appendix B.

To select the tube sizes for the leg aligner, deflection calculations were performed to ensure the rider's legs would be supported. The maximum deflection for various tube sizes was calculated for a 50 pound horizontal load acting on the vertical tube. The horizontal tubes were chosen to have an outer diameter of 0.75 inches and the vertical tube was chosen to have a diameter of 1.50 inches, both with a 0.125 inch wall thickness.

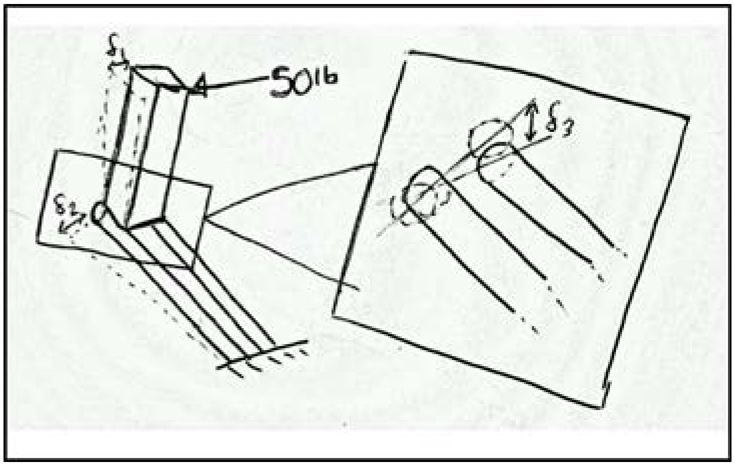


Figure 4-12 Deflections on Leg Aligner where δ1, δ2, and δ3 are Deflection from Vertical Tube Bending, Horizontal Tube Bending, and Horizontal Tube Torsion, Respectively

For the selected tube sizes, the deflection was calculated for the bending in both horizontal and vertical tubes and torsion in the horizontal tubes. The maximum deflection due to bending was 0.0006 inches and 0.012 inches for the vertical tube and horizontal tubes, respectively. The maximum deflection due to torsion on the horizontal tubes was 0.260 inches and the total deflection of the leg aligner was calculated to be 0.270 inches. Detailed analysis can be found in Appendix E.

Cost Analysis

Table 4-1 Tricycle Cost Analysis

Item	Purpose	Quantity	Price
Multipurpose 6061 Aluminum (1"x6"x1')	Pedal Casing Bottoms	1	30.65
Multipurpose 6061 Aluminum (1/2"x6"x1')	Pedal Casing Tops	1	17.99
Multipurpose 6061 Aluminum (3/4"x3"x1')	Pedal Heel	1	13.49
4130 Steel Dropouts	Dropouts	1 (set)	24.00
Crankset Arm	Crank Arm	1	49.00
Chainring	Chainring	1	30.00
Bottom Bracket Shell	BB Shell	1	16.95
Shimano UN55 68x115 English	BB	1	19.49
Zimmer HK Manual Clamp	Clamp seat in place	1	154.33
Origin 8 Pro Thread	Headset	1	27.98
HT 2005	Head Tube	1	20.52
4130 Chromoly (D 0.75"x0.12")	2-Force Tubing	7.5 Ft	47.60
4130 Chromoly (D 1"x0.065")	Handlebars	5.33 Ft	23.70
4130 Chromoly (D 1"x0.12")	Frame	16 Ft	102.08
4130 Chromoly (2"x1.5"x0.188")	Seat Bracket	1 Ft	18.00
4130 Chromoly (D 1.5"x0.12")	Bottom Tube	4.75 Ft	38.75
4130 Chromoly (1.5"x1"x0.065")	Rail Mount	3 Ft	66.44
4130 Chromoly (D 0.125"x12"x24”)	Dropout Mount	1	52.61
Sunlite MX	Fork	1	25.49
Boulevard Gel Plus Women's	Saddle	1	44.99
ARC 30 ML	Rail	30 in.	Donated
ARC 30 ML	Carriage	1	Donated
Tuffwheel 14"	Wheels	3	150.00
Jagwire	Brake Cable	1	4.00

Jagwire	Cable Housing	25 Ft	21.00
Softride Super Straps	Pedal Straps	1 Set	9.99
Sturmey Archer S3X	3spd Hub	1	129.49
Rifton Trunk Support System	Seat back & trunk support	1	451.50
Rifton Padded Loop Handlebar	Handlebar Assy	1	110.00
Pedals			
90585A206	Casing Fastener	1 Pack of 10	3.29
90585A204	Heel Fastener	1 Pack of 10	2.71
19011	Wing Nut	1 Pack of 4	1.18
90585A542	Wing Nut Fastener	1 Pack of 10	5.15
Toe clips	Toe Clips	1 Set	20.00
Pedals	Pedals	1 Set	15.00
Drivetrain			
1L012AMK	Shaft Collar	1	73.24
2299K340	Sturmey machined sprocket	1	22.95
2299K350	Drive shaft Sprocket	1	29.41
6117K120	Partially Keyed Drive Shaft	1	39.62
6384K365	Drive Shaft Bearings	2	23.14
HSL942	Sturmey Sprocket	1	3.24
98870A340	Key	1 Pack of 10	4.63
		Total Price:	**1,943.60**

Safety Considerations

Several potential hazards include getting hands and feet getting caught in the drivetrain, rider discomfort, and tricycle tip over. The team has considered these safety concerns and has incorporated solutions to reduce these safety hazards. The first important safety issue is the prevention of pinch points on the tricycle. To account for this, the team is designing a plastic casing to cover all drivetrain components including the sprockets, chains, and S3X hub. This will reduce the possibility of harm caused hands, feet, and loose articles of clothing getting caught in the drivetrain.

To account for rider comfort, the handlebar is covered in closed-cell foam, the leg aligner is covered in foam and PVC fabric, and the seat and seatback are heavily padded. Additionally, the seatback will provide the rider with trunk support that will prevent any discomfort due to bad posture.

Basic dynamic analysis of the tricycle was performed to determine the speed and turning radius at which tip over will occur. For this analysis, the rider was assumed to be light weight (75 pounds), seated at the highest position, traveling at a constant velocity, and any corrective actions from the rider were neglected. This represents the worst case loading scenario for stability. It was found that the maximum lateral acceleration before tip over occurs is 9.92 ft/s^2, which is equivalent to 0.308 g's. This lateral acceleration corresponds to a turning radius of 5.25 feet and 11.8 feet at velocities of 5 mph and 7 mph, respectively. This loading condition is very unlikely to occur based on the anthropomorphic data. Also with the drive being a fixed gear it will be difficult for the rider to maintain the speed of their pedaling while trying to execute a tight turn. Although it is unlikely that the steering wheel will be able to produce sufficient lateral force to achieve the lateral acceleration necessary for tip over, currently, there is not enough data on the chosen tires to support this claim.

Maintenance and Repair Considerations

The customer and engineering requirements dictate that this tricycle should not need maintenance for at least five years. To accommodate this, the team selected components designed with long life cycles and minimal required maintenance. For example, on the drive shaft, the bearings are sealed to maintain prevent the need for re-lubrication. Conditions that could cause the bearings to fail are unlikely to occur in this application. In addition to reducing pinch points, the plastic enclosure for the drivetrain also isolates the drivetrain from outside environment to reduce the amount of debris that can be introduced to the system. The linear motion system used for the seat adjustment is designed to work in dirty environments, minimizing the likelihood of binding at any adjustment height. The team has also decided to powder coat the frame and paint accessory pieces to protect against corrosion. Additionally, many standard bicycle parts were incorporated that can be easily purchased and replaced in the future if necessary.

CHAPTER 5: PRODUCT REALIZATION

Frame

The first step for creating the frame involved notching the tubes in order for them to fit precisely together. Tube notching was done using a Dremel 3000 variable speed rotary tool with cutoff disc, grinding wheel and grinding stone attachments. Miter templates from metalgeek.com's online tube coping calculator were used to provide a guide for the general shape of the notch. The fit of the tubes were then verified and fine-tuned by hand. To ensure the need of minimal jigging, notches were adjusted until the angle between the tubes was within less than half a degree from their position in the design. Taking the time to create a fit as close to perfect as possible, prior to welding, decreases the likelihood that the deformation from welding will cause the pieces to be out of tolerance.

Before the frame could be welded together, two tubes had to be bent to create the back bars of the tricycle frame. For this process a SharkPool device was used, specifically the TubeShark attachment, connected to local compressed air lines in the Cal Poly manufacturing facilities. The TubeShark uses a pneumatically driven piston and radial clamp to wrap metal tubing around a variety of small metallic dies that define the bend radius. Unfortunately, the manufacturing facilities did not possess dies that were capable of bending the specified tubing to the desired bend radius, therefore, a different radius for bending was chosen. Fortunately, this change did not significantly impact the overall design; it simply made the rear part of the frame more rounded. The TubeShark has no built-in measurement or alignment devices, as such, the operations were aligned and managed by hand while the actual bending was performed with the machine. The back bars of the tricycle frame can be seen in Figure 5-1.

Figure 5-1 Back Bars of the Frame

The main spar of the tricycle could not be bent with the TubeShark because no die existed that would accept that size of tubing and bend radius needed. On account of size limitations for the overall length of the frame, a larger radius curve was not an option like with the back pieces. Instead, a die had to be found that would give the radius of curvature required while being as close as possible to the tube diameter. This forced the utilization of a different tube bender using hydraulic hand pumps to bend the larger 1.5” O.D. tube.

The frame was constructed in several sections that were welded together for the final assembly. Each section was selected because the tube pieces were located on the same plane, which allowed the pieces to lie flat on jigging tables, simplifying the welding set-up. Additionally, any gaps between notched tube pieces were evaluated and deemed small enough for the team welder to use the TIG process to weld the frame.

To allow for drivetrain work to begin, the axle shroud was the first frame component welded together. Three tube pieces were cut, notched, welded together, and welded to the axle shroud to form the “U” shape that surrounds the driveshaft sprocket. Once in place, the middle portion of the axle shroud was cut out using a hacksaw and the edges were ground even by a dremel tool.

The second piece to be assembled was the back of the frame. This process simply involved welding together the two back bars that had previously been bent. Next, the main spar was welded to the “U” shape, by laying the “U” flat on the table and holding the spar in position with welding magnets. After the spar was welded on, the back bars of the frame were then joined to the axle shroud. The rectangular seat support tube was then set in place and welded to the back bars and the main spar. Figure 5-2 shows the frame after the seat support tube had been tack welded in place. Before the diagonal support members could be joined to the frame, their lengths were reduced through additional grinding, to compensate for the thermal deformation of the other frame pieces that resulted from the welding process. After the diagonal support members were welded to the seat support tube and axle shroud, the bottom bracket shell, headtube and headtube gusset were welded.

Figure 5-2 Partially Welded Frame

The bracket used to mount the S3X was created by cutting pieces of 0.125" steel plate with an optical plasma cutter, seen in Figure 5-3. The plates were then cleaned up using a grinder and dremel with a grinding stone attachment. The plates were then welded together and allowed to cool before they were joined to the frame.

Figure 5-3 S3X Bracket Plate Cutting with an Optical Plasma Cutter

The bends for the leg aligner, seat back bar, and rear steering bar were produced by tack welding jigging tubes down to the welding table in formation to bend the target tube around. The target tube was then heated up until it was glowing red using an oxyacetylene torch and then bent around the jigging tubes until the proper bend was achieved. This process can be seen in action in Figure 5-4.

Figure 5-4 Tube Bending with an Oxyacetylene Torch

The Sturmey Archer shifter mount was created by notching some extra tubing with files so that it fit into the corner of the frame. The tubes were then joined by fillet brazing because of their relatively thin walls. Fillet brazing uses an oxy-acetylene torch to melt a brass rod; the melted brass is then used like glue to hold the tubes together. This technique was used because it did not pose a risk of ruining the tubes because the only metal that is melted is the brass. After joining, the tubes were then slotted using a hacksaw to allow pipe clamps to slide through in order to attach the shifter mount to the frame. The attached shifter mount can be seen in Figure 5-5.

Figure 5-5 Sturmey Archer Shifter Mount

Pedal Fabrication

Due to the intricacy of the pedal design, the top and bottom casings and the pedal heel were machined using a CNC mill by Cal Poly Shop Technician, Philippe Napaa. To machine the pedal components, the SolidWorks part files produced by the Trikeceratops Team were converted into Computer Aided Manufacturing (CAM) files by Philippe. CAM files control the machining processes of the mill through lines of code that specify type of tool, path of tool, depth of cut, etc.

As a result of setting inconsistent reference points on the CNC mill, the first iteration of the machining of the top and bottom casings resulted in misaligned features. For the second iteration, the machined casings were completed by hand filing to ensure they fit securely around the pedals. The pedal heels were machined correctly on the first attempt and were finished by hand filing. While the casings and pedal heel were machined using a CNC mill, the slotted plate in the pedal assembly was machined by hand. The slot in the plate was machined using a manual mill and the hole pattern was made using a drill press. After painting the pedal components, grip tape with an adhesive backing was applied to the top casings to decrease foot slippage by increasing the coefficient of friction on the casing surfaces. Various pedal assembly components can be seen in Figure 5-6.

Figure 5-6 Completed Pedal Base and Heel

Drivetrain Fabrication

To drive the second chain in the drivetrain, the S3X was modified to accept a second sprocket (Sprocket 2 in Figure 4-10) on the hub shell. For the modification, the S3X was disassembled to separate the hub shell from all other components. Holes were then drilled into the hub shell using a drill press and tapped by hand. Additionally, to mount onto the hub shell, Sprocket 2 was modified using a manual mill. A boring bar was used to increase the size of the sprocket's center bore and a rotary vise was used to drill the hole pattern around the center bore. Using a similar process, Sprocket 3 in the drivetrain was modified to attach to the shaft collar on the drive shaft.

For the first iteration, the drive shaft and idle shaft were machined on a manual lathe where they were faced to length and turned to specified diameters. A high machining feed speed resulted in unsatisfactory surface finishes, and as a result, it was not possible to keep the die aligned for proper external threading. In attempt to improve the shaft's surface finish and cut the threads, it was placed inside a CNC lathe where it snapped at a shoulder due to large stress concentrations that resulted from the cutting tool getting caught on the part. The eccentricity of the shaft caused the cutting tool to take too deep of a cut, which resulted in it getting caught on the part. Additionally, the drive shaft was composed of relatively hard steel, which unlike mild steel, fractures instead of bends.

The second iteration of the drive shaft and idle shaft were machined by Bodin Rojanachaichanin, using a CNC lathe. Additionally, 1144 steel was chosen as the material for both shafts for its higher yield strength and lower hardness compared to the 1117 steel used in the first iteration. The keyways on the driveshaft were machined using a manual mill by Loren Sunding and the external threads were cut manually on both shafts using a die. The Drivetrain assembly can be seen in Figure 5-7.

Figure 5-7 Drivetrain Assembly

The steel insert rings that were used to mount the bearings into the frame were machined using a manual lathe where they were faced to length and turned to their specified outer diameter. Drill bits and a boring bar were then used on the lathe to machine the inner diameter of the insert rings to the specified value.

Leg Aligner Fabrication

The leg aligner was created by welding a 6.5 inch vertical tube and two 11 inch horizontal tubes to a base plate. The foam used to cover the vertical tube was shaped by hand using a kitchen knife and a cheese grater. The PVC fabric was attached to the foam using Weldwood® Contact Cement and the foam was attached to the vertical tube using Loctite® Super Glue. Additionally, the PVC fabric edges were secured using the super glue.

Drivetrain Cover

The drivetrain cover was created using 1/16" sheets of Acrylonitrile Butadiene Styrene (ABS). For the first iteration of the cover, the ABS was shaped by hand using a heat gun. Although the resulting shape was deemed acceptable for the application, the team opted to attempt ABS shaping by vacuum forming. To do this, a mold was created out of a Styrofoam ® block and Floracraft ® Dry Foam bricks. The mold was then coated with Bondo ® filler and an epoxy to create an airtight, smooth surface. The hole pattern that would allow air to be suctioned out of the mold was then created. To vacuum form the cover, the ABS was heated at 325 °F for five minutes. The heated ABS was then placed over the mold, where suction from a vacuum shaped the ABS to the contours of the mold. Once the ABS was cooled, it was removed from the mold and any additional cutouts were shaped by hand. The vacuum forming set up can be seen in Figure 5-8.

Figure 5-8 ABS Vacuum Forming Set Up

Painting and Powder Coating

Table 5-1 summarizes the coatings that were applied to the tricycle components to protect them from oxidation. All components coated with RUST-OLEUM® Hammered Silver were also finished with RUST-OLEUM® Crystal Clear Enamel and the seat bracket was finished with a Dupli-Color® Clear Coat.

Table 5-1. Tricycle Component Finishes Summary

Tricycle Component	Action	Manufacturer/Type	Responsible Party
Frame	Powder Coat	N/A	Central Coast Powder Coating
Seat Bracket	Spray Paint	Dupli-Color® Black Wheel Paint	Trikeceratops Team Member
Seat Back Bars	Spray Paint	RUST-OLEUM® Hammered Silver	Trikeceratops Team Member
Pedal Casings	Spray Paint	RUST-OLEUM® Hammered Silver	Trikeceratops Team Member
Pedal Heels	Spray Paint	RUST-OLEUM® Hammered Silver	Trikeceratops Team Member
Quill Stem	Spray Paint	RUST-OLEUM® Hammered Silver	Trikeceratops Team Member
Leg Aligner	Spray Paint	RUST-OLEUM® Hammered Silver	Trikeceratops Team Member
Rear Steering Bar	Spray Paint	RUST-OLEUM® Hammered Silver	Trikeceratops Team Member

Assembly

After the frame was powder coated, the bottom bracket shell was faced and its threads were chased using a Park Tool BTS-1. The Shimano square tapered bottom bracket was then installed with a liberal application of grease to ensure that over time it will not oxidize and fuse to the bottom bracket shell. The Origin8 threaded headset was mounted into the headtube with a Park Tool HHP-2. Normally the headtube would need to be faced and reamed before mounting the headset due to possible deformation from welding, but this was not necessary as steel insert rings (similar to the ones used in the drivetrain) were machined and press fit into the headtube to accept the headset.

For mounting the rail, strips of toolbox liner were cut and laid between the rail and the frame to provide a surface for the rail to mount against that would not mar the powder coat beneath it.

The liner also serves to fill the small gap that exists in places between the rail and the frame as the rectangular part of the frame did not remain perfectly straight after joining. The bolts were then torqued down alternating from each side of the rail going in towards the middle.

The Sturmey Archer shifter mount was attached to the frame using pipe clamps. To provide a better surface for the clamps to press against, thick strips of rubber were first wrapped around the frame. The clamps were then tightened around the rubber to secure the shifter mount.

For the assembly of the drivetrain components, the bearing located near the middle of the frame was pressed into place first with the careful utilization of a hammer. The driveshaft then had to be filed down by hand to decrease interference with the bearing, as well as the drive wheel. After the interference was an acceptable amount the bearing was pressed into place by setting a tube against the bearing and hammering it into place. The driveshaft and bearing were then placed in the frame by tapping the bearing into place with a hammer. The far side of the driveshaft was braced with a tube as the drive wheel was tapped onto the shaft with its key in place. After the driveshaft and associated components were in place, the half shaft was fit into place with the use of a 4lb engineer’s hammer. The frame was braced by two members while the other hit a tube that was against the half shaft to press the piece into the frame. Once it was fit into place the wheels were locked on with lock washers and nuts.

The Sturmey Archer S3X hub was inserted into its mount with the chain from the crank around its cog. The hub was then straightened out and pulled back until that chain was taut. The #40 roller chain was then wrapped around its corresponding sprockets, links were removed until the chain was the correct length, and the master link was set in place.

Assembly of the remaining components was straightforward; they were set in place and fastened by tightening bolts and nuts.

CHAPTER 6: DESIGN VERIFICATION

Table 6-1 contains a summary of the measurements taken to determine if the prototype's physical properties were within tolerance of the design criteria. Length measurements were taken using a tape measurer with a resolution of 1/32". The weight measurements were taken using a scale with a resolution of 1 lb. To determine the weight of the tricycle, a team member was weighed while holding the tricycle. Their weight without the tricycle was then subtracted to calculate the tricycle's weight.

Table 6-1 Tricycle Measurements

Property	Measured Value
Track Width	32 - 1/8"
Length	65"
Weight	102 lbs
Height (Seat in the Highest Position)	53-7/8"
Height (To Top of the Frame)	41-1/16"

The test to determine the maximum possible speed consisted of measuring the amount of time it took the tricycle to cover a 15 foot concrete span. To ensure that the tricycle's maximum speed was reached and could be maintained, the rider began pedaling a distance before the measured span. This test was performed five times in each gear and the results can be seen in Table 6-2. The maximum speed achieved was approximately 10 mph using the first gear (1:1 gearing ratio) on the S3X. The Trikeceratops' team member with the highest level of physical fitness, Ryan Hirahara, was chosen as the rider to show the extent of the tricycle's performance capabilities. Although the maximum speed was measured at 10 mph, it is unlikely that the students riding the tricycle will be able to deliver enough power at a given cadence to achieve this speed.

Table 6-2. Maximum Speed Test Results

Attempt	1st Gear			2nd Gear			3rd Gear		
	Time (s)	Speed (ft/s)	Speed (mph)	Time (s)	Speed (ft/s)	Speed (mph)	Time (s)	Speed (ft/s)	Speed (mph)
1	1.01	14.85	10.13	1.46	10.27	7.00	1.53	9.80	6.68
2	1.04	14.42	9.83	1.36	11.03	7.52	1.62	9.26	6.31
3	1.12	13.39	9.13	1.41	10.64	7.25	1.66	9.04	6.16
4	1.13	13.27	9.05	1.56	9.62	6.56	1.47	10.20	6.96
5	1.07	14.02	9.56	1.51	9.93	6.77	1.68	8.93	6.09

The braking test was performed by measuring the distance the tricycle traveled from where the brakes were first applied to where the tricycle came to a full stop. For the test, the tricycle was taken up to maximum speed, after which the rider was able to brake by ceasing to pedal. At a speed of 10 mph, the stopping distance was 5 feet. This test was performed twice with the same results.

Figure 6-1 Tricycle Testing

Top speed cadence is difficult to maintain, therefore it is unlikely that a student rider will be able to outrun a supervisor. Although there is no exact test to determine tricycle tip over, test riding the tricycle showed even when executing turns at the maximum tricycle speed, the chance of tip over on flat ground is very unlikely. Additional testing showed that from a stop, the tricycle is also able to execute turns when the front wheel is turned greater than 90 degrees from the forward position. Therefore, it is possible to achieve a turning radius that is smaller than the length of the vehicle.

Figure 6-2 Test Rider Kemely Chow

Figure 6-3 Test Rider Bodin Rojanachaichanin

Figure 6-4 Test Rider Jenna Becker

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

Despite being slightly over the specified weight and track width, the tricycle still performs as designed and will serve the Buena Park School district for years to come. Additionally, after testing, the team determined that the pedal heel pieces did not provide any positive value to the pedal assembly. The pedal casings, toe clips, and rubber heel straps provided sufficient support for a large variety of foot sizes.

To improve the tricycle, butted steel tubing could be used to lower the frame weight. Another option for cutting weight would be to redesign the pedal assembly to incorporate attachable shoe cleats and clipless pedals. This idea was discarded early on in the conceptual design phase because the team assumed that the highest priority of the pedals was to improve upon Rifton's design and lock the rider's feet in place. After test riding the tricycle, the team determined that although the Trikeceratops' pedals adequately secure the rider's feet, the location of the spindles near the arches of the foot results in an awkward pedaling experience (especially if the rider is accustomed to riding a bicycle where strokes are driven with the balls of the feet).

Additionally, altering the frame geometry would allow the tricycle to accept a variety wheel sizes that are more readily available. One of the largest obstacles faced during the project was obtaining the specified wheel size from Skyway Machine, Inc.

REFERENCES

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APPENDIX A: QFD

Adaptive Adjustable Tricycle

Children with disabilities, Lisa Colburn

Customer (Step #1) Requirements (Whats)	Weighting (Total 100)	3 Wheels	Rider weight up to 150lbs w/ FS 1.5 to 3	Rider height range 4' to 5'10"	Max track width 30"	Hand brakes require less than 5lbs gripping strength	Achieve full stop w/in 10ft of full brake application from 5mph on asphalt	Tricycle weigh less than 75 lbs	Cost less than $2500 in materials	Length and height (TBD)	Pedaling force required (?) lbs	Ratios (?) for different pedaling abilities	Seat back angle ?	Require basic maintance every (?) years	Attach feet to pedals	Provide resting point for feet	Person can aid rider in achieving motion	Support rider's body up through shoulders	Person can aid steering from behind	Person can apply brakes from behind	Movable hand brake for rider	Maximum operating speed of 15mph	Rifton Adapted Trike	Freedom Concepts Discovery	Pioneer Mobility Cycle
Tricycle	*	9																					5	5	5
Help kids learn to ride a bike	*	1															1		1				5	5	5
Foot straps	5							1	1		3				9								5	5	5
Foot bar/plate	2							1	1							9							0	0	0
Push handle	6							1	1		3						9						5	5	5
Fit through door	4.5				9					3													3	5	5
For 6-12 years	*		9	9																			5	5	5
Weight range up to 150lbs	10		9																				4	4	3
Height range 4' to 5'10"	9.5			9																			3	2	3
Full trunk support	7							1	1									9					5	5	5
For use on asphalt	7.5						9				1												5	5	5
Hand brake for rider	9					9	9														9		5	5	5
Providing varying resistance for different pedaling abilities	4										3	9											0	0	-
Rear steering	3							1	1										9				5	5	0
Upright sitting position for rider	7												9										5	5	5
Used at low speeds	9						3															9	5	5	5
Low maintance	7.5													9									4	4	4
Storable in classroom	4				9					9													3	5	4
Brake for pusher	5					3	9	1	1											9			5	5	5
Units		Wheels	lbs	in.	in	lbs	ft	lbs	$	in	lbs		deg	item/yr								mph			
Targets		3	225	48-70	30	5	10	75	2500	?	?	1	?	?	1	1	1	1	1	1	1	15			
Benchmark #1																									
Benchmark #2																									

Customer Requirements (Step #2)

Engineering Requirements (HOWS)

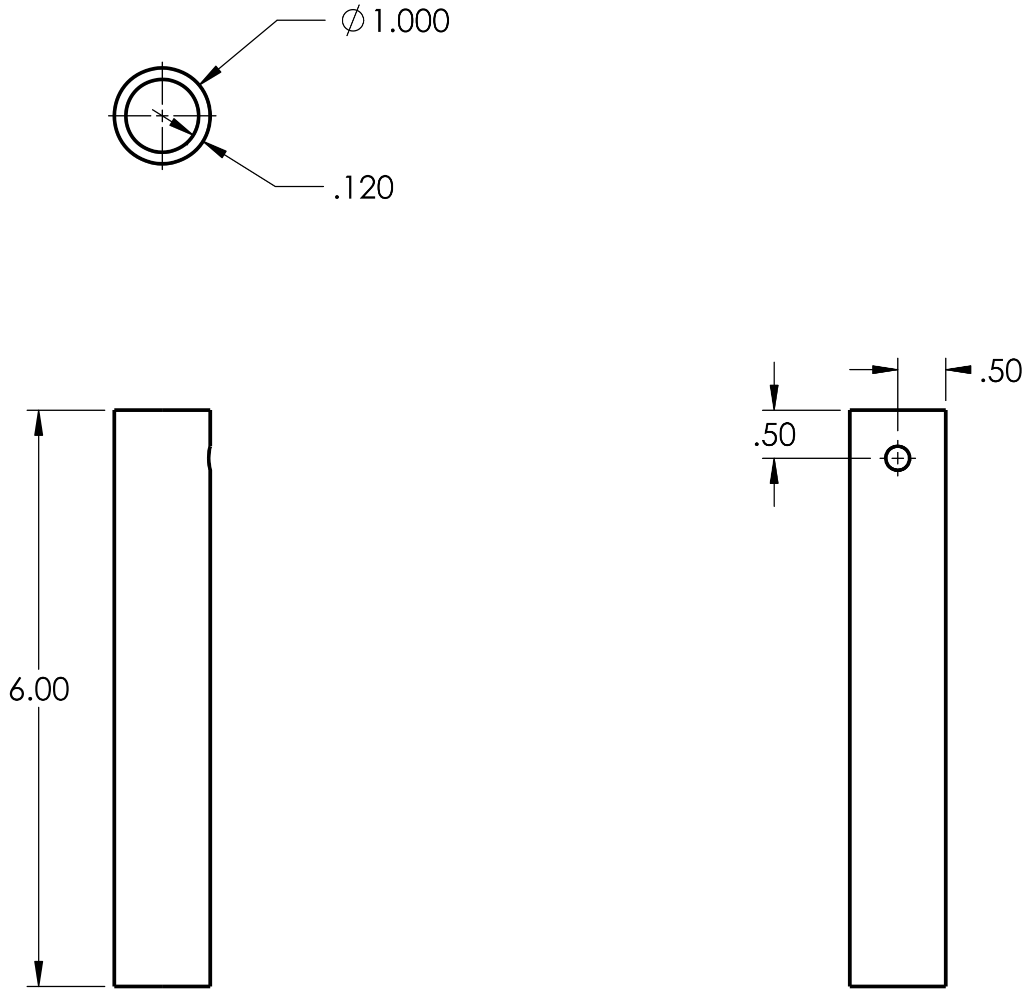
Benchmarks

● = 9	Srong Correlation
○ = 3	Medium Correlation
Δ = 1	Small Correlation
Blank	No Correlation

Appendix B: Drawings

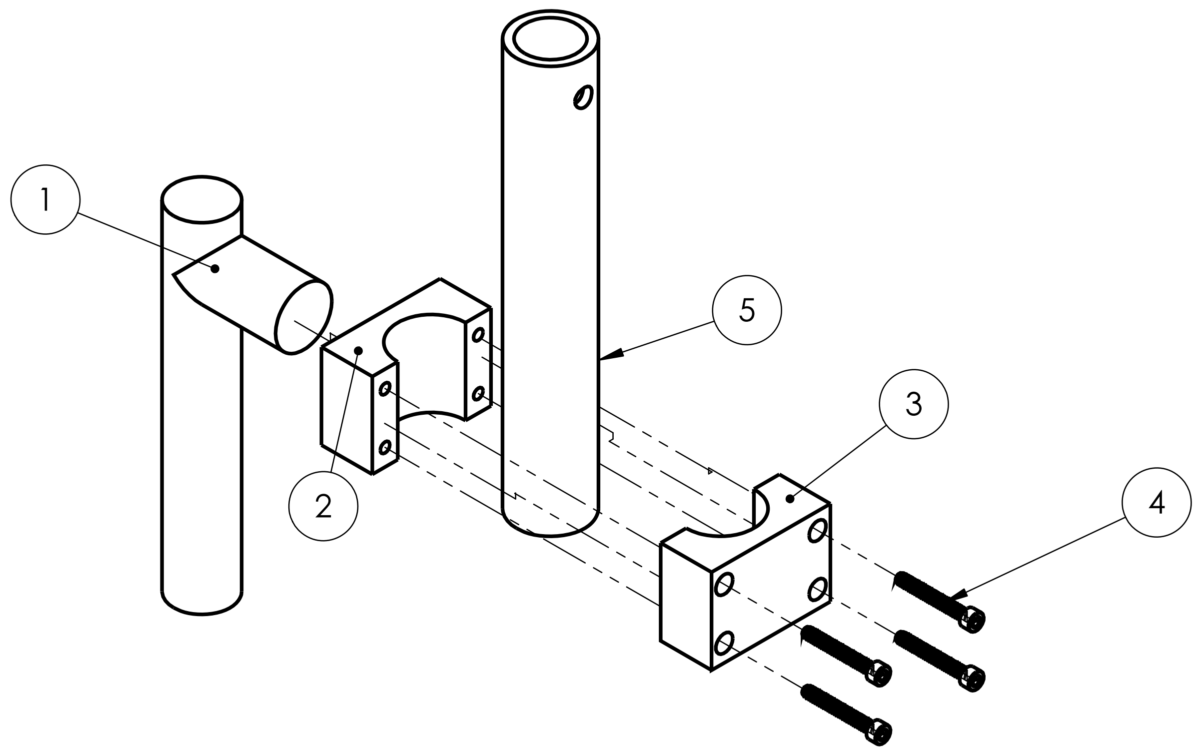
Table of Contents

Note: Drawings do not include mirrored parts (e.g. Pedal Top Case Left)



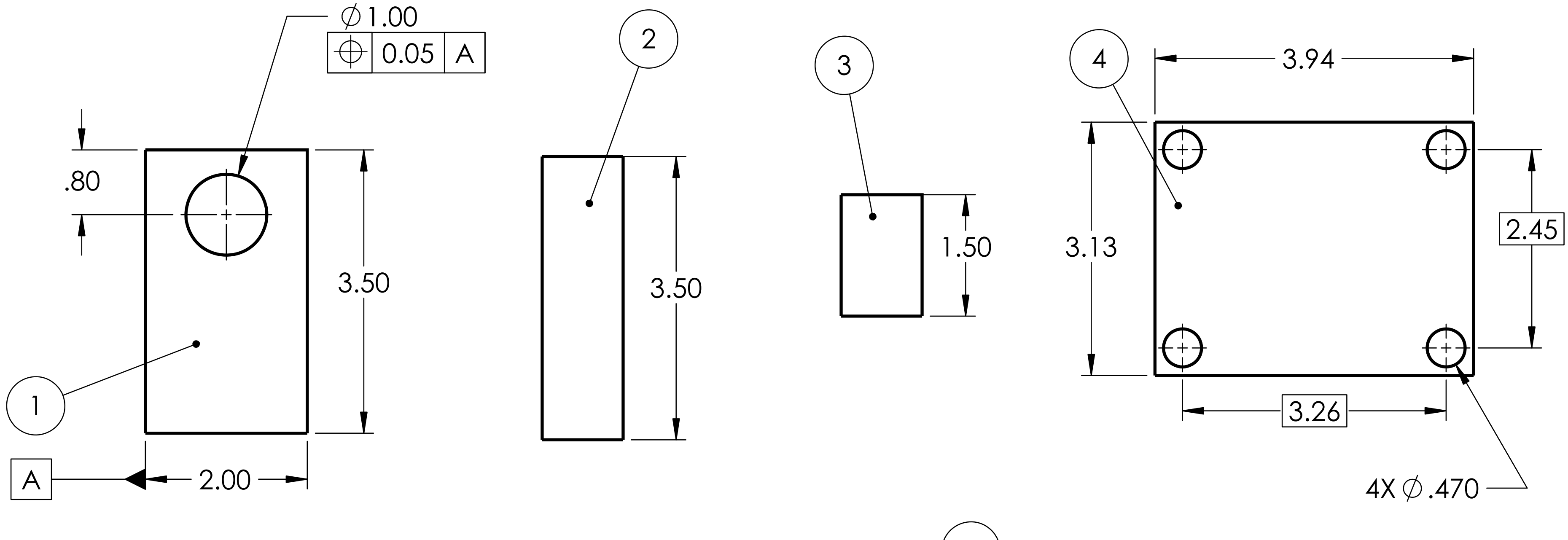
			Tolerances:	2 Decimals ±0.10
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0101	Title: Handlebar Holding Tube	Weight: 0.56lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0199	Date: 02-06-14	Scale: 1:2	Chkd. By: Kemely Chow

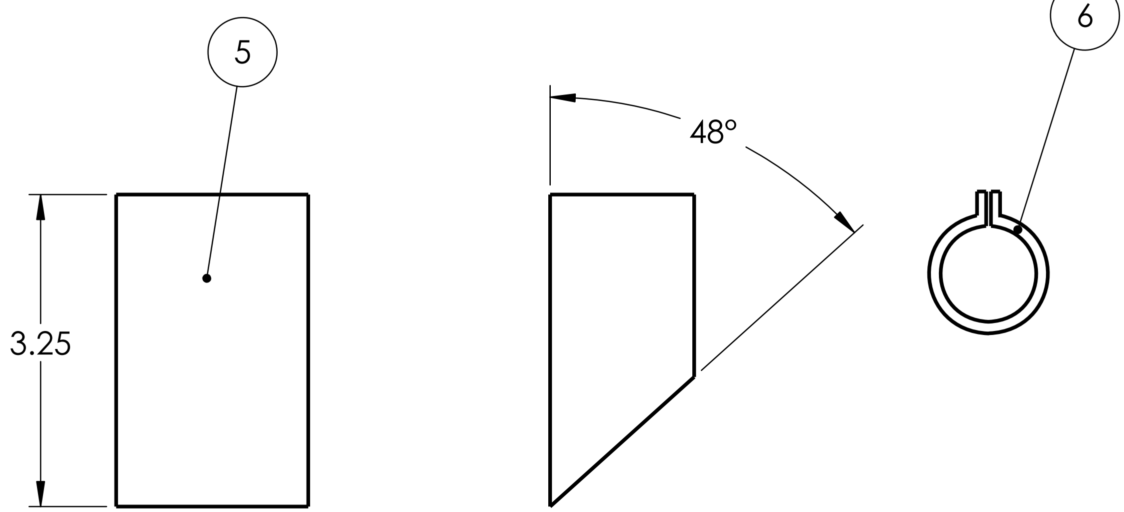
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	N/A	Handlebar Stem	1
2	N/A	Stem Grabber	1
3	N/A	Stem Grabber 2	1
4	91205A153	6-32, 1" Socket Head Cap Screw	4
5	T0101	Handlebar Holding Tube	1



Tolerances:	See part drawings
Units: Inches	Material: See Part Drawings

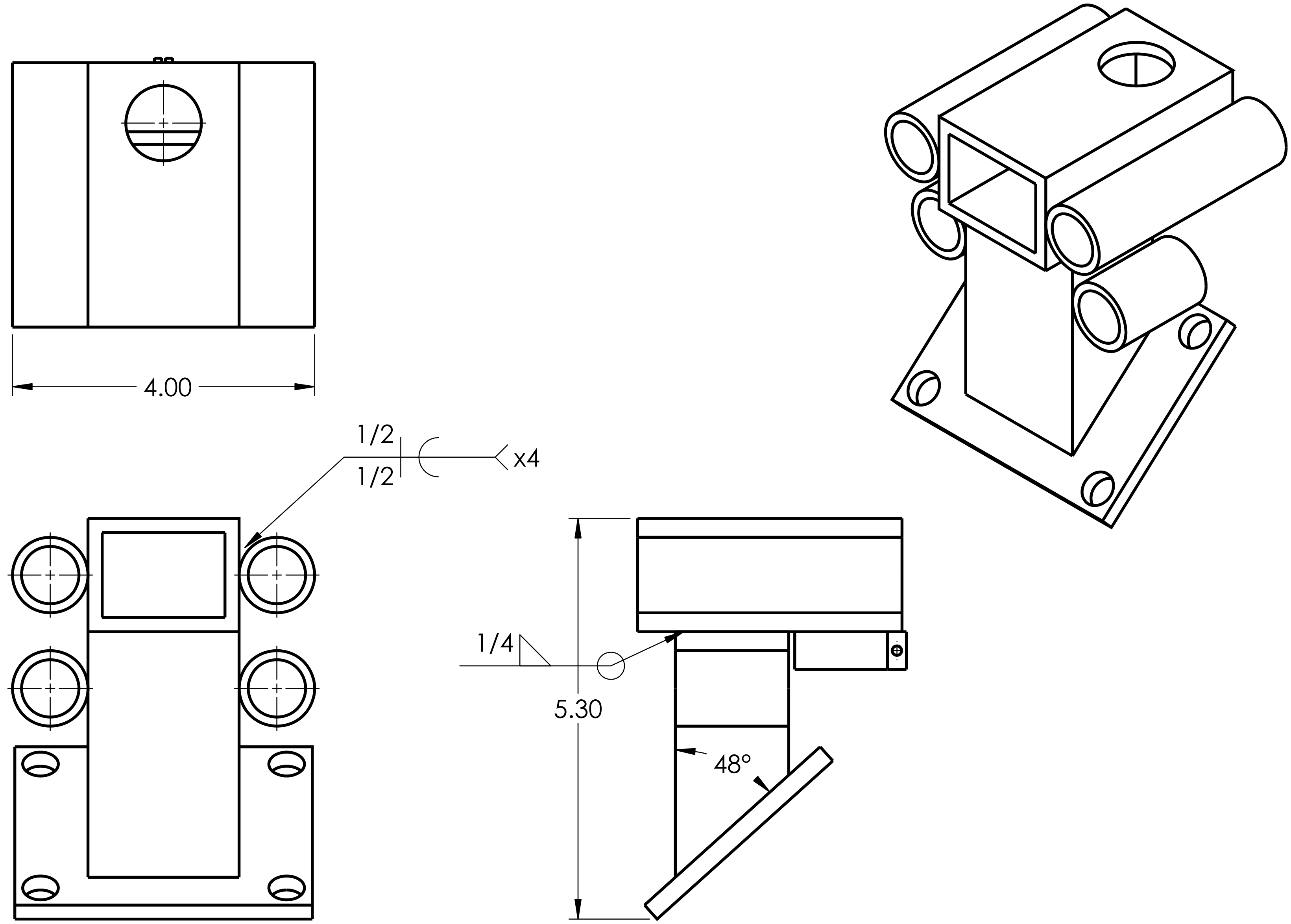
Cal Poly Mechanical Engineering	Dwg.#: T0199	Title: Handlebar Stem Assembly	Weight: N/A	Drwn. By: Heather Instasi
Trikeceratops	Nxt Asb: T1000	Date: 02-06-14	Scale: 1:2	Chkd. By: Kemely Chow





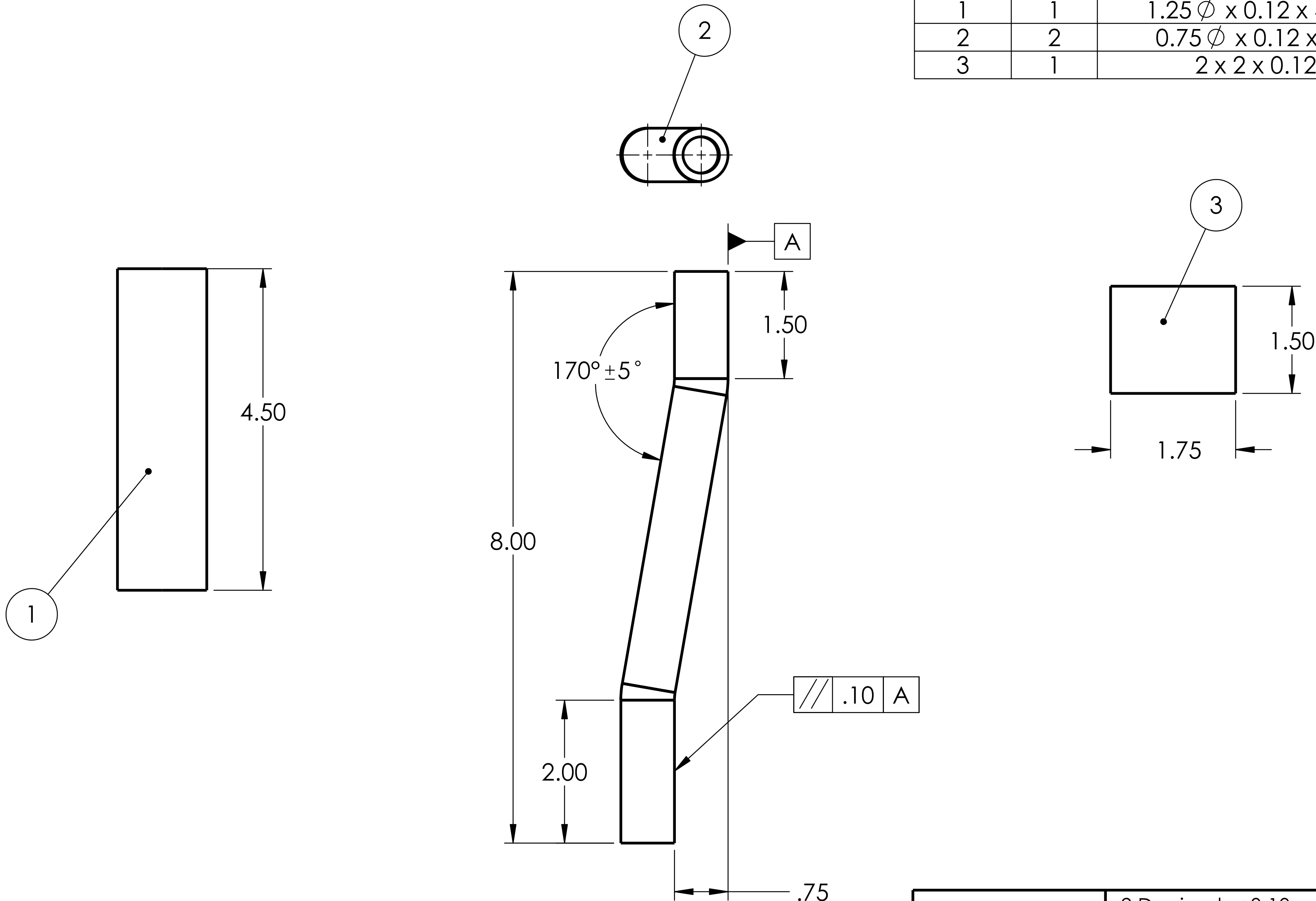
	QTY.	DESCRIPTION
1	1	2 x 1.5 x .188 x 3.50 LG
2	2	1 ∅ x 0.12 x 3.50 LG
3	2	1 ∅ x 0.12 x 1.50 LG
4	1	4 x 3.25 x 0.25
5	1	2 x 1.5 x 0.188 x 3.50 LG
6	1	Seat Post Clamp

			Tolerances:	2 decimals ±0.10
				3 decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0201	Title: Seat Bracket Weld Prep	Weight: N/A	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0299	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow

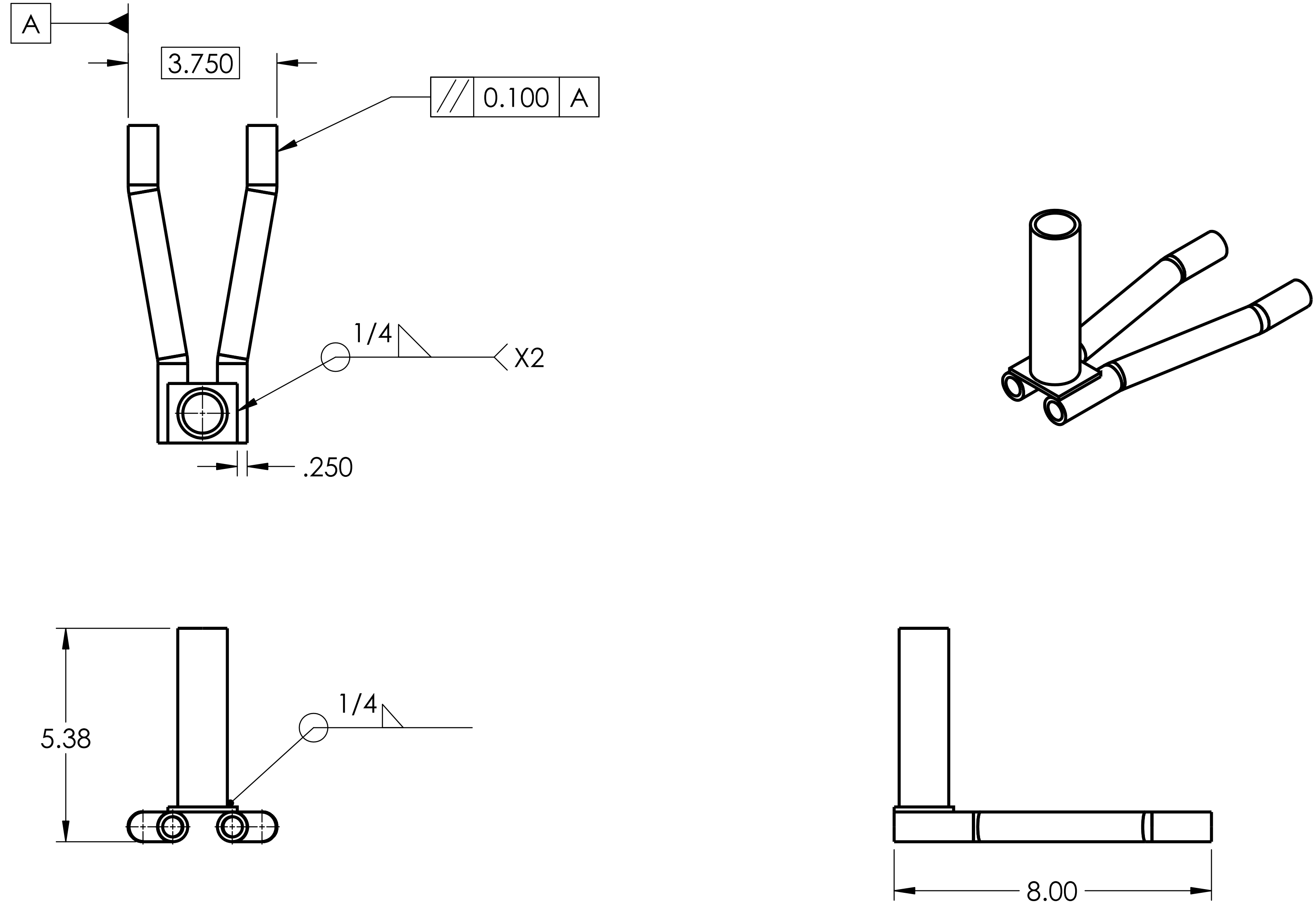


			Tolerances:	2 Decimals ±0.10
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0202	Title: Seat Bracket Weldment	Weight: 3.77lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0299	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow

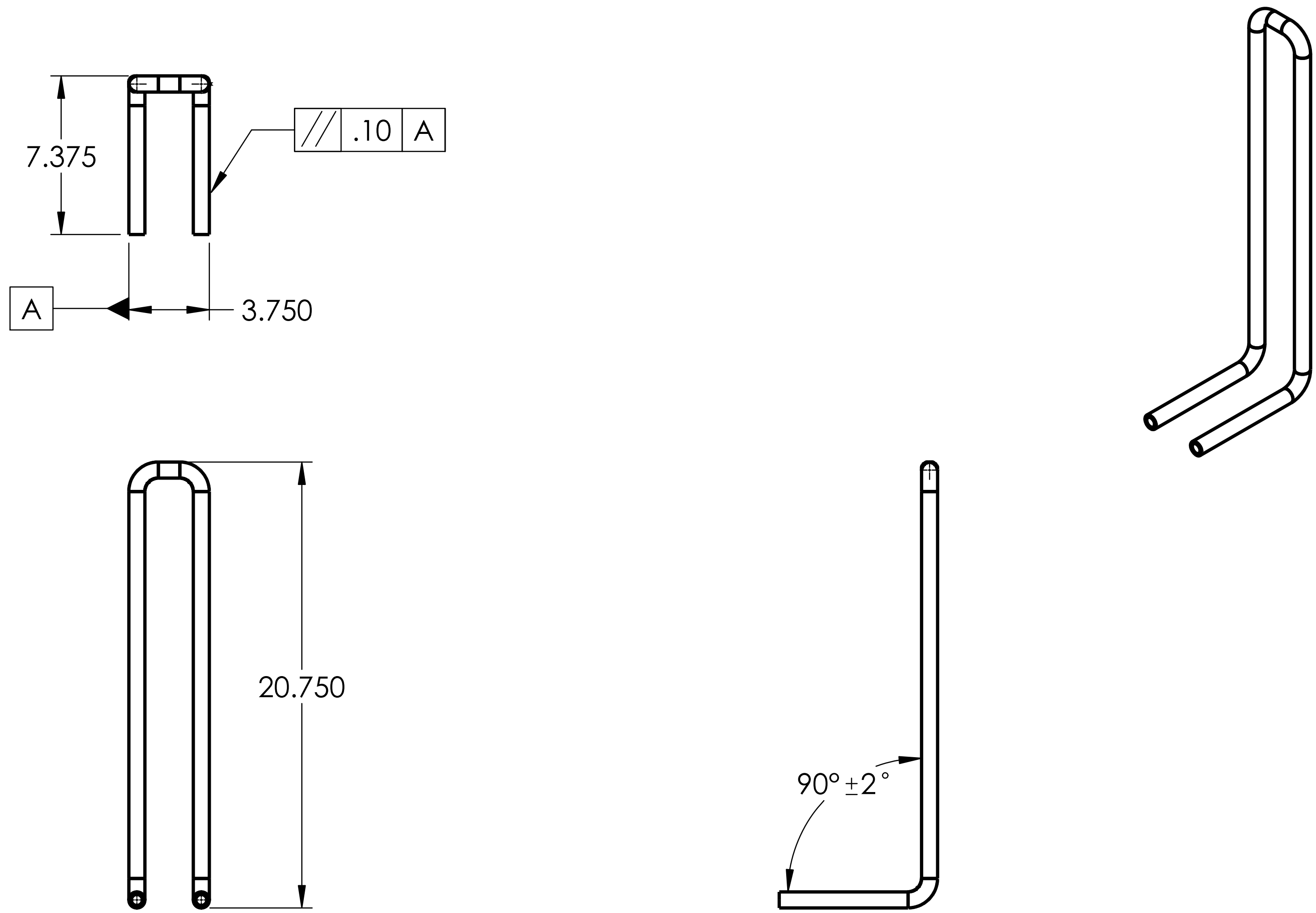
ITEM	QTY.	DESCRIPTION
1	1	1.25 ∅ x 0.12 x 4 LG
2	2	0.75 ∅ x 0.12 x 9 LG
3	1	2 x 2 x 0.125



			Tolerances:	2 Decimals ±0.10
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0203	Title: Leg Aligner Weld Prep	Weight: N/A	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0299	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow



			Tolerances:	2 Decimals ±0.10
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0204	Title: Leg Aligner Weldment	Weight: 1.74 lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0299	Date: 01-29-14	Scale: 1:4	Chkd. By: Kemely Chow

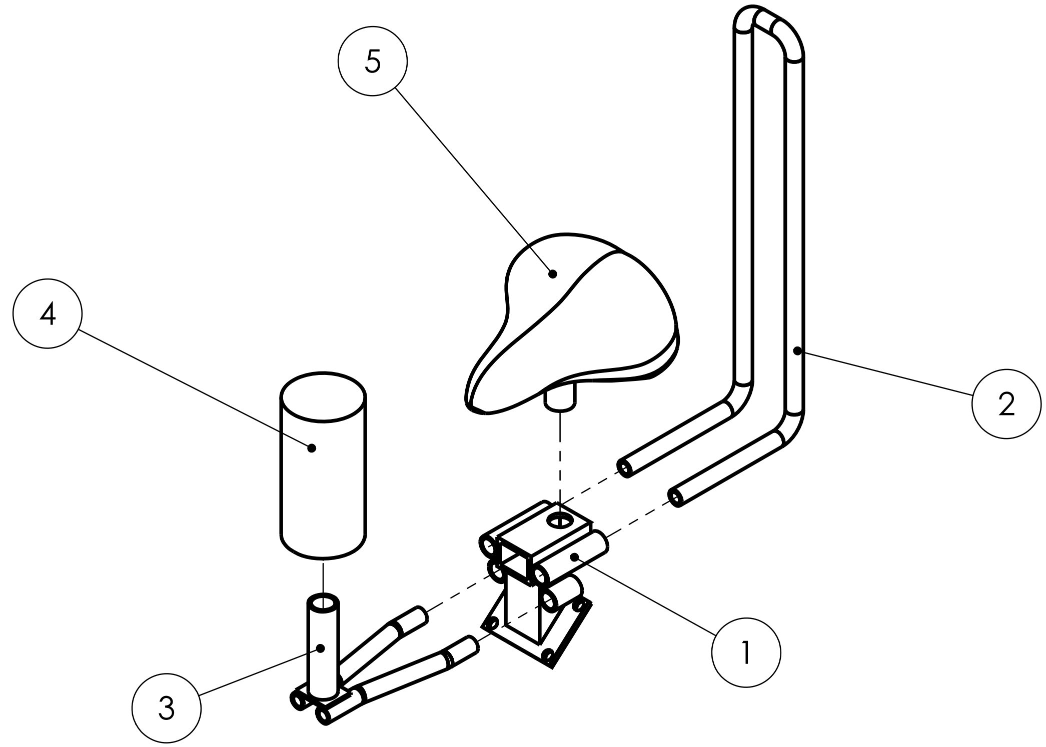


Note:
Tube Dimensions are as follows:
0.750 O.D. with 0.120 Wall Thickness

Tolerances:	2 Decimals ±0.10
	3 Decimals ±0.05
Units: Inches	Material: 4130 Steel

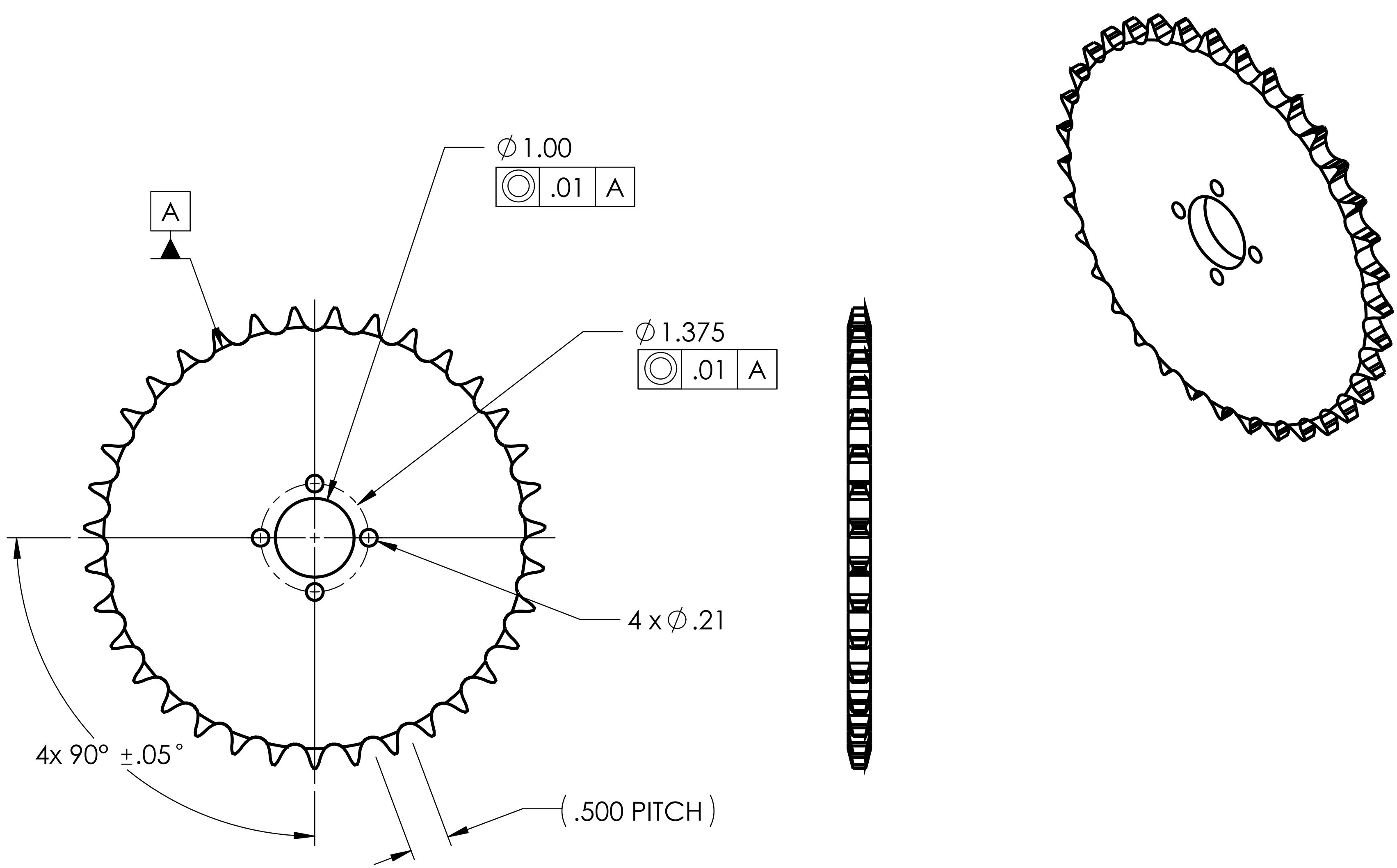
Cal Poly Mechanical Engineering	Dwg.#: T0205	Title: Seatback Bar	Weight: 3.72 lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0299	Date: 01-29-14	Scale: 1: 8	Chkd. By: Kemely Chow

ITEM NO.	PART #	DESCRIPTION	QTY.
1	T0202	Seat Bracket	1
2	T0205	Seatback Bar	1
3	T0204	Leg Aligner	1
4	N/A	Leg Aligner Cushion	1
5	N/A	Seat	1

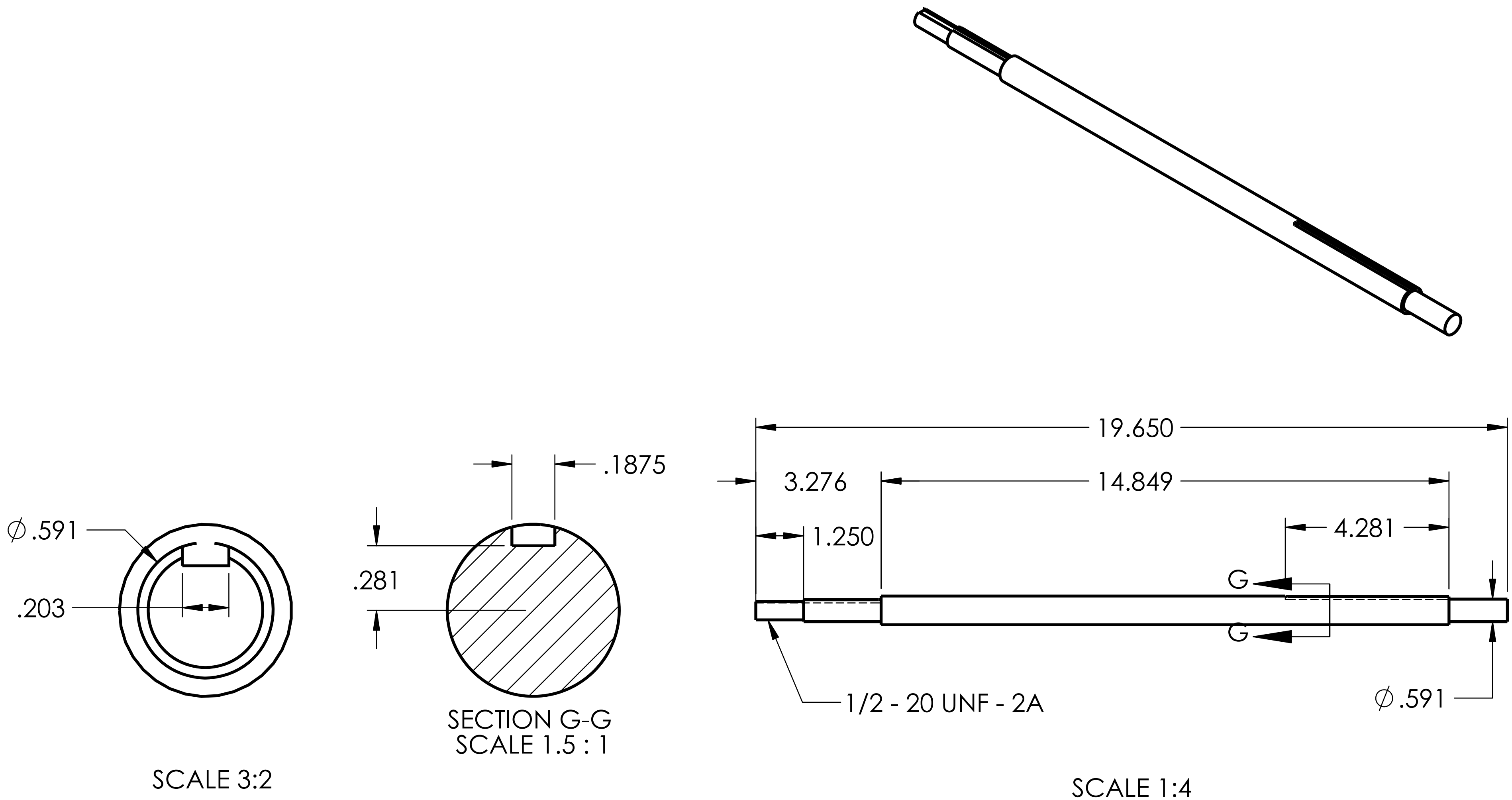


Tolerances:	See Part Drawings
Units: Inches	Material: See Part Drawings

Cal Poly Mechanical Engineering	Dwg.#: T0299	Title: Seat Assembly	Weight: 10.56 lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T1000	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow



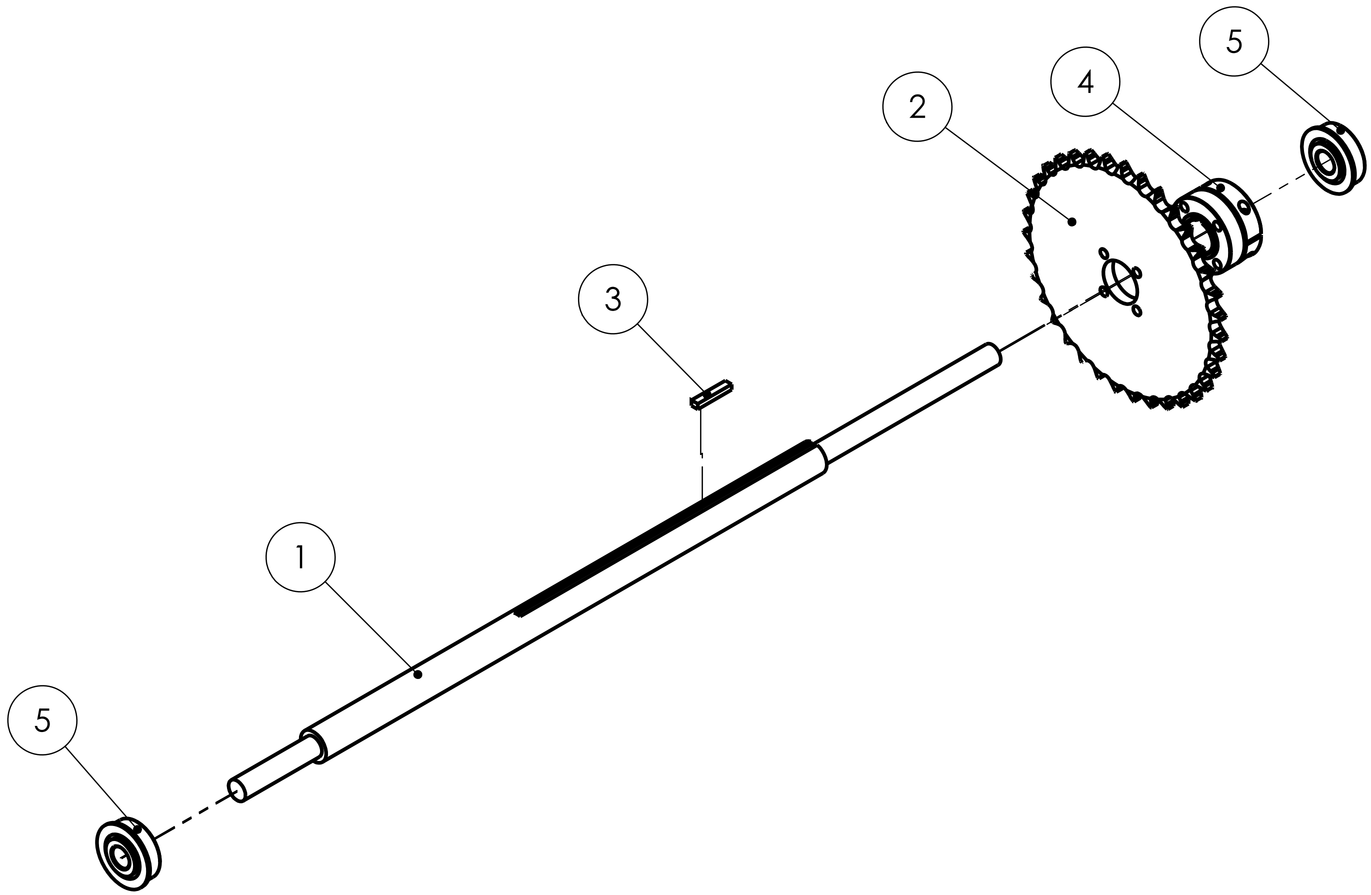
			Tolerances:	2 Decimals ± 0.05
				3 Decimals ± 0.01
			Units: Inches	Material: Steel
Cal Poly Mechanical Engineering	Dwg.#: T0302	Title: 35 Teeth #40 Chain Sprocket	Weight: 1.768 lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb: T0399	Date: 01-29-14	Scale: 1:2	Chkd. By: Ryan Hirahara



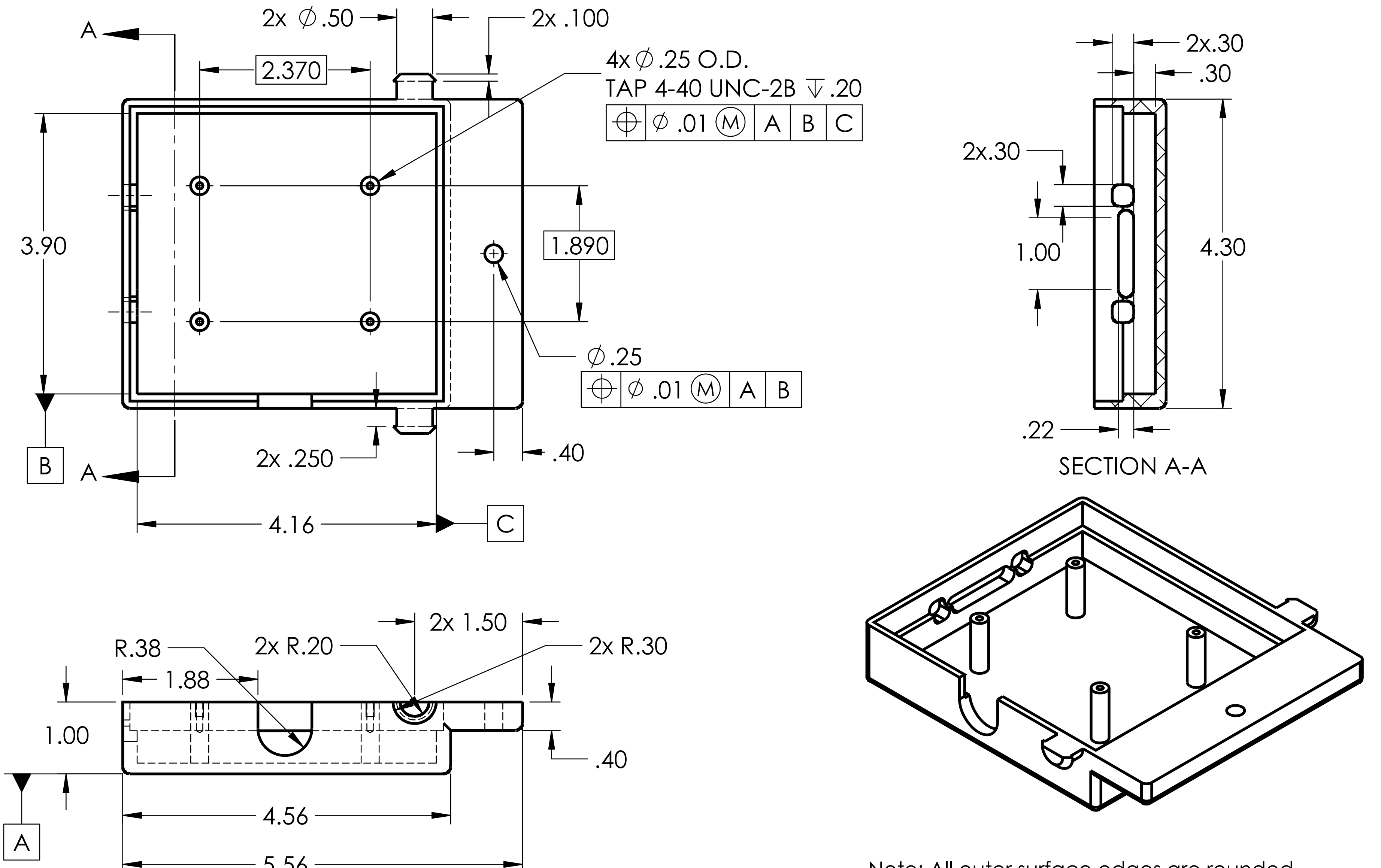
NOTE: Keyway depths are equal to 1/2 Keyway widths

			Tolerances:	
			Units: Inches	Material: 1144 Steel
Cal Poly Mechanical Engineering	Dwg.#:	Title: Drive Shaft 2.0	Weight: lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb:	Date: 06.03.14	Scale: N/A	Chkd. By:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	T0301	Partially Keyed Drive Shaft	1
2	T0302	35 Teeth #40 Chain Sprocket	1
3	98870A340	3/16" x 3/16" x 1" Key	1
4	1L012AMK	Shaft Collar	1
5	6384K363	Bearing	2

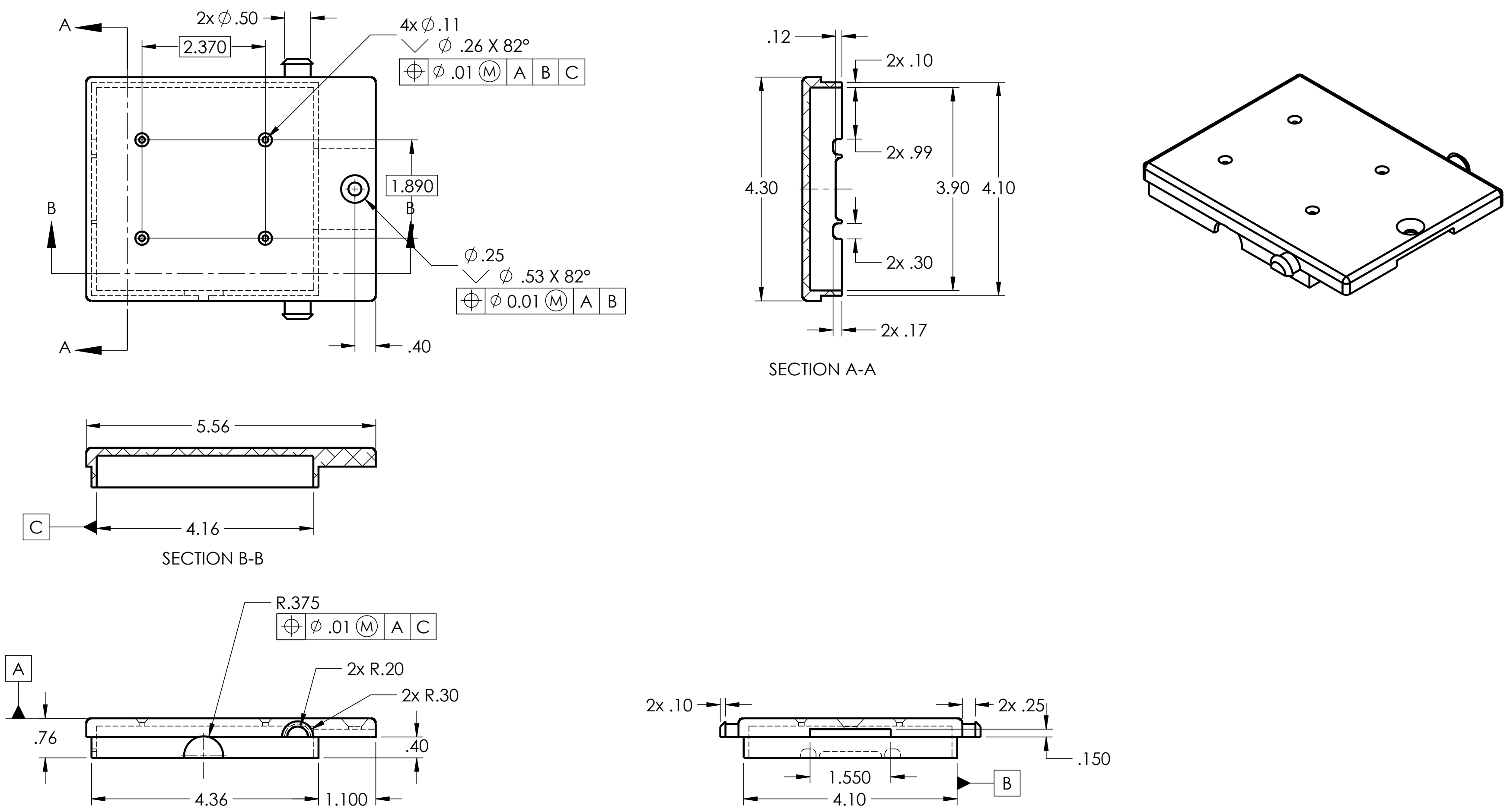


			Tolerances:	See Part Drawings
			Units: Inches	Material: See Part Drawings
Cal Poly Mechanical Engineering	Dwg.#: T0399	Title: Drive Shaft Assembly	Weight: N/A	Drwn. By: Heather Instasi
Trikeceratops	Nxt Asb: T1000	Date: 01-29-14	Scale: 1:4	Chkd. By: Kemely Chow



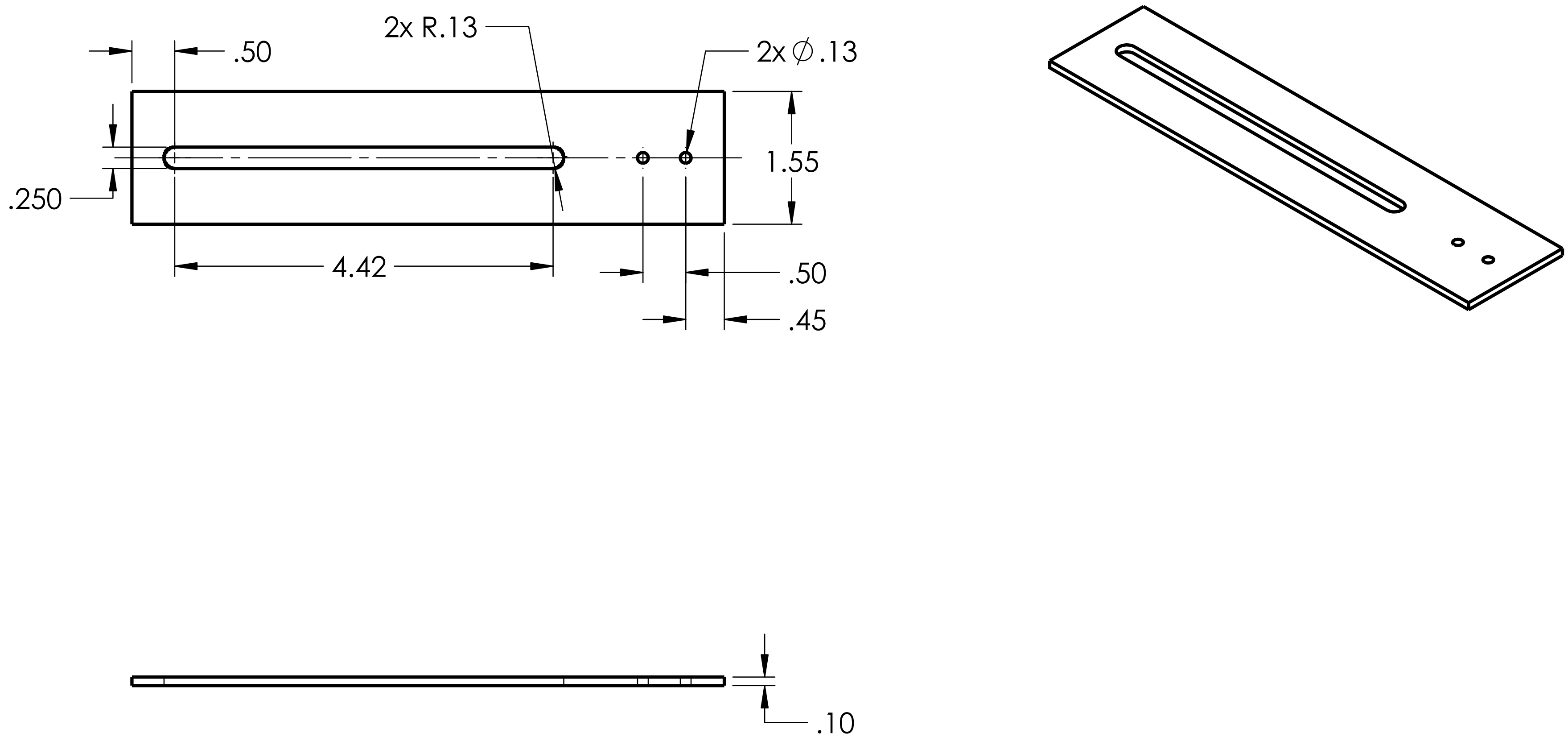
Note: All outer surface edges are rounded

			Tolerances:	2 Decimals ±0.01
				3 Decimals ±0.005
			Units: Inches	Material: AL 6061
Cal Poly Mechanical Engineering	Dwg.#: T0501	Title: Pedal Casing Bottom Right	Weight: 0.668 lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb: T0599	Date: 02-04-14	Scale: 1:2	Chkd. By: Ryan Hirahara



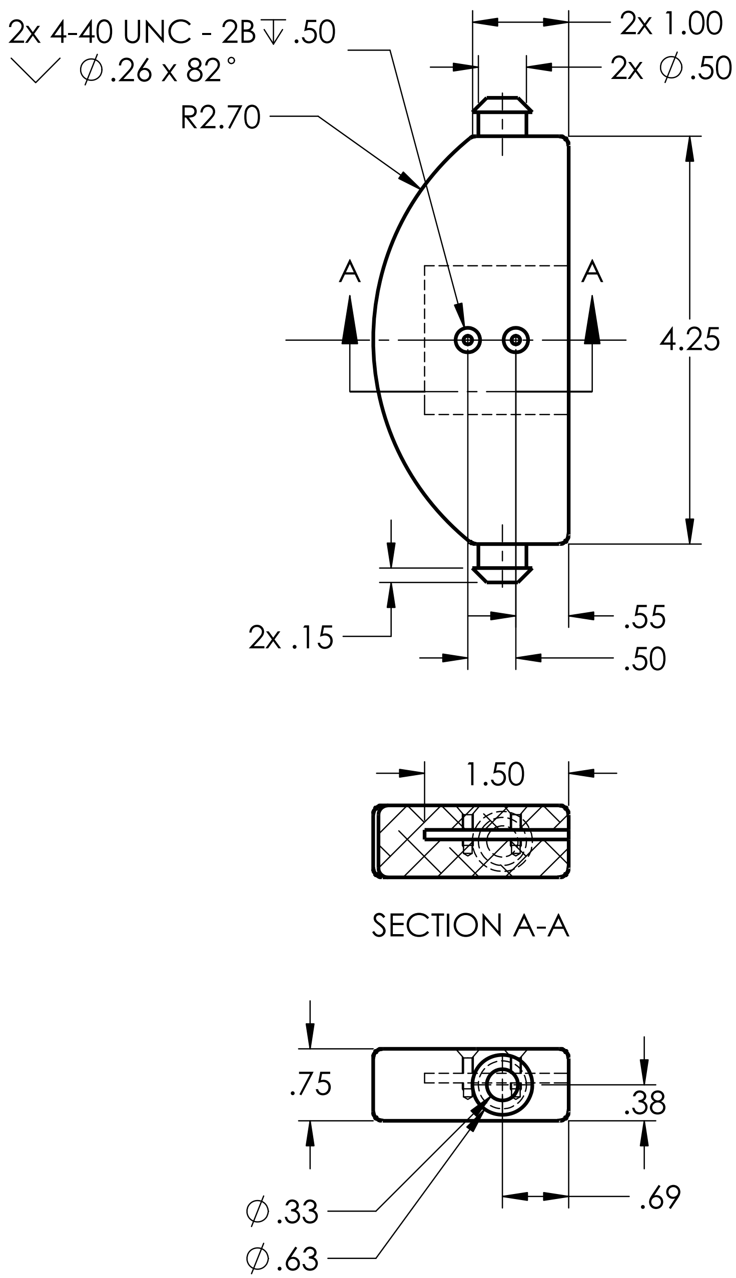
Note: All outer surface edges are rounded

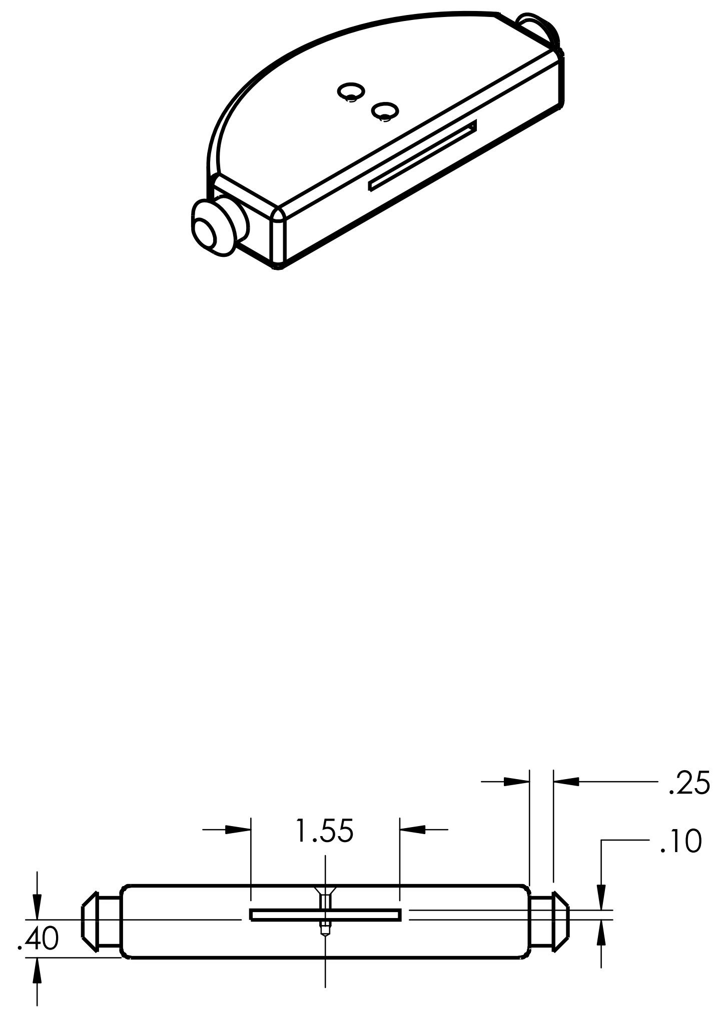
			Tolerances:	2 Decimals ±0.01
				3 Decimals ±0.005
			Units: Inches	Material: 6061 Aluminum
Cal Poly Mechanical Engineering	Dwg.#: T0502	Title: Pedal Top Case Right	Weight: 0.538 lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb: T0599	Date: 01-30-14	Scale: 1:2	Chkd. By: Ryan Hirahara



Note: All outer surface edges are rounded

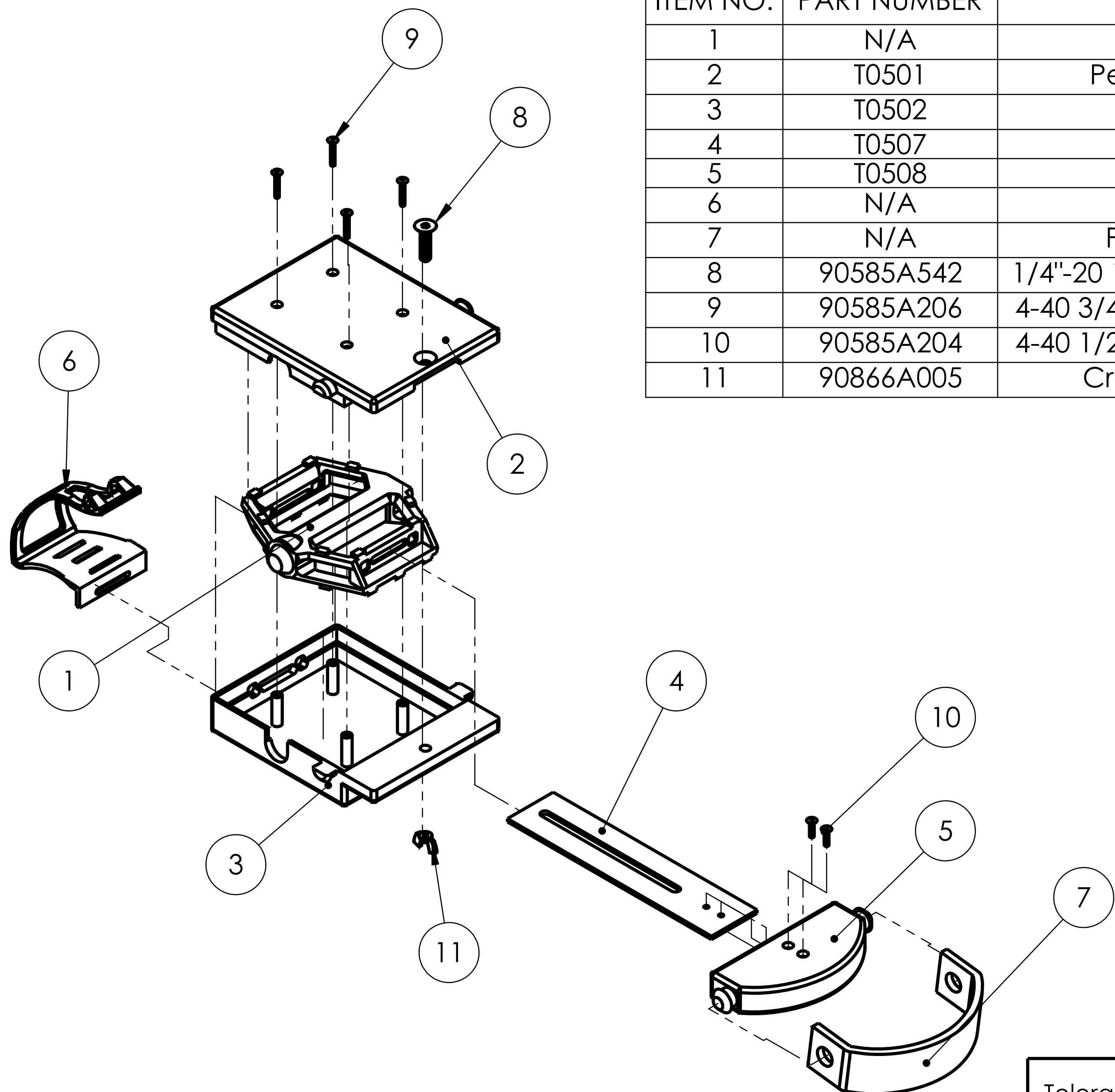
			Tolerances:	2 Decimals ±0.01
				3 Decimals ±0.005
			Units: Inches	Material: 6061 Aluminum
Cal Poly Mechanical Engineering	Dwg.#:T0506	Title: Pedal Slider	Weight: 0.088 lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb: T0599	Date: 01-31-14	Scale: 1:2	Chkd. By: Ryan Hirahara





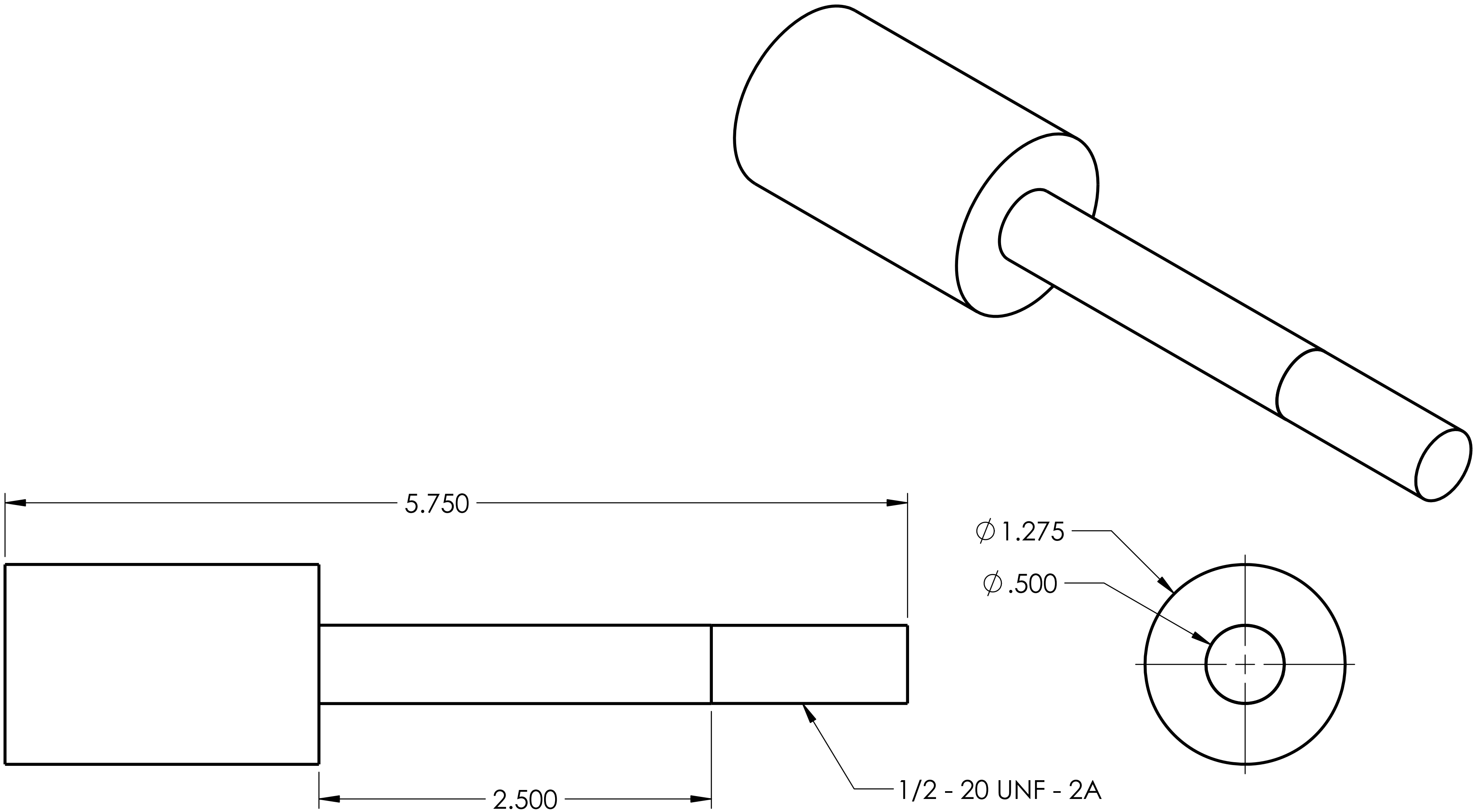
Note: All outer surface edges are rounded

			Tolerances:	2 Decimals ±0.01
				3 Decimals ±0.005
			Units: Inches	Material: 6061 Aluminum
Cal Poly Mechanical Engineering	Dwg.#: T0505	Title: Pedal Heel	Weight: 0.522 lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb: T0599	Date: 01-30-14	Scale: 1:2	Chkd. By: Ryan Hirahara

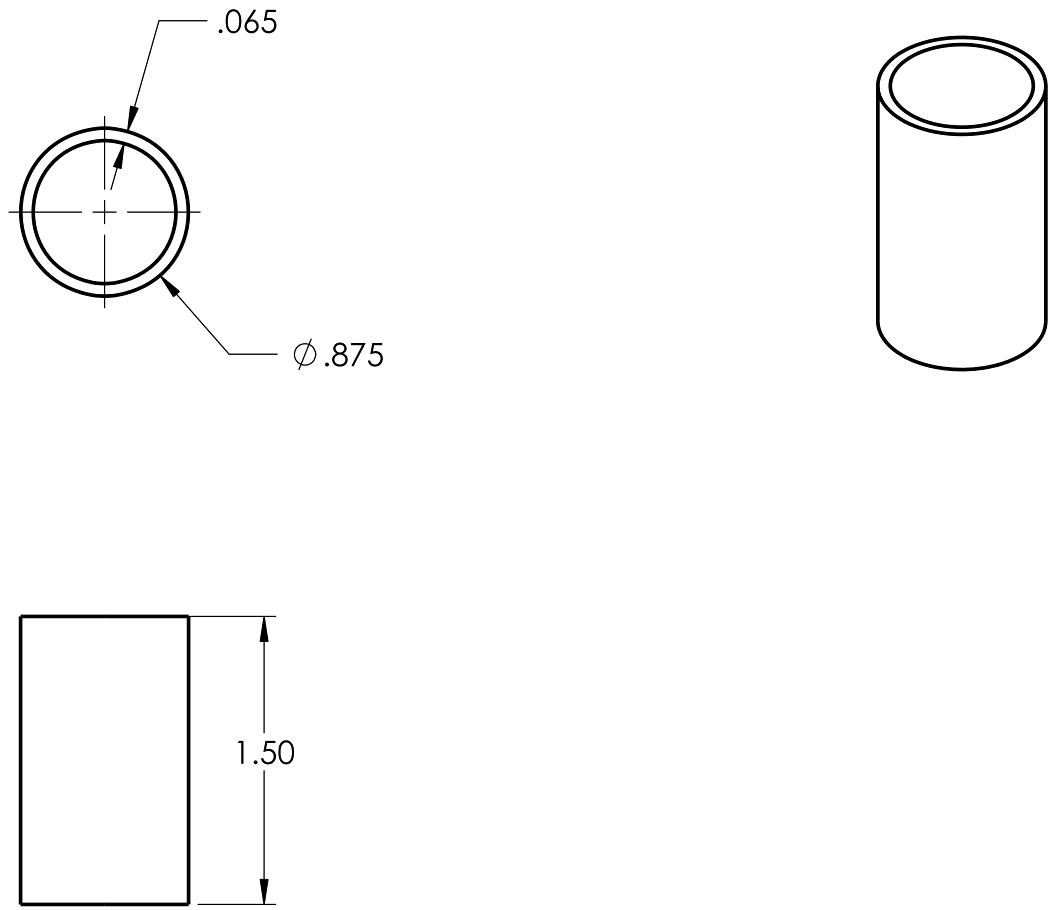


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	N/A	Pedal-Right	1
2	T0501	Pedal Casing Bottom-Right	1
3	T0502	Pedal Casing Top-Right	1
4	T0507	Pedal Slider	1
5	T0508	Pedal Heel	1
6	N/A	Pedal Toe Clip	1
7	N/A	Pedal Rubber Heel Strap	1
8	90585A542	1/4"-20 1" Flat Head Socket Cap Screw	1
9	90585A206	4-40 3/4" Flat-Head Socket Cap Screw	4
10	90585A204	4-40 1/2" Flat-Head Socket Cap Screw	2
11	90866A005	Crown Bolt 1/4"-20 Wing Nut	1

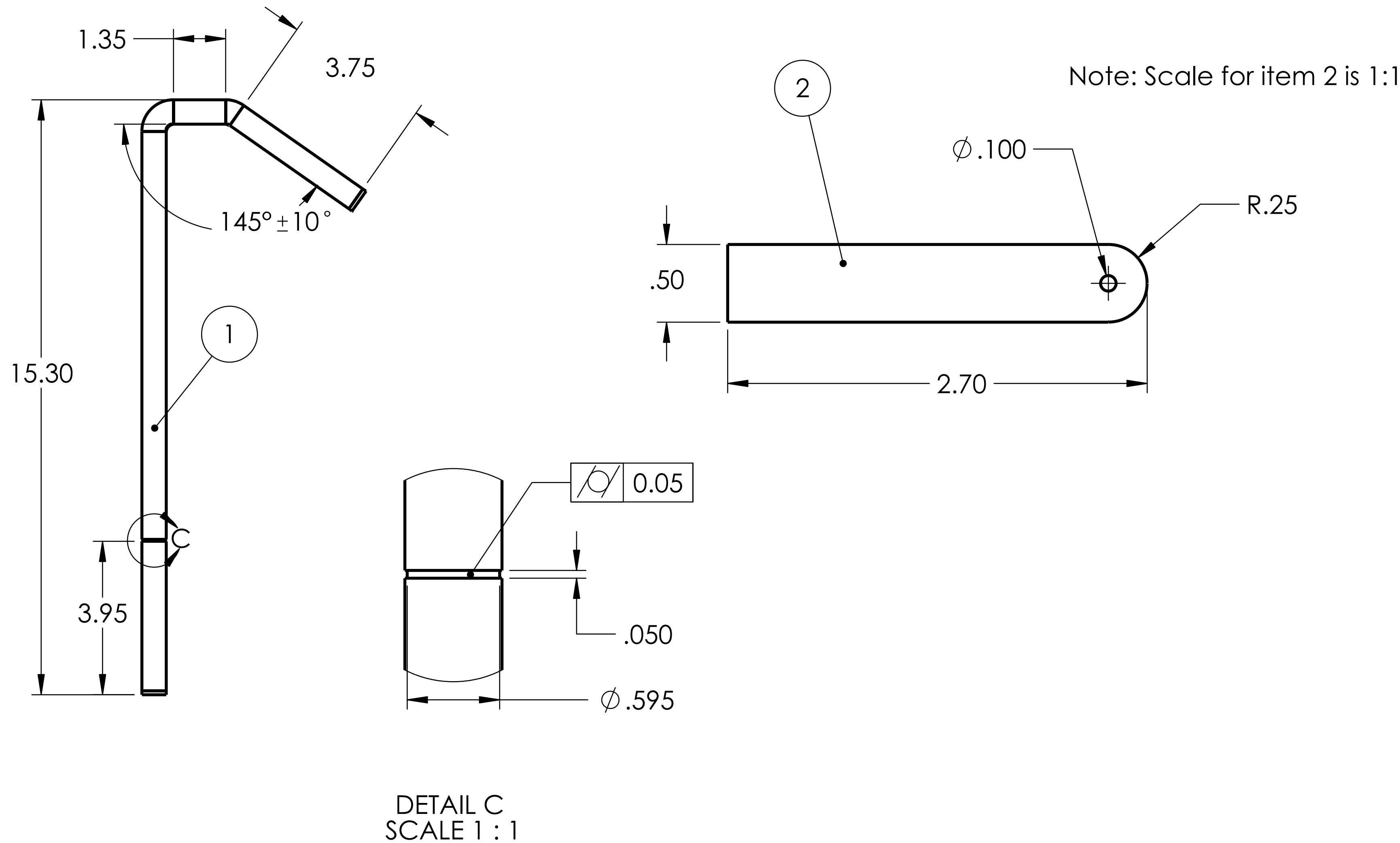
			Tolerances:	See part drawings
			Units: Inches	Material: See Part Drawings
Cal Poly Mechanical Engineering	Dwg.#: T0599	Title: Right Pedal Assembly	Weight: N/A	Drwn. By: Heather Instasi
Trikeceratops	Nxt Asb: T1000	Date: 01-29-14	Scale: 1:4	Chkd. By: Kemely Chow

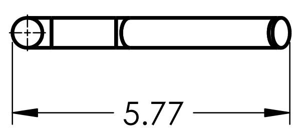


			Tolerances:	
			Units: Inches	Material: 1144 Steel
Cal Poly Mechanical Engineering	Dwg.#:	Title: Idle Shaft 2.0	Weight: lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb:	Date: 06.03.14	Scale: 1:1	Chkd. By:



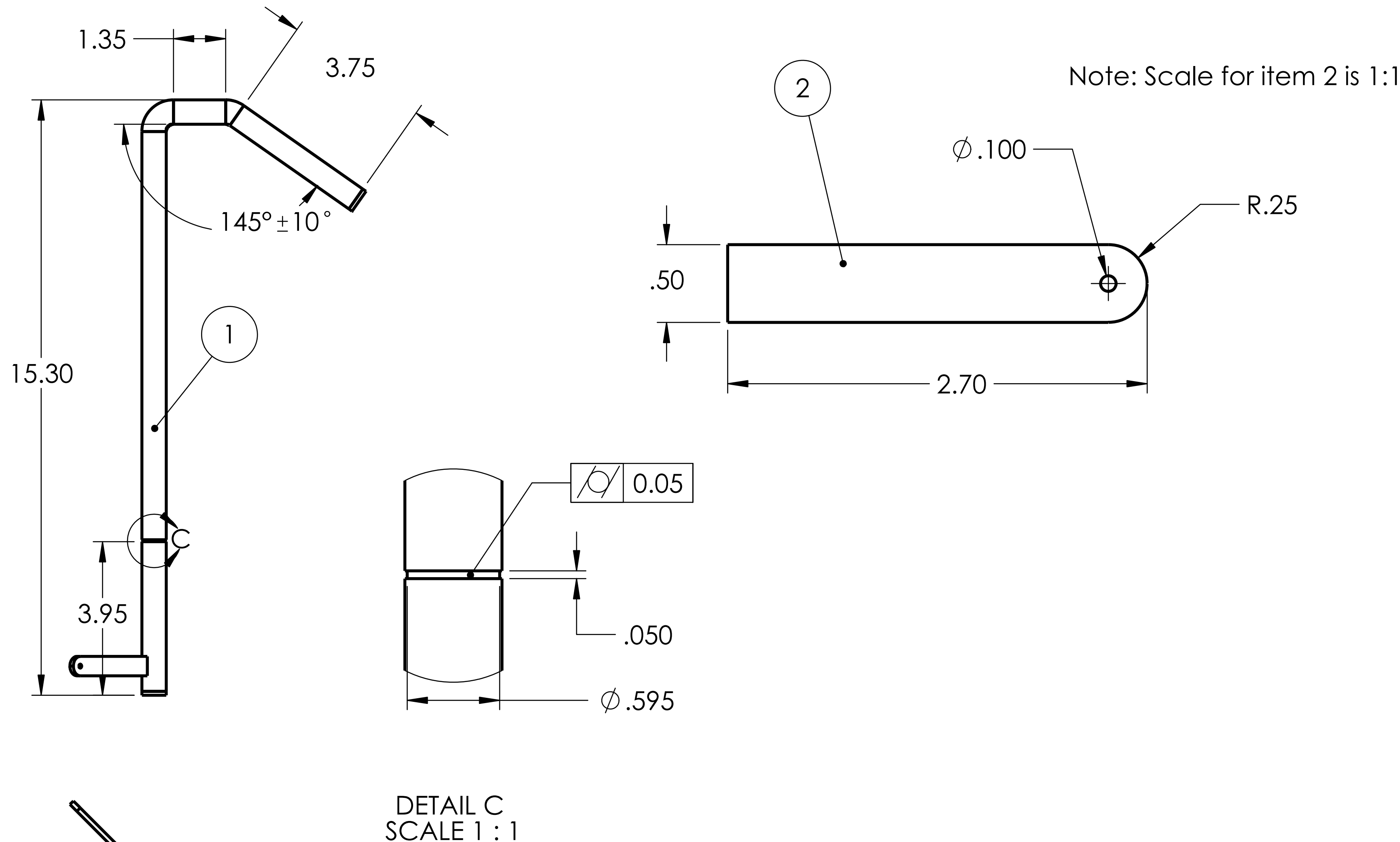
			Tolerances:	2 Decimals ±0.10
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0702	Title: Rear Steering Mount	Weight: 0.07lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0899	Date: 01-29-14	Scale: 1: 1	Chkd. By: Kemely Chow

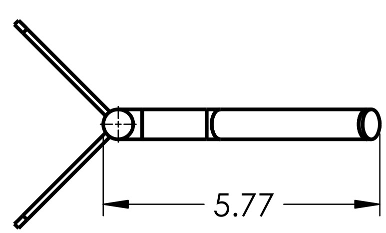




	QTY.	DESCRIPTION
1	1	0.625 ⌀ X 0.035 X 24 LG
2	2	3 X 0.5 X 0.125

			Tolerances:	2 Decimals ±0.10 3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0703	Title: Rear Steering Bar Weld Prep	Weight: N/A	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0704	Date: 01-29-14	Scale: 1: 4	Chkd. By: Kemely Chow

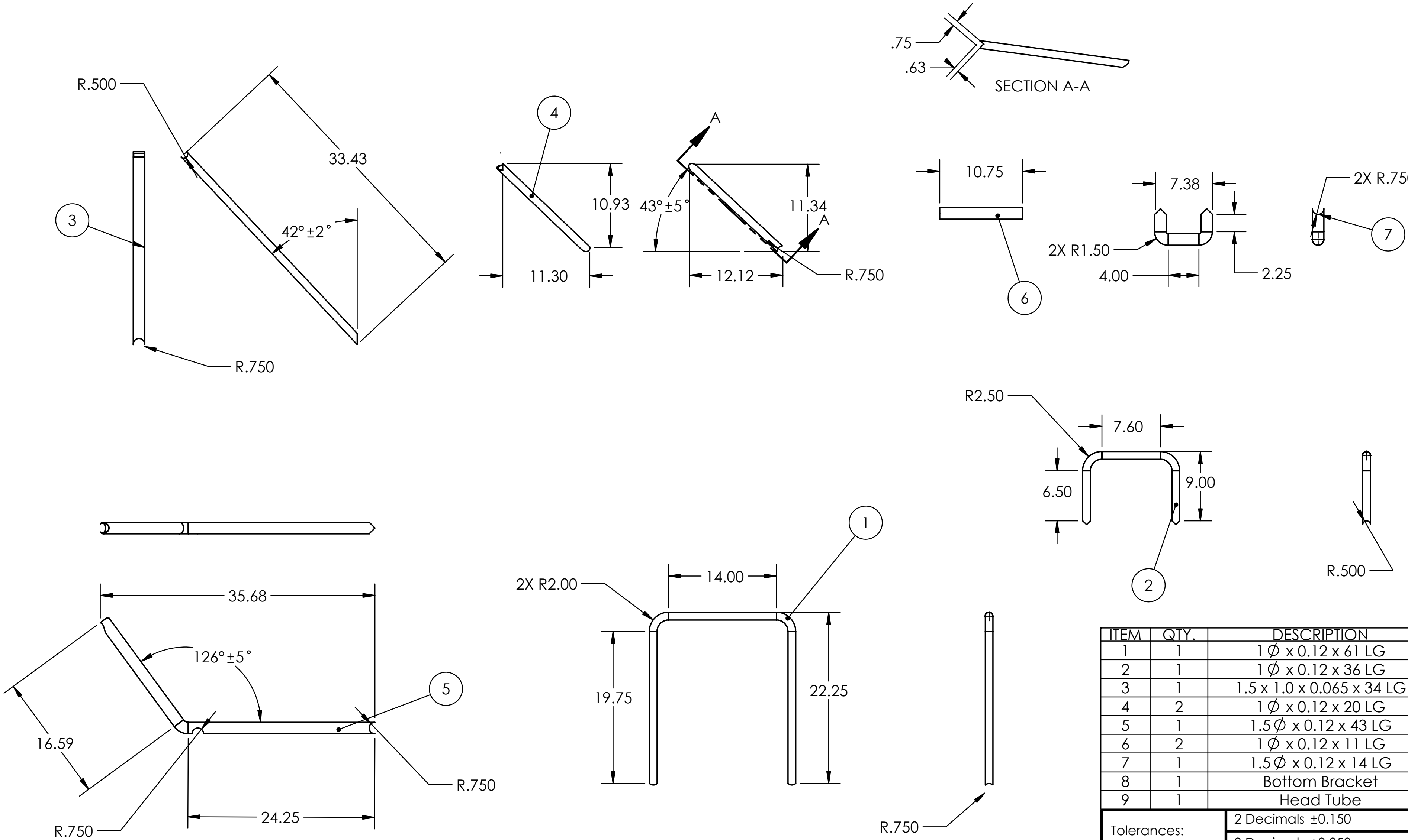




	QTY.	DESCRIPTION
1	1	0.625 ∅ X 0.035 X 24 LG
2	2	3 X 0.5 X 0.125

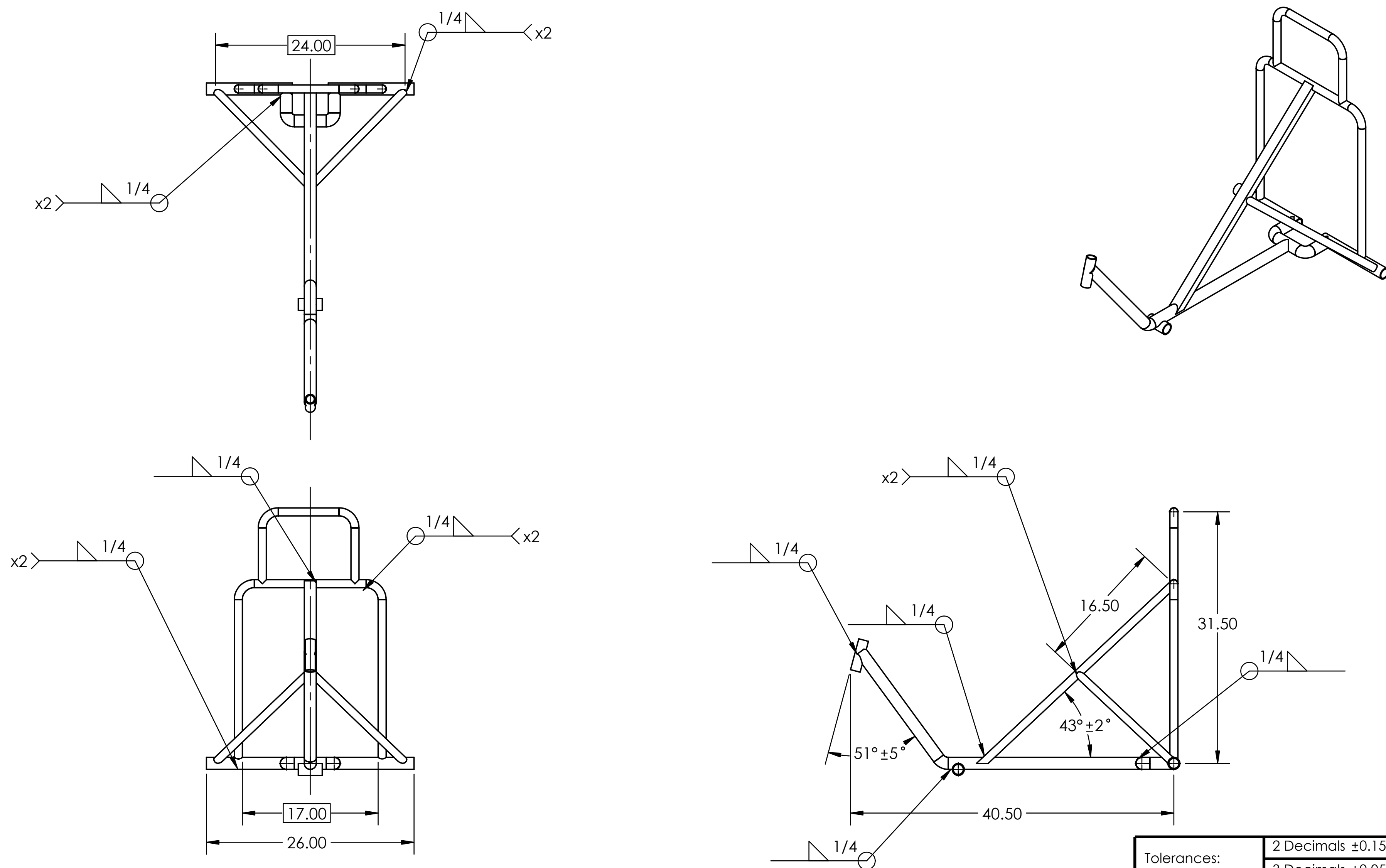
Tolerances:	2 Decimals ±0.10
	3 Decimals ±0.05
Units: Inches	Material: 4130 Steel

Cal Poly Mechanical Engineering	Dwg.#: T0703	Title: Rear Steering Bar Weld Prep	Weight: N/A	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T1000	Date: 01-29-14	Scale: 1: 4	Chkd. By: Kemely Chow



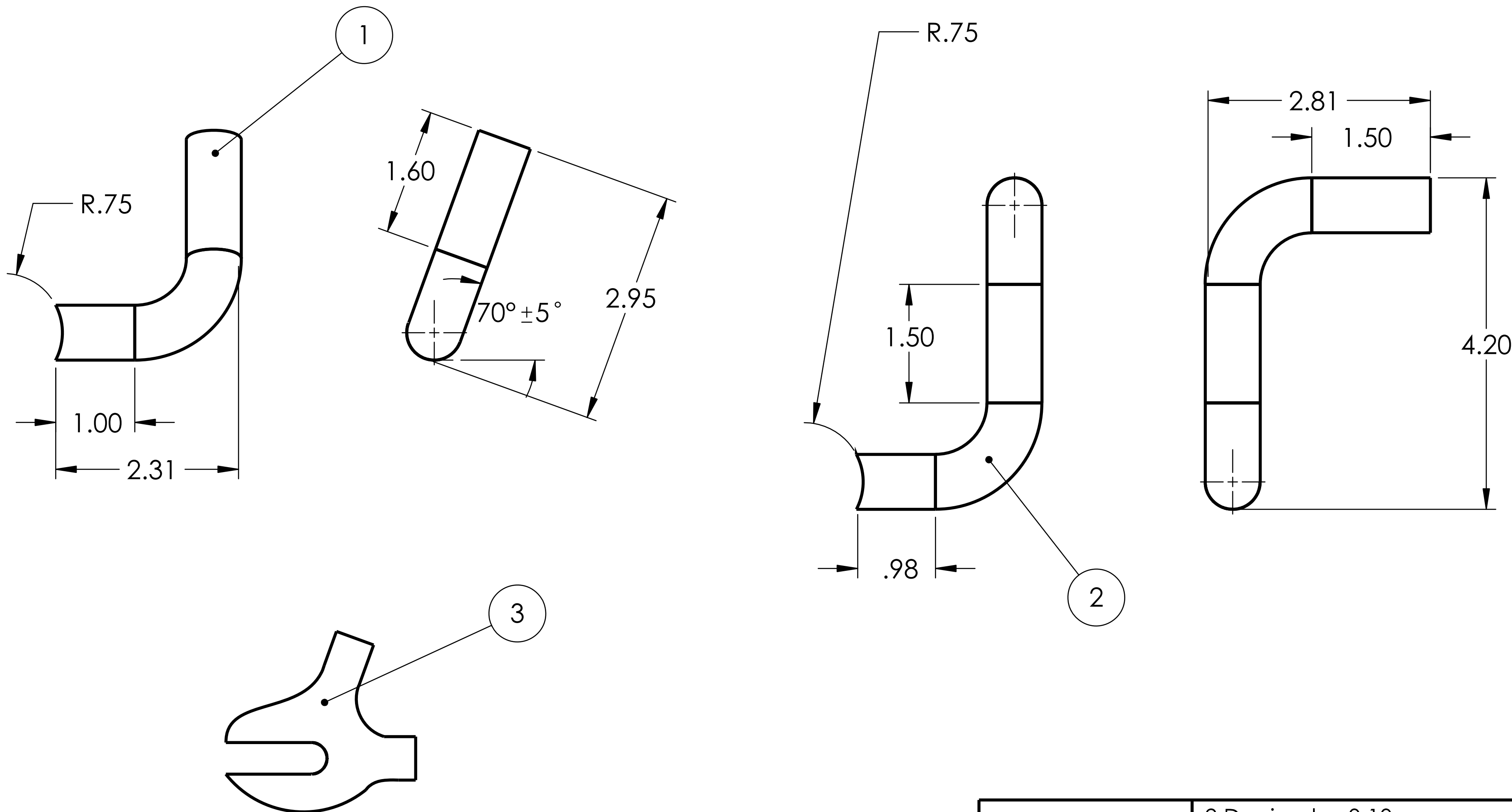
ITEM	QTY.	DESCRIPTION
1	1	1 Ø x 0.12 x 61 LG
2	1	1 Ø x 0.12 x 36 LG
3	1	1.5 x 1.0 x 0.065 x 34 LG
4	2	1 Ø x 0.12 x 20 LG
5	1	1.5 Ø x 0.12 x 43 LG
6	2	1 Ø x 0.12 x 11 LG
7	1	1.5 Ø x 0.12 x 14 LG
8	1	Bottom Bracket
9	1	Head Tube

			Tolerances:	2 Decimals ±0.150 3 Decimals ±0.050
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0801	Title: Tricycle Frame Weld Prep	Weight: N/A	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0899	Date: 01-29-14	Scale: 1:12	Chkd. By: Kemely Chow



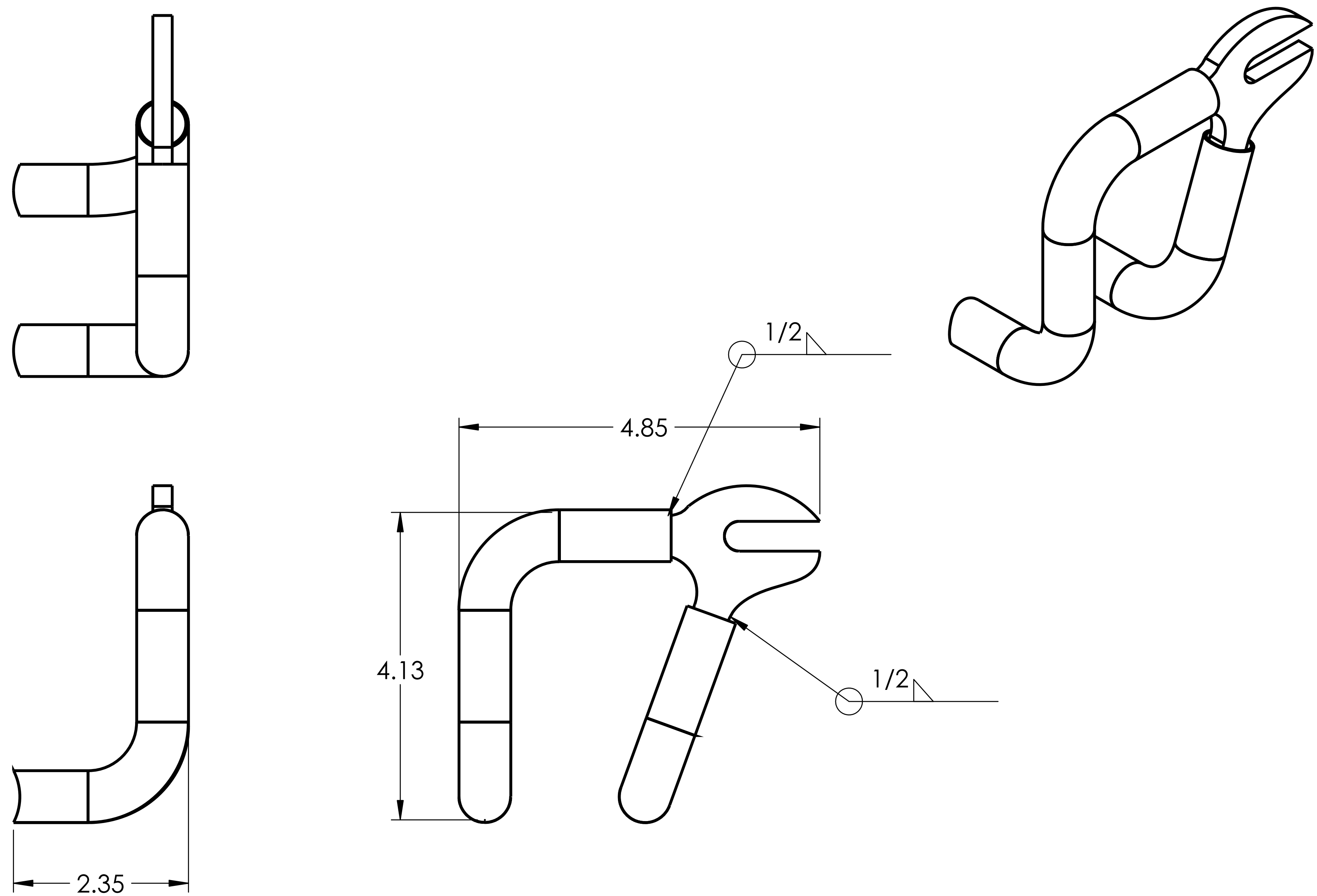
			Tolerances:	2 Decimals ±0.15
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0802	Title: Tricycle Frame Weldment	Weight: 26.42lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0899	Date: 01-29-14	Scale: 1:12	Chkd. By: Kemely Chow

	DESCRIPTION	QTY.
1	0.625 ∅ x 0.035 x 6 LG	2
2	0.625 ∅ x 0.035 x 7.5 LG	2
3	Horizontal Dropout	2



Tolerances:	2 Decimals ±0.10	
	3 Decimals ±0.05	
Units: Inches	Material: 4130 Steel	

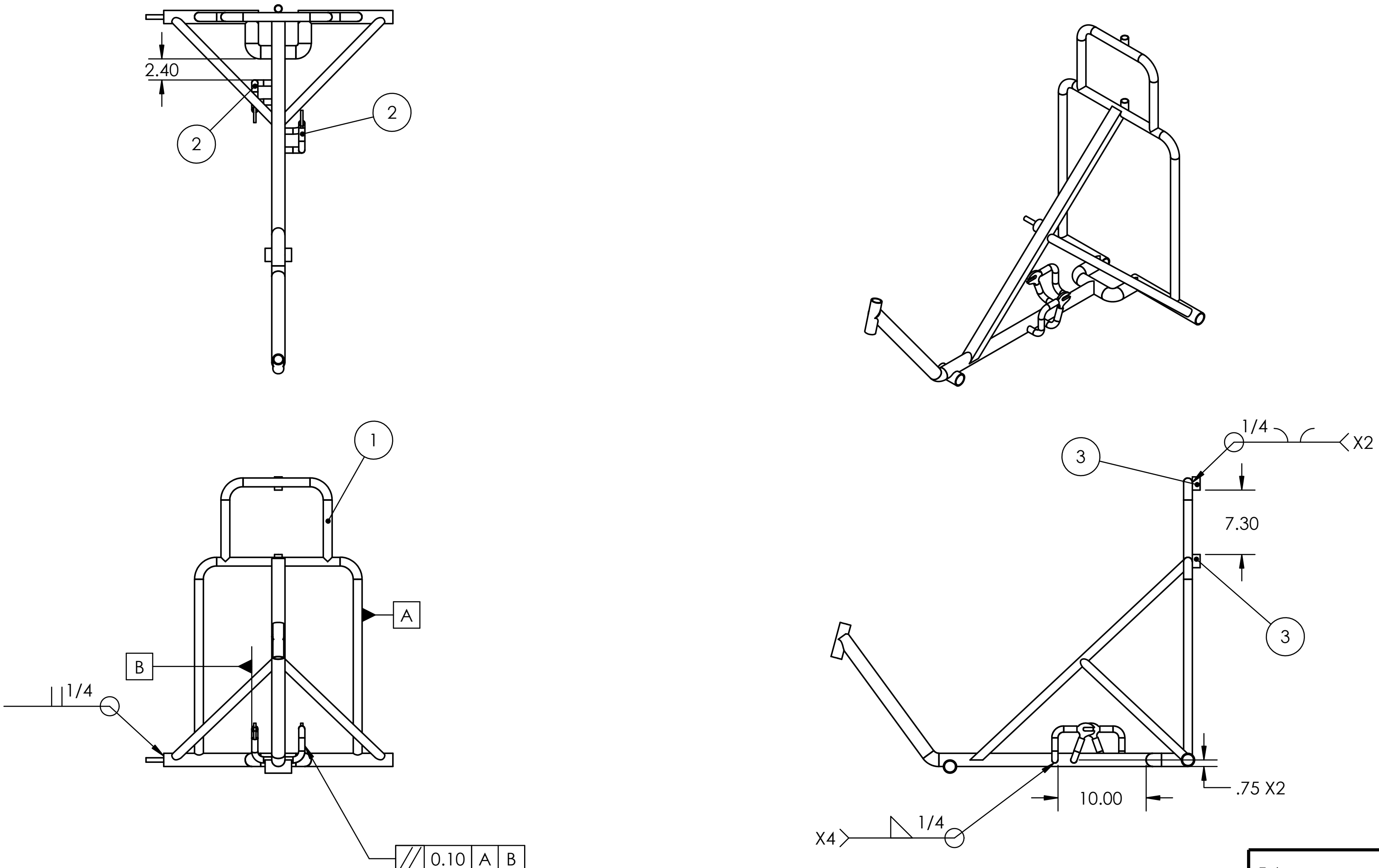
Cal Poly Mechanical Engineering	Dwg.#: T0803	Title: Dropout Mount Weld Prep	Weight: N/A	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0899	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow



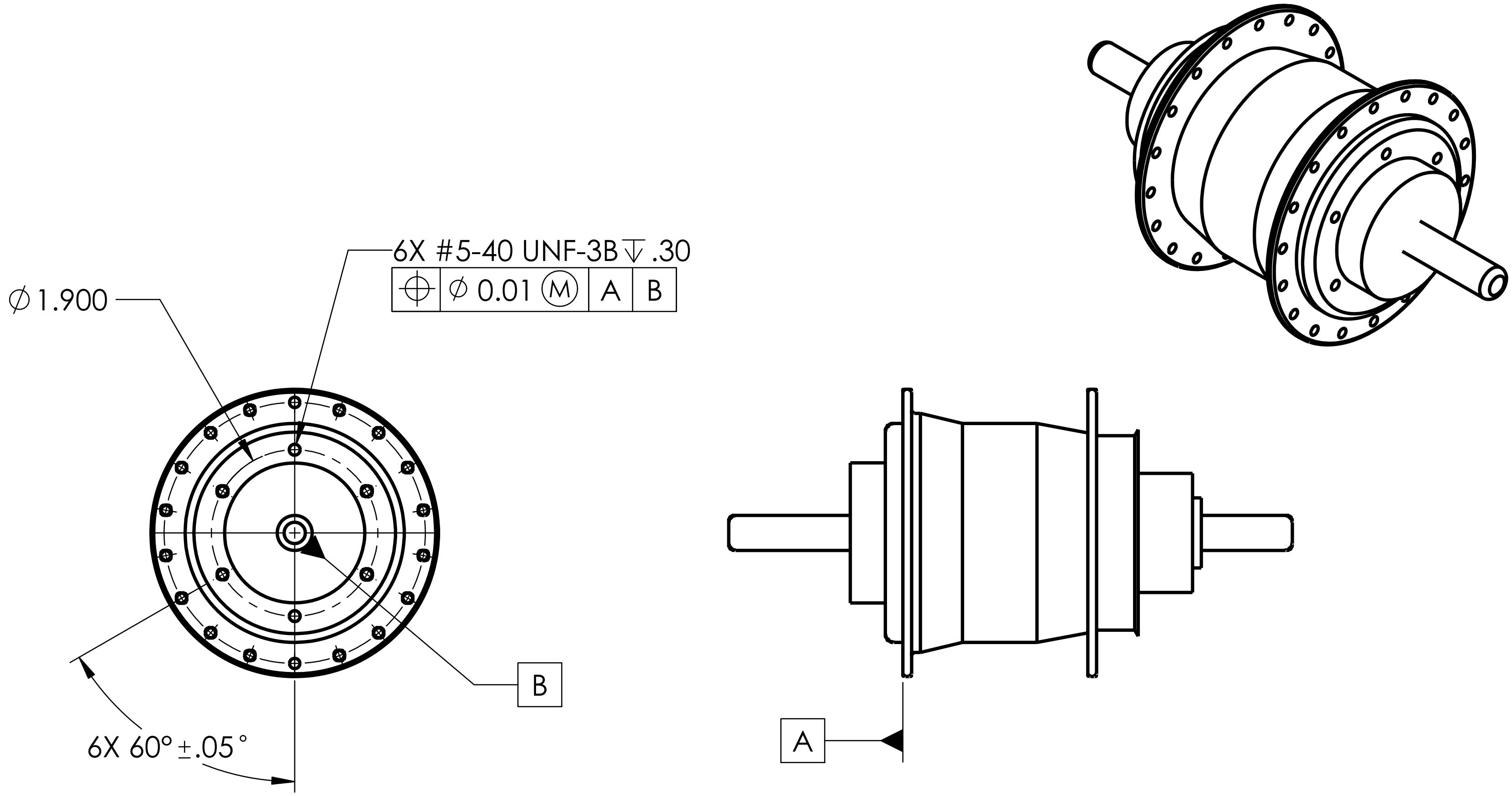
Tolerances:	2 Decimals ±0.10
	3 Decimals ±0.05
Units: Inches	Material: 4130 Steel

Cal Poly Mechanical Engineering	Dwg.#: T0804	Title: Dropout Mount Weldment	Weight: 0.48lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0899	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow

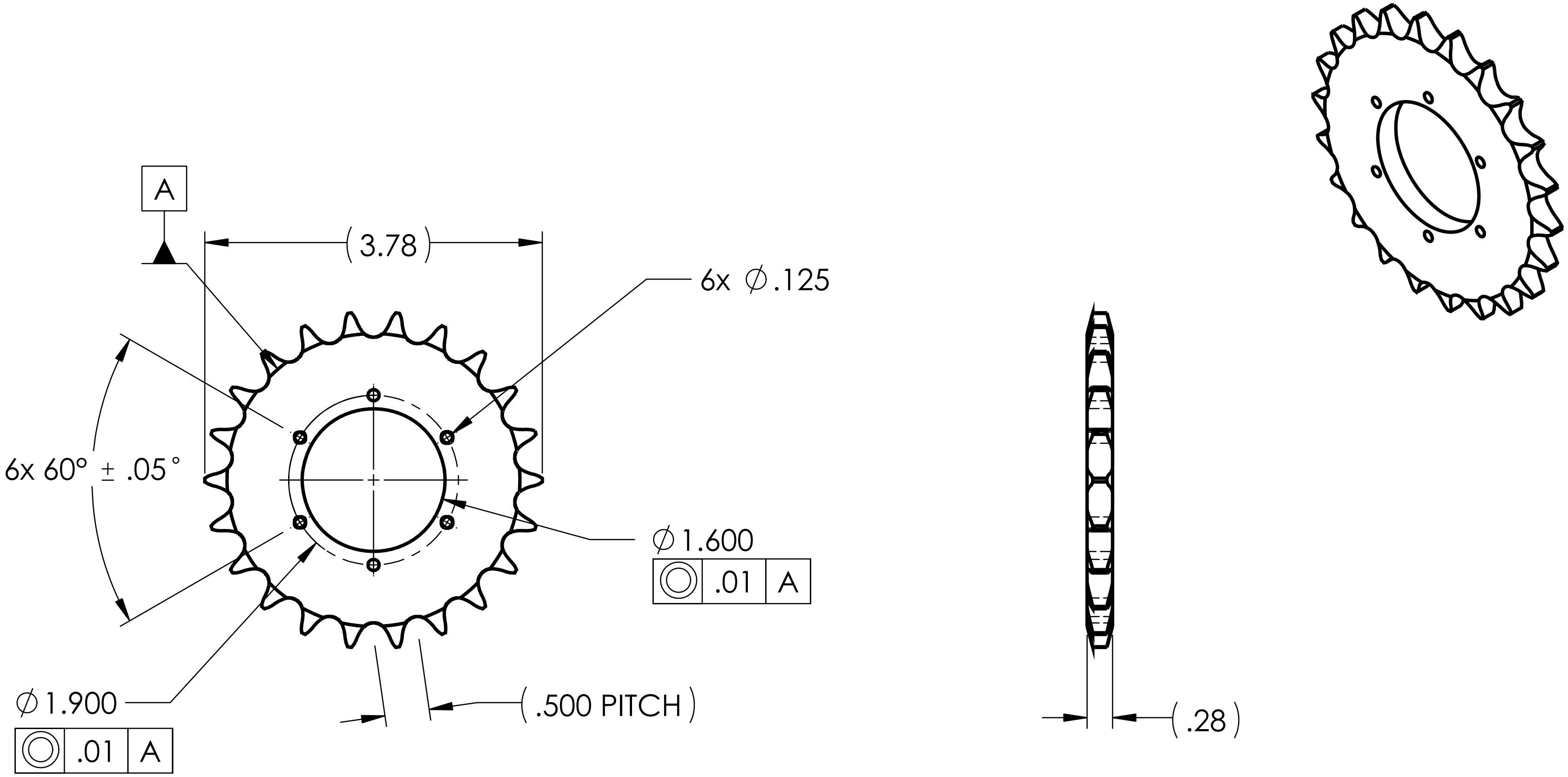
ITEM	PART NUMBER	DESCRIPTION	QTY.
1	T0802	Tricycle Frame	1
2	T0804	Dropout Mount	2
3	T0702	Rear Steering Mount	2



			Tolerances:	2 Decimals ±0.10
				3 Decimals ±0.05
			Units: Inches	Material: 4130 Steel
Cal Poly Mechanical Engineering	Dwg.#: T0899	Title: Mounting Weldments	Weight: 28.58 lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T1000	Date: 01-29-14	Scale: 1:12	Chkd. By: Kemely Chow

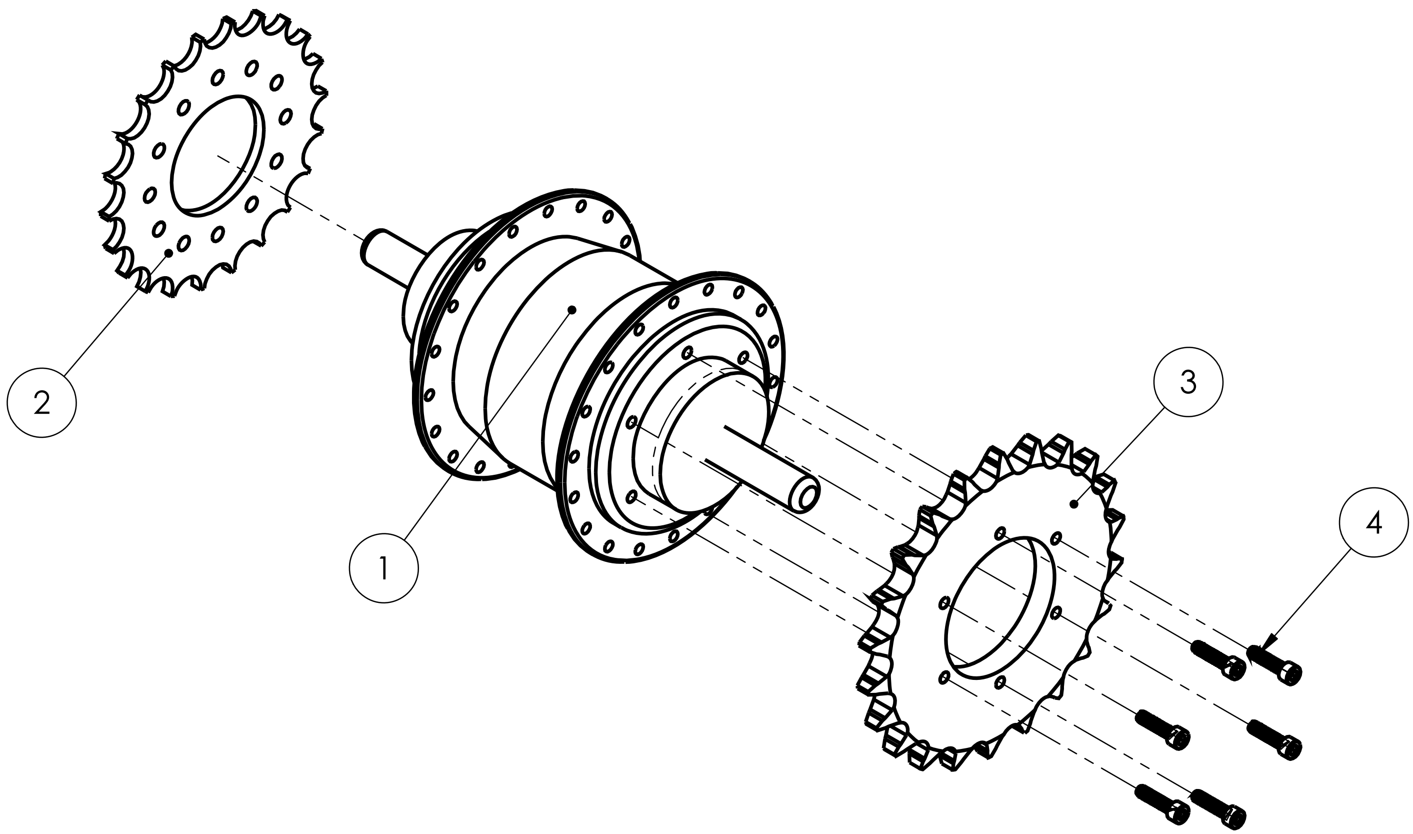


			Tolerances:	2 Decimals ± 0.10
				3 Decimals ± 0.05
			Units: Inches	Material: N/A
Cal Poly Mechanical Engineering	Dwg.#: T0901	Title: Sturmey S3X Modification	Weight: 2.16 lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: T0999	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow



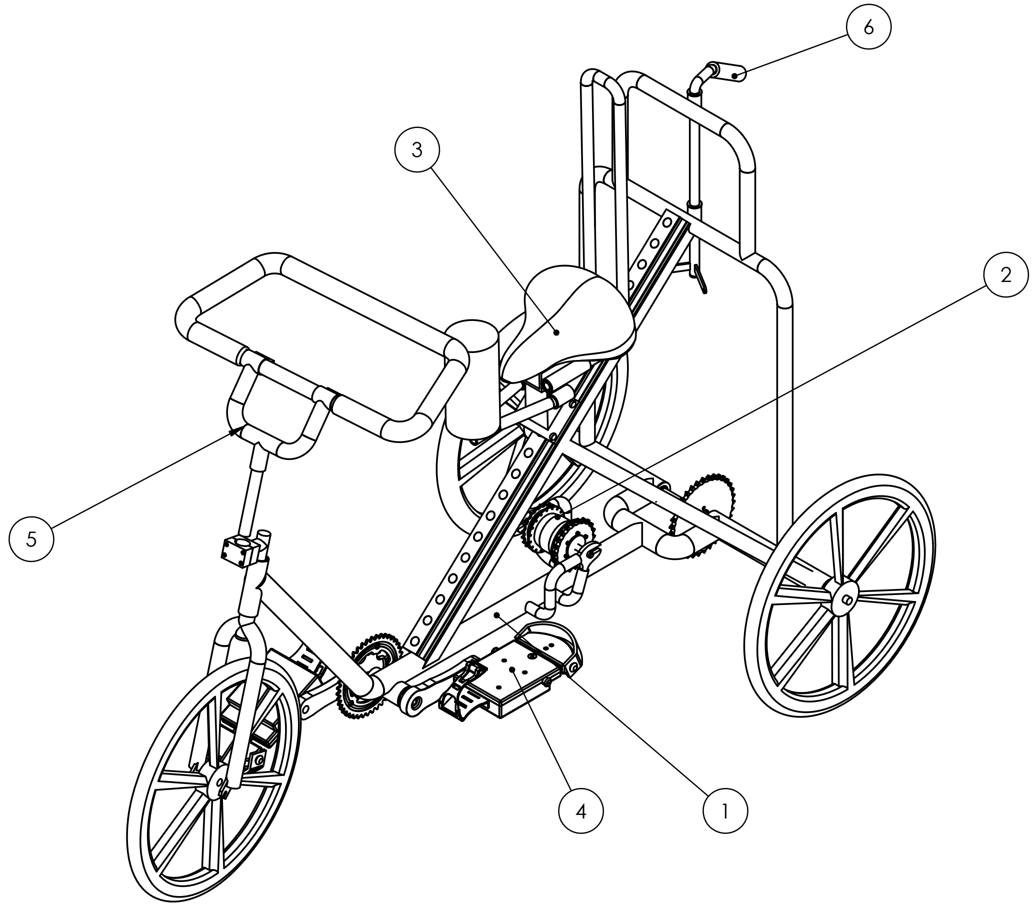
			Tolerances:	2 Decimals ± 0.05
				3 Decimals ± 0.01
			Units: Inches	Material: Steel
Cal Poly Mechanical Engineering	Dwg.#: T0902	Title: 22 Teeth #40 Chain Sprocket	Weight: 0.545 lbs	Drwn. By: Kemely Chow
Trikeceratops	Nxt Asb: T0999	Date: 01-29-14	Scale: 1:2	Chkd. By: Ryan Hirahara

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	T0901	Sturmey Archer S3X	1
2	T0902	22 Teeth #40 Chain Sprocket	1
3	N/A	Sturmey Archer 22 Teeth Sprocket	1
4	91205A124	5-40 1/2" Socket Head Cap Screw	6



			Tolerances:	See Part Drawings
			Units: Inches	Material: See Part Drawings
Cal Poly Mechanical Engineering	Dwg.#: T0999	Title: Hub Assembly	Weight: N/A	Drwn. By: Heather Instasi
Trikeceratops	Nxt Asb: T1000	Date: 01-29-14	Scale: 1:2	Chkd. By: Kemely Chow

1	Frame
2	Drivetrain
3	Seat Assembly
4	Pedal Assebly
5	Forkand Handlebar Assembly
6	Rear Steering



			Tolerances:	See Part Drawings
			Units: Inches	Material: N/A
Cal Poly Mechanical Engineering	Dwg.#: T1000	Title: Tricycle Assembly	Weight: 70.91lbs	Drwn. By: Ryan Hirahara
Trikeceratops	Nxt Asb: N/A	Date: 02-06-14	Scale: 1:8	Chkd. By: Kemely Chow

Appendix C: List of Vendors, Contact Information, and Pricing

Item	Purpose	Quantity	Price	Link
Multipurpose 6061 Aluminum (1"x6"x1')	Pedal Casing Bottoms	1	30.65	http://www.onlinemetals.com/merchant.cfm?pid=1189&step=4&showunits=inches&id=997&top_cat=60
Multipurpose 6061 Aluminum (1/2"x6"x1')	Pedal Casing Tops	1	17.99	http://www.onlinemetals.com/merchant.cfm?pid=1173&step=4&showunits=inches&id=997&top_cat=60
Multipurpose 6061 Aluminum (3/4"x3"x1')	Pedal Heel	1	13.49	http://www.onlinemetals.com/merchant.cfm?pid=1181&step=4&showunits=inches&id=997&top_cat=60
	Pedal Tongue			
4130 Steel Dropouts	Dropouts	1 (set)	24.00	http://www.paragonmachineworks.com/cgi-bin/commerce.cgi?preadd=action&key=DR2013
Crankset Arm	Crank Arm	1	49.00	http://www.amazon.com/Origin8-Crankarm-Set-Forged-
Chainring	Chainring	1	30.00	http://www.amazon.com/Surly-Stainless-Steel-Ring-110mm/dp/B001CK0BZG/ref=sr_1_5?s=sporting-goods&ie=UTF8&qid=1391371080&sr=1-
Bottom Bracket Shell	BB Shell	1	16.95	http://atomiczombie.com/BBRAC%20Steel%20Bottom%20Bra
Shimano UN55 68x115 English	BB	1	19.49	http://www.chainreactioncycles.com/us/en/shimano-un55-square-taper-bottom-bracket/rp-prod71369?utm_source=Google&utm_medium=Shopping&utm_name=UnitedStates&gclid=CLTh7r6zpbwCFaU5Qgodg24
Zimmer HK Manual Clamp	Clamp seat in place	1	UNK	http://www.zimmer-
Origin 8 Pro Thread	Headset	1	27.98	http://smartbikeparts.com/search_details.php?itm=SBP35494a&gclid=COWKsYW5pbwCFc41QgodhRAAHQ
HT 2005	Head Tube	1	20.52	http://www.paragonmachineworks.com/cgi-bin/commerce.cgi?preadd=action&key=HT2005
4130 Chromoly (D 0.75"x0.12")	2-Force Tubing	7.5	47.60	Aircraft Spruce & Specialty Co.
4130 Chromoly (D 1"x0.065")	Handlebars	5.33	23.70	Aircraft Spruce & Specialty Co.
4130 Chromoly (D 1"x0.12")	Frame	16	102.08	Aircraft Spruce & Specialty Co.
4130 Chromoly (2"x1.5"x0.188")	Seat Bracket	1	18.00	McMaster Carr
4130 Chromoly (D 1.5"x0.12")	Bottom Tube	4.75	38.75	Aircraft Spruce & Specialty Co.
4130 Chromoly (1.5"x1"x0.065")	Rail Mount	3	66.44	McMaster Carr
4130 Chromoly (D 0.625"x0.035")	Dropout Mount	2.2	?	?
Sunlite MX	Fork	1	25.49	http://velostarusa.com/sunlite-
Boulevard Gel Plus Women's	Saddle	1	44.99	http://www.bontrager.com/model/11854
ARC 30 ML	Rail	30 in.	UNK	Chieftek Precision
ARC 30 ML	Carriage	1	UNK	Chieftek Precision
Tuffwheel 14"	Wheels	3	UNK	Skyway Wheels
?	Quill Stem	?	UNK	?
?	Head Tube	?	UNK	?
Jagwire	Brake Cable	1	4.00	http://www.jensonusa.com/Brake-Cable-and-Housing/Jagwire-

Jagwire	Cable Housing	25	21.00	http://www.jensonusa.com/Brake-Cable-and-Housing/Jagwire-Brake-Housing-Roll25
Softride Super Straps	Pedal Straps	1 Set	9.99	http://www.softride.com/accessories/specifications/softride_hang5_replacement_strap
Sturmey Archer S3X	3spd Hub	1	129.49	http://www.bikeparts.com/search_results.asp?id=BPC361376&gclid=CJSW95-2trwCFRSUfgodTToAyg
Rifton Trunk Support System	Seat back & trunk support	1	451.50	http://www.rifton.com/products/special-needs-tricycles/adaptive-tricycles?tab=accessories
Rifton Padded Loop Handlebar	Handlebar Assy	1	110.00	http://tadpoleadaptive.com/rifton-conventional-handlebar.html

Pedal

90585A206	Casing Fastener	1 Pack of 10	3.29	http://www.mcmaster.com/#90585a206/=qiatoo
90585A204	Heel Fastener	1 Pack of 10	2.71	http://www.mcmaster.com/#90585a204/=qiatv1
19011	Wing Nut	1 Pack of 4	1.18	http://www.homedepot.com/p/Crown-Bolt-1-4-in-20-Coarse-Zinc-Plated-Steel-Wing-Nuts-4-Pack-19011/202704514
90585A542	Wing Nut Fastener	1 Pack of 10	5.15	http://www.mcmaster.com/#90585a542/=qib04t
Toe clips	Toe Clips	1 Set	20.00	In Store Purchase
Pedals	Pedals	1 Set	15.00	In Store Purchase

Drive Train

1L012AMK	Shaft Collar	1	36.62	https://ec.kamandirect.com/us/catalog/searchResults.jsp?typeSrch=1&_requestid=49747
2299K340	Sturmey machined sprocket	1	22.95	http://www.mcmaster.com/#2299k29/=qit63z
2299K350	Drive shaft Sprocket	1	29.41	http://www.mcmaster.com/#2299k35/=qib54e
6117K120	Partially Keyed Drive Shaft	1	39.62	http://www.mcmaster.com/#6117k12/=qib5pc
6384K365	Drive Shaft Bearings	2	23.14	http://www.mcmaster.com/#6384k365/=qib6t1
HSL942	Sturmey Sprocket	1	3.24	http://www.cambriabike.com/Sturmey-Archer-Coaster-Brake-Cog-Silver-HLS830.asp
98870A340	Key	1 Pack of 10	4.63	http://www.mcmaster.com/#98870a340/=qiekw2

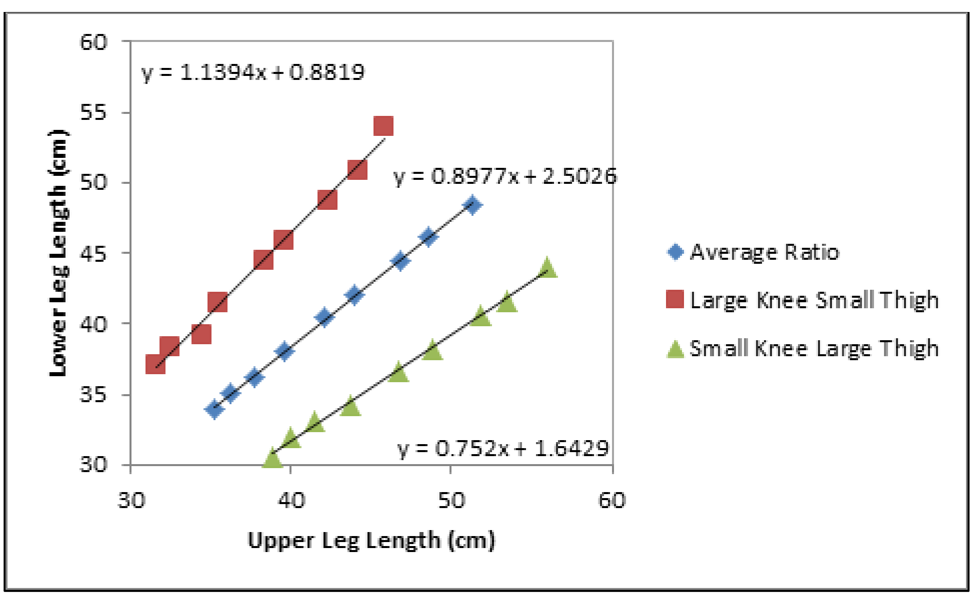
Total Price: 1,550.04

APPENDIX D: ANTHROPOMORPHIC DATA

Upper and Lower Leg Length Data

Age (years)	Average Knee Height (cm)	Average Thigh Length (cm)	Knee (95)	Thigh (5)	Knee (5)	Thigh (95)	Range of Movement (cm)	Range of Movement (in)
6	34	35.2	37.1	31.6	30.6	38.8	43.99	17.32
6.5	35.1	36.2	38.4	32.4	32	39.9		
7	36.2	37.7	39.25	34.5	33.1	41.5		
8	38	39.6	41.5	35.4	34.3	43.7		
9	40.5	42.1	44.45	38.3	36.6	46.7		
10	42	43.9	45.85	39.6	38.2	48.8		
11	44.5	46.8	48.7	42.3	40.6	51.8		
12	46.2	48.6	50.85	44.2	41.6	53.4		
13	48.4	51.3	53.9	45.8	44	55.9	77.65	30.57
								13.25

Plotted Leg Length Ratios



Foot Length Data

Age (years)	Average Foot Length (cm)	Foot (95)	Foot (5)	Range of Movement (cm)	Range of Movement (in)
6	17.2	18.8	15.1	15.10	5.99
6.5	17.6	19.3	15.9		
7	18.1	19.9	16.4		
8	18.8	20.7	17		
9	19.7	21.5	17.9		
10	20.2	22.3	18.4		
11	21.2	23.3	19.3		
12	21.9	23.9	19.9		
13	22.6	24.3	20.4	24.30	9.65
					3.65

Calculated Seat Angle

	Average	Large Knee Small Thigh	Small Knee Large Thigh
Angle From Horizontal	41.91	48.73	36.94

*Parentheses () indicate percentiles

Appendix E: Supporting Analysis

Table of Contents

Frame Calculations - Forces

Weight Distribution

W (lbs)	200
L (in)	60
a (in)	45
b (in)	15

N_f (lbs)	50
N_r (lbs)	150

Member CG

see page 40 of Ryan's notebook

(in Y-Z plane)

l_{CW} (in)	
l_{CE} (in)	25
h_G (in)	22.5
l_{AC} (in)	20
h_A (in)	
θ (deg)	42
α (deg)	41.98

F_A (lbs)	0
F_D (lbs)	
F_G (lbs)	150
M_{AC} (lb*in)	1000

Method of joints

l_{CE} (in)	25
h_G (in)	22.5
l_{DG} (in)	12.5
l_{DW} (in)	4.5
l_{GW} (in)	8

θ (deg)	42
α (deg)	41.98

W_G (lbs)	72
W_D (lbs)	128
F_G (lbs)	72
F_{DG} (lbs)	0
F_D (lbs)	116.6
F_{CD} (lbs)	116.7
F_{CEF} (lbs)	86.7
F_A (lbs)	0

→

$F_{GE, GF}$ (lbs)	36

→

$F_{DE, DF}$ (lbs)	58.3

in yz

total $F_{DE,DF}$ (71.30989

in 3d

Frame Calculations - Bending

Frame Section **Point C**

MATERIAL	*4130 steel*
Parameters	
Tube Diameter (in)	1.5
Wall Thickness (in)	0.035
	60
E (psi)	29000000
I (in^4)	0.04324
c (in)	0.75
density (lb/in^3)	0.284
weight (lb)	2.744891

σ_{yield} (psi)	70000
σ_{max} (psi)	17345
FS	4.035761

MATERIAL	*4130 steel*	$58.56/6ft
Parameters		
Tube Diameter (in)	1.5	
Wall Thickness (in)	0.12	
	60	
E (psi)	29000000	
I (in^4)	0.124781	
c (in)	0.75	
density (lb/in^3)	0.284	
weight (lb)	8.865022	

σ_{yield} (psi)	70000
σ_{max} (psi)	6011
FS	11.64627

MATERIAL	*6160 Al*	$36.76/6ft
Parameters		
Tube Diameter (in)	1	
Wall Thickness (in)	0.065	
	60	
E (psi)	10000000	
I (in^4)	0.020965	
c (in)	0.5	
density (lb/in^3)	0.284	
weight (lb)	3.253452	

σ_{yield} (psi)	40000
σ_{max} (psi)	23849
FS	1.677227

MATERIAL	*6160 Al*	$36.76/6ft

Parameters

Tube Diameter (in)	1
Wall Thickness (in)	0.25
	60
E (psi)	10000000
I (in^4)	0.046019
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	10.03739

σ_{yield} (psi)	40000
σ_{max} (psi)	10865

FS 3.681554

Frame Section DG

L_{DG} (in) 16.815

MATERIAL	*4130 steel*
Parameters	
Tube width (in)	1
Wall Thickness (in)	0.035
L_{DG} (in)	16.815
E (psi)	29000000
I (in^4)	0.020996
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	0.506711

$41.41 for 3ft

δ_{max} (in)	0.024178
σ_{yield} (psi)	70000
σ_{max} (psi)	14879

MATERIAL	*4130 steel*
Parameters	
Tube width (in)	1
Wall Thickness (in)	0.049
L_{DG} (in)	16.815
E (psi)	29000000
I (in^4)	0.028171
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	0.699104

$45.47 for 3ft

δ_{max} (in)	0.01802
σ_{yield} (psi)	70000
σ_{max} (psi)	11090

MATERIAL	*4130 steel*
Parameters	
Tube width (in)	
Wall Thickness (in)	0.049
L_{DG} (in)	16.815
E (psi)	29000000
I (in^4)	0.039259
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	1.124124
$width_O$ (in)	1.5
$height_O$ (in)	1

$57.28 for 3ft

δ_{max} (in)	0.01293
σ_{yield} (psi)	70000
σ_{max} (psi)	7957

MATERIAL	*4130 steel*

Parameters

Tube width (in)	
Wall Thickness (in)	0.065
L_{DG} (in)	16.815
E (psi)	29000000
I (in^4)	0.049821
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	1.471319
$width_O$ (in)	1.5
$height_O$ (in)	1

$66.44 for 3ft

δ_{max} (in)	0.010189
σ_{yield} (psi)	70000
σ_{max} (psi)	6270

Frame Section	**IJ**

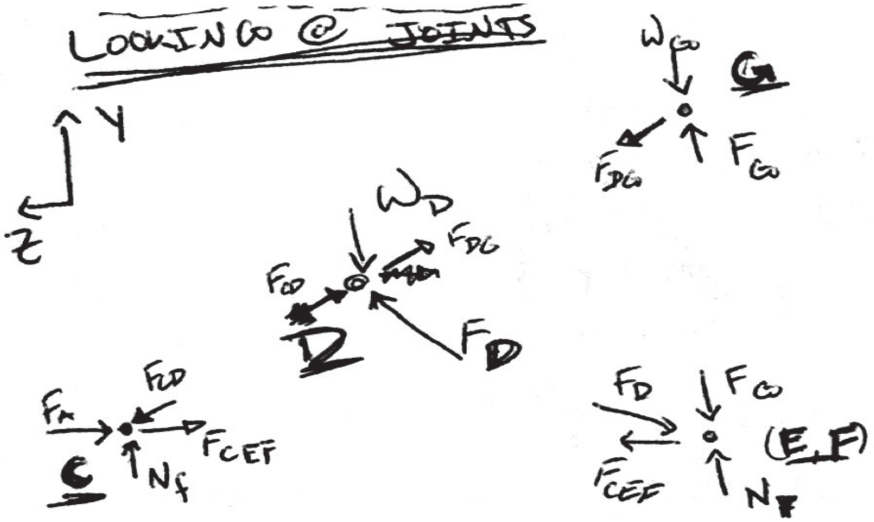
MATERIAL	*4130 steel*
Parameters	
Tube width (in)	1
Wall Thickness (in)	0.035
L_{IJ} (in)	18
E (psi)	29000000
I (in^4)	0.020996
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	0.54242

δ_{max} (in)	0.029932
σ_{yield} (psi)	70000
σ_{max} (psi)	16075

MATERIAL	*4130 steel*
Parameters	
Tube width (in)	1
Wall Thickness (in)	0.12
L_{IJ} (in)	18
E (psi)	29000000
I (in^4)	0.055532
c (in)	0.5
density (lb/in^3)	0.284
weight (lb)	1.695917

δ_{max} (in)	0.011317
σ_{yield} (psi)	70000
σ_{max} (psi)	6078

LOOKING @ JOINTS



$$W_G = \frac{l_{GW}}{l_{DG}} W$$

$$W_D = \frac{l_{GW}}{l_{DG}} W$$

(E, F)

$$\Sigma F_y = 0 = N_f - F_D \sin\alpha - F_G$$

$$\Sigma F_z = 0 = F_{CEF} - F_D \cos\alpha$$

$$F_{CEF} = F_D \cos\alpha$$

G

$$\Sigma F_y = 0 = F_G - W_G - F_{DG} \sin\theta \quad (F_{DG} \to 0)$$

$$\Sigma F_x = 0 = -F_{DG} \cos\theta \quad \Rightarrow F_{DG} = 0$$

D

$$\Sigma F_y = 0 = F_D \sin\alpha + F_{CD} \sin\theta - W_D + F_{DG} \sin\theta \quad (F_{DG} \to 0)$$

$$\Sigma F_z = 0 = F_D \cos\alpha - F_{CD} \cos\theta - F_{DG} \cos\theta \quad (F_{DG} \to 0)$$

$$F_{CD} = \frac{F_D \cos\alpha}{\cos\theta}$$

C

$$\Sigma F_y = 0 = N_f - F_{CD} \sin\theta$$

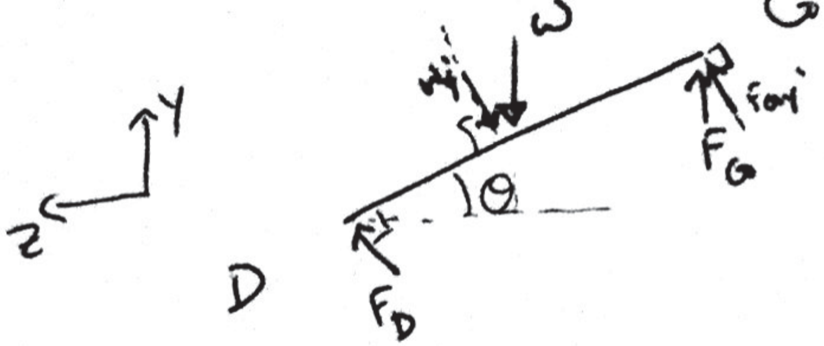
$$F_{CD} = \frac{N_f}{\sin\theta}$$

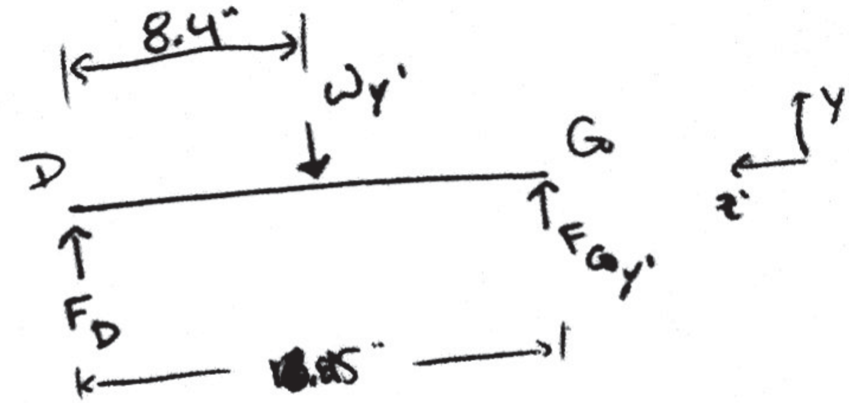
$$\Sigma F_z = 0 = F_{CD} \cos\theta - F_{CEF} - F_A$$

YII

DG in bending

- can only deflect so far until carriage will bind





- worst case when W is in middle

$W_{y'} = W\cos\theta$

$\Sigma F_{y'} = 0 = F_D - W_{y'} - F_{Gy'}$

$F_{Gy'} = F_D - W_{y'}$

$\circlearrowleft \Sigma M_D = 0 = F_{Gy'}(16.815") - W_{y'}(8.4")$

$F_{Gy'} = \frac{1}{2} W_{y'}$

$F_D = \frac{1}{2} W_{y'}$

$\delta_{max} = \frac{W_{y'} L^3}{EI\,48}$ $\sigma_{max} = \frac{y W_{y'} L}{4I}$

Frame Calculations - Buckling

Frame Section	CD

MATERIAL	*4130 steel*
Parameters	
Tube Diameter (in)	1
Wall Thickness (in)	0.12
Length (in)	16.815
E (psi)	29000000
n	1
I (in^4)	0.032711
density (lb/in^3)	0.284
weight (lb)	1.584269

$31.55 for 6ft

Force allowable (lbs)
33112.70849
Force applied (lbs)
116.6510315
FS
283.8612574

MATERIAL	*6160 Al*
Parameters	
Tube Diameter (in)	1
Wall Thickness (in)	0.065
Length (in)	16.815
E (psi)	10000000
n	1
I (in^4)	0.020965
density (lb/in^3)	0.0975
weight (lb)	0.313023

$34.85 for 6ft

Force allowable (lbs)
7318.26114
Force applied (lbs)
116.6510315
FS
62.73636027

Frame Section	DE,DF

MATERIAL	*4130 steel*
Parameters	
Tube Diameter (in)	1
Wall Thickness (in)	0.12
Length (in)	16.815
E (psi)	29000000
n	1
I (in^4)	0.032711
density (lb/in^3)	0.284
weight (lb)	1.584269

$31.55 for 6ft

Force allowable (lbs)
33112.70849
Force applied (lbs)
71.30988711
FS
464.3494729

MATERIAL	*4130 steel*
Parameters	
Tube Diameter (in)	0.75
Wall Thickness (in)	0.035
Length (in)	16.815
E (psi)	29000000
n	1
I (in^4)	0.005036
density (lb/in^3)	0.284
weight (lb)	0.375439

$31.55 for 6ft

Force allowable (lbs)
5097.878368
Force applied (lbs)
71.30988711
FS
71.48908202

MATERIAL	*6160 Al*
Parameters	
Tube Diameter (in)	1
Wall Thickness (in)	0.065
Length (in)	16.815
E (psi)	10000000
n	1
I (in^4)	0.020965
density (lb/in^3)	0.0975
weight (lb)	0.313023

$36.76 for 6ft

Force allowable (lbs)
7318.26114
Force applied (lbs)
71.30988711
FS
102.6261776

Frame Section	**GE,GF**

MATERIAL	*4130 steel*
Parameters	
Tube Diameter (in)	1
Wall Thickness (in)	0.12
Length (in)	22.5
E (psi)	29000000
n	1
I (in^4)	0.032711
density (lb/in^3)	0.284
weight (lb)	2.119896

$31.55 for 6ft

Force allowable (lbs)
18493.68316
Force applied (lbs)
36
FS
513.7134211

MATERIAL	*6160 Al*
Parameters	
Tube Diameter (in)	1
Wall Thickness (in)	0.065
Length (in)	22.5
E (psi)	10000000
n	1
I (in^4)	0.020965
density (lb/in^3)	0.0975
weight (lb)	0.418853

$36.76 for 6ft

Force allowable (lbs)
4087.300887
Force applied (lbs)
36
FS
113.5361358

Tip Over

V(mph)	5
V(ft/s)	7.33
R(ft)	10
a(ft/s^2)	5.38

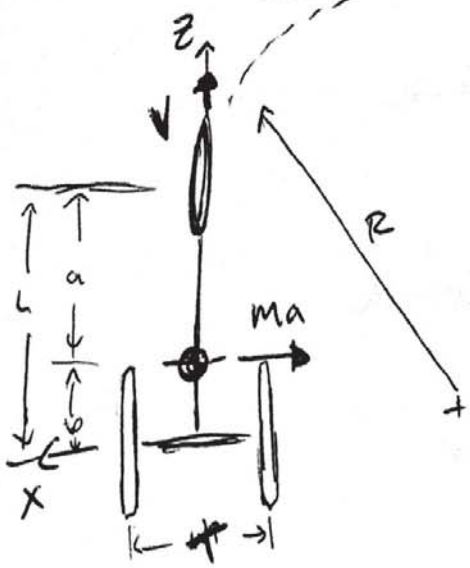
W(lb)	150
Wr(lb)	112.5
h(ft)	3.04
T(ft)	2.5

Nr(lb)	25.77
Nl(lb)	86.73

max accel (ft/s^2)	9.92
at 5mph	
R(ft)	5.26
at 10mph	
R(ft)	21.03
at 7.5mph	
R(ft)	11.83

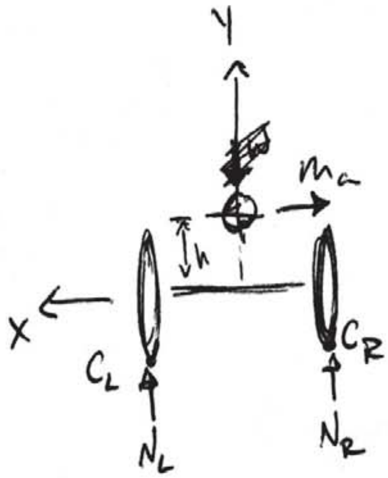
1/16

Tip Over



$$a = \frac{V^2}{R}$$ ⇒ defined by engineering req

$$W_R = W\left(\frac{a}{L}\right)$$



- for right ~~road~~ turn tip over occurs when $N_R \le 0$

$$N_R = \frac{W_R}{2} - ma\frac{h}{T}$$

$$N_L = \frac{W_R}{2} + ma\frac{h}{T}$$

$$N_R \le 0 = \frac{W_R}{2} - ma\frac{h}{T}$$

$$a = \frac{W_R T}{2mh}$$ ← acceleration when tipover occurs

Drivetrain Calculations

AB (in)	BC (in)	CD (in)	DE (in)	EF (in)	FG (in)	GH (in)	HI (in)	IJ (in)	JK (in)	KL (in)
1.000	1.000	1.000	0.250	0.250	10.000	1.000	1.000	3.000	0.250	0.250

N_{RL} (lb)	N_{RR} (lb)	N_F (lb)
80.000	80.000	40.000

Max Pedal Force (lb)
200.000

Chainring (Rotating With Crank)

N_1 (teeth)	R_{Pedal} (in)	D_1 (in)	T_1 (lb in)
35.000	6.693	6.000	1338.600

Sprocket 1 (Rotating With Sturmey Archer / Connected to Sprocket 1 By Chain)

N_2 (teeth)	T_2 (lb in)
22.000	841.406

Gear Ratio	T_{Output}(lb in)
1.000	841.406

Sprocket 2 (Rotating With Sturmey Archer / Connected to Sprocket 4 By Chain)

N_3 (teeth)	D_3 (in)	T_3 (lb in)
22.000	5.860	841.406

Sprocket 3 (Rotating With Drive Shaft / Connected to Sprocket 3 By Chain)

N_4 (teeth)	D_4 (in)	T_4 (lb in)	W_t (lb)
35.000	6.970	1338.600	384.103

Sprocket Loads

B_{1z} (lb)	B_{3z} (lb)
-105.319	-278.785

Wheel Loads

B_{1y} (lb)	B_{3y} (lb)
-91.613	11.613

Moments From Combined Loads

M_{Az} (lb in)	M_{Bz} (lb in)	M_{Cz} (lb in)	M_{Dz} (lb in)	M_{Ez} (lb in)	M_{Fz} (lb in)	M_{Gz} (lb in)	M_{Hz} (lb in)	M_{Iz} (lb in)	M_{Jz} (lb in)	M_{Kz} (lb in)	M_{Lz} (lb in)
0.000	0.000	0.000	0.000	0.000	-26.330	-1079.516	-1184.835	-906.050	-69.696	0.000	0.000

M_{Ay} (lb in)	M_{By} (lb in)	M_{Cy} (lb in)	M_{Dy} (lb in)	M_{Ey} (lb in)	M_{Fy} (lb in)	M_{Gy} (lb in)	M_{Hy} (lb in)	M_{Iy} (lb in)	M_{Jy} (lb in)	M_{Ky} (lb in)	M_{Ly} (lb in)
0.000	0.000	80.000	160.000	180.000	177.097	60.968	49.355	37.742	2.903	0.000	0.000

M_A (lb in)	M_B (lb in)	M_C (lb in)	M_D (lb in)	M_E (lb in)	M_F (lb in)	M_G (lb in)	M_H (lb in)	M_I (lb in)	M_J (lb in)	M_K (lb in)	M_L (lb in)
0.000	0.000	80.000	160.000	180.000	179.043	1081.236	1185.862	906.836	69.757	0.000	0.000

Moments of Inertia

D_{AB}, D_{BC}, D_{CD}, D_{DE}, D_{EF} (in)	D_{FG}, D_{GH}, D_{HI}, $D_{IJ,}$ (in)	D_{JK}, D_{KL} (in)
0.590	0.750	0.500

I_{AB}, I_{BC}, I_{CD}, I_{DE}, I_{EF} (in^4)	I_{FG}, I_{GH}, I_{HI}, $I_{IJ,}$ (in^4)	I_{JK}, I_{KL} (in^4)
0.006	0.016	0.003

Bending Stress

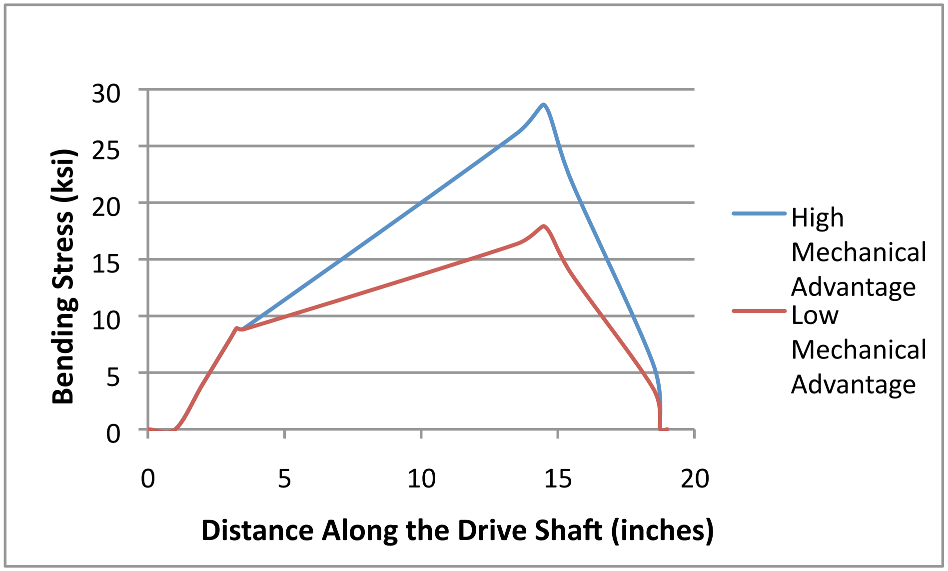
σ_A (psi)	σ_B (psi)	σ_C (psi)	σ_D (psi)	σ_E (psi)	σ_F (psi)	σ_G (psi)	σ_H (psi)	σ_I (psi)	σ_J (psi)	σ_K (psi)	σ_L (psi)
0.000	0.000	3967.656	7935.313	8927.227	8879.781	26105.798	28631.926	21895.003	5684.280	0.000	0.000

Deflection

At A	At H
0.007	0.050

Estimated Required Pedaling Force

μ_f	F_f (lb)	D_{Wheel} (in)	T_{Shaft} (lb in)	T_{Crank} (lb in)	L_{Crank} (in)	F_{Pedal} (lb)
0.100	20.000	20.000	200.000	200.000	5.000	40.000
0.200	40.000	20.000	400.000	400.000	5.000	80.000

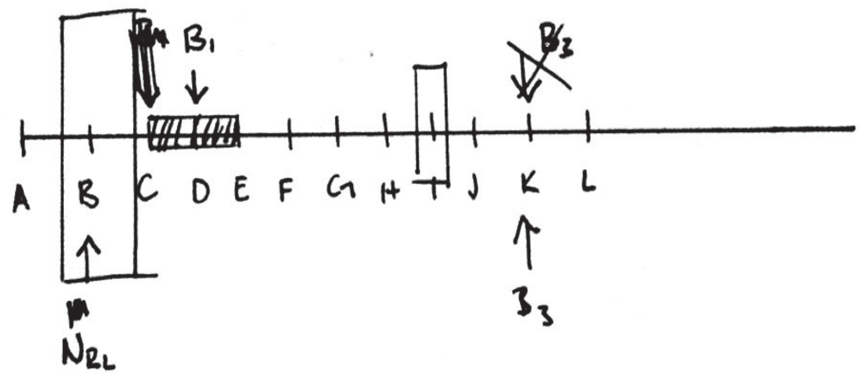


30
25
20
15
10
5
0
0
5
10
15
20
Bending Stress (ksi)
Distance Along the Drive Shaft (inches)
High Mechanical Advantage
Low Mechanical Advantage

NEW ~~SH~~ DRIVE SHAFT DESIGN

DRIVING LEFT WHEEL

WHEEL LOADS



$$\Sigma M_{B_1} = (-N_{RL})(\overline{BD}) + (B_3)(DK) = 0$$

$$B_3 = \frac{N_{RL}\, BD}{DK}$$

$$\Sigma M_{B_3} = (-N_{RL})(BK) + (B_1)(DK) = 0$$

$$B_1 = \frac{(N_{RL})(BK)}{DK}$$

BEAM DEFLECTION

~~A/D~~ ~~$\delta = \frac{PL^3}{3EI}$~~

$$\delta_{MAX} = \frac{Pa^2}{6EI}(3l - a)$$

$l = \overline{EA}$

$a = \overline{BE}$

} BEARING TO WHEEL TO SHAFT END

$$\delta_{MAX} = \frac{Pb(l^2 - b^2)^{3/2}}{9\sqrt{3}\, l\, EI}$$

b = SMALLER LENGTH

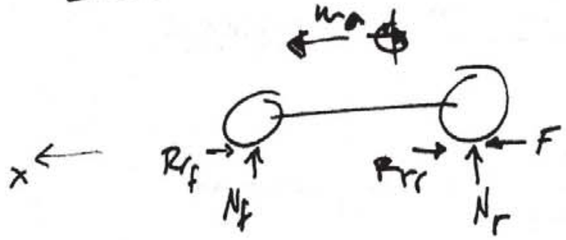
$b = \overline{HK}$

$a = \overline{EH}$

} BEARING TO BEARING W/ SPROCKET

$E \approx 29{,}000$ ksi

FORCE TO MOVE ~~TRIKE~~



$R_{rr} = \mu_{RR} N_r \quad R_{rf} = \mu_{RR} N_f$ $\quad (\mu_{RR} \approx 0.1)$

$F > \mu_s N_r$

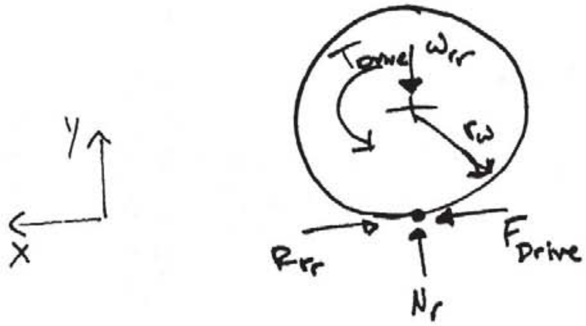
$F = F_p(gr)$

$\Sigma F_x = ma$

2/1

DRIVE WHEEL

$F_{Drive} = \dfrac{T_{Drive}}{r_w}$, where $T_{Drive} = T_{in}(r_{ratio})$



Examining overall body

$\Sigma F_x = ma$

$ma = F_{Drive} - R_{rr} - R_{rf}$, where R_{rr} is rolling resistance for both wheels

& $R_{rr} = \mu_{RR}(N_r)$, N_r is normal force on both rear wheels

$R_{rf} = \mu_{RR}(N_f)$, N_f is normal force front

$ma = \dfrac{T_{Drive}}{r_w} - \mu_{RR} N_r - \mu_{RR} N_f$

→ $a = \dfrac{1}{m}\left(\dfrac{T_{in}(ratio)}{r_w}\right) - \mu_{RR} N_r - \mu_{RR} N_f$ $\quad$ assume $\mu_{RR} = 0.01$

Leg Aligner Deflection Calculations

Given	
Side Force, Fz (lb)	50
Modulus of Elasticity, E (psi)	29000000
x inside diameter (in)	0.5000
x Tube thickness (in)	0.1250
xoutside diameter (in)	0.75
Ix (in^4)	0.012464
h inside diameter (in)	1.25
h Tube thickness (in)	0.125
h outside diameter (in)	1.5
Ih (in^4)	0.128663
height, h (in)	5
Length, x (in)	8
center distance, c (in)	1.5
deflection1 (in)	0.000558
deflection2 (in)	0.011804
deflection3 (in)	0.262322
Total deflection (in)	0.274685

deflection A 0.078697

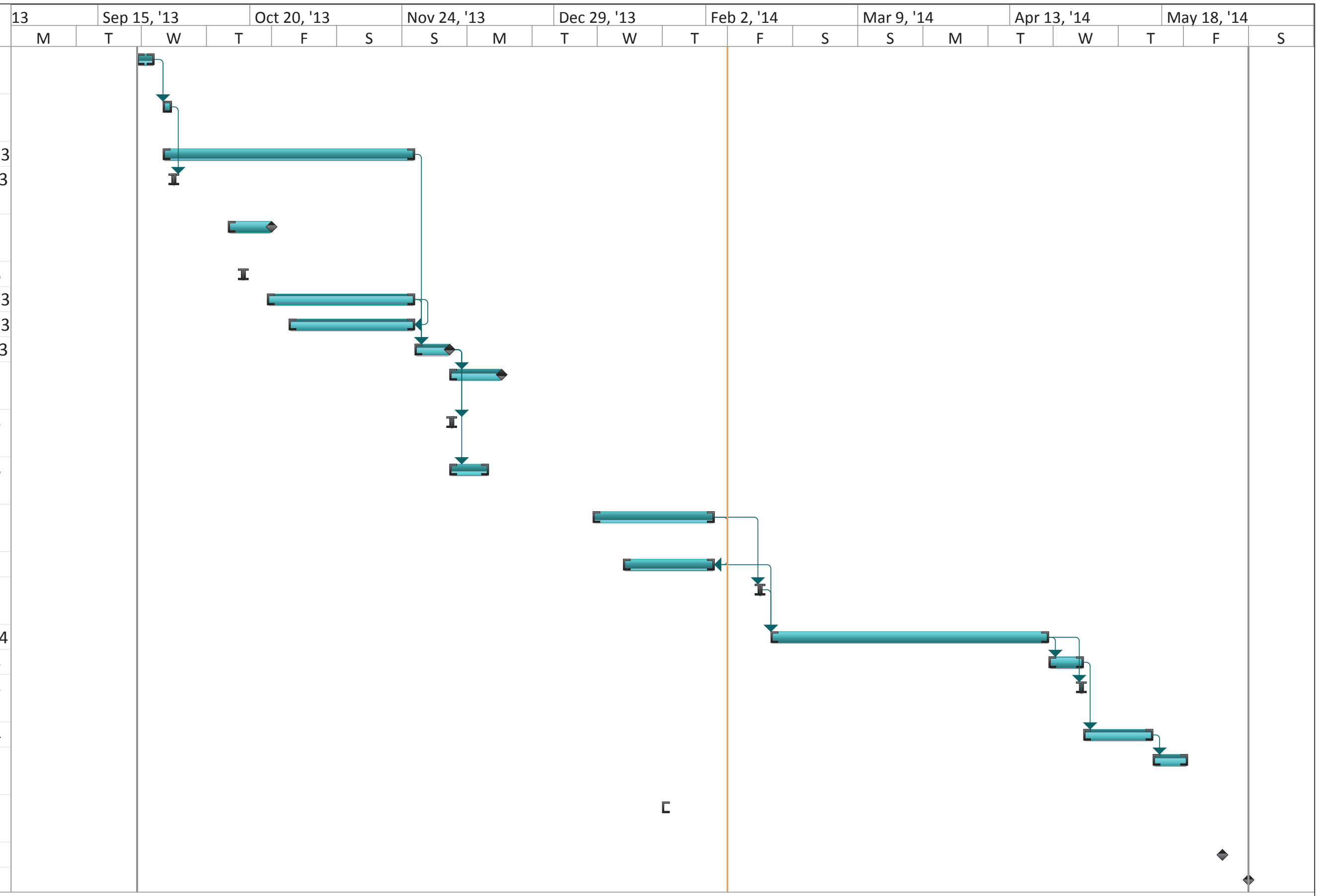
Leg Aligner Deflection Calculations

Parameters

Side Force, Fz (lb)	50
Modulus of Elasticity, E (psi)	29000000
horizontal tube inside diameter (in)	0.5000
horizontal tube thickness (in)	0.1250
horizontal tube outside diameter (in)	0.75
Ix (in^4)	0.012464
vertical tube inside diameter (in)	1.25
vertical tube thickness (in)	0.125
vertical tube outside diameter (in)	1.5
Ih (in^4)	0.128663
height of vertical tube, h (in)	5
Length of horizontal tubes, x (in)	8
center distance, c (in)	1.5
deflection1 (in)	0.000558
deflection2 (in)	0.011804
deflection3 (in)	0.262322
Total deflection (in)	0.274685

Appendix F Gantt Chart

ID	Task Mode	Task Name	Duration	Start	Finish
1		Project Preference Decision	4 days	Tue 9/24/13	Fri 9/27/13
2		Project / Team Assignment	2 days	Mon 9/30/13	Tue 10/1/13
3		Background Research	42 days	Mon 9/30/13	Tue 11/26/13
4		Introduction Letter to Sponsor	1 day	Wed 10/2/13	Wed 10/2/13
5		Project Proposal Document	8 days	Tue 10/15/13	Thu 10/24/13
6		Site Visit	1 day	Fri 10/18/13	Fri 10/18/13
7		Concept Generation	24 days	Thu 10/24/13	Tue 11/26/13
8		Concept Modeling	21 days	Tue 10/29/13	Tue 11/26/13
9		Concept Selection	6 days	Wed 11/27/13	Wed 12/4/13
10		Conceptual Design Report	8 days	Thu 12/5/13	Mon 12/16/13
11		Conceptual Design Review (Lab)	1 day	Thu 12/5/13	Thu 12/5/13
12		Concept Design Review (Sponsor)	7 days	Thu 12/5/13	Fri 12/13/13
13		Detailed Design and Analysis	20 days	Tue 1/7/14	Mon 2/3/14
14		Test Plan Development	15 days	Tue 1/14/14	Mon 2/3/14
16		Critical Design Review (Sponsor)	1 day	Fri 2/14/14	Fri 2/14/14
17		Fabrication	46 days	Mon 2/17/14	Mon 4/21/14
18		Prototype Testing	6 days	Tue 4/22/14	Tue 4/29/14
21		Project Hardware & Assembly Demo	1 day	Tue 4/29/14	Tue 4/29/14
19		Prototype Modifications	12 days	Wed 4/30/14	Thu 5/15/14
20		Additional Prototype Testing	6 days	Fri 5/16/14	Fri 5/23/14
15		Long Lead Items On Order		Thu 1/23/14	
22		Senior Expo			Sat 5/31/14
23		Final Design Report			Fri 6/6/14



Project: Gnatt Chart
Date: Fri 2/7/14

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

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