6-12-2013

Cerberus : a human powered vehicle

Colin Austin
Santa Clara University

Miles Graugnard
Santa Clara University

Max Herrmannsfeldt
Santa Clara University

Dane Kornasiewicz
Santa Clara University

Leif Kjos
Santa Clara University

See next page for additional authors

Author
Colin Austin, Miles Graugnard, Max Herrmannsfeldt, Dane Kornasiewicz, Leif Kjos, Terra Oldham, Toban Platt, Theodore Schapp, and Sean Smith

SANTA CLARA UNIVERSITY

Department of Mechanical Engineering

Date: June 12, 2013

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

Colin Austin, Miles Graugnard, Max Herrmannsfeldt, Leif Kjos, Dane Kornasiewicz, Terra Oldham, Toban Platt, Theodore Schapp, and Sean Smith

ENTITLED

CERBERUS: A HUMAN POWERED VEHICLE

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Prof. Terry Shoup: Project Advisor — Date: 6-13-13

Prof. Drazen Fabris: Department Chair — Date: 6-18-13

CERBERUS: A HUMAN POWERED VEHICLE

by

Colin Austin, Miles Graugnard, Max Herrmannsfeldt, Leif Kjos, Dane Kornasiewicz, Terra Oldham, Toban Platt, Theodore Schapp, and Sean Smith

THESIS

Submitted in Partial Fulfillment of the Requirements for the
Bachelor of Science Degree in
Mechanical Engineering in the School of Engineering
Santa Clara University, 2013
Santa Clara, California

Prof. Terry Shoup, Advisor

CERBERUS: A HUMAN POWERED VEHICLE

Colin Austin, Miles Graugnard, Max Herrmannsfeldt, Leif Kjos, Dane Kornasiewicz, Terra Oldham, Toban Platt, Theodore Schapp, and Sean Smith

Department of Mechanical Engineering
Santa Clara University
Santa Clara, California
2013

ABSTRACT

A recumbent trike was designed and built for the ASME Human Powered Vehicle Challenge held at San Jose State University in April of 2013. The vehicle was designed to be low cost for use by commuters and as primary transportation in developing countries. The vehicle placed 11th overall in the competition out of 29 teams, and scored 8th in the innovation event, which was its best ranking out of the 5 individual events.

ACKNOWLEDGMENTS

The authors would like to thank the following people for their support in this project:

- Professor Terry Shoup: for his support and for sharing knowledge of human powered vehicles.
- Don MacCubbin: for teaching us how to weld and answering all of our questions in the machine shop.
- Professor Timothy Hight: for providing input on our design and assisting us with the design process.
- Dr. Shoba Krishnan: for helping design and build the energy generation circuit.
- Professor Donald Riccomini: for sharing his knowledge of technical communication and making himself available for questions.
- Tread Bike Shop: for sponsoring our project and providing discounted parts.
- R.E. Borrmann's Steel Co.: for sponsoring our project and providing materials for our prototype.

Contents

List of Figures

List of Tables

Chapter 1: Introduction

The goal of the project was to design and build, from the ground up, a human powered vehicle suitable to compete in the Human Powered Vehicle Challenge (HPVC) sponsored by the American Society of Mechanical Engineers (ASME). This competition is designed to test the endurance, speed, design, and innovation of the vehicles. The Santa Clara University vehicle, *Cerberus*, was designed for ease of manufacture, practicality, and cost effectiveness, while still being competitive in the challenge.

The Human Powered Vehicle Challenge rules and events played a large role in the design of the trike. The competition was based on four categories: a design report, innovation demonstration, top speed event, and endurance race. The endurance race had obstacles such as stop signs, grocery drop offs, and hairpin turns, used to simulate realistic commuting environments and to promote practical designs. The competition also required the use of an aerodynamic device, in addition to storage space and a roll protection system (RPS).

Our design was based on the concept of a three-wheeled "tadpole trike" design, which was chosen for stability and ease of use. Tadpole describes the wheel configuration. There are two wheels in the front, as opposed to a delta design with two in the back. The frame represents the goals of frugality and sustainability, and was designed to be inexpensive and easy to make. *Cerberus* was designed with the idea of open source sharing and implementation worldwide. Our goal was to have a vehicle that could be manufactured easily in locations where skilled labor is hard to find.

Electricity is often unreliable in many rural areas of the world, so an innovative method of generating and storing lost braking energy was developed for the rear wheel of the trike. This energy storage system powers a USB device, a removable set of rechargeable batteries, and mounted lights on the vehicle. This innovation will benefit users locally and globally.

Chapter 2: System-Level Considerations

2.1 Systems Overview Requirements

2.1.1 Design Specifications

The design specification called for practicality, ease of manufacture, and cost effectiveness. The specifications are shown below, in Table 2.1. Many of the specifications were determined per the ASME regulations and are denoted by the "Competition" category. Other specifications were based off of a previous entry from Colorado State University.

Table 2.1 Product Design Specifications

Category	Requirement	Metric	Datum	Target	Achieved
Overall	Total Weight	Pounds	<40	<50	66
Overall	Ease of ingress/egress	Seconds to enter and exit	Unknown	<10	5
Overall	Storage	Cubic Feet	N/A	>1	4
Overall	Under budget	US Dollars	N/A	<5000	$2,280.90
Overall	Top speed	MPH	30	25	22
Frame	Track Width	Inches	Unknown	<35	34
Frame	Wheel Base	Inches	Unknown	<40	45
Frame	Frame Weight	Pounds	N/A	<20	12
Frame	Easily manufactured	Single axis cuts and welds, less than 7 custom parts	N/A	Pass	Pass
Energy Storage	Energy storage	Watt hours	N/A	11	
Energy Storage	Energy output	Volts	N/A	5	5
Competition	Braking Distance	Feet from MPH	20 from 15	15 from 15	5 from 15
Competition	Turn radius	Feet	<15	<26.24	8
Competition	Roll Over Protection System: Top Load	Pounds	600	600	*Pass
Competition	Roll Over Protection System: Side Load	Pounds	300	300	*Pass
Competition	Safety Harness	Pass/Fail	Pass	Pass	Pass

**See information on page 4*

The final column of Table 2.1 depicts the values achieved by *Cerberus* as measured during the competition. With the exception of a few of the targets, the trike met and exceeded the expectations that were set before the design and construction. The target was not reached for certain aspects of the trike, including total weight and the top speed. Another iteration of this trike would easily reach the goals established. The frame is overly stiff, so reducing the weight is just a matter of running an optimization study on the steel tubing used or picking a lighter material. Reducing the weight will help the top speed, but the main hinderance to it currently is poor rider geometry, causing inefficient pedaling. For more information on possible future improvements, see Section 14 on page 59. Additionally, the team was not able to test the 600 pound top load or 300 pound side load requirements besides the use of FEA. This analysis showed that the system would not plastically deform, but these specific loads were never applied directly the trike. See Section 3.4.3 on page 22 for more information. During the competition the trike rolled over three times, inadvertently testing the roll bar under realistic riding conditions. The only damage to the RPS was to its paint finish.

2.1.2 ASME Competition Guidelines

The ASME Human Powered Vehicle Challenge is an annual international competition consisting of four main events: design, innovation, endurance, and speed. The design event is scored off of a detailed design report that was submitted 31 days prior to the competition. The innovation event is scored based on a live demonstration given by the teams to a panel of judges. The endurance event tests vehicle durability, and is scored by the number of 950 meter laps completed in 2.5 hours. The endurance event focuses on practicality and features obstacles such as stop signs and slaloms as well as a simulated grocery pick up and drop off. This year, the speed event took place at Hellyer Park Velodrome, and tested the top speeds of the vehicles. Each team was given one lap to accelerate to speed, and the average speed was recorded in a 40-meter time trap.[1]

The competition provided many design specifications relating to safety for all entrants. The most significant requirement was the need for a roll protection system that could withstand 600 pounds applied 12 degrees from the vertical, and 300 pounds applied

[1] ASME. *Rules for the 2013 Human Powered Vehicle Challenge*. June 2012.

horizontally at shoulder height. These loading conditions can be seen in Figure 2.1.

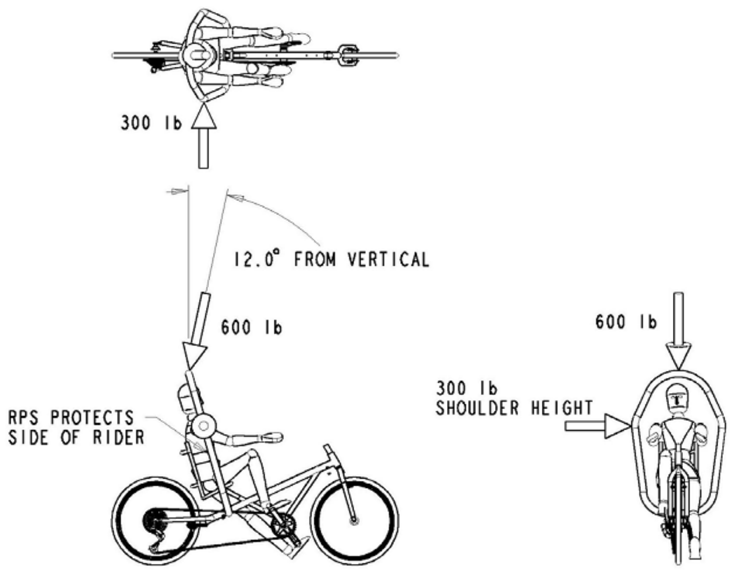


Figure 2.1 Shows the loading conditions that the roll protection system was designed to withstand.[1]

The obstacles in the endurance event played a considerable role in the design of the trike, as it added to the practicality of the vehicle. Other requirements such as stopping distance, turning radius, and an aerodynamic device, also provided direction for the design. A detailed outline of the requirements can be found in Appendix I. Unfortunately the original venue, NASA Ames at Moffett Field, became unavailable. This led to a venue change, which caused the drag race to be turned into a top speed test. This caused problems because the SCU trike was geared for acceleration, not pure top speed. Additionally, certain obstacles the rules advertised, such as speed bumps, were not actually present on the endurance course. These changes were made days before the competition, and did not allow enough time to alter the design or accommodate for the changes.

2.1.3 Customer Needs

There are a surprising number of recumbent trikes currently on the market, with many variations to accommodate different customers. The categories for trike design range from style and comfort to speed and ruggedness. This trike was designed to be a hybrid model, to take into account both ends of the spectrum. It was intended to be a cheap, reliable, and easy form of single-person transportation, in addition to being entered into ASME's competition. This means that the trike had to be lightweight, low-profile, and efficient.

To help research and evaluate customer needs, a datum was modeled after Utah Trikes. Utah Trikes is an industry leader in the recumbent trike market. The catalog alone boasts over 100 specific trike models.[2] The company takes pride in their wide variety and ability to produce a perfect trike for the customer. Trikes featured on the company's website range from $800 to $5,000 and are available with a variety of features. Some common specifications for trikes include: weight and weight capacity, size dimensions, adjustability, and frame rigidity.

Most high-end trikes weigh less than 40 pounds and some feature adjustable seats and folding frames. The frames for these high-end models are constructed of aluminum alloy or carbon fiber. This company sells the lightest trike frames on the market, but these trikes can cost the consumer over $4000. Additionally, Utah Trikes does not offer any vehicles with roll protection systems, or energy storage/generation devices on any of their vehicles

In order to better understand what the average customer wants in a tricycle, a survey was conducted. Eight students and adults from around Santa Clara University were asked a series of questions to determine what the most important factors in a human powered vehicle were. Interviewees were male and female riders ranging from age 18 to 45. The survey focused on people who spend more than three hours a week on a bicycle either for leisure or commuting. The four questions in the survey as well as the individual responses, can be found in Appendix H. Our interpretation of the results are shown in Table 2.2.

After conducting the survey, the team developed a design plan to make the vehicle good for commuting and short trips by focusing on rider safety, rider comfort, and vehicle storage space. The interviews indicated that safety was one of the bigger concerns with commuting by HPV, so to improve safety the vehicle team developed a roll protection system, seat belt, and improved vehicle visibility by adding 80 lumin headlights and a

[2] *Online Catalog* Utah Trikes 2013 URL: http://www.utahtrikes.com/catalog.html.

Table 2.2 Market research results and corresponding design plan.

Area of Improvement	Customer Need	Design Plan
Safety	Safer transportation than a traditional bike	Improve visibility, add lights, install a roll bar
Efficiency	A vehicle that is easier to ride	Optimize drivetrain and aerodynamics
Comfort	Comfort for long distance travel	Design ergonomic steering system.
Storage	Compartment for cargo	Incorporate storage area

brake light. The drivetrain was designed to allow the rider to shift gears while at a stop, so that he can shift down while waiting at a stop sign. The interviews also indicated that the limited storage space of a bike makes it difficult to run errands, so *Cerberus* has two baskets that hold a total of just over 4 cubic feet of cargo–enough to hold four gallon-size jugs of milk and still have space left over. The goal was not to reinvent the bicycle, but instead to improve the areas in which bicycles are limited because of their inherent design.

2.2 Benchmarking

Recumbent tricycles made for road racing, recreation, and commuting are all currently on the market, so there were many options to benchmark against. However, the team's goal was to build one that was competitive yet practical and easy to manufacture. After researching and establishing customer needs, design specifications were developed. Some of the available racing trikes offer seat adjustability to accommodate different sized riders and originally the seat was designed be adjustable. However, this was not possible on *Cerberus* due to manufacturing constraints.

Most of the tricycles currently on the market offer little to no aerodynamic drag reduction. Drag is a substantial limiting factor in the top speed of a moving vehicle. To reduce drag at high speeds, the final design included a fairing that prevents the rider from being exposed to wind. In addition to increasing aerodynamic efficiency, the device also improved the experience of the rider in a number of ways. It protected the rider from road dirt and mud, allowed for a higher top speed, and reduced the wind chill discomfort associated with long distance rides at high speed. Additionally, the ASME competition required all vehicles to be equipped with a roll bar and safety harness, features that are not seen on any currently available tricycles. These two safety factors provide even more reason to invest in this design.

Table 2.3 Relevant specifications for current recumbent trikes on the market.

Product	Price	Wheelbase (in)	Track Width (in)	Weight (lbs)	Frame Material	Other features
TerraTrike Sportster Elite	$2,599	45	31	36.5	Heat treated aluminum	Disk brakes, direct steering
Greenspeed x5 Sport	$4,490	38.58	29.5	37	Aluminum	Disk brakes, folding
KMX Venom	$1,999	42	30.5	38	Aluminum	Narrow wheels, disk brakes, direct steering
ICE Vortex	$3,860	48.5	27.5	32.3	4130 chromoly	Disk brakes, racing wheels

The unique combination of an energy storage system and a recumbent tadpole trike design makes *Cerberus* unlike any vehicle that is currently on the market. These characteristics represent frugality, innovation, and practicality, which set the vehicle apart from any other competition.

2.3 System Layout

The trike was designed to appeal to both high and low budget riders. First, everyday bikers in cities may use this recumbent trike as a safe and sustainable alternative to a car. The second application is for those in developing countries. The trike can be used as a reliable means of transportation and provides battery power for charging small appliances. Figure 2.2 shows a rough sketch of the system as a whole.

2.4 Functional Analysis

The main function of a human powered vehicle is to transform human movement into linear motion. The mechanical process of accomplishing this task is completely open to interpretation; the most popular method uses chain-driven gears powered by pedals. Due

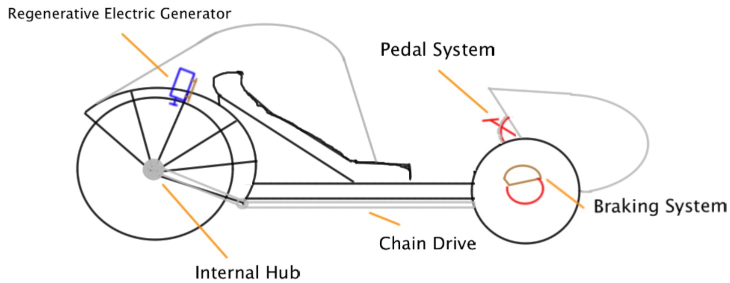


Figure 2.2 A rough sketch of the competition tricycle with partial fairing.

to key constraints and considerations, there are a number of different features, trade-offs, and components that improve the efficiency of this process. They all depend on the category that this function falls under. This system must support the rider and drive train, minimize drag, and provide means for controlling the overall vehicle.

This system can be broken down into the following sub-systems: frame, steering, fairing, drive train, and energy storage.

2.4.1 Frame

The main function of the frame was to provide sound structural support for the rider, and all components of the trike. The seat had to support the weight of a 250lb rider without deflecting significantly. When loaded with a rider, the frame needed to be able to clear a 3.5 inch speed bump without bottoming out. The frame also features a roll protection system and safety harness, which were required by the HPVC rules. This roll bar was designed to withstand a 600lb vertical load and a 300lb side load without deflecting more than 2 inches and 1.5 inches respectively, and without plastic deformation to any member of the frame or roll bar.

2.4.2 Drivetrain

The primary function of the drivetrain was to convert the energy input of the rider into energy in order to power the trike. As a rider applies force to the pedals, the force is translated to rotational energy through the cranks and front gears. The chain, which is attached to the front and rear hub, translates the energy from the front gear to the rear hub along the frame of the trike, guided by two separate idler wheels. The rear hub turns the rear tire, driving the trike forward. Depending on the gear ratio between the front gear and rear hub, the rider is able to rotate the rear tire one to three times per rotation of the front gear. As the rear tire drives the trike, the front two tires spin to allow the trike to move forward while remaining balanced.

In order to stop the trike, brakes were attached to the front two tires. They are used to slow the rotation of the wheels and bring the trike to a stop. The trike's center of gravity is low enough that reducing the speed of the front tires will not cause the trike to tip forward. The brake pads cause friction against the rotors, changing the rotational energy of the wheels to heat through friction. This slows down the wheels until the rotational energy cannot overcome the friction of the brake pads and the wheels come to a stop.

2.4.3 Energy Storage

The main function of the energy storage system was designed to harness energy generated by the human rider from the vehicle and store this energy in a way in which it can be accessed. The system was designed to convert mechanical energy to electrical energy, store that electrical energy for an extended period of time if necessary, and allow the stored electrical energy to be used at will. This system was created to be simple and straightforward but provide for a wide range of applications.

The first input for the system is the mechanical energy of the rotating back wheel of the trike. Using the friction between the rear tire and a dynamo generator, the energy is harvested and then stored in a battery. Depending on the demands of the operator, the electricity is used to charge a set of rechargeable batteries, operate the front and rear safety lights, or is redirected to charge a small personal device.

One of the greatest restraints for this system is the inefficiency of friction energy transfer. The angle at which the dynamo contacts the wheel and the pressure which it applies to the wheel has a large effect on the efficiency of power transfer. Additionally, the generator itself has internal resistances that lead to loss of energy. As such, the generator is only modestly efficient. The dynamo produces a large range of current from 0 A to well over 30 A at full speed. The goal is to regulate the voltage at 5 volts and smooth current spikes for a smooth power curve. At 5 volts, USB devices may be charged.

2.4.4 Steering

The function of the steering system was to provide reliable and responsive control of the vehicle. The steering was designed to be ergonomic, lightweight, and provide supports for brake levers and other necessary mechanisms on the handlebars. To meet the goals of practicality and simplicity, the steering was designed to be constructed by a semi-skilled laborer.

2.5 Design Process

This project was started from scratch. There were no previous vehicles to build off of, so there were many decisions that needed to be made early in the process. In order to organize these decisions, the options were mapped out in a web of decisions and the pros and cons of each were listed and prioritized. The main web can be seen in Figure 2.3.

Figure 2.3 The web of options considered when choosing a design.

A similar web was made for each subsystem to determine the most effective system design. These design matrices will be discusses in further detail in each specific subsystem.

2.6 Project Management

The team of nine was split into two groups in order to manage tasks and responsibilities more effectively: The Frame and Fairing (FF) team and The Drivetrain and Energy Storage (DT) team. The FF team was responsible for designing the frame, steering, braking, and fairing of the trike. The DT team designed the propulsion and energy storage mechanisms on the vehicle.

2.6.1 Budget

The budget for this project was originally determined by estimated material and component costs. The frame was designed to be as simple as possible to minimize the budget. The School of Engineering as well as the Center for Science, Technology, and Society granted a total of $5,000 to the project, shown in Table 2.4.

The grant received through the center for Science, Technology, and Society was awarded to the team to support the development of a vehicle that could potentially be used in developing countries as a primary mode of transportation.

The cost of the base frame was originally estimated to be $200, and would be fitted with inexpensive components. For the final design, high-end racing components were installed. This made the vehicle more competitive for the race. This was made possible through the generous grants that the team received.

The final vehicle prototype costs $2,280.90. A more detailed cost breakdown is in Chapter 10 on page 47, and a complete bill of materials is in Appendix C.

Table 2.4 Project income.

Source	**Amount**
Center for Science Technology and Society	$2,500
Engineering Undergraduate Programs	$2,500
Total	**$5,000**

2.6.2 Timeline

The design process started in October of 2012, shortly after the beginning of the academic year. The timeline for the project is shown in Figure 2.4. The goal was to have a working prototype by January in order to have the ability to develop a final design for the competition. As the manufacturing began, we realized we would not have the resources to develop a second vehicle in time for the competition. The first steel order was placed at the beginning of November, which marked the beginning of the manufacture for the project.

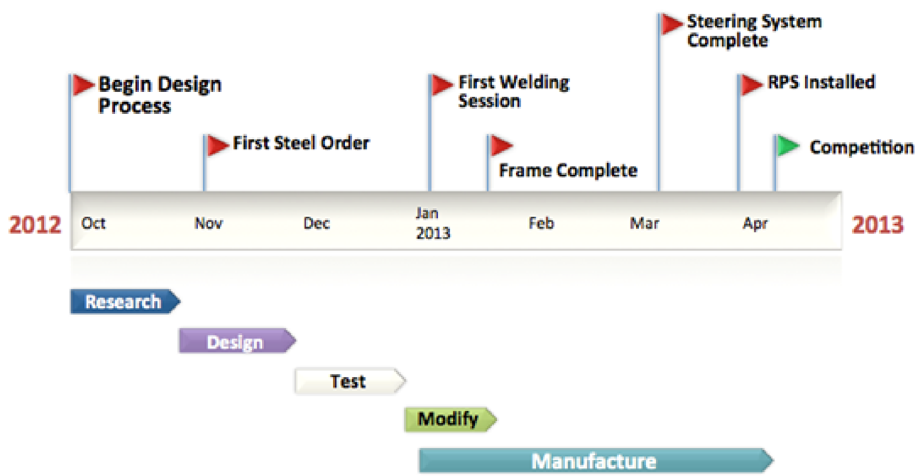


Figure 2.4 Project Timeline.

One of the major issues that the team encountered during this project was delays in the approval process for welding on the vehicle. This date was pushed back multiple times, and the team was not given permission to weld until after the first of January 2013. The frame was completed halfway through January. The energy storage system, drivetrain, steering system, and RPS all had to be installed after the frame was developed and tested.

The steering system was completed in early March. The drivetrain took more time and required design modifications post-manufacture. Unfortunately, the RPS and the modifications were not complete before the design report was due, which resulted in a lower score. However, the RPS and the modifications were presented at the competition. The trike was complete by the April 12th start date, and passed the safety test that ASME sanctioned. Once the competition finished the team continued to work on the trike and modify the energy storage system to produce a more attractive vehicle for buyers.

2.6.3 Project Challenges and Constraints

This project presented substantial challenges in the design process, manufacture, and competition. As stated before, the team of nine was split into two different groups. This was a source of problems for the group as a whole. The disconnect between the two teams caused communication issues, and made creating a single, completed project difficult. Communicating effectively between the two teams was the most difficult part of this project. In addition, problems arose when deadlines were continually missed. The original timeline was much too ambitious, and time was not appropriately distributed. The frame and fairing team ran into problems when they began fabrication. The shop at Santa Clara had strict welding restrictions which pushed back the frame completion date. This in turn, pushed back the installation of the energy storage device. Although the two teams were separate entities, they relied heavily upon one another, which led to difficulties throughout the process especially when deadlines were pushed back. The team also had less time to complete the project in relation to typical senior design projects because ASME required a detailed report on March 8th, and the start of the competition was April 12th. Although the project had challenges, each challenge allowed the students to grow in their knowledge of engineering and project management.

2.6.4 Risk Mitigation

Safety played a large role in many of the decisions that the team made throughout the design process for the trike. Not only was the team designing for the safety of the eventual rider, but also for those who were to manufacture the vehicle. The students who used the shop were trained on safe practices and were required to pass the Santa Clara Shop Safety Test prior to any work on the vehicle. Additionally, the students who performed welding on the frame went through extra training on the welding equipment.

To address rider safety a comprehensive roll protection system, an automobile seatbelt, head lights, and brake lights were included on *Cerberus*. The team also made a set of safety rules for students riding the prototype during development and the competition which is in Appendix E.

In addition to the physical risks the risk of project failure had to be accounted for.

Because of the early deadline, the team ran the risk of not finishing the project on time. This would have reflected poorly on the school and the team, and resulted in a loss of funds that were invested in the competition fees. In order to avoid this, the team set hard deadlines at which different aspects of the trike had to be finished by. This proved to be challenging, yet very important for the completion of the project. When goals were not met on time, the scope of the project had to be reduced in order to have a working vehicle by the date of the competition. For example, due to resource constraints and limited capabilities in the shop, the team was unable to make a second revision of the frame before the competition. The project plan was re-scoped and the team focused on revising the existing prototype instead of making a second revision for the competition.

Chapter 3: Frame

3.1 Background

The goal was to produce a practical and cost-effective human powered vehicle. This had an impact on the complexity of design and type of material that could be incorporated in the frame. The entire trike was built in the university machine shop by semi-skilled students to simulate a realistic environment in a developing community.

3.2 Requirements

The requirements of the frame are based upon both the team goals of practicality and frugality, as well as the competition specifications. For example, the cost to build one frame was not to exceed $150, and it was to weigh no more than 15 pounds. In regards to function, the frame was required to support a 200-pound rider, aerodynamic device, and roughly 50 pounds of cargo. Due to the large variation of possible rider size, the frame also needed to accommodate riders ranging from 5’ 10" to 6’ 3".

3.3 Design

The frame is a recumbent, tadpole-style tricycle configuration. The recumbent feature refers to the seating position. This position is much lower to the ground, and more reclined, than a traditional rider position. A tadpole tricycle has two wheels in front, and one in the back. This configuration was chosen because of its stability and ease of use. A tadpole trike, as opposed to a delta-style wheel configuration, is better for high-speed stability and handling. Stability was an important criterion for the competition in order to navigate through the obstacles during the endurance event, such as a hairpin turn. The frame was designed for roughly 4 inches of ground clearance to accommodate a 3.5 inch speed bump.

Simplicity ranked above all else as a key design requirement. All cuts and welds are straightforward single-axis features. This means that no complicated jigging is required for the manufacturing and welding of the tubes that make up the frame. The roll protection system was required for the competition. Its design does not strictly follow the philosophy of practicality and manufacturability. The 3/4" tubes used for the roll protection system are slightly more complicated to weld, but could be easily formed with a hand-operated tube bender.

To estimate some of the ergonomic size requirements of the frame, a rudimentary sizing experiment was performed. The purpose of this was to get a general idea of some specifications the frame needed to meet. Shown below in Figure 3.1 is a picture of the setup used. The results of the experiment can be found in Table 3.1.

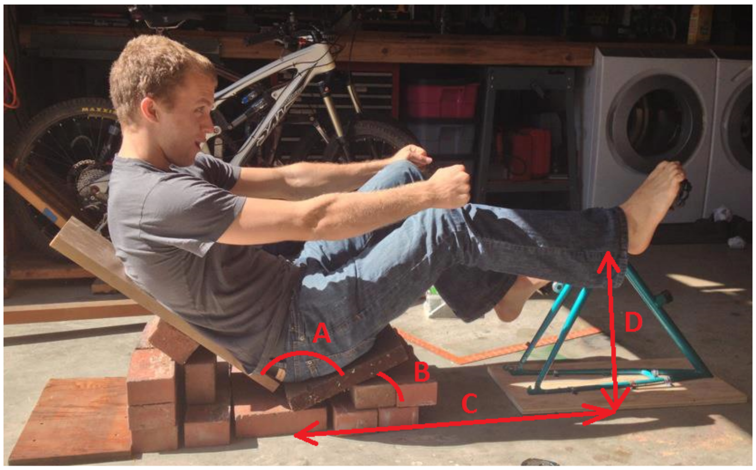


Figure 3.1 Shows the experimental set up used to determine ideal rider geometry.

Table 3.1 Shows the results of the rider geometry for a rider who is 5' 10".

Variable	Test Result
A: Angle between rider's Back and Legs	120°to 140°
B: Angle between seat and Horizontal	10° to 15°
C: Horizontal distance from Seat Pivot to Bottom Bracket	42 inches
D: Vertical distance from Seat Pivot to Bottom Bracket	9 inches

3.4 Analysis

3.4.1 Track Width and Roll Speed

The track width of the vehicle was determined based on the estimated roll speed. The roll speed of the vehicle was found using a simple free body diagram of an outside wheel going around a corner, shown in Figure 3.2. This free body diagram assumes that that the inside front wheel has begun to lift off the ground, so it is not present. Summing the moments about A, Equation 3.1 shows the relation between the moment produced by the rider weight and the moment created by accelerating around a turn.

$$\sum M_A = W d_\perp - F_{wheel} d_\perp \tag{3.1}$$

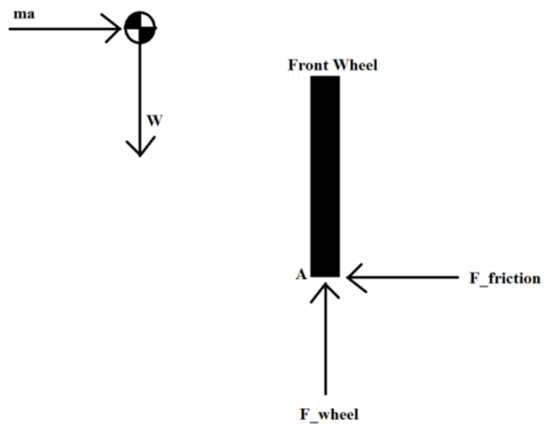


Figure 3.2 The free body diagram used to estimate the roll speed.

Using Equation 3.1, the roll speed was calculated and plotted, shown in Figure 3.3. The roll speed is where the two lines intersect, where the moment due to acceleration increases to be greater than the moment due to the rider weight. These calculations were made for a 25-foot turn radius, the minimum radius required for the competition. Assuming a 25-foot turning radius, the trike is expected to roll at 18 mph. This was deemed acceptable, and a track width of 32" was chosen. In reality the trike can turn at a much sharper radius, which significantly lowers the roll speed.

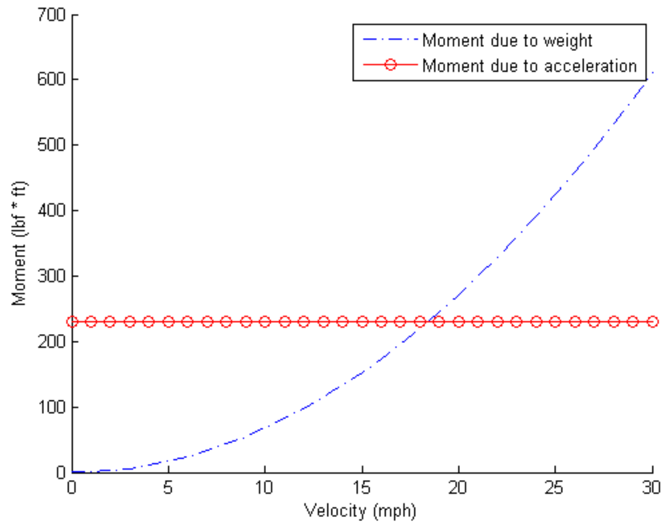


Figure 3.3 Shows the free body diagram used to estimate the roll speed.

3.4.2 Frame Body

The simple calculations made to initially estimate the stresses in the frame due to static rider weight of 200 lbs are shown in Appendix A. The stresses were calculated at three of the main welds, shown as points A, B, and C in Figure 3.4, and took combined loading into account.

Table 3.2 shows the stresses calculated at each of these points and the percent yield of the material (approximately 40 ksi). The stresses present in the frame at all welds are far below the yield strength of the material.

Table 3.2 The estimated stresses at each weld.

Weld	**Hand Calc Stress (ksi)**	% yield
A	13.0	3.25
B	6.96	1.74
C	9.33	2.33

The strength of the frame was also analyzed to confirm that the material would not yield under worst case riding conditions. This occurs when a force is applied to the cranks in high gear from a dead stop. A force of 100 pounds pushing and 30 pounds pulling was

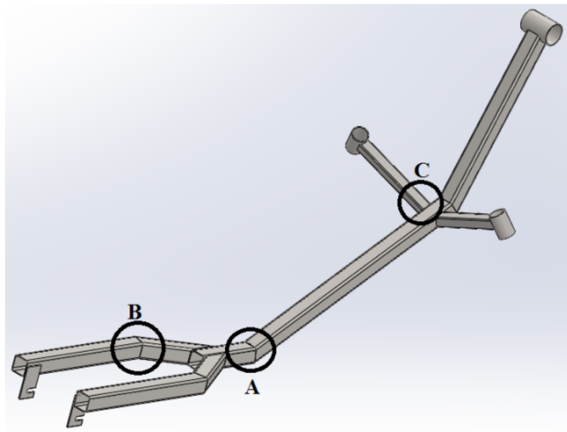


Figure 3.4 Shows which welds were analyzed for stress.

considered to be the worst-case scenario. Calculations were made to distribute this force to the idlers, and as reaction forces at the wheel mounts, shown in Figure 3.5.

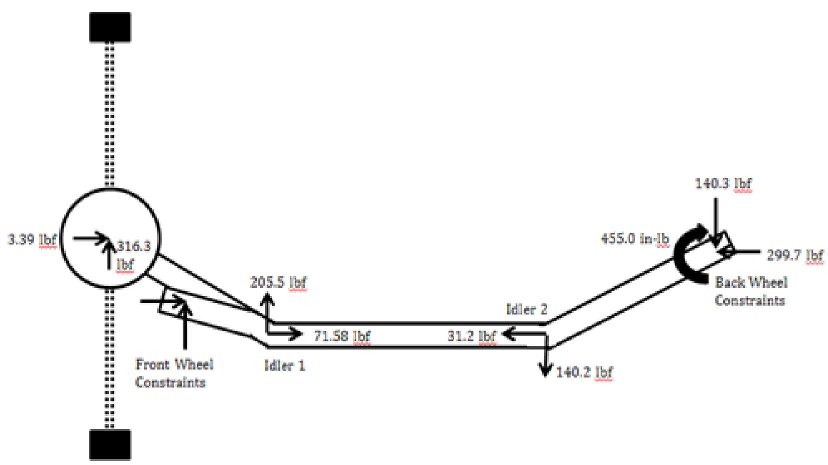


Figure 3.5 Shows the idler forces due to 100 pounds of pushing force and 30 pounds of pulling force on the pedals.

The results of the finite element analysis are shown in Figure 3.6 and the results are shown in Table 3.3. The maximum stress was found to be 21.7 ksi, allowing for a factor of safety of 1.8 to account for any stress concentrations in the welds. These calculations, which can be found in Appendix A, confirm our FEA results.

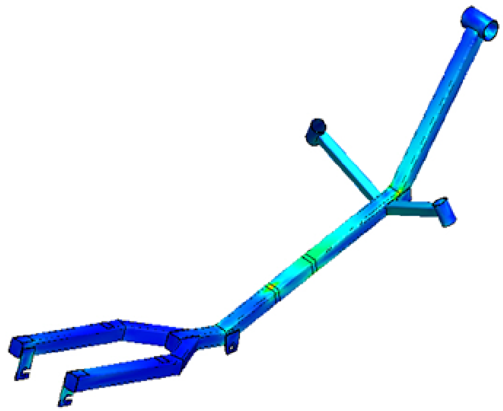


Figure 3.6 Shows the FEA results for normal riding conditions.

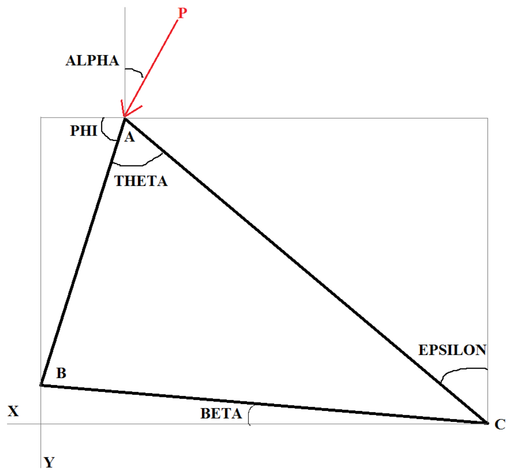
Table 3.3 FEA results for normal pedaling.

Description	Max Stress (ksi)	Deflection (in)
Riding Loads	21.7	0.13

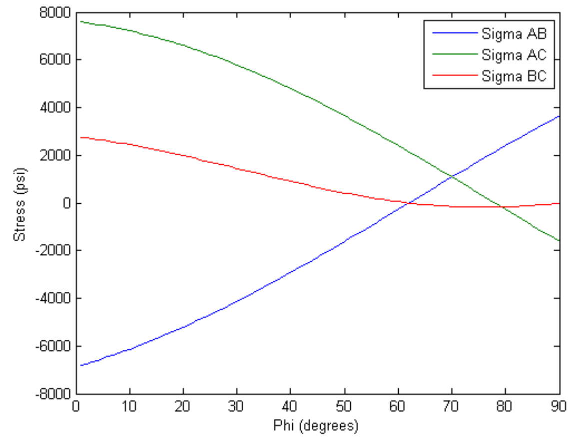
3.4.3 Roll Protection System

To begin the design of the roll protection system, a simple truss was analyzed and optimized for the vertical loading condition of 600 lbs at 12 degrees from the vertical. Figure 3.7a shows the variables optimized for the given loading. Angle β and θ were fixed, due to the geometry of the frame, and the stresses in each member were calculated for a varying angle ϕ.

Figure 3.7b shows the resulting stresses in each member as a function of ϕ. There is an obvious low stress point at angles of phi from 60-80 degrees. This gave significant direction in the initial design stages of the RPS. The actual RPS is not a simple truss, so the final design was analyzed with finite element analysis software.



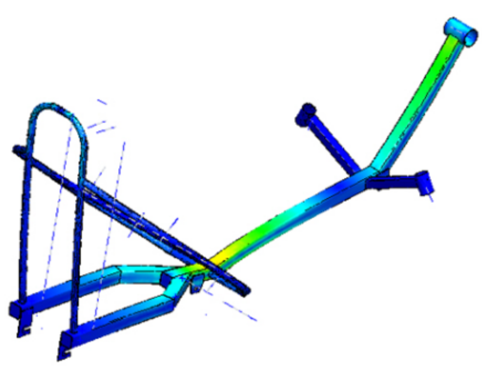
(a) Angle definitions for simple truss.



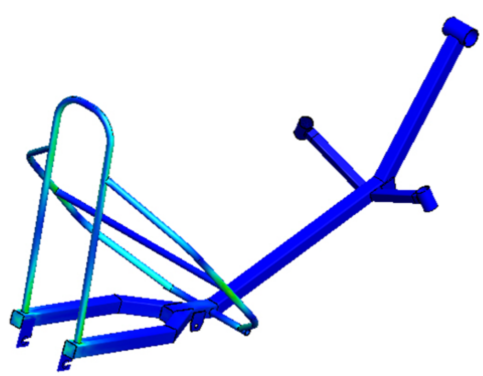
(b) Plot of stresses in each member of the truss with varying angle ϕ.

Figure 3.7 Roll bar truss optimization.

The FEA was performed after fitting the RPS within the spatial constraints of the vehicle. The loading conditions that were tested are outlined in the ASME competition rules. The results of these analyses are shown below in Figure 3.8a and Figure 3.8b, and the numerical results are in Table 3.4. For the side load test, a maximum stress of 31 ksi was found on the side member of the roll bar, where it joined with the cross member. The top load test resulted in a maximum stress of 17 ksi.



(a) Top Load



(b) Side Load

Figure 3.8 FEA of side and top load applied to roll bar.

Table 3.4 FEA results for roll bar loading.

Description	Max Stress (ksi)	Deflection (in)
Top Load	17.07	0.19
Side Load	31.38	0.18

3.5 Manufacture

The frame was designed for manufacturability. This made the manufacturing process simple and painless, and required little specialty tools and skills. This could be built with only a chop saw, an angle grinder, an arch welder, and a drill press–which are commonly found in most shops and garages. The tube joints are all on a single axis, and are welded with a standard TIG welder. No extensive jigging was used besides C-clamps and magnets. The absence of a full jig did produce some minor discrepancies in the positioning of the front forks, but were easily bent to the proper specifications.

Chapter 4: Drivetrain

The trike uses a chain-driven system, similar to that found on a regular bicycle. The system includes a 46-tooth cog on the front pedals, two idler cogs to guide the chain, and an 18-tooth cog on an 11 speed internal hub in the rear wheel. The team opted to use a single chain for simplicity, and for ease of gear shifting. The drivetrain is equipped with a full range of gear ratios from 1.3 to 4.5.

To choose the best possible crank gear, a series of hand calculations were performed to understand the gearing ratios. A 46 tooth front crank was selected because produced the most desirable ratios at a reasonable cost. This was decided by comparing the 8 speed and 11 speed ratios to the standard high and low ratios for typical racing bicycles. Figure 4.1 shows the similarities in the standardized ratios when graphed with the 46 tooth crank. Because these values are comparable, it is ideal to use the less expensive alternative.

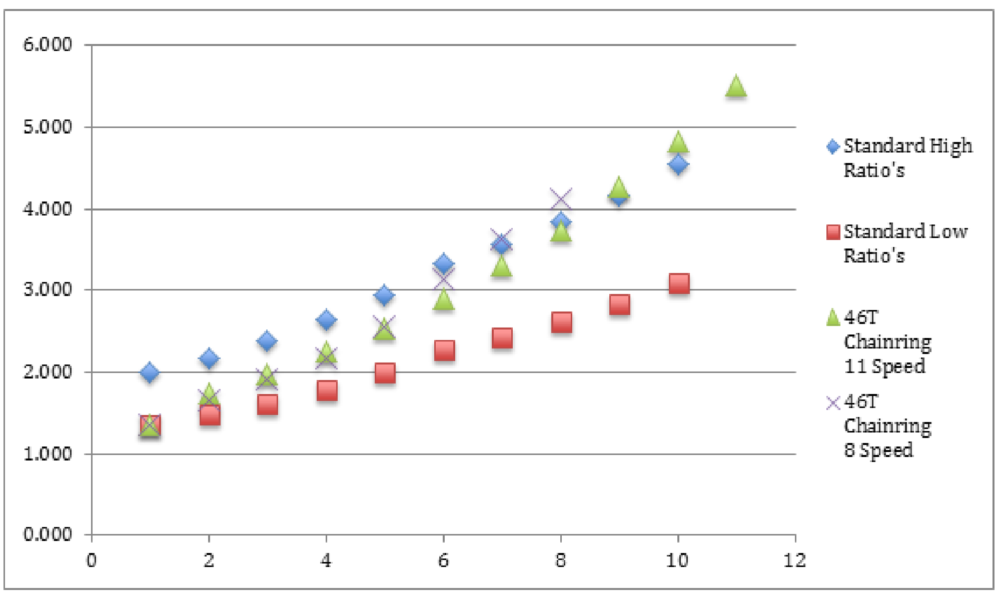


Figure 4.1 46T Gear Ratio Comparison. Gear Ratio plot for 46 tooth crank compared to standard ratios.

The drivetrain path is illustrated in Figure 4.2. The single chain ensures simplicity in the design. The two 2.75" idlers in the middle of the tricycle keep the chain in tension, and are crucial for the efficiency of the tricycle.

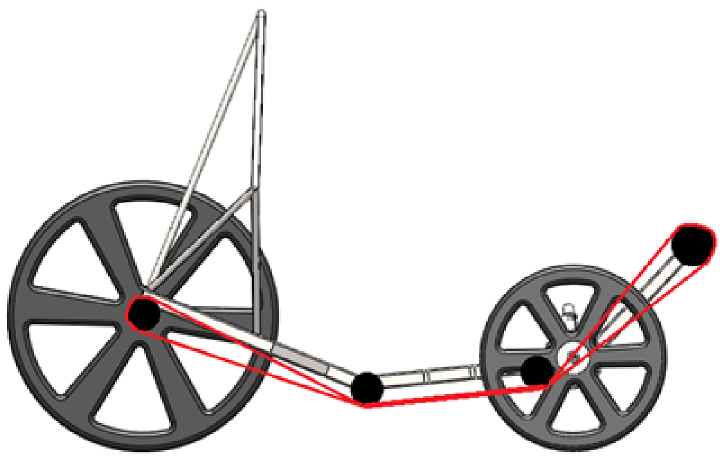


Figure 4.2 Schematic of the chain system for *Cerberus*. The chain is shown in red.

4.1 Background

The overall goal was to design and implement a drivetrain that could be used for urban commuting as well as in developing nations. This required a drivetrain that can be used on rough dirt roads and smooth asphalt. Since funding was available, the drivetrain was built using high-end components that were chosen for their performance capabilities to make the trike competitive in the ASME Human Powered Vehicle Challenge.

4.2 Requirements

The requirements of the drivetrain serve to fulfill the goals set forth for the competition as well as applications in developing nations. The cost of the drivetrain was not to exceed the $2,000 budget allotted for the system. This system was constructed for well under this value as all the components totaled to approximately $1,580, which is 79% of the allotted budget. The drivetrain had to withstand the force that a 200 lb rider could exert on the pedals when the trike was completely stopped. The drivetrain also had to drive the trike from a dead stop to top speed within 100 meters to fulfill the sprint event of the ASME Human Powered Vehicle Challenge.

The components of the drivetrain were carefully chosen to meet the previously stated requirements and provide the best results at the competition. High-end components were purchased for the competition, which included an 11-speed internal hub. These components are interchangeable with less-expensive components that would be more readily available in developing nations. These alternative components include a rear derailleur rather than a rear internal hub, as well as cheaper front and rear chain rings and less expensive cranks. These components still provide effective means of providing motion to the vehicle, but they will not be as efficient or durable as the high-end components.

4.3 Design

There were several designs that were assessed before a final drivetrain was built. A belt-driven system, driveshaft and flexible driveshaft were all considered and were ultimately deemed to be impractical to fulfill the requirements. A chain system was found to be more efficient, practical, and durable in this type of application than any of these three alternatives. Once it was determined that a chain system would be used, the choice had to be made between a standard derailleur gear shifting system or an internal hub. The internal hub was ultimately chosen because it required a straight chain line (making it more efficient), the gearing was enclosed so it would not be affected by dirt or inclement weather, and it allows for gear shifting when the vehicle is at a stop unlike a derailleur which requires the vehicle to be in motion.

After the type of drivetrain was determined, the system as a whole was designed. The system consists of a front chain ring, two idlers, and an internal hub within the rear wheel. All these components are connected by a single chain. The chain is guided by the two idlers attached to the frame and used to drive an 11-speed internal hub that is part of the rear wheel assembly. The drivetrain was designed to be used with either a 46 tooth or a 32 tooth chain ring in the front. The rear internal hub can also be switched with a rear cassette to reduce cost if desired.

4.4 Front Chain Ring and Pedal Analysis

The tension in the chain was analyzed using free body diagrams and a 100 lb force exerted on the pedals by the rider. The calculations yielded a 331 lbf of tension on the idlers. After collecting these results, as well as witnessing bending in the idler mounts, the idlers in the drivetrain were reinforced to ensure their strength.

Chapter 5: Energy Storage

The ASME dedicated a portion of the competition to innovation and the effective use of an energy storage device. For this event, *Cerberus* showcased a small electrical generation and storage system, which powers LEDs around the tricycle as well as a USB device. In this system, a dynamo is powered by the motion of the rear tire. The dynamo is attached to an electrical circuit that contains four diodes, three capacitors, a transistor, and resistors. The purpose of the circuit was to take the AC current from the dynamo and convert it to DC with minimal losses. A Wheatstone configuration was used to eliminate the directional losses and discharge of the battery from the AC current. Figure 5.1 illustrates the devised circuit with the specified parts.

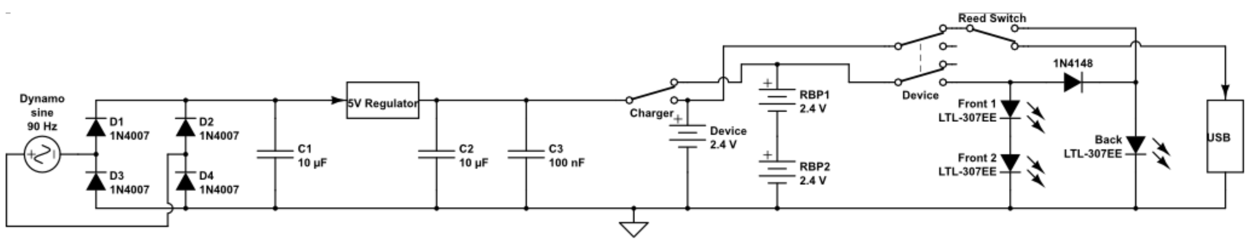


Figure 5.1 Circuit created to minimize losses from AC to DC conversion.

5.1 Background

The goal of the energy storage system was to use regenerative braking to harness and store energy from the trike. This meant creating a system that was able to be mechanically engaged and disengaged with ease. The energy storage system was designed to be used by urban commuters and those in developing nations.

5.2 Requirements

The requirements of the energy storage system were to generate electricity at different speeds and to store it in a battery pack. The system can also power lights or charge a personal electronic device, such as a cellular telephone. The cost of the energy storage system was not to exceed $500. The energy storage circuit was analyzed using LTSpice in the design phase and a current meter once a prototype was developed.

The energy storage system runs device lights and can charge a personal device to at least 50% power during a one hour commute. The system needed to fulfill these requirements with and without the circuit drawing extensive energy from the trike.

5.3 Design

Three systems were analyzed to determine the best option to fulfill the energy storage requirements. A flywheel was considered for this project. However, a flywheel would not successfully fulfill the requirements because of the large mass necessary to generate the required energy. The added weight of the flywheel would be more of a hindrance than an advantage for the trike. A spring was also considered for the energy storage system but was also determined to be unrealistic. A large enough spring would have been very hard to obtain in rural settings. If the spring were to break, it would be near impossible to repair and replace. After conducting research, the team determined that the energy storage device would work best if it was powered by a dynamo. Such a system would have an energy density of 84.4 Watt-hours per pound making it the system with the highest energy-to-weight ratio of the systems analyzed.

5.3.1 Final Design

The energy storage system on the trike is an electricity generation system that uses a bike dynamo to capture energy from the system while the trike is braking. The energy storage system uses a locking brake lever to move the dynamo on and off the rear tire. This enables the system to generate electricity by using the dynamo as a regenerative brake. The energy storage circuit was designed to reduce the variable voltage generated by the dynamo and give a steady 5 volt output to charge a removable battery pack and a personal accessory. The user of the trike is able to choose between charging the removable battery pack with the dynamo and charging the personal device battery pack. Independently, the user is able to pick whether he wants to run lights off of the removable battery pack or charge a personal device using a USB charging circuit running off of the personal device battery pack. While the USB circuit is engaged, the lights of the trike are turned off, but when the hand brake is pulled, a reed switch is engaged, and the rear brake light will turn on. This enables the rider to signal when he is coming to a stop for those people traveling behind him. Figure 5.2 depicts the energy storage options and switch that the rider can use.

5.4 Analysis

The output current was tested at various speeds when the dynamo was engaged and disengaged. The output current of the system was measured at 1.5 amps when the trike was

Figure 5.2 Top Left: vehicle lights. Bottom Left: circuit housing. Center: user interface box. Top Right: iPhone being charged by vehicle. Bottom Right: removable batteries

traveling at a leisurely speed of 17 mph and 2.2 amps when traveling at top speed of 22 mph. The circuit was built so that the output voltage would always be 5 volts. 7.5 watts were generated at the slower pace and 11 watts were generated at the maximum trike speed.

To fully charge the battery pack would require 5.3 hours at commuting speed and 3.5 hours at top speed. To fully charge the personal device battery pack it would take 2.6 hours at commuting speed and 1.8 hours at top speed. Table 5.1 depicts the charging time at various speeds. These times were calculated assuming the batteries had a 2200 mA-hour capacity. If different batteries were used, these charge times would vary. The circuit for the energy storage device was designed to regulate variations in speed so the current output for the two speeds tested should remain constant.

Table 5.1 Charging times for onboard battery pack at different currents.

	Charge Time (Hours)	
Current Generated (Amps)	Device Battery Pack	Removable Battery Pack
1.5	2.6	5.3
2.2	1.8	3.5

After testing the device, it was determined that the removable battery pack can power the vehicle lights for two hours without reengaging the dynamo. This is double the one-hour goal that was established in the system requirements. With the dynamo engaged, the lights can be powered almost indefinitely as the lights can be run directly from the current supplied by the dynamo. The excess current is used to power the device charger or batteries.

The personal device charger can charge an iPhone between 50% and 80% depending on the phone's charge mode and the age of the batteries being used in the battery pack. These percentages were determined when the dynamo was not engaged. This result also exceeds the requirements for the energy storage system. Like the lights, the personal device charger is able to charge an iPhone to a higher percentage if the dynamo is engaged.

Chapter 6: Steering

6.1 Background

The steering system for any three- or even four-wheeled vehicle is very complex. It must be stable, lightweight, and ergonomic. These characteristics all contribute to the agility of the trike. The system also had to be designed with the customer needs in mind. In this case, the trike needed to do well in competition yet also be very frugal. Designing the vehicle for two separate audiences is a complex, yet very common, engineering problem. The steering system played a huge part in the vehicle's success both on and off the track.

6.2 Requirements

The competition required that all vehicles be capable of turning within a radius of 26.2 feet (8 meters).[1] This was the only hard set guideline for steering set by the competition rules. The trike exceeded the expectations and had a much smaller turning radius than required. The small turning radius added to the maneuverability of the trike and improved the performance in the competition, especially during the endurance race.

6.3 Design

Figure 6.1 shows a design web for the steering system. Included in this matrix are the final options that were considered for the steering system. These options include front wheel steering with direct actuation, as well as optimized kingpin, camber, and caster angles.

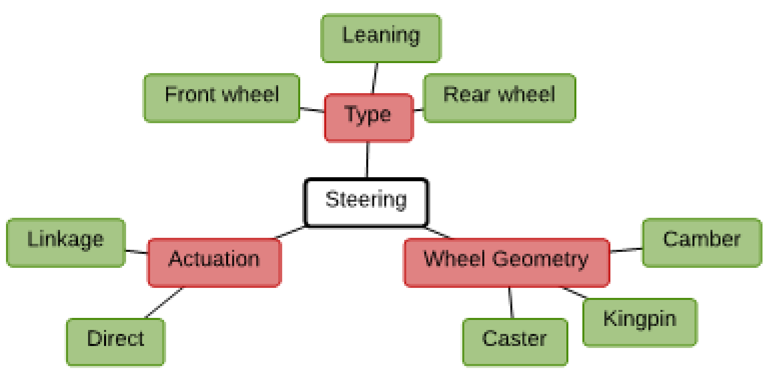


Figure 6.1 Design web for the steering system.

The kingpin angle is the angle of the main pivoting axis, measured in reference to a vertical orientation. An optimized kingpin angle reduces the effects of bump steer – that

[1]ASME. *Rules for the 2013 Human Powered Vehicle Challenge*. June 2012.

is, the input force to the steering system generated from riding over a bump.

Camber is the angle of the wheel itself relative to a vertical reference from the front view. Neutral camber describes a trike with vertical wheels. Negative camber represents a negative angle from vertical, and positive is the opposite. Figure 6.2 shows examples of neutral, negative, and positive camber, respectively.

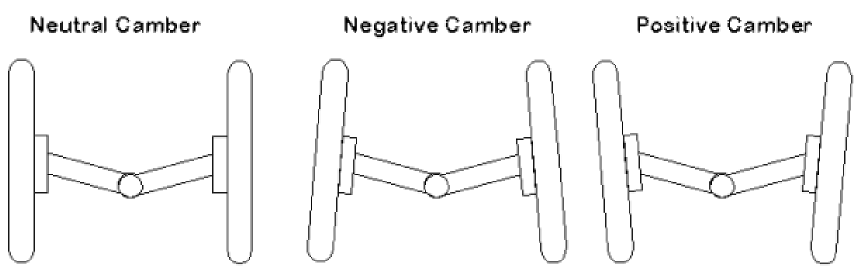


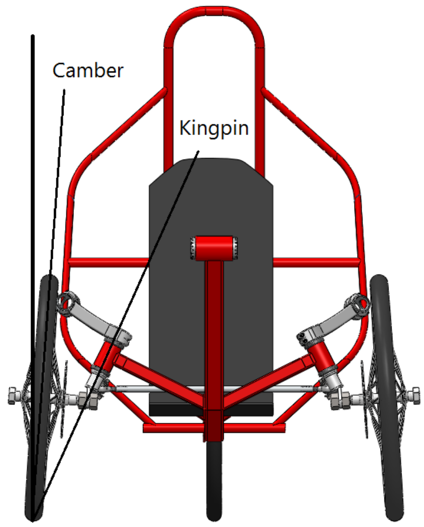
Figure 6.2 Neutral, negative, and positive camber, respectively.[3]

For performance design, positive camber is not ideal. Positive camber narrows the track width when referencing the contact path of the wheels, and can cause the trike to be unstable. Neutral camber handles much better and is more stable than positive camber. However, the best performance is found with a negative camber.[3] Negative camber gives the best handling because it has the largest track width, and also distributes the force during cornering along the plane of the wheel. In a traditional bicycle, single axis vertical loading is experienced, which is what the wheels are designed to handle. Since bicycle riders lean when they turn, the load is always single-axis, along the wheel's plane. However, most trikes do not lean, so the wheels will experience a combined multi-axis load when turning. With negative camber, the trike is better supported on a single axis while experiencing the highest load, which is generated from cornering.

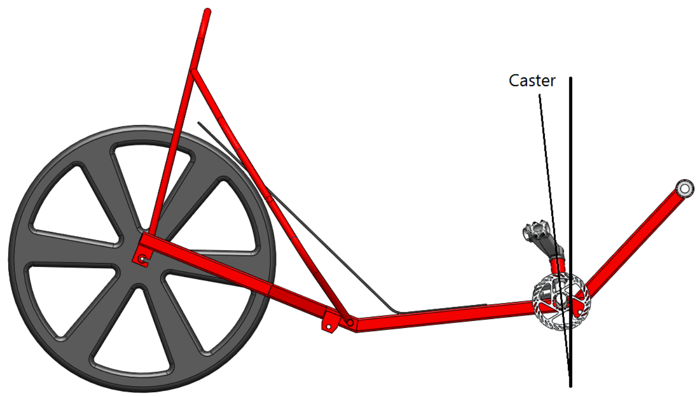
The next angle considered was caster. Caster is the angle from the centerline of the kingpin to a vertical reference, from the side view of the trike. An idealized caster angle can help self-center the steering, as constant vertical force on the trike due to gravity forces the wheels to track straight. Caster angle should be between 10 and 14 degrees for a performance vehicle.[3] If the caster angle is too large, then the steering can be difficult to actuate.

[3]Rickey M. Horwitz *The Recumbent Trike Design Primer* tech. rep. Hell-Bent Cycle Works, 2010.

Figure 6.3a and Figure 6.3b show the kingpin, camber, and caster angles optimized for performance.



(a) Front View: Shows the kingpin and camber angles of the steering system.



(b) Side view: shows caster angle.

Figure 6.3 Front and Side view of trike with steering angles labeled.

The kingpin, camber, and caster all play pivotal roles when designing a steering system. Additionally, it is important to consider how the wheels relate to each other. Rudolph Ackerman developed a system for designing the steering of three–and four–wheeled vehicles, which is known as Ackerman steering.[3] Ackerman steering is ideal for this system. Ackerman realized and acknowledged that if two wheels track at the same rate and angle, the outside wheel will be forced to drag across the ground because it must cover a greater distance. The solution he proposed was to have the inside wheel track a sharper angle. The system functions by the use of a controlling arm. The controlling arm follows a centerline connecting the main kingpin and the center of the rear wheel. This is shown in Figure 6.4, where the desired angle X is in reference to the forward path of the trike. The figure illustrates how, in order to reduce drag, the inside angle I will always be greater than outside angle O.

The final step in designing the steering system was to design the connecting rods and controls. The connection rods had to be lightweight and have minimal resistance. The

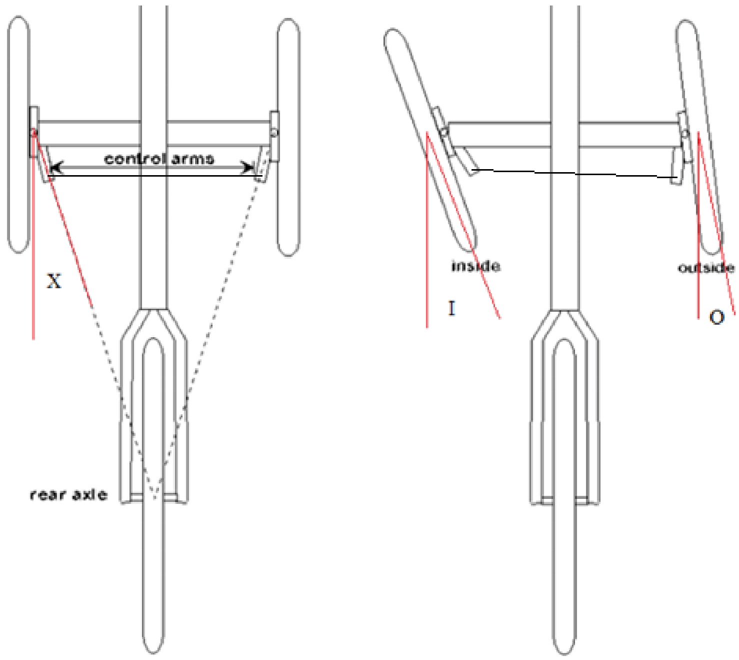


Figure 6.4 Ackerman steering system implemented on a tricycle.[3]

controls had to be ergonomic and easily adjustable. Two main designs were considered in this engineering process: single tie and dual drag links. Figure 6.5 illustrates a single tie rod system with a single stabilization bar. This system is lightweight, uses minimal pivot points, and creates very little resistance. The system is also simple, easy to adjust, and can be used in conjunction with the Ackerman steering system.

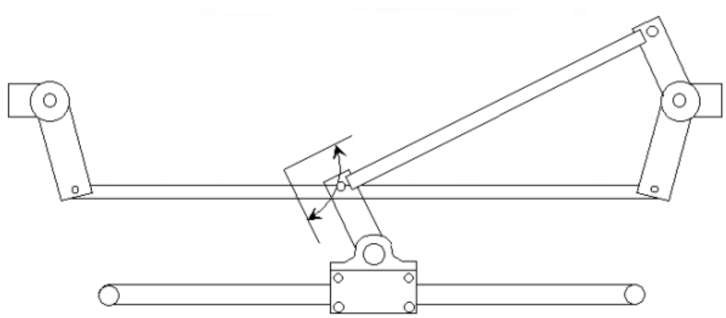


Figure 6.5 Single tie rod and drag link steering system. Tie rod and levers maintain a 90 degree relationship.[3]

Figure 6.6 shows a dual drag link system that contains two stabilization bars. The most important part of this system is the distance between the kingpin and the stabilization bar's central pivots. This distance must equal the distance between the kingpin pivot and the outer pivot of the stabilization bar.[3] When these distances are equal, the steering becomes easy to operate. The main advantage of this system is that it is more stable at high speeds and under severe braking conditions. This system also provides room for adjustability. However, it is very complex and introduces drag and excess play in the steering controls. Drag is the added resistance from the friction of the linkage while steering. Play is the error in the system added from inconsistencies in the bearing surfaces and flex in the system under given loads and compounded tolerances.

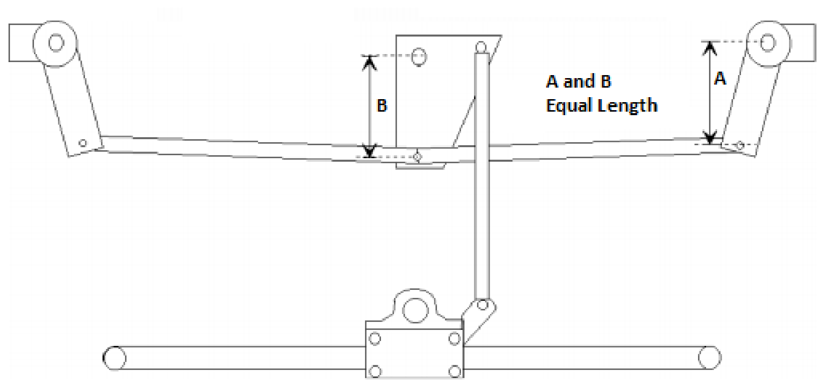


Figure 6.6 Dual drag link steering system with single pivot input.[3]

When all things were considered, the single tie rod was chosen for the maneuverability, as well as the simplicity, of the design. These two criteria fall in line with the project goals and vision. Furthermore, the cost of the single tie system is far less than the dual drag link. Figure 6.7 depicts the single tie rod system chosen. This system features controls mounted directly to the upper kingpin bearings, rather than to a drag link. This design is optimal because it gives the rider more space for a consistent pedal stroke. These controls can also be easily designed to be adjustable to various rider heights and body types. Since the controls are also connected directly to the kingpin itself, both control and stability are optimized.

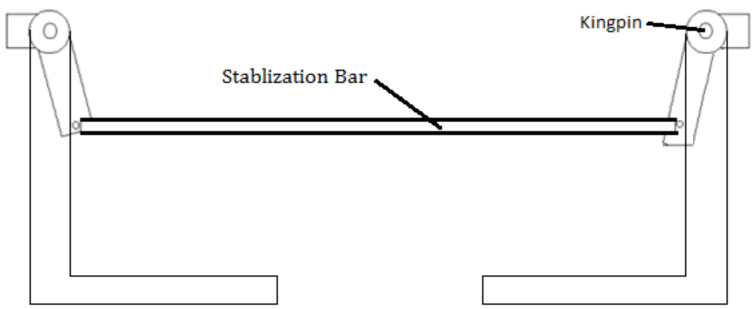


Figure 6.7 Single tie rod steering system with controls directly mounted to kingpin bearings.[3]

Chapter 7: Braking

7.1 Background

The braking system for this trike was optimized for performance and cost and was designed to stop the trike quickly upon user command. The performance of the system was gauged on a ratio of initial speed to stopping distance as well as the durability of the system under strained conditions. The brakes experienced high loads during the 2.5 hour endurance race as the event included coming to a complete stop from near top speed a total of 52 times as well as continuous speed checks throughout. Because of the minimalist design, the system performed admirably and there were no significant problems during these 2.5 hours despite the repeated stress.

7.2 Requirements

The braking system was designed to meet the ASME guidelines that stated that a vehicle must come to a complete stop in 10 feet when the brakes were applied at a speed of 15 miles per hour. The activation of the brake also had to be user-friendly, meaning that the user had to easily stop the trike without exerting excess force. The ability for the rider to carefully control the braking force was vital to stopping in a controlled manner.

7.3 Design

Two Avid BB7 mechanical disk brakes were used for the vehicle. An image of these brakes, which are attached to the front wheels, is shown in Figure 7.1. The brakes were linked together and actuated by a single lever which allowed the force to be distributed evenly. The disc brakes were used instead of typical friction bicycle brakes (v-brakes) for a number of reasons. First, because of the requirements of a tadpole trike design, it would be very impractical to install a traditional v-grip bracket to each wheel. Disk brakes can be mounted closer to the center axis of the wheel and do not require a fork around the front wheels. Second, disk brakes provide a more reliable means of stopping control than do v-brakes.

Figure 7.1 Shows the disc brakes purchased for the braking system. [4]

A third disk brake was not installed on the rear wheel. Instead, a regenerative braking system was incorporated that could be toggled on and off based on the needs of the rider. This energy storage device uses a toggled dynamo, which adds a considerable amount of rolling resistance when engaged. For more information regarding the regenerative system, refer to section 5.1 on page 29.

Chapter 8: Fairing

8.1 Background

An aerodynamic fairing was incorporated into the design of the vehicle to meet ASME competition requirements. In a non-competition environment the addition of this device increases the cost, but decreases the ease of ingress and regress to the vehicle. The simplest design was used for the trike in general, and the fairing was only used to meet competition requirements.

8.2 Requirements

ASME Human Powered Vehicle Challenge guidelines require an aerodynamic device, but say nothing specifically about the design of the device. In order to perform well in the design portion of the competition, the device needed to reduce the drag induced while riding without adding too much additional weight. In addition, the fairing subsystem could not negatively affect the ingress or egress of the vehicle.

8.3 Design

Initially, the plan was to design and build a unique full fairing in-house. However, after analyzing the resources and cost of such an undertaking, the team determined that it was not relevant for the scope of the project. A cost estimate for a full fairing projected an added $670 to the budget. In addition, the process required sophisticated manufacturing necessitating the use of a large-scale, fully ventilated and protected workspace. After careful analysis, this was deemed a poor use of money and resources, as it did not align with the project objective and goals. The estimated bill of materials can be seen on the next page in Table 8.1.

In order to comply with the competition guidelines, an aerodynamic shield was purchased from a company that manufactures recumbent trikes and it was mounted to the front of the vehicle. A custom mount was created to attach it to the frame. Because the shield acted only as a partial fairing and did not require the rider to open or close any doors, the ingress and egress remained relatively unaffected. The final fairing shield is a molded sheet of clear polycarbonate, and costs $225. The system was mounted to the front of the trike using 1/2" aluminum tubing, and was positioned to reduce the frontal area exposure without interfering with the rider.

Table 8.1 Shows the estimated cost of a custom made fairing.

Item	Size	Qty	Estimate	Dealer
Polystyrene	6’ x 4’ x 2’	1	$353.00	Univfoam.com
Fiberglass	3’ x 30’	1	$60.00	Fiberglasswarehouse.com
Clear Polycarbonate	3’ x 4’	2	$140.00	Lowe’s
Spandex	5’ x 3’	2	$28.00	Spandexworld.com
Release Wax	14oz.	2	$42.00	Fiberglasssupply.com
Glue	1 pint	1	$38.00	Eplastics.com
Sandpaper	9" x 11"	10	$9.00	Fiberglasssupply.com
Total			**$670.00**	

Chapter 9: Testing

9.1 Materials

A standard 3-point bending test was performed in order to confirm the yield and stiffness of the materials used in production. The ASTM E290 standard procedure was followed, and a diagram of the set up can be seen below in Figure 9.1. [5]

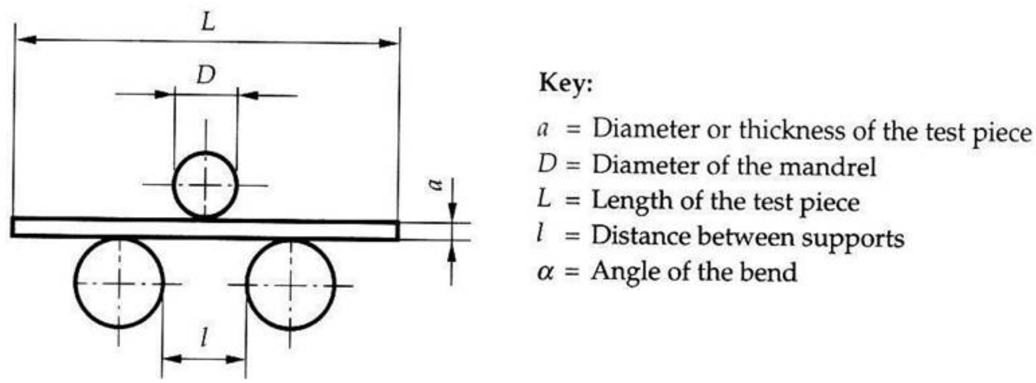


Figure 9.1 Shows the experimental set up for an ASTM E290 three point bending test.

The results of the test are shown in Figure 9.2. This test confirmed a yield strength of approximately 40 ksi, and a bending stiffness of 38.5 kips/inch.

9.2 Welds

Before the main frame was manufactured, weld tests were performed on test specimens that replicated actual welds in the design. The test specimens were cut out from square steel tubing, and destructively tested to confirm their integrity. The testing process included bending the specimen 180 degrees on the weld seam and re-bending it back into its original flat form. The welds passed if no failures were observed on the weld seam during the bending process. Sample specimens can be seen in Figure 9.3.

9.3 Performance

In order to test the feasibility of *Cerberus,* a variety of tests aimed to measure the peak performance of the vehicle were conducted. The descriptions and the results of each test are as follows, and the results are summarized in Appendix D.

[5] *ASTM E290-09: Standard Test Methods for Bend Testing of Material for Ductility* West Conshohocken, PA: ASTM, 2009 DOI: 10.1520/E0290-09.

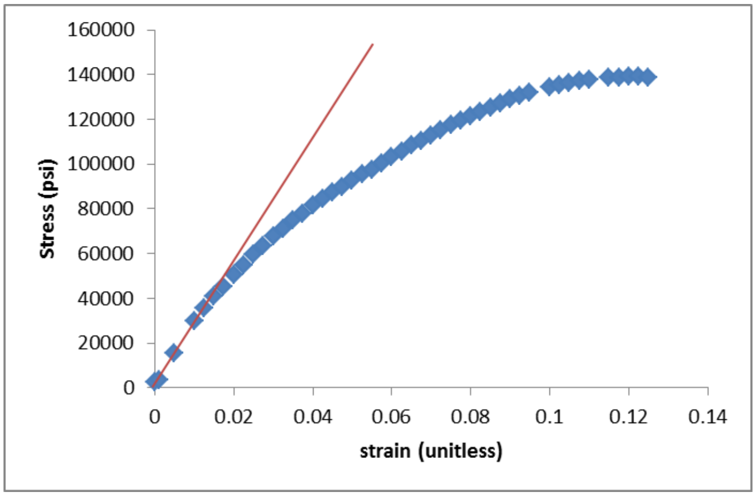


Figure 9.2 Shows the stress-strain curve generated from the 3-point bending test. The straight red line is the slope of the elastic region and deviates from the curve at the yeild point.

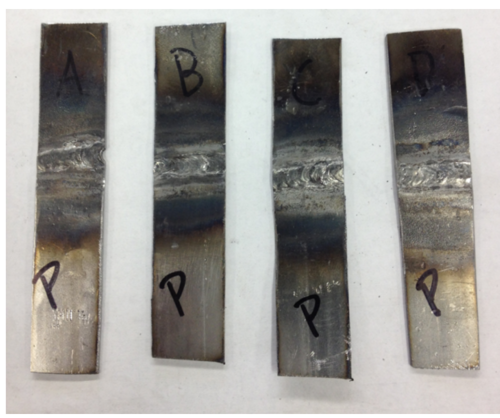


Figure 9.3 Shows sample specimens used in the weld testing process.

9.3.1 Stopping Power

One of the most important safety features of a recumbent tricycle is its stopping power. In other terms, how long it takes for the vehicle to come to a complete stop when the braking system has been applied. *Cerberus* has two devices that contribute to its stopping capabilities: two disk brakes mounted on the front wheels of the vehicle, and the variable energy storage dynamo that can be engaged to provide drag on the rear wheel, in the form of regenerative braking. In order to determine how much of an additional stopping effect the dynamo can apply to the vehicle, a basic test was conducted. First, a strip of tape was laid across a flat cement surface that has a significant run-up area. Then, using a cadence computer mounted on the trike, the rider brought *Cerberus* up to a speed of 17 mph (a good average speed representing a casual ride) in the run-up area. Upon reaching the line, the braking system was fully applied to stop the trike. The distance that the bike traveled before coming to a complete stop was then measured.

The first trial involved applying only the disk brakes on the front wheels, while the second trial included the application of the dynamo. Because the disk brake system alone has already been proven to meet the requirements of our datum (20 ft stopping distance from 15 mph) by a significant margin through physical testing in a competition setting, this test acted only to determine if the energy storage system had any potential as a backup, emergency braking system. In the first trial, a distance of 19.2 ft was needed to completely stop the trike from 17 mph. In the second trial, a distance of 14.5 ft was needed to completely stop the trike from 17 mph. These results supported the belief that the dynamo generator added roughly 20% stopping power.

9.3.2 Top Speed

To measure the maximum speed of *Cerberus,* two tests were conducted. During the competition, the trike was tested with five different riders on a velodrome. The riders were given one and a half laps to bring the trike up to speed, then they passed through two timing gates to find an average speed over a 40 meter section of track. During the competition the top speed was measured to be 22 mph. To verify this result, the team tested the trike in a similar fashion on a flat track. Using the on board computer, and a set of timing gates spaced 60 feet apart, the team again found the maximum speed to be 22 mph.

9.3.3 Weight

At the ASME Human Powered Vehicle Challenge, the weight of *Cerberus* was measured by placing the vehicle on a large wooden plate that was supported by four separate scales. The readings from all four scales were then summed to provide a total weight for the vehicle. The final weight of *Cerberus* and all of its components was 66 lbs.

9.3.4 Acceleration

The acceleration capabilities of a 32-tooth front chain ring were tested. To do this, the driver of *Cerberus* brought the vehicle from a complete stop up to a speed of 15 mph (verified with an on-board cadence computer) while a third party measured the time necessary to achieve such an acceleration. Using the equation

$$v^2 = v_0^2 + \frac{1}{2}at^2 \tag{9.1}$$

we were able to determine a fairly accurate estimate for the acceleration. The maximum acceleration was found to be 4.2 ft/s^2.

9.3.5 Battery Life

In order to test the battery life of the energy storage system, the rechargeable battery cells were fully charged using the dynamo applied to the rear wheel. Then the vehicle safety lights were turned on and were left drawing power from the large battery pack (which in turn received no additional charge from the dynamo) until the batteries were drained. This test showed that the large battery pack supplied power to the lights for 1 hour and 50 min. A second test was run to determine the battery life for the smaller battery pack that supplies power to the USB device. The device, an iPhone 4S, was plugged in starting with zero charge and was left drawing power from the battery pack until the time when the batteries could no longer provide the power to activate the device. The device was charged to 65% power in 1 hour and 15 minutes. This result could vary depending on the device being charged, the charge mode the device is in, and the status of the charging circuit.

9.3.6 Turn Radius

The tightest turn on the course had a radius of 8 meter. Before the competition, a hairpin turn was set up with the 8 meter radius turn and the vehicle was driven through. The minimum turning radius of the vehicle was tested separately by turning the vehicle in as tight a manner as possible at a slow speed. The distance between outer front wheel on either side of the turn was measured, and the turn radius was found to be 5' 8".

Chapter 10: Cost Analysis

Initial cost estimates placed the project budget at roughly $6,000. Included in this estimate were all the materials needed for construction and any labor or manufacturing costs. The steel used for the frame was relatively inexpensive, so the majority of this estimate came from high-end components. The complete vehicle ended up costing $2,280.

Funding was applied for directly through the University, from both the engineering school and the Center for Science, Technology, and Society. When applying for these grants, the low risk factor of the project was emphasized, as well as the positive exposure the school received. Minimal funds were required for travel, so the majority of donations and grants went directly into developing the product. Grants for $2,500 were received from both the Center for Science, Technology, and Society and also the Undergraduate Engineering department.

Sponsorships were obtained from two outside companies. Tread Bicycle Shop agreed to supply bicycle components at a discounted rate, giving at least 30% off all available parts. R.E. Borrmann's Steel Co. donated the steel material needed for the project. A detailed bill of materials can be found in Appendix C. A breakdown of the final costs can be found in Table 10.1.

This first prototype was well under budget. If this vehicle were to be manufactured on a large scale, the process could be streamlined to reduce production costs. Also, a lot of expensive, high-performance components were used on this prototype vehicle, such as the brakes and the internal hub gearing system. This was to maintain a competitive edge in the ASME Human Powered Vehicle Challenge. A production version of this vehicle could have more practical and inexpensive components, lowering costs by about $500.

Table 10.1 Estimated bill of materials for one prototype.

Component	Item	Quantity	Price	Subtotal
Frame	Steel	1	$277.00	$277.00
Wheels	Front hub	2	$79.95	$159.90
Wheels	Spokes	108	$1.00	$108.00
Wheels	Rims	3	$60.00	$180.00
Wheels	Rim strips	3	$5.00	$15.00
Wheels	Tires	3	$40.00	$120.00
Wheels	Disc brakes	2	$41.00	$82.00
Wheels	Tubes	3	$5.00	$15.00
Drive Train	Chain	3	$5.00	$15.00
Drive Train	Cranks	1	$173.00	$173.00
Drive Train	Internal Hub	1	$475.00	$475.00
Drive Train	Derailleur cables	2	$4.00	$8.00
Drive Train	Shifters	1	$95.00	$95.00
Steering	Handle bars	1	$40.00	$40.00
Steering	Ball Joints	2	$12.00	$24.00
Steering	Threaded Shafts	1	$18.00	$18.00
Steering	Uprights	2	$30.00	$60.00
Steering	Bearings (Bicycle Headsets)	2	$20.00	$40.00
Energy storage	Alternator	1	$75.00	$75.00
Energy storage	Batteries	4	$9.00	$36.00
Fairing	Windscreen	1	$225.00	$225.00
Fairing	Mounts	1	$40.00	$40.00
			Total	$2,280.90

Chapter 11: Patent Search

11.1 Field of the Invention

This invention generally relates to a bicycle or trike system mount that can be used in conjunction with a dynamo generator. It provides a toggle option that can be activated by the rider while in motion to limit the drag caused by electricity generation as defined by the user.

11.2 Background Information

Human powered vehicles have become increasingly popular due to a generational tendency towards cleaner, more sustainable methods of transportation and travel. Whether for recreation, transportation of goods, or personal travel, the industry continues to strive towards better components that support a healthy and efficient lifestyle. Recently, these vehicles have been equipped with more and more components requiring the use of electrical energy. It is impractical to generate electricity separately from the vehicle and then transport it in addition to the rider and electrical components. Many bicycles and trikes have been outfitted with permanently mounted dynamo generators to supply power for lights, cycle computers, electric shifters, etc. Two examples of current mounting systems available are disclosed in U.S. Patent No. 7,059,989 and WIPO No. 089289 assigned to Shimano Inc. and Ezra Kieron Loy, respectively.[6] [7]

The mounting systems currently available require that the dynamo be permanently engaged with the wheel, ensuring constant electricity generation, but also adding considerable drag to the wheel. This additional drag does not make the vehicle unusable. However, when used for long distances or on steep gradients it can require considerably more effort from the rider. In some instances, this additional work outweighs the value of the lights or electrical components on the vehicle, thereby voiding their potential value.

The amount of force necessary to produce sufficient friction to activate the dynamo when in direct contact with the wheel is minute. In practice, the design of most marketed bicycle dynamo generators requires a single point of contact to cause activation of a rotating wheel. Besides the contact point, the remainder of the dynamo body can be restricted

[6] Seiji Fukui "Bottom Bracket Structure with Dynamo" pat. US 7,059,989 June 2006.
[7] Kieron Ezra LOY "Improvements in Charging Mobile Phones" pat. WO2002089289 A1 July 2002.

by a mounting bracket preventing it from shifting and ensuring that it does not disengage from the wheel. Currently, the rider must stop the vehicle and dismount in order to disengage the dynamo. This invention provides the ability for the rider to engage and disengage the dynamo from the wheel using a hand operated lever.

11.3 Summary of the Invention

The system design and components can be seen in Figure 11.1. The object of the present invention is to provide the opportunity to engage or disengage the dynamo (2) from contact with the vehicle wheel (6) without having to stop and dismount the vehicle to do so. To achieve this goal, the invention makes use of a swivel arm design operated by the rider by means of a locking hand brake such as that defined in U.S. Patent No. 8,381,884 assigned to Shimano Inc.[8] The dynamo of choice is held within the confines of an aluminum bracket (1) designed to securely hold any dynamo with height, length, and width dimensions smaller than 2"x4"x1.5" and larger than 1"x2.5"x1".

When the hand brake is engaged, a cable (4) is drawn which causes the swivel arm to move to a specified position. This forces the dynamo generator into contact with the drive wheel. Due to the locking design of the handbrake, the rider can toggle the dynamo to be engaged or disengaged. When the brake is released, a spring (3) attached to the bracket and the frame (5) of the vehicle produces a force which pulls the dynamo out of the engaged position (a) to a point where no contact between the dynamo disk and the vehicle wheel exists. Because of the passive nature of the spring force being applied, the lever arm and bracket can remain in this disengaged position (b) indefinitely without interfering with the movement of the bicycle wheel.

11.4 Description of the Preferred Embodiments

While the dynamo lever is released, there is no contact between the dynamo and the bicycle wheel, so there is no induced drag. This allows the rider to define the time when they feel the value of electricity generation is preferable, as well as when the harm of the drag outweighs the electrical value. By disengaging the system, they can alleviate themselves of the drag temporarily before then re-engaging the system to provide electrical energy for the on-vehicle electrical components. This variability is unique from mounting

[8] Etsuyoshi Watarai "Locking Bicycle Braking System" pat. US 8,381,884 Sept. 2008.

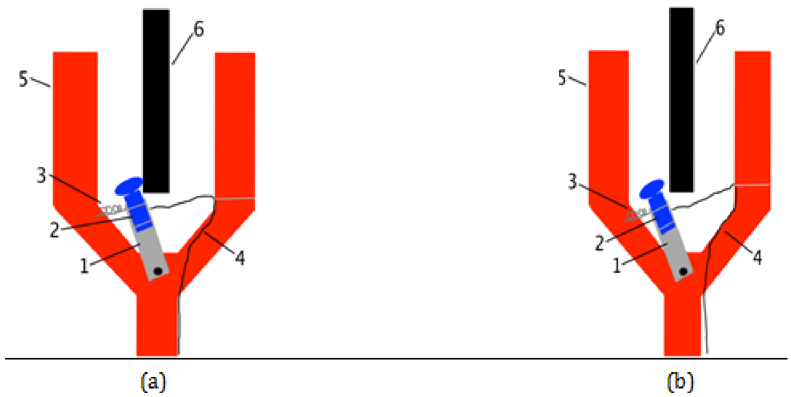


Figure 11.1 Dynamo toggle system (a) engaged and (b) disengaged.

systems available commercially at present time which force the rider to stop and physically dismount from the vehicle in order to deactivate the electrical generator. This saves the rider both time and the hassle of using tools to attach and detach a dynamo generator without sacrificing any of the value brought by the inclusion of a portable generator or the electrical components that can be run by the energy it harnesses.

Other dynamo designs currently available on the commercial market include those designed to be mounted within the hub of a bicycle or trike wheel. Two examples of such hub dynamos are disclosed in U.S. Patent Nos. 6,409,197 and 6,559,564, which are both assigned to Shimano Inc.[9] While such systems eliminate the need for an external dynamo or mounting bracket, they do not allow the user to toggle the generator on or off, thereby ensuring that the drag induced by electricity generation is constantly present. Additionally, though the swivel arm with its bracket and cable add additional components to the frame of a human powered vehicle, the weight of the innovative system is negligible (being itself less than the added weight of a half-filled water bottle). As such, the Bicycle/Trike Dynamo Toggle System presented provides value for recreational, competitive, and transport-minded users that is not currently available on the open market.

[9]Nobukatsu Hara "Bycicle Head Cap Unit" pat. US 6,559,564 Mar. 2005.

Chapter 12: Engineering Standards and Constraints

12.1 Economic

Cerberus provides urban commuters and those in developing countries with an inexpensive solution for mid-distance transportation. According to Forbes Magazine the average cost for a passenger vehicle in America is $30,303.[10] Americans also spend roughly $2,100 on gas per year.[11] In contrast, a human powered vehicle can be produced for a few hundred dollars and does not come with any fuel costs. The maintenance on a trike is also minimal compared to a car. All things considered, use of a human powered vehicle would save an average commuter thousands of dollars each year.

12.2 Environmental

This vehicle was designed to provide an alternative solution for those who regularly commute in an urban setting. The first step for creating a desirable vehicle for sustainable transportation was to create an available, accessible, and attractive trike for a potential user. Americans travel 34% more miles per year now than they did in 1990, which has caused a spike in carbon emissions.[12] An average passenger car emits 271 grams of carbon dioxide per kilometer traveled, where a cycle produces only 21 grams per kilometer.[13] When compared with a traditional passenger vehicle, the use of a cycle could cut carbon emissions 10 times. The infrastructure needed to support the over 250 million passenger vehicles in the United States also contributes an additional 10% to America's carbon footprint yearly.[14] With this being said, if only 5% of New York City's 8 million person population switched from personal vehicles to cycles, 150 million pounds less of

[10] Nickel. Moneybuilder *Average Price of a New Car?* Forbes May 2012 URL: http://www.forbes.com/sites/moneybuilder/2012/05/10/average-price-of-a-new-car/.

[11] *How Much Americans Spend On Gas Every Year* Huffington Post Mar. 2012 URL: http://www.huffingtonpost.com/2012/03/04/gas-prices-infographic_n_1316919.html.

[12] *U.S. Climate Action Report* Environmental Protection Agency Jan. 2010 URL: http://unfccc.int/resource/docs/natc/usa_nc5.pdf.

[13] Ben Daly *Quantifying the C02 Savings of Cycling* May 2012 URL: http://www.urbanvista.net/quantifying-co2-savings/.

[14] *Passenger Vehicles in America* Wikipedia May 2013 URL: http://en.wikipedia.org/wiki/Passenger_vehicles_in_the_United_States.

carbon would be emitted into the atmosphere each year.[15] The benefits of cycling not only reduce traffic, resource consumption, and pollution, but also increase the health and safety of a community.

12.3 Sustainability

Cerberus provides an innovative solution for developing countries by providing citizens access to battery packs, lights, and device chargers without relying on electricity from the grid. The frame of the trike is also designed using common and readily available materials. The removable battery pack outputs 11 watt-hours of energy when used, and is charged using human power. The EPA equates 33.7 kW-hours to burning a single gallon of gasoline.[16] If a community of 6,000 people who each used one gallon of gas to light their homes, were given the opportunity to use *Cerberus* or a similar vehicle, 730 gallons of gasoline could be saved annually. This is turn could prevent 14,600 pounds of carbon dioxide from entering the atmosphere each year. By using a renewable source for energy, the trike offers a feasible solution for promoting sustainability in developing countries and in the United States.

12.4 Manufacturability

This vehicle was designed to be easily manufactured and built within simple machine shops. The vehicle's frugal design is evident as the frame is composed of 1.5" square steel tubing. The frame uses only single axis cuts, which makes the welding simple and easy to do. Additionally, many of the high-end parts used specifically for the competition can be replaced by inexpensive substitutes. If a larger quantity of bikes were to be produced, the vehicles would also be completed more quickly and easily as the manufacturing process would be sped up significantly.

12.5 Health and Safety

As a solution for urban transportation, *Cerberus* provides many health and safety benefits. This trike design is much safer than a bicycle. The low center of gravity, ease of operation,

[15] *Rolling Carbon: Greenhouse Gas Emissions from Commuting in New York City* Transportation Alternatives 2008 URL: http://www.bikesbelong.org/resources/stats-and-research/statistics/environmental-statistics/.

[16] *Fuel Economy and Environmental Labels* Environmental Protection Agency Mar. 2013 URL: http://www.epa.gov/fueleconomy/.

built in brake and safety lights, seatbelt, roll protection system, and maneuverability make the trike a better transportation alternative to a traditional bicycle.

The tricycle also promotes healthy habits because it encourages people to exercise and stay active instead of passively sitting in an idling vehicle. The World Health Organization also analyzed vehicles and pollution and found that 30% of fine particle pollution in urban areas originates automobile exhaust gases. Extreme exposure to this can lead to respiratory problems, severe allergies, asthma, and mortality. The WHO estimated that "tens of thousands of deaths per year are attributable to transport-related air pollution–similar to the death toll from traffic accidents." These numbers speak volumes about the potential that a human powered vehicle can have upon society and the environment. This trike offers a healthy alternative to a fuel consuming car.

12.6 Ethical

The integrity of engineering is arguably the most important aspect any project. For obvious moral reasons, it is not right to lie to a customer about what a product is capable of. Companies that produce faulty products or services go out of business in a free market society. Nobody wants to buy a bike that breaks after 100 miles especially if they bought it thinking it would last a lifetime. This means that, durability is especially important. Making sound calculations, testing the design thoroughly, and overseeing the fabrication of the project are all required to accomplish this goal. It is also important to document all work so that if something does go wrong, the problem can be fixed quickly and transparently.

For this senior design project, documentation was especially important. Part of the success in the competition was based on the design report. Future seniors, who will most likely reference the work done this year, may pick up this project. In order to ensure that future design teams do not make the same mistakes or waste time researching things that have already been looked into, a detailed report will be left for students who are interested in the project.

12.7 Social

Four years ago *The New York Times* published an article regarding the United Nations' most recent publication on developing nations and the energy need in those communities.

Among other statistics, the article mentioned that 79% of those in developing countries lack reliable access to electricity.[17] Although the trike does not provide a long-term solution for the energy crisis, it does give community members the opportunity to have access to reliable electricity for small appliances. The trike has the potential to impact communities indirectly by encouraging mobility throughout regions, stimulating economies, enabling employment, and promoting community awareness.

In urban communities, officials estimate that Americans spend over 500,000 years in traffic annually, equating to 4.2 billion hours per year.[18] This number will continue to grow as populations increase. This adds time on to commuter's workday, and studies have shown that there are direct links between people's livelihood and the amount of time they spend away from their home doing work related things or commuting. Essentially, the shorter and simpler a commute is, the better.

[17] Felicity Barringer *Lighting the Hopes of the Gridless* New York Times June 2011 URL: http://green.blogs.nytimes.com/2011/07/15/if-everyone-lighted-one-little-led/.

[18] *The Case for U.S. Infrastructure Investment* Building America's Future Dec. 2010 URL: http://www.bafuture.com/sites/default/files/Fast_Facts_12.10.10.pdf.

Chapter 13: Competition Results

The Santa Clara team and their vehicle, *Cerberus*, took 11th place overall. The design event was judged off of a comprehensive design report that included the plans for the vehicle as well as important safety information like the FEA report of the roll protection system. Santa Clara University received 52.3 points out of 100 in this event, which translates to 12th place. The report was due in early March when the vehicle had yet to be completed.

The second event that the team competed in was the speed event, held at the Hellyer Park Velodrome. The banked track proved to be difficult for many of the vehicles. The drivetrain on *Cerberus* was set up to accelerate quickly, which is ideal for a drag race. However, this event was more focused on top speed. Vehicles were allowed 1.5 laps before their top speed was measured. This was done by recording the time it took to travel across a 40 meter section of the track. In the men's event, the fastest time was 4.21 seconds which earned 19th place. In the women's event, the best time was 4.23 seconds which earned a 10th place spot.

The next day of the competition showcased the innovation of each vehicle. The competition guidelines suggested that teams create an energy storage device for this component of the challenge. The team scored highest in this event for the energy storage device with regenerative braking that was created. *Cerberus* took 8th place.

The final event took place on April 14th, and consisted of a 2.5 hour endurance race. The goal was to complete as many laps as possible. In the race, certain obstacles were created to simulate real life commuting. The competition included a parcel pick-up and drop-off, slalom turns, a 180 degree hairpin turn. Each rider could not ride more than 22 laps, and at the end of the 2.5 hours the number of laps was recorded. The Santa Clara team rode 51 laps, each of which was just under1 kilometer. The team took 10th in this event.

Overall the vehicle did well with respect to the prior experience many other teams had. Santa Clara University took second out of the rookie teams, being beat by only UC Berkeley. This exceeded to the goals and expectations of the team, and was considered a huge success.

Chapter 14: Future Improvements

Although the completion of this project is a great accomplishment there are many improvements that can be made to both the trike itself and the overall project approach. This year's team has learned many things simply from attending the competition. Having the opportunity to meet with other, more experienced teams to discuss various hurdles and an array of designs was invaluable.

The first thing that should be changed to have a more successful team is the team structure itself. The entire team learned the hard way that sticking to a specific structure and timeline is key to being competitive. There are always going to be things that push both the ability of a team and the schedule, yet it is crucial to delegate accordingly and adapt.

The other improvements are for the trike itself. The trike was designed to fit through a doorway. This was good for the practical aspect of our design yet it affected our handling tremendously. For the future it would be good to design the trike in a way that it fits through a doorway and handles well. This can be done by lowering the center of gravity and fine-tuning the kingpin, camber, and caster angles. The current trike could easily be used as a prototype for the next years design allowing the team to make more tangible adjustments.

Although *Cerberus* was among the lightest at the competition its weight could be reduced further. Weight optimization could help the trike brake, accelerate, and handle better with little loss in strength or stiffness. If the material were changed to aluminum or perhaps even carbon, the performance has potential to increase dramatically.

Next the fairing could be improved. The fairing was among one of the weakest aspects of our trike lacking in aerodynamics, aesthetics, and rigidity. After attending the competition it became obvious that there were simple solutions to the competition's demand for an aerodynamic device. One team even used taught cloth and tent poles for theirs. Both the mounting system and the fairing itself are in need of immediate attention. An addition of reflectors and more stable mirrors would also please the judges.

The gearing of the trike could also be improved. With 11 speeds the trike did not have a broad enough gear range to have a high top speed and acceleration. Although the physical number of gears was sufficient, the range could use improvement. By using a front sprocket with more teeth, the gear range could be shifted up, allowing for a higher top speed at the expense of low range gearing. For a top speed event, this would be a good trade.

On the energy storage system, super capacitors can be implemented to greatly reduce charging times of the devices. The circuit can also be optimized to reduce losses and reduce noise from the dynamo. An indicator could also be added to show the charge of the batteries.

The biggest known issue with the current *Cerberus* revision is the rider geometry. The trike does not currently have an adjustable seat, so most riders are not in an ideal position for maximum power transfer and comfort. Later revisions should conduct more testing and improve the rider geometry by lowering the angle of the seat back with respect to the ground and designing an adjustable seat. This would improve the ergonomics and the comfort of the rider, allowing for more efficient pedaling.

Chapter 15: Summary and Conclusions

The purpose of this project was to create a safe, ergonomic, high performance human powered vehicle. This vehicle was created to compete successfully in the ASME Human Powered Vehicle Challenge, while also maintaining a general theme of minimalist design and manufacture. Santa Clara University promotes service and sustainability, ideals that *Cerberus* exemplifies. The recumbent trike design was chosen in order to offer the average person who must commute to work on a regular basis a more comfortable alternative to a traditional bicycle. Additionally, in developing countries, *Cerberus* can serve as a mode of transportation within rural areas where buses are not available and walking is not an option.

When fully assembled, the *Cerberus* trike weighed a total of 66 lbs and utilized a tadpole style design with two smaller wheels in front and a larger, primary drive wheel in the rear. The frame was made of 1.5" square steel tubing with a roll protection system constructed from .75" steel tubing that successfully underwent a series of tests for strength in accordance with ASME competition guidelines. Disk brakes were attached to each of the front wheels and could be activated with a single brake lever to bring the trike to an unassisted stop in 19.2 ft from a speed of 17 mph. An Ackerman steering system was chosen because of its ease of construction and because it has the capability to maintain a tight turning radius. The minimum turning radius of the trike was 5' 8". A frontal fairing was mounted to the frame that provided aerodynamic properties but did not add any structural assistance.

Cerberus utilized a single line chain drivetrain system linked from a 32 tooth front chain ring and pedal system along the length of the trike to an 11-speed internal hub. Two idlers protect and guide the chain along the bottom of the frame, keeping it at a distance greater than 6 inches from the pavement and maintaining the chain tightness. The maximum trike speed was 22 mph, though that would increase with the addition of a larger front chain ring. However, were the ring size to be increased, the maximum acceleration of the trike, which currently stands at 4.2 ft/s^2, would decrease.

Bibliography

[1] ASME. *Rules for the 2013 Human Powered Vehicle Challenge*. June 2012 (see pp. 4, 5, 33)

[2] *Online Catalog* Utah Trikes 2013 URL: http://www.utahtrikes.com/catalog.html (see p. 6)

[3] Rickey M. Horwitz *The Recumbent Trike Design Primer* tech. rep. Hell-Bent Cycle Works, 2010 (see pp. 34–38)

[4] *Avid BB7 Mechanical Disk Brake* JensonUSA 2011 URL: http://www.jensonusa.com/!nDYgCHvDiqcy9gUoXVmLCg!/Avid-BB7-Mechanical-Disc-Brake-2011?utm_source=FRGL&utm_medium=organic&gclid=CKHYtsPnrbcCFSiCQgodbRgA9w (see p. 40)

[5] *ASTM E290-09: Standard Test Methods for Bend Testing of Material for Ductility* West Conshohocken, PA: ASTM, 2009 DOI: 10.1520/E0290-09 (see p. 43)

[6] Seiji Fukui "Bottom Bracket Structure with Dynamo" pat. US 7,059,989 June 2006 (see p. 49)

[7] Kieron Ezra LOY "Improvements in Charging Mobile Phones" pat. WO2002089289 A1 July 2002 (see p. 49)

[8] Etsuyoshi Watarai "Locking Bicycle Braking System" pat. US 8,381,884 Sept. 2008 (see p. 50)

[9] Nobukatsu Hara "Bycicle Head Cap Unit" pat. US 6,559,564 Mar. 2005 (see p. 51)

[10] Nickel. Moneybuilder *Average Price of a New Car?* Forbes May 2012 URL: http://www.forbes.com/sites/moneybuilder/2012/05/10/average-price-of-a-new-car/ (see p. 53)

[11] *How Much Americans Spend On Gas Every Year* Huffington Post Mar. 2012 URL: http://www.huffingtonpost.com/2012/03/04/gas-prices-infographic_n_1316919.html (see p. 53)

[12] *U.S. Climate Action Report* Environmental Protection Agency Jan. 2010 URL: http://unfccc.int/resource/docs/natc/usa_nc5.pdf (see p. 53)

[13] Ben Daly *Quantifying the C02 Savings of Cycling* May 2012 URL: http://www.urbanvista.net/quantifying-co2-savings/ (see p. 53)

[14] *Passenger Vehicles in America* Wikipedia May 2013 URL: http://en.wikipedia.org/wiki/Passenger_vehicles_in_the_United_States (see p. 53)

[15] *Rolling Carbon: Greenhouse Gas Emissions from Commuting in New York City* Transportation Alternatives 2008 URL: http://www.bikesbelong.org/resources/stats-and-research/statistics/environmental-statistics/ (see p. 54)

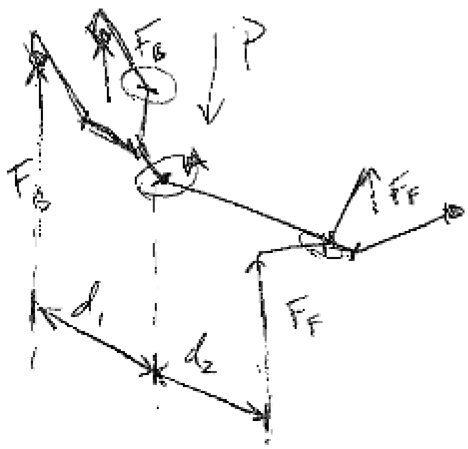
[16] *Fuel Economy and Environmental Labels* Environmental Protection Agency Mar. 2013 URL: http://www.epa.gov/fueleconomy/ (see p. 54)

[17] Felicity Barringer *Lighting the Hopes of the Gridless* New York Times June 2011 URL: http://green.blogs.nytimes.com/2011/07/15/if-everyone-lighted-one-little-led/ (see p. 56)

[18] *The Case for U.S. Infrastructure Investment* Building America's Future Dec. 2010 URL: http://www.bafuture.com/sites/default/files/Fast_Facts_12.10.10.pdf (see p. 56)

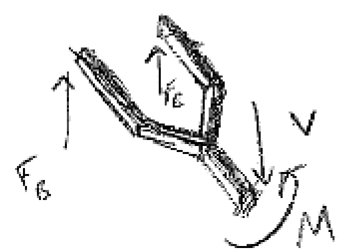
Appendix A: Detailed Calculations

A.1 Weld Stress Analysis



$$F_G = \frac{d_2}{d_1} F_F$$
$$F_B + F_F = P$$
$$F_B = P - F_F$$
$$F_F \left(\frac{d_2}{d_1} \right) = P - F_F$$
$$F_F = \frac{P}{1 + \frac{d_2}{d_1}}$$

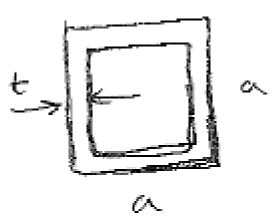
At Face *A*, looking at the rear of the vehicle *shear* and *bending* exist.



$$V = 2 \cdot F_B$$
$$M = 2 \cdot F_B \cdot d_1$$

$$\theta_B = \frac{M_C}{I};\ \theta_V = \frac{VQ}{It}$$

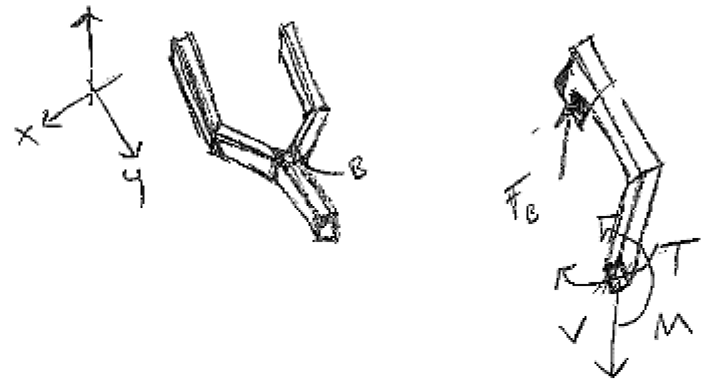
Tube Profile:



$$A = a^2 - (a - 2t)^2$$
$$I = \frac{a^4 - (a - 2t)^4}{12}$$
$$Q = \frac{a^3 - b^3}{2}$$
$$c = \rho = \frac{a}{2}$$
$$J = \frac{a^4 - (a - 2t)^4}{6}$$

$$J_{total} = \frac{\theta_N}{2} \pm \left[\theta_S^2 + \left(\frac{\theta_N}{2} \right)^2 \right]^{\frac{1}{2}}$$

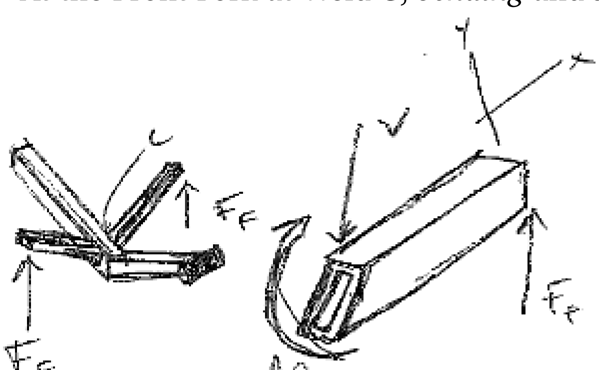
At the Back Fork at Weld *B*, *shear*, *moment*, and *torsion* exist.



$$V = F_B$$
$$T = F_B \cdot d_x,\ where\ d_x = 2.2”$$
$$M = F_B \cdot d_y,\ where\ d_y = 14.56”$$

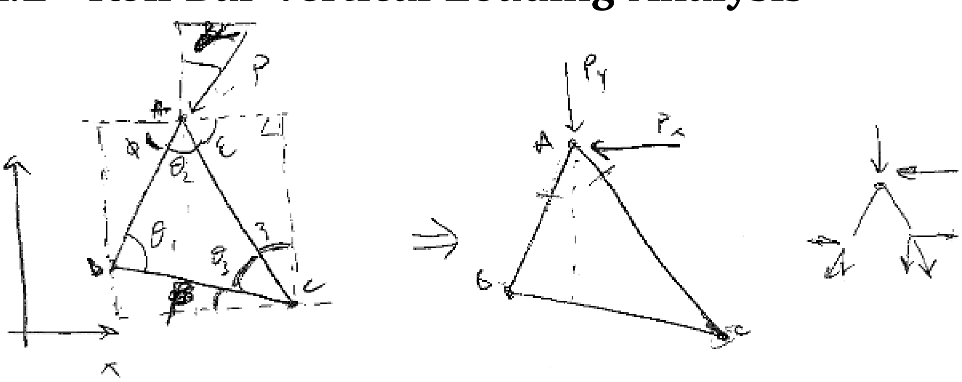
$\theta_v = \frac{VQ}{It}$; $\theta_T = \frac{T\rho}{J}$; $\theta_B = \frac{Mc}{I}$

At the Front Fork at Weld *C*, *bending* and *shear* exist.

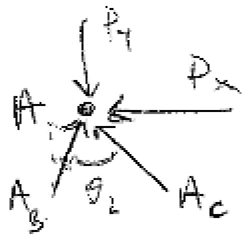


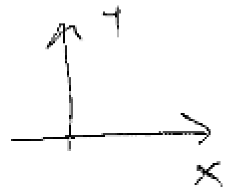
$$\theta_V = \frac{VQ}{It}$$
$$\theta_B = F_F \cdot d_x$$

A.2 Roll Bar Vertical Loading Analysis

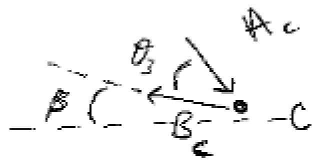


Assume a pinned-pinned connection.

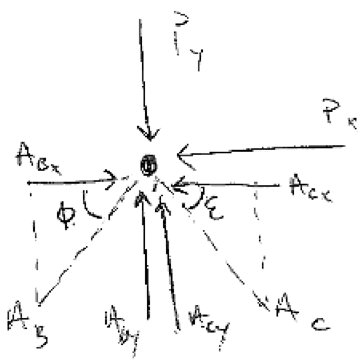




$\theta_1 + \theta_2 + \theta_3 = 180°$
$\phi + \theta_2 + \varepsilon = 180°$



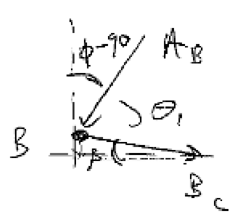
At Joint A:

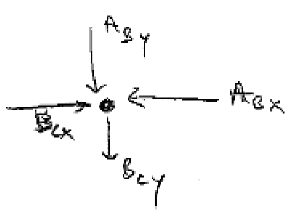


$$\sum F_x = -P_x + A_{Bx} - A_{Cx} = -P_x + A_B \cos\phi - A_c \cos\varepsilon \qquad (A.1)$$

$$\sum F_y = -P_y + A_B \sin\phi + A_C \sin\varepsilon \qquad (A.2)$$

At Joint B:





$$\sum F_x = B_{Cx} - A_{Bx} = B_C \cos\beta - A_B \cos\phi = 0 \qquad (A.3)$$

$$\sum F_y = -A_B \sin\phi - B_C \sin\beta = 0 \qquad (A.4)$$

At Joint C:

$$\sum F_x = -B_C \cos\beta + A_C \cos\varepsilon = 0 \quad (A.5)$$
$$\sum F_y = B_C \sin\beta - A_C \sin\varepsilon = 0 \quad (A.6)$$

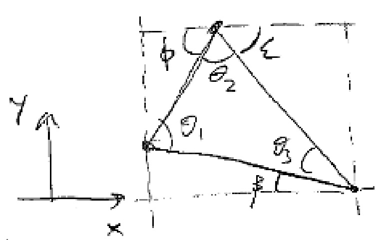
We have 6 equations, with 3 unknowns: $[A_B, A_C, B_C]$

$$A_B \cos\phi - A_C \cos\varepsilon = P_x \quad (A.7a)$$
$$A_B \sin\phi + A_C \sin\varepsilon = P_y \quad (A.7b)$$
$$-A_B \cos\phi + B_C \cos\beta = 0 \quad (A.7c)$$
$$-A_B \sin\phi - B_C \sin\beta = 0 \quad (A.7d)$$
$$-A_C \cos\varepsilon - B_C \cos\beta = 0 \quad (A.7e)$$
$$B_C \sin\beta - A_C \sin\varepsilon = 0 \quad (A.7f)$$

$$A_B \cos\phi - A_C \cos\varepsilon + 0B_C = P \sin\beta$$
$$A_B \sin\phi + A_C \sin\varepsilon + 0B_C = P \cos\beta$$
$$A_B \cos\phi + 0A_C + B_C \cos\beta = 0$$

$$\begin{bmatrix} \cos\phi & -\cos\varepsilon & 0 \\ \sin\phi & \sin\varepsilon & 0 \\ \cos\phi & 0 & \cos\beta \end{bmatrix} \begin{bmatrix} A_B \\ A_C \\ B_C \end{bmatrix} = \begin{bmatrix} P\sin\beta \\ P\cos\beta \\ 0 \end{bmatrix}$$

From Solidworks Model: Iteration 1



$$\theta_1 = 76.52^\circ$$
$$\theta_2 = 28.03^\circ$$
$$\theta_3 = 48.49^\circ$$
$$\phi = 81.38^\circ$$
$$\varepsilon = 180^\circ - \theta_2 - \phi = 70.59^\circ$$
$$\beta = 22.1^\circ (\mathit{fixed})$$

$A_B = 332.7$ lbs (torsion)

$A_C = 37.64$ lbs (compression)

$B_C = 53.815$ lbs (tension)

Iteration 2:

$$\theta_1 = 83.03^\circ \qquad \phi = 74.87^\circ$$
$$\theta_2 = 30.64^\circ \qquad \varepsilon = 180^\circ - \theta_2 - \phi = 74.49^\circ$$
$$\theta_3 = 52.39^\circ \qquad \beta = 22.1^\circ (fixed)$$

$A_B = 271.898$ lbs (torsion)

$A_C = 32.1412$ lbs (compression)

$B_C = 76.6$ lbs (tension)

Iteration 3:

$\theta_2 = 31.81^\circ$

$\phi = 65.23^\circ$

$\varepsilon = 180^\circ - \theta_2 - \phi = 82.96^\circ$

$A_B = 185.672$ lbs (torsion)

$A_C = 125.8$ lbs (compression)

$B_C = 83.96$ lbs (tension)

Results:

· When ϕ decreases, all members are in tension and forces in each member are more distributed.

· Design for minimum allowable ϕ, up to 45°

Now, hold θ_2 fixed at 30°

$\beta = constant = 22.1^\circ$

$\phi = variable$

$\varepsilon = f(\phi) = 180^\circ - \phi - \theta_2 = 150^\circ - \phi$

Three equations become:

$$A_B \cos\phi - A_C \cos 150^\circ - \phi + 0B_C = P \sin\alpha$$
$$A_B \sin\phi + A_C \sin 150^\circ - \phi + 0B_C = P \cos\alpha$$
$$A_B \cos\phi + 0A_C + B_C \cos\beta = 0$$

$$\theta_{AB} = \frac{A_B}{A_{AB}}; \quad \theta_{AC} = \frac{A_C}{A_{AC}}; \quad \theta_{BC} = \frac{B_C}{A_{BC}}$$

A.3 Drive Train Force Calculations

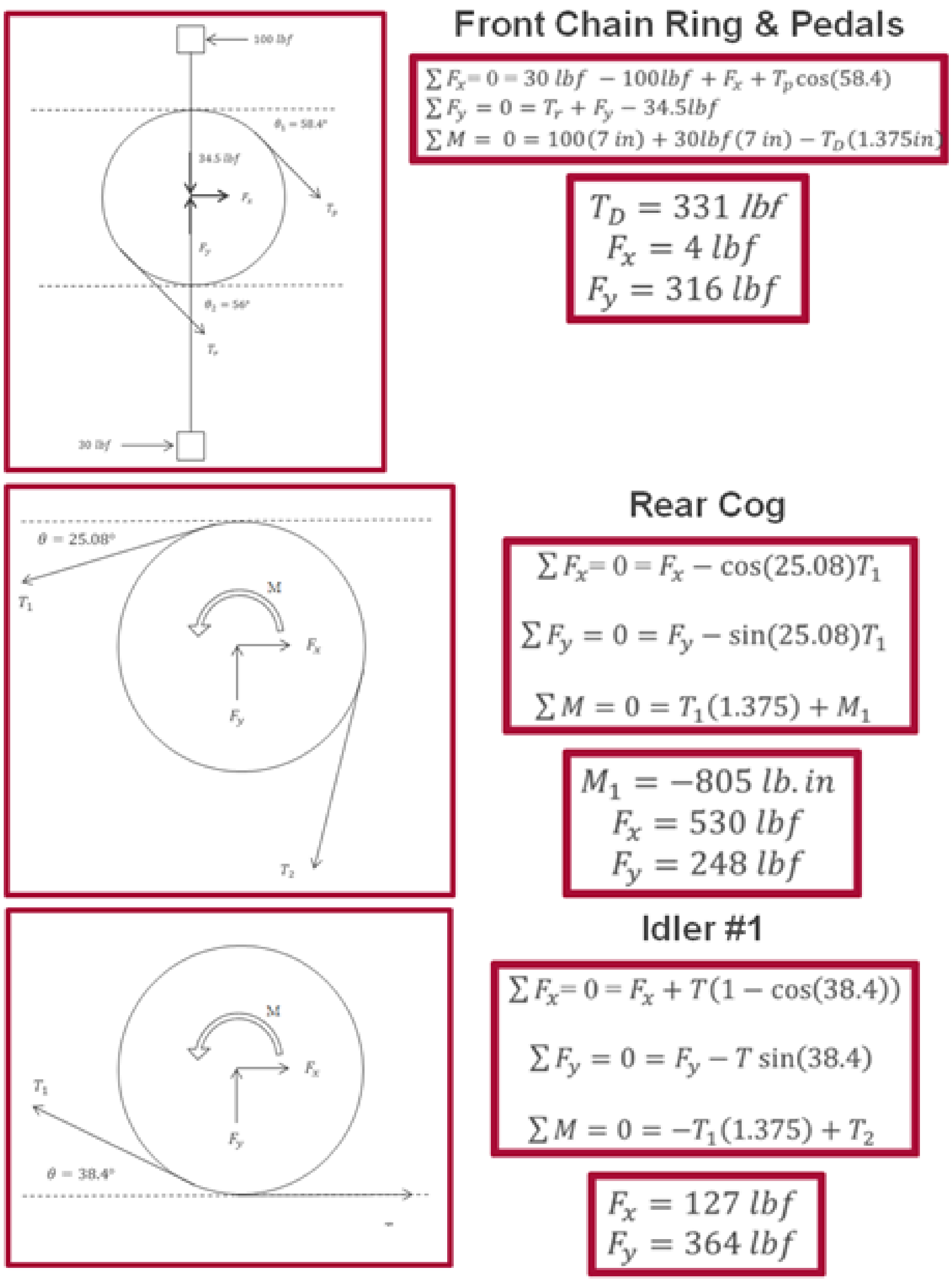
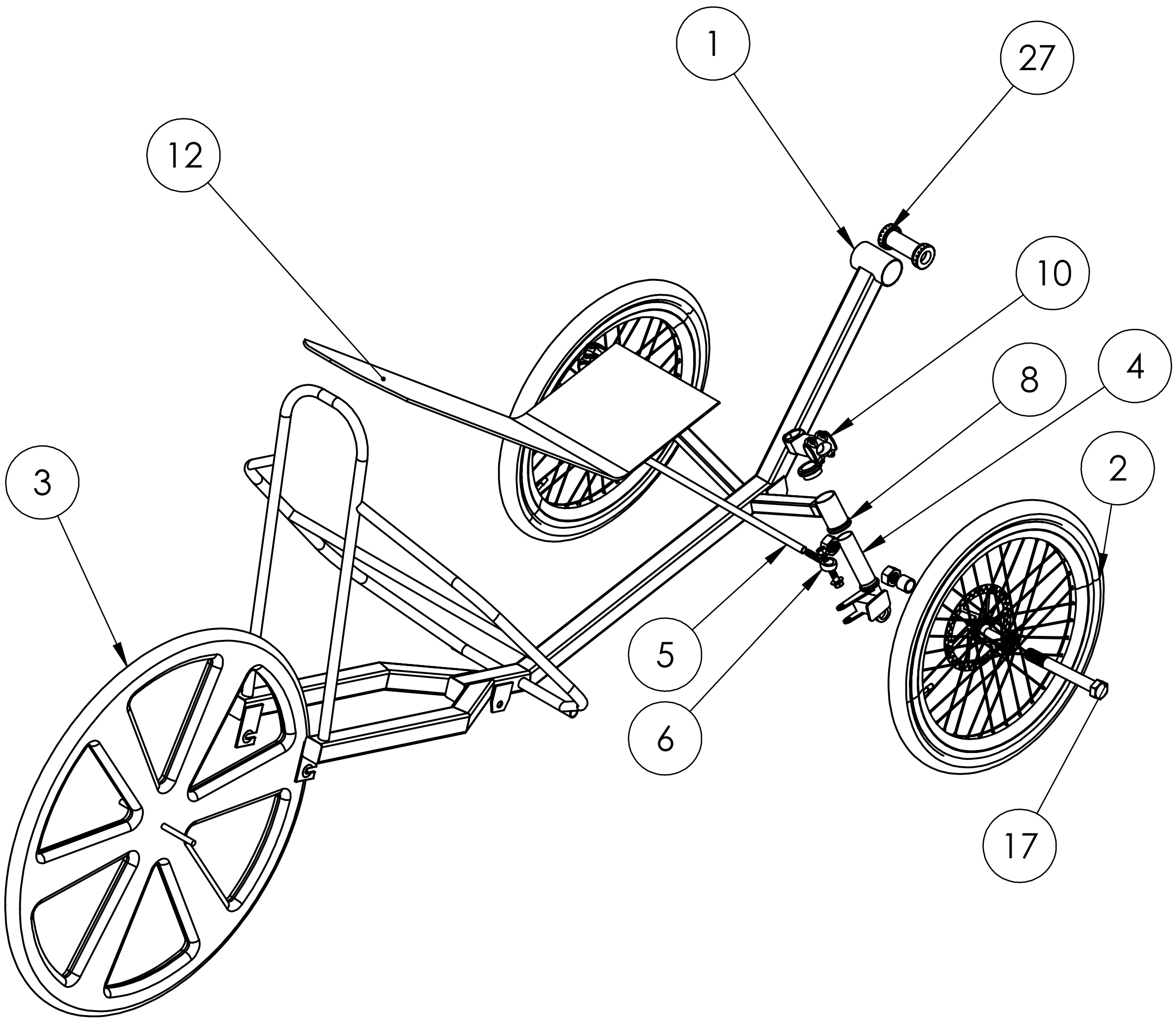


Figure A.1 Free body diagrams of the idlers and chain sprocket when a 100 pound pushing and 30 pound pulling force is applied to the cranks at rest.

Appendix B: Assembly Drawings

See following pages for assembly drawings.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FR000	FRAME WELDMENT	1
2	WA001	FRONT WHEEL ASSM	2
3	WA002	REAR WHEEL ASSM	1
4	ST000	STEERING ASSM	2
5	S001	STEERING LINKAGE, ALUMINIUM	1
6	S002	BALL JOINT	2
7	S003	5/16" - 24 HEX NUT	2
8	S004	HEADSET, 1-1/8" DIA.	4
9	S005	5/16" - 24 X 1.5" HEX BOLT	2
10	S006	STEM ASSM	2
11	S007	BRAKE, DISC, CALIPER	2
12	M001	SEAT	1

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

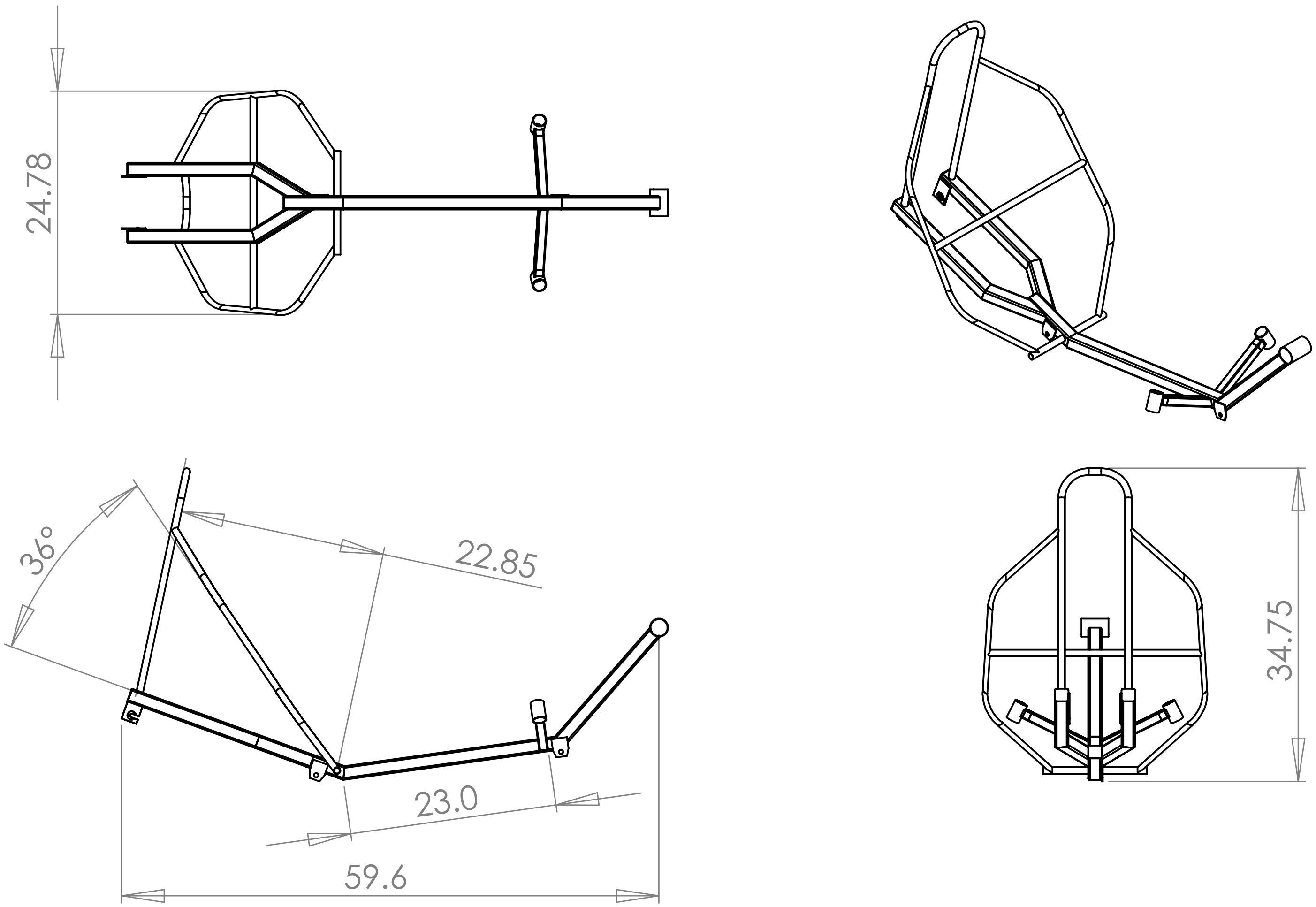
TITLE:

TOP ASSEMBLY

SIZE A | DWG. NO. T000 | REV 2

SCALE: 1:24 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

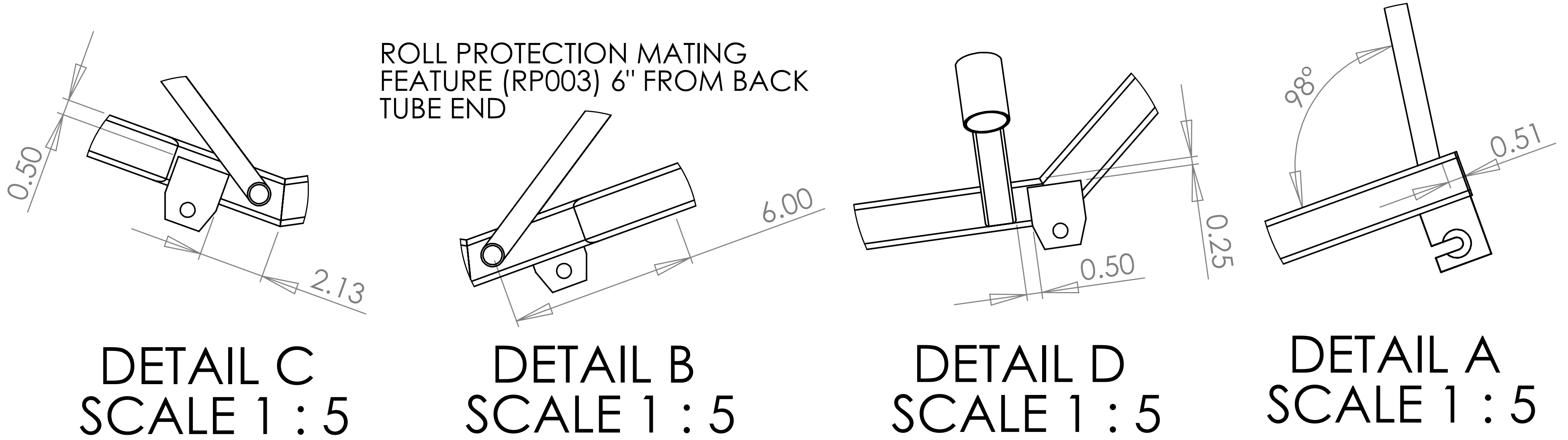
TITLE:

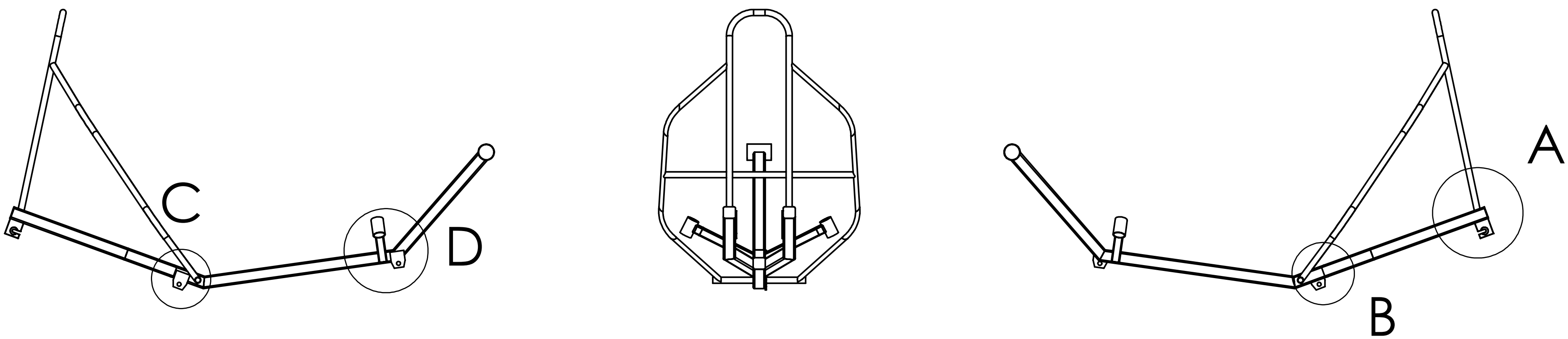
FRAME WELDMENT

SIZE A | DWG. NO. FR000 | REV 2

SCALE: 1:16 | WEIGHT: | SHEET 1 OF 2

5 4 3 2 1





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	MJG	6/2/13
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MILD STEEL	COMMENTS:		
NEXT ASSY	USED ON	FINISH NONE			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

SANTA CLARA UNIVERSITY

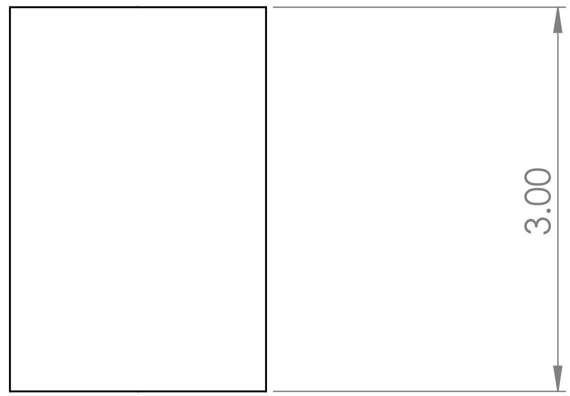
TITLE:

FRAME WELDMENT

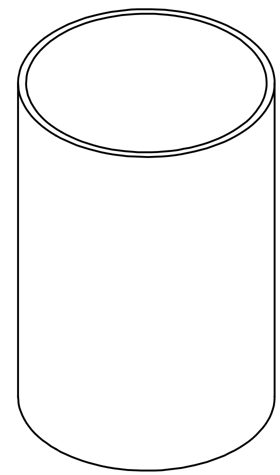
SIZE	DWG. NO.	REV
A	FR000	2

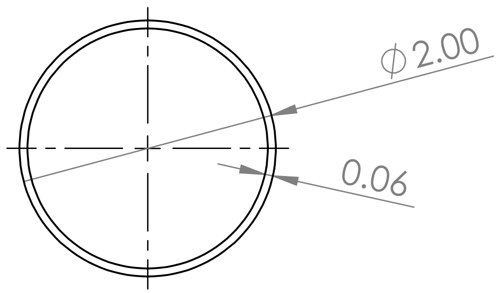
SCALE: 1:20 WEIGHT: SHEET 2 OF 2

5 4 3 2 1



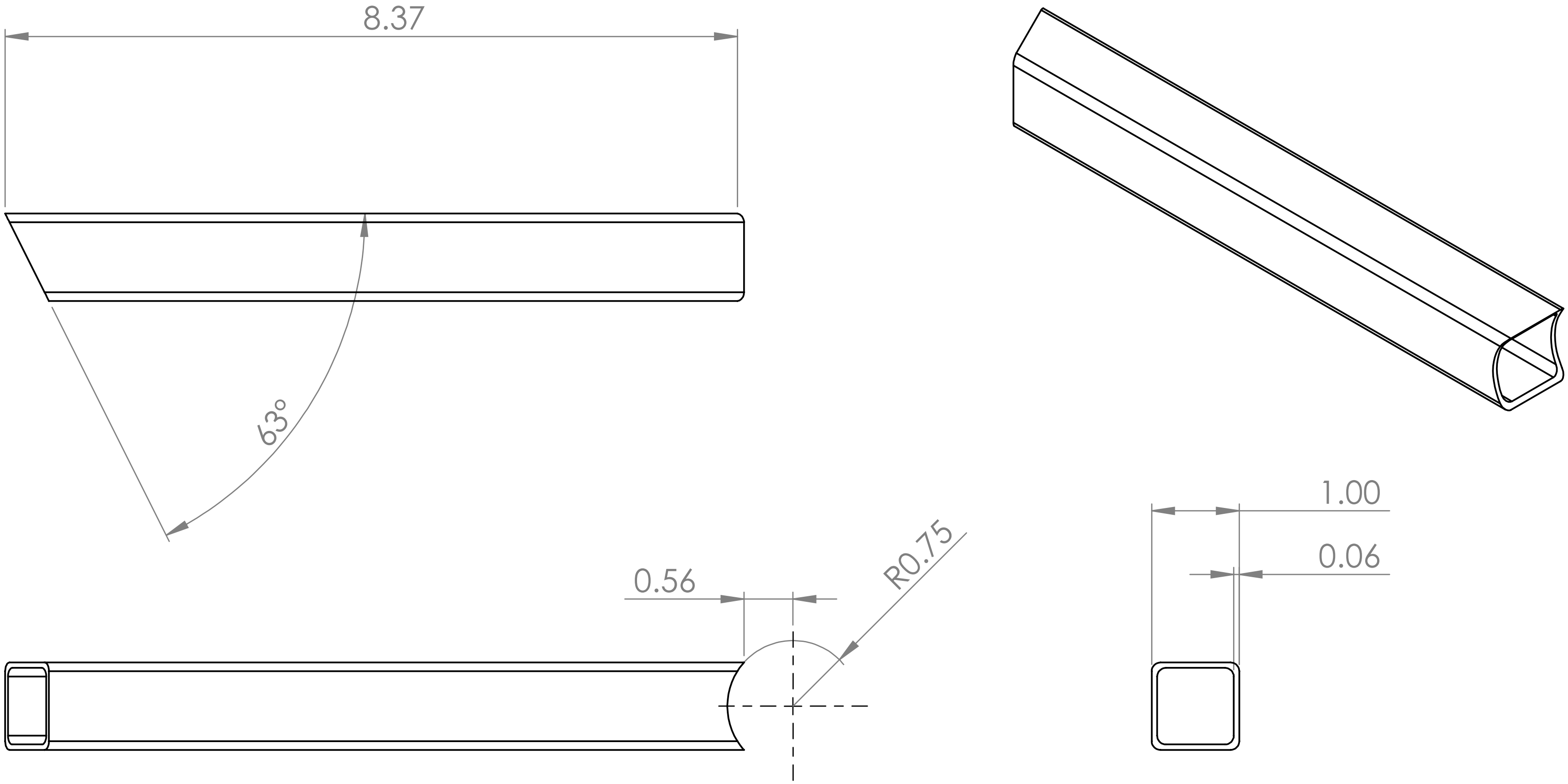
QTY: 2





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	SANTA CLARA UNIVERSITY
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	LEK	5/27/13	TITLE:
			CHECKED			BOTTOM BRACKET SHELL
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL MILD STEEL	COMMENTS:			SIZE A · DWG. NO. FR001 · REV 2
NEXT ASSY	USED ON	FINISH NONE				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 2:3 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LEK	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

FRONT FORK

SIZE	DWG. NO.	REV
A	FR002	2

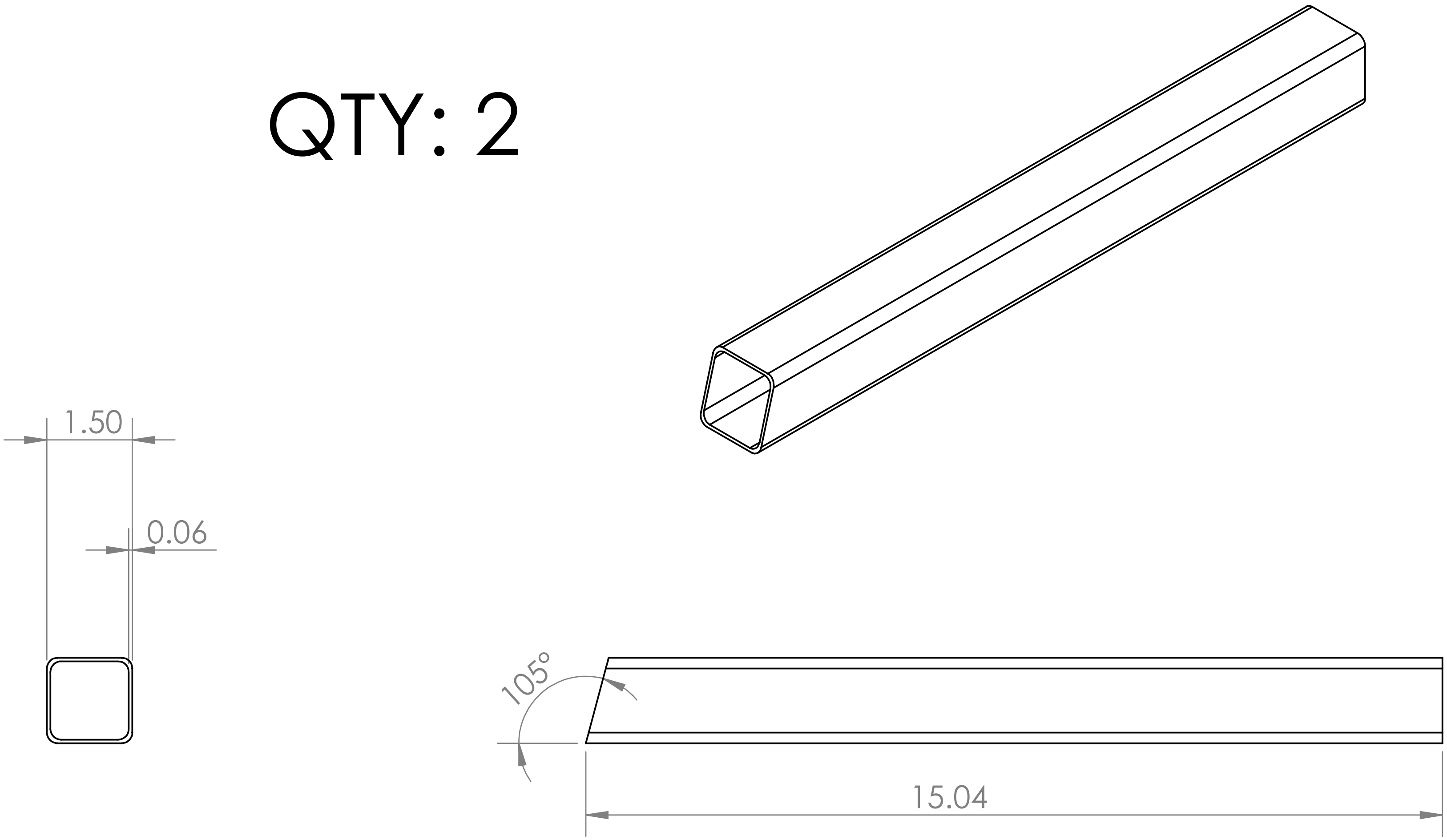
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1

QTY: 2

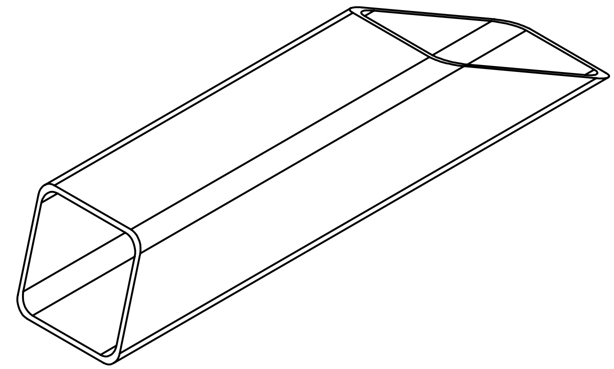


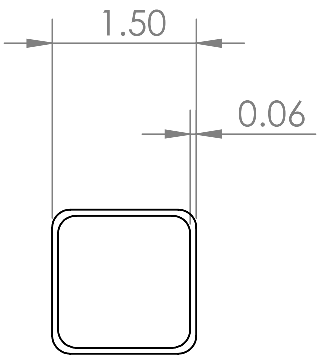
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	SANTA CLARA UNIVERSITY	
DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	LEK	5/27/13	TITLE:	
	CHECKED			BACK FORK 1	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL MILD STEEL	COMMENTS:			SIZE A	DWG. NO. FR003 / REV 2
FINISH NONE					
DO NOT SCALE DRAWING				SCALE: 1:3 / WEIGHT:	SHEET 1 OF 1

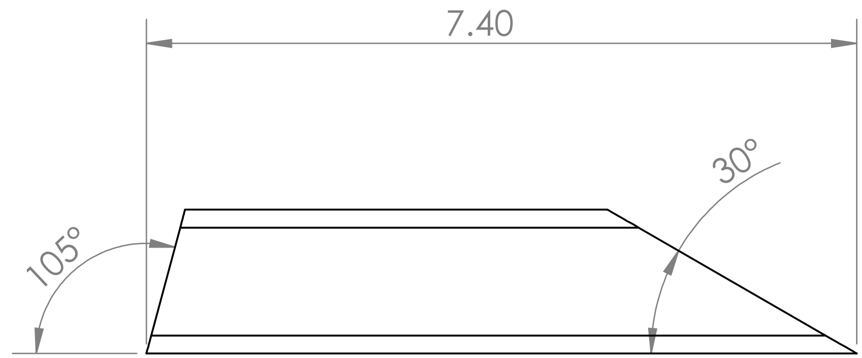
NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1

QTY: 2

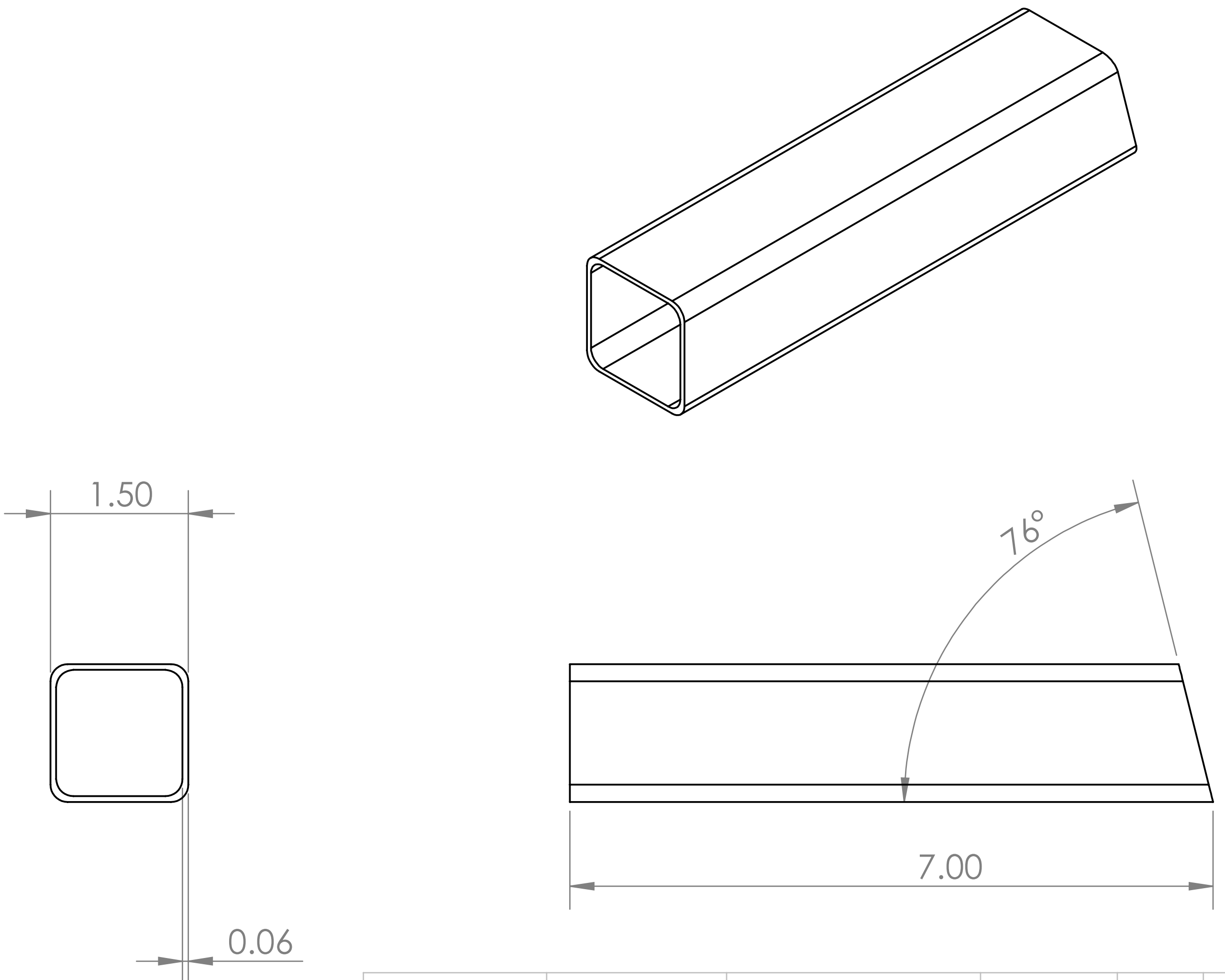






		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	SANTA CLARA UNIVERSITY
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	LEK	5/27/13	TITLE:
			CHECKED			BACK FORK 2
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL MILD STEEL	COMMENTS:			SIZE A · DWG. NO. FR004 · REV 2
NEXT ASSY	USED ON	FINISH NONE				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LEK	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

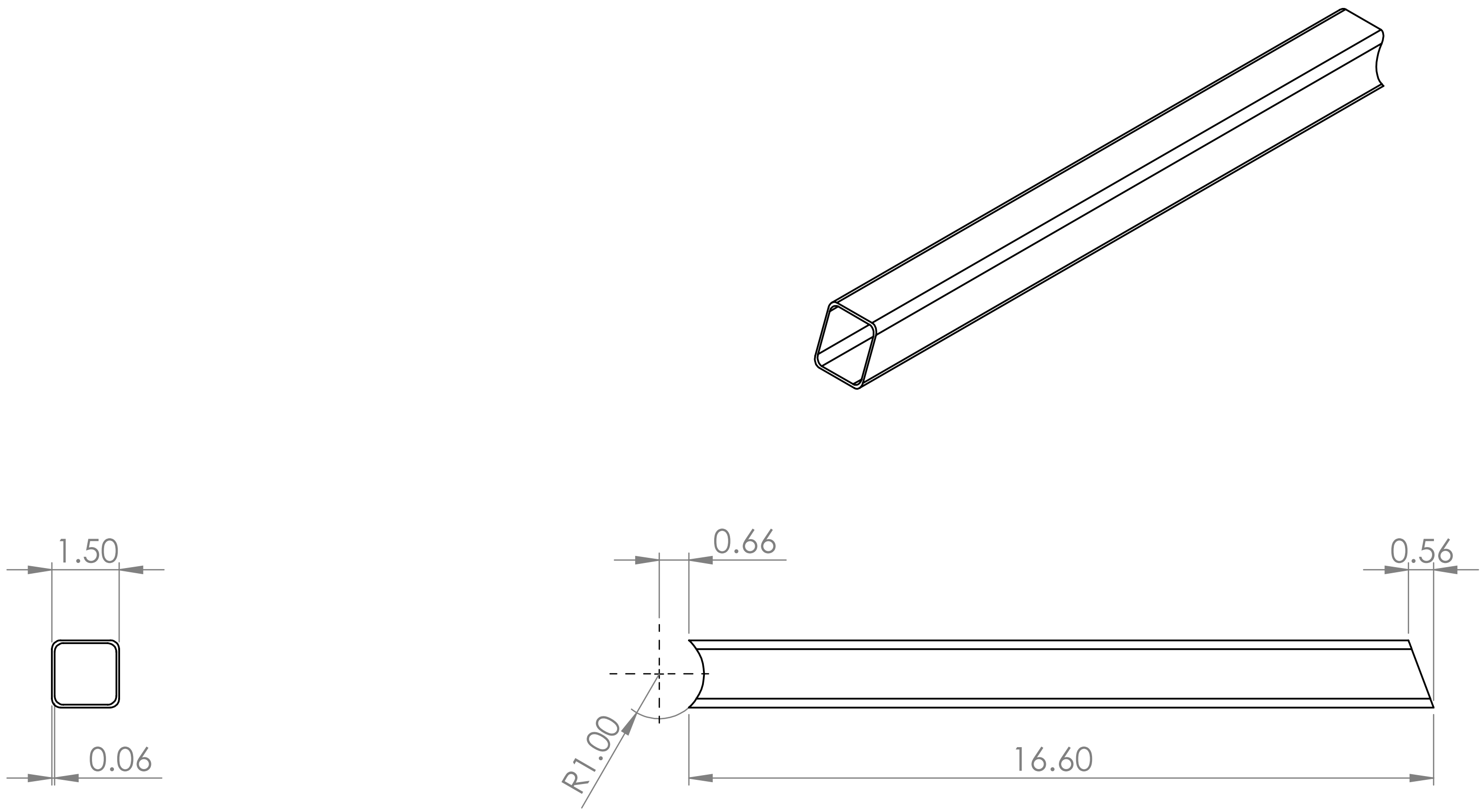
TITLE:

BACK FORK 3

SIZE A | DWG. NO. FR005 | REV 2

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LEK	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

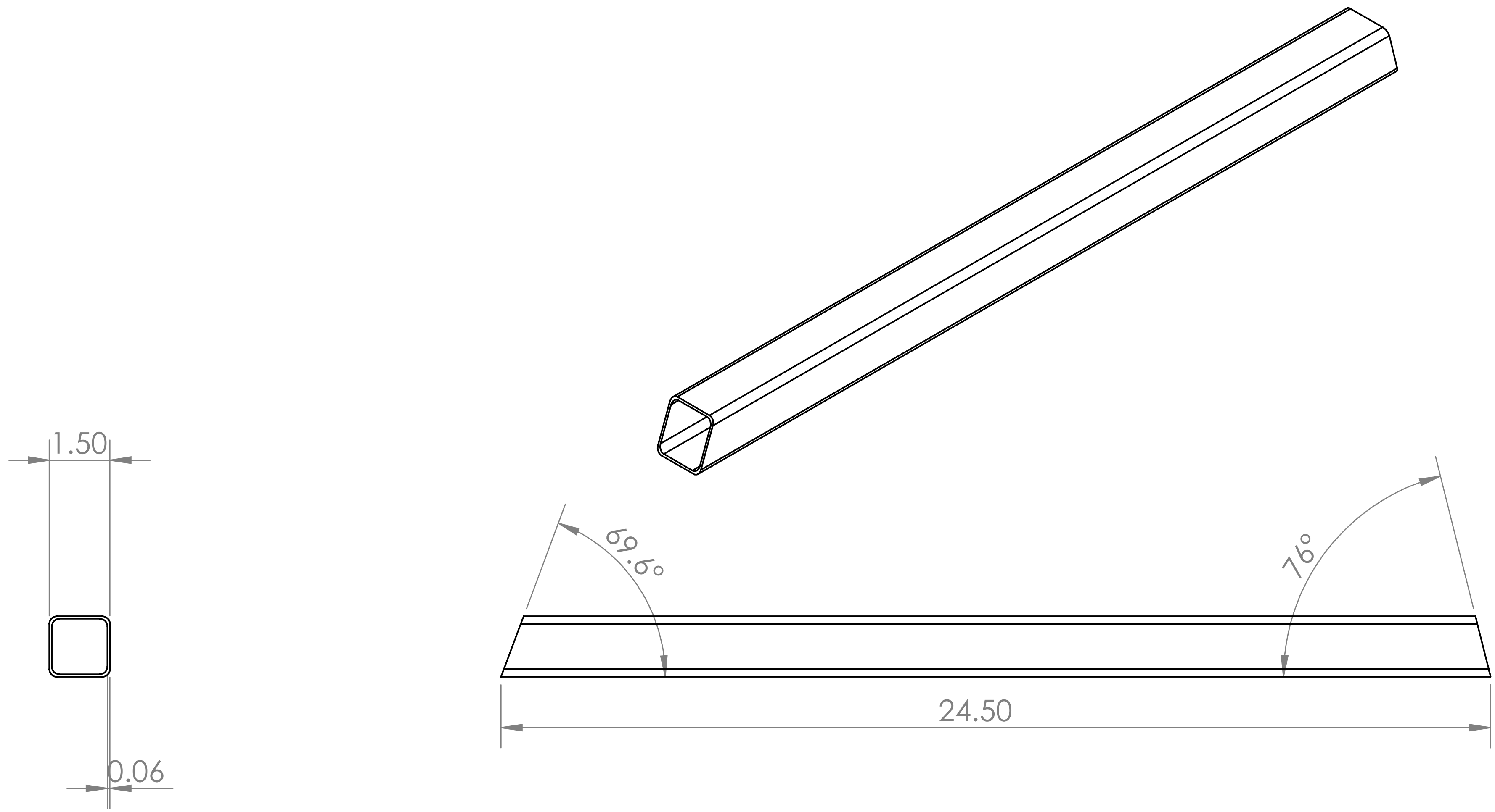
TITLE:

CRANK TUBE

SIZE	DWG. NO.	REV
A	FR007	2

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL MILD STEEL
NEXT ASSY	USED ON	FINISH NONE
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LEK	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

SANTA CLARA UNIVERSITY

TITLE:

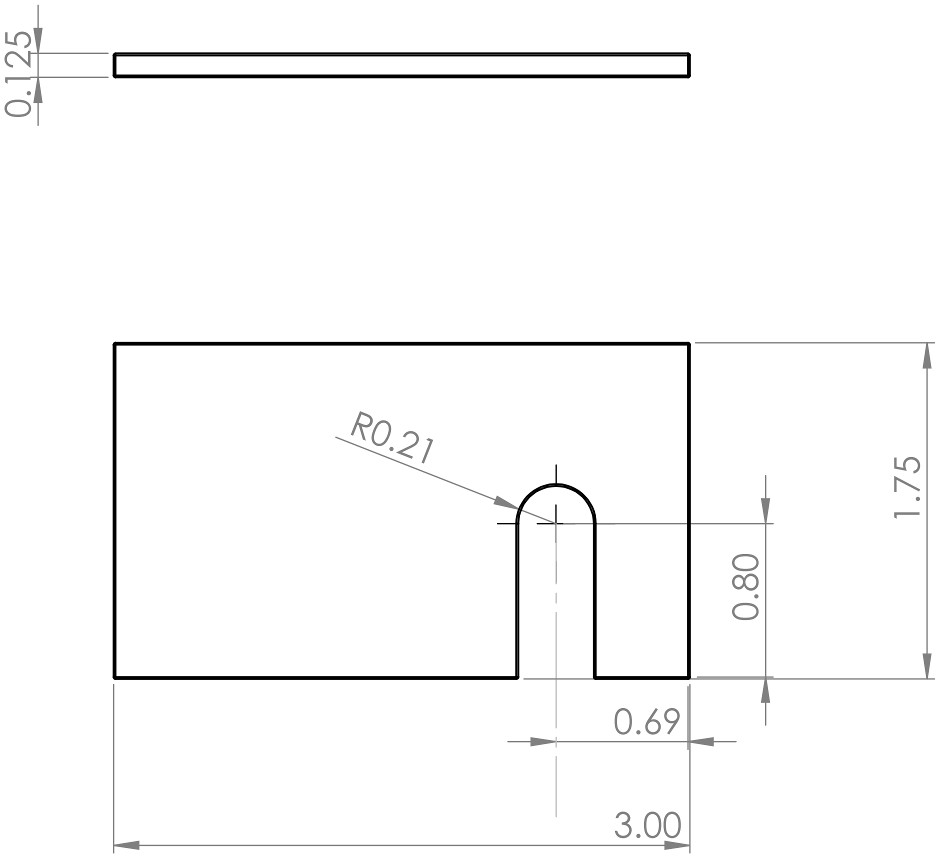
MAIN TUBE

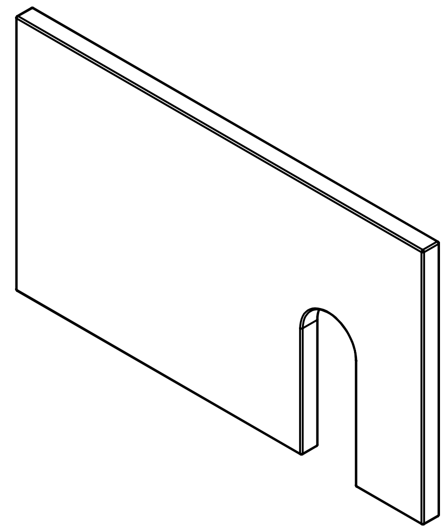
SIZE	DWG. NO.	REV
A	FR008	2
SCALE: 1:4	WEIGHT:	SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1

QTY: 2





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	LEK	5/27/13
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MILD STEEL	COMMENTS:		
NEXT ASSY	USED ON	FINISH NONE			
APPLICATION		DO NOT SCALE DRAWING			

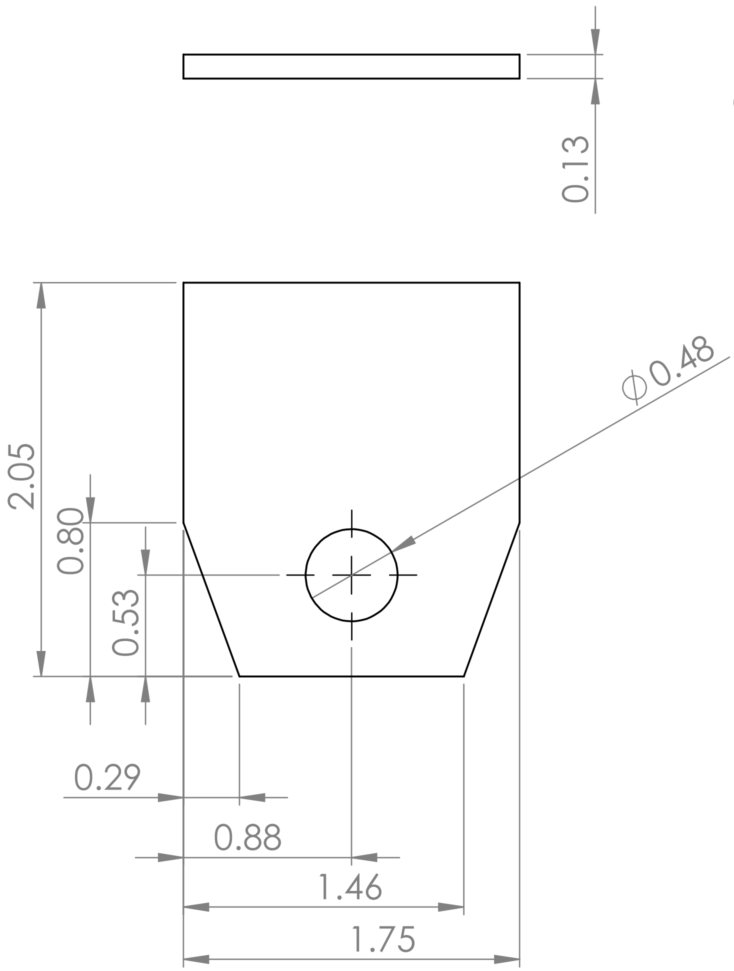
SANTA CLARA UNIVERSITY

TITLE:

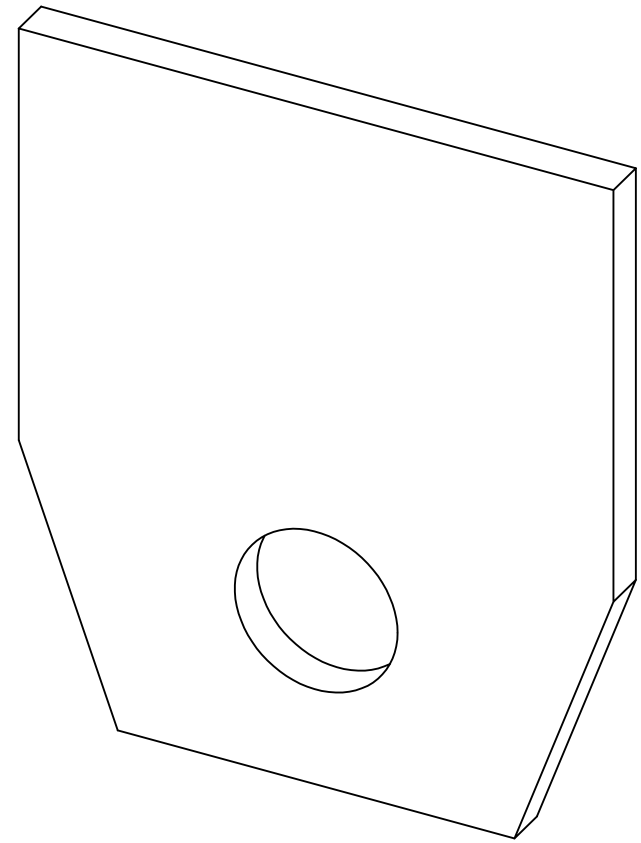
DROP DOWN

SIZE	DWG. NO.	REV
A	FR009	2
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



QTY: 2



NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LEK	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

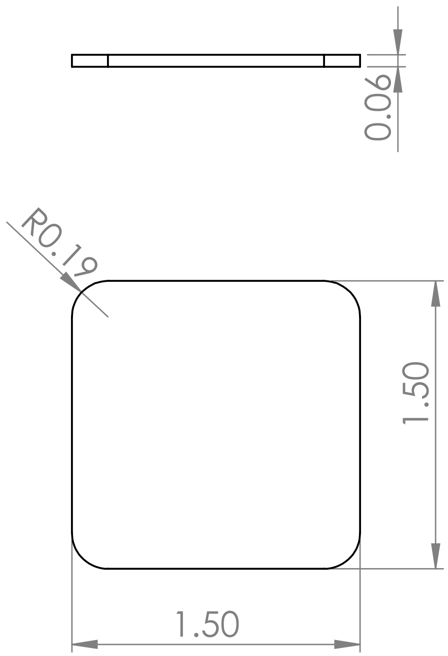
IDLER TAB

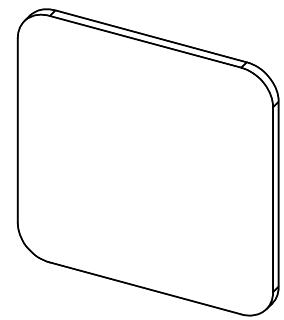
SIZE	DWG. NO.	REV
A	FR010	2

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

QTY: 3





		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL MILD STEEL
NEXT ASSY	USED ON	FINISH NONE
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	LEK	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

SANTA CLARA UNIVERSITY

TITLE:

END CAP

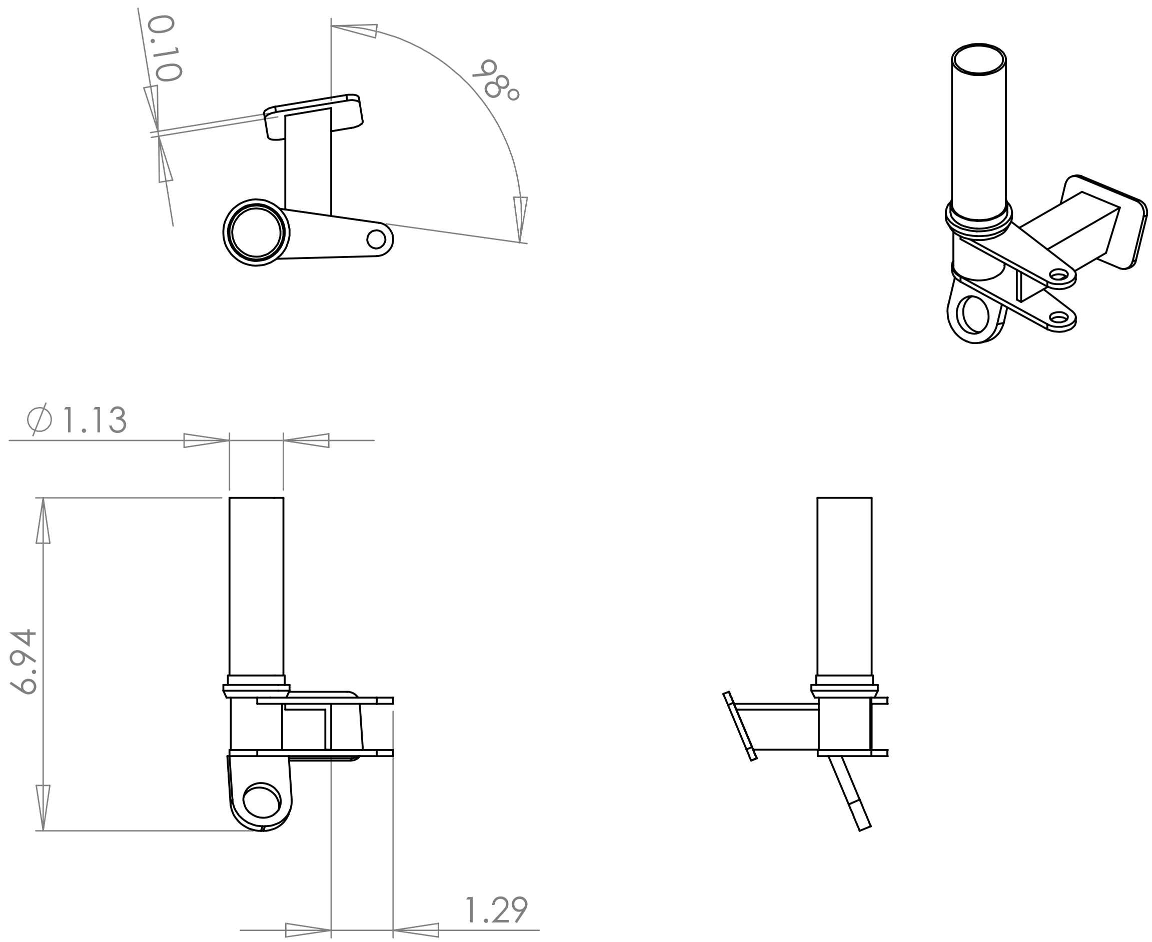
SIZE	DWG. NO.	REV
A	FR011	2

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1

QTY: 2



NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

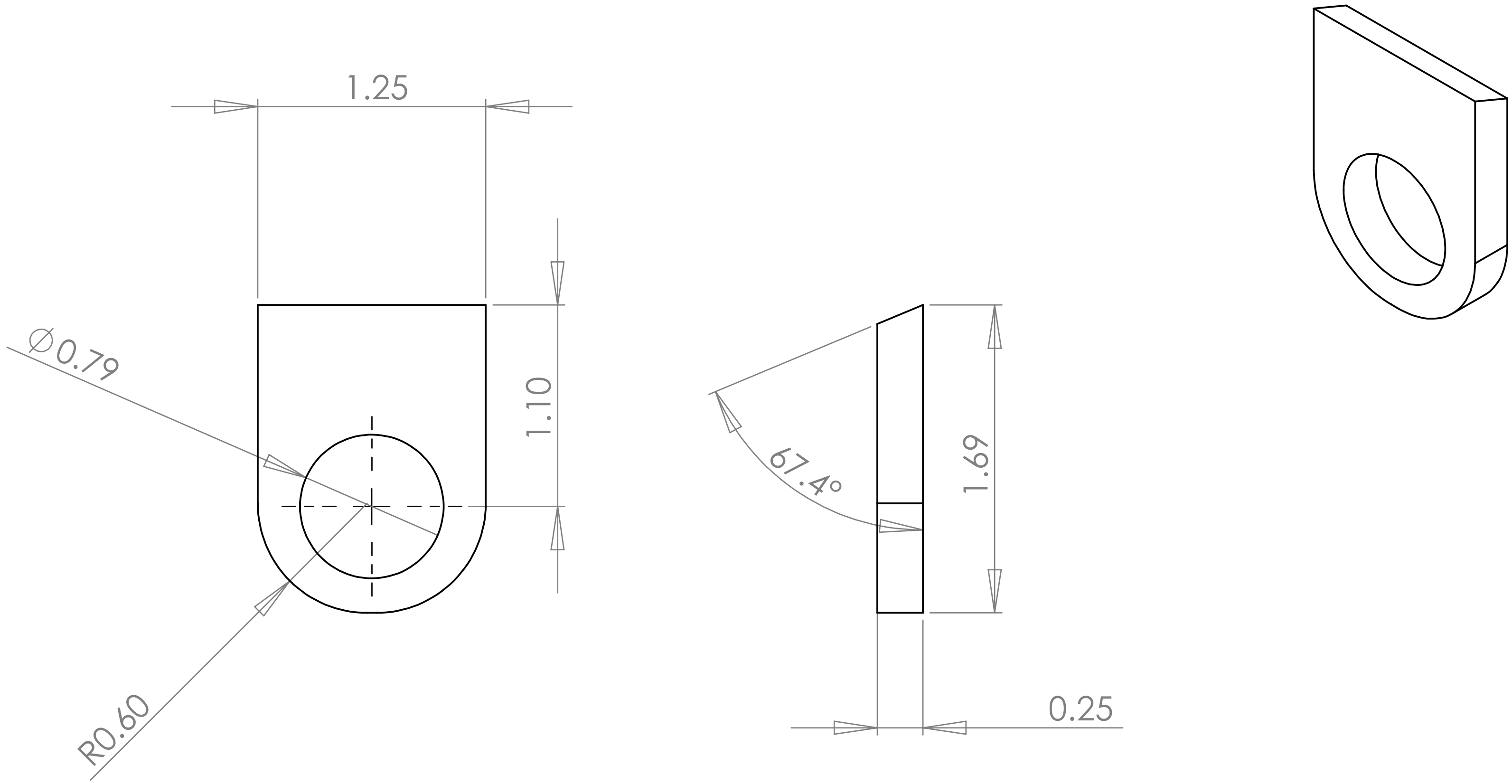
STEERING ASSM

SIZE	DWG. NO.	REV
A	ST000	2

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

QTY: 2



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	MJG	5/27/13
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MILD STEEL	COMMENTS:		
NEXT ASSY	USED ON	FINISH NONE			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

SANTA CLARA UNIVERSITY

TITLE:

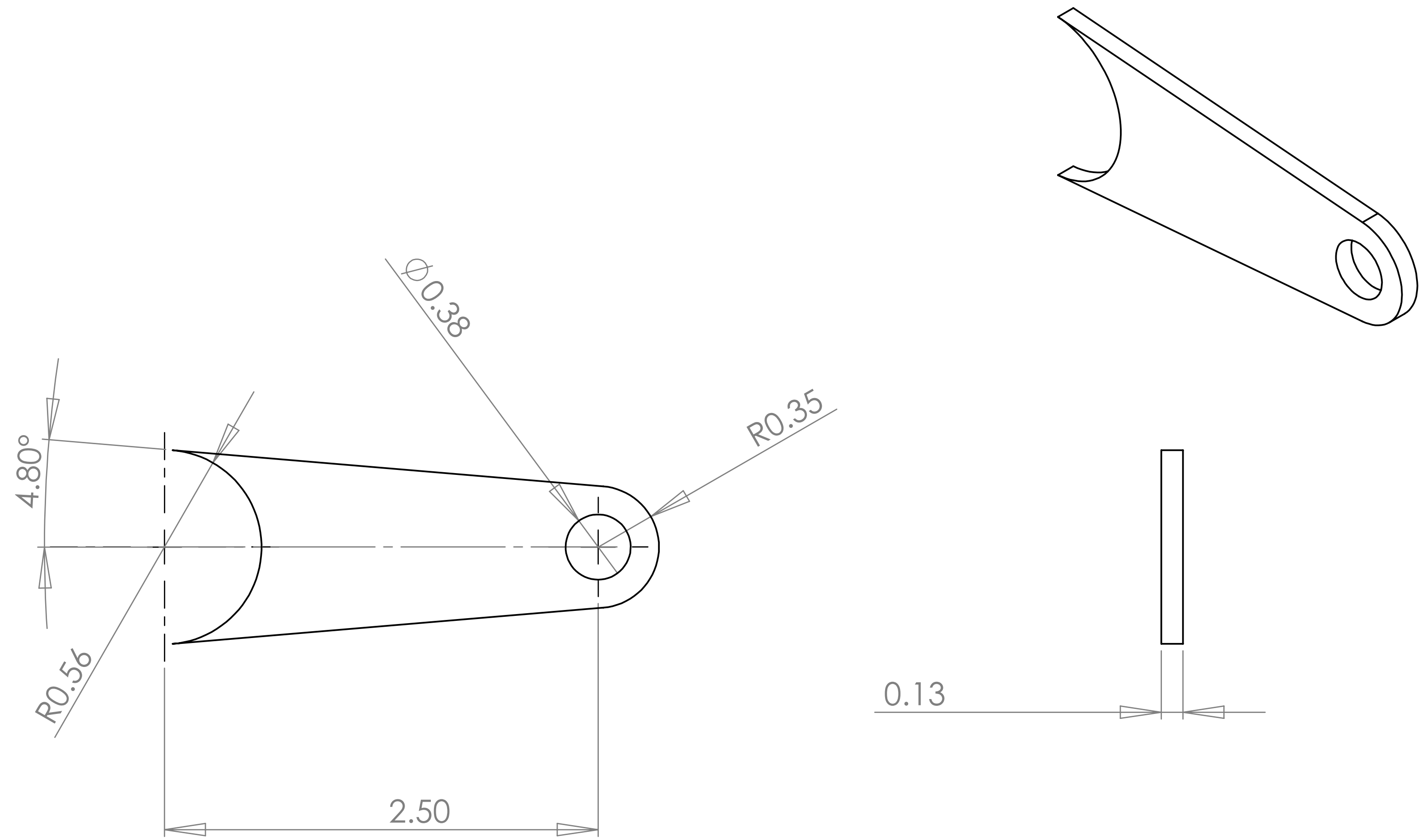
AXLE TAB

SIZE	DWG. NO.	REV
A	ST000-1	2

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

QTY: 2



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	MJG	5/27/13
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL MILD STEEL	COMMENTS:		
NEXT ASSY	USED ON	FINISH NONE			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

SANTA CLARA UNIVERSITY

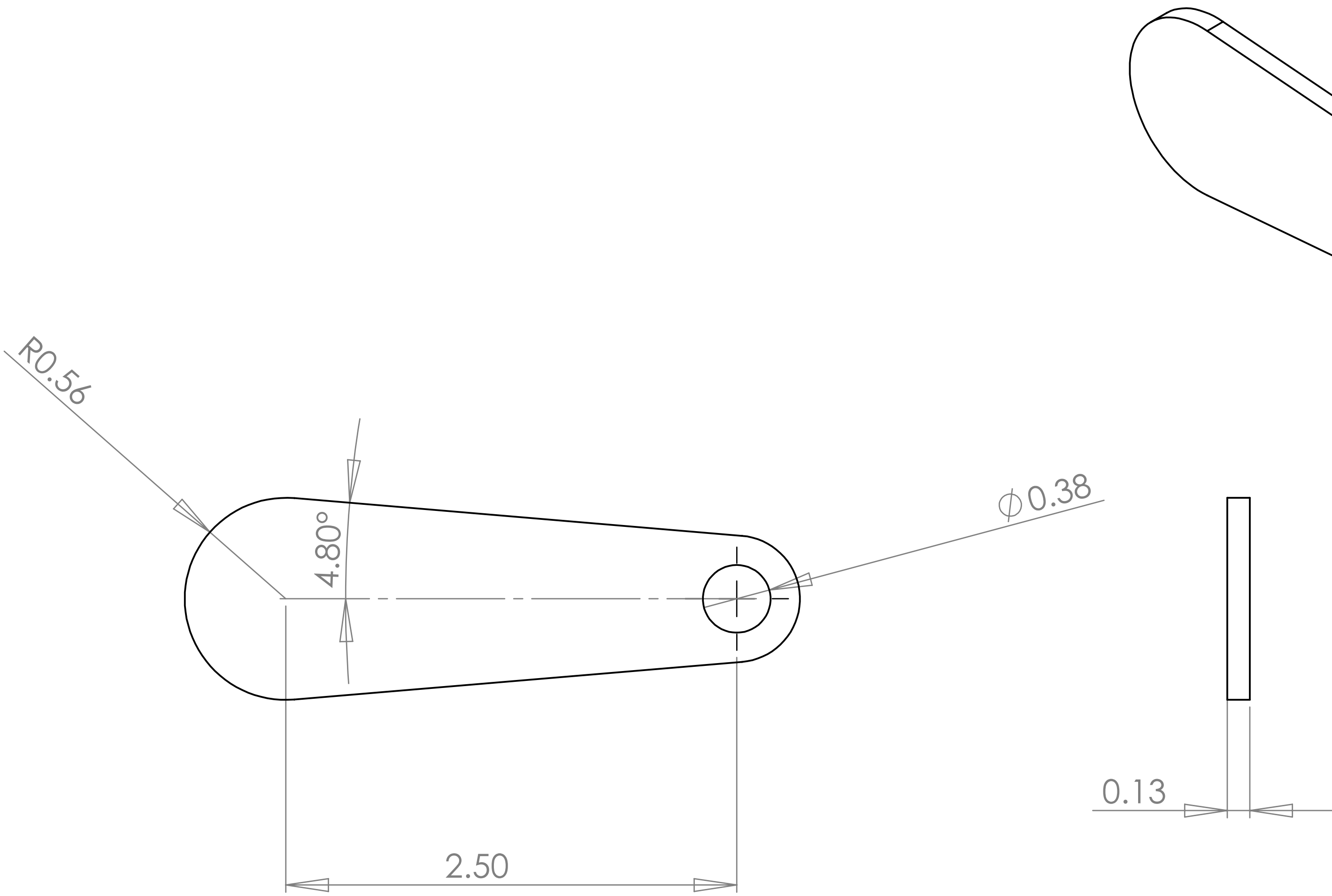
TITLE:

UPPER CONTROL ARM

SIZE	DWG. NO.	REV
A	ST000-2	2
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

QTY: 2



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

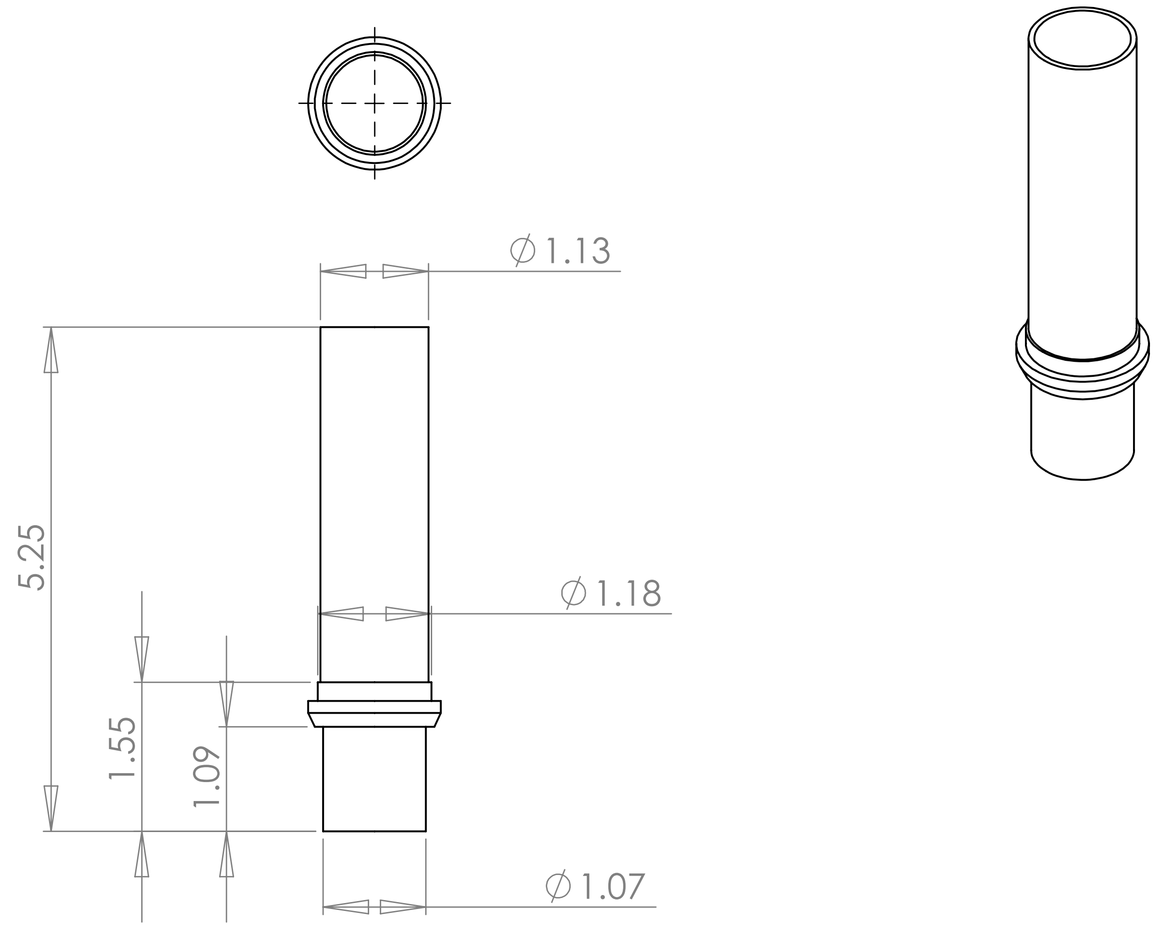
LOWER CONTROL ARM

SIZE	DWG. NO.	REV
A	ST000-3	2

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

MADE FROM STANDARD 1-1/8"
BICYCLE STEER TUBE.
QTY: 2



NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

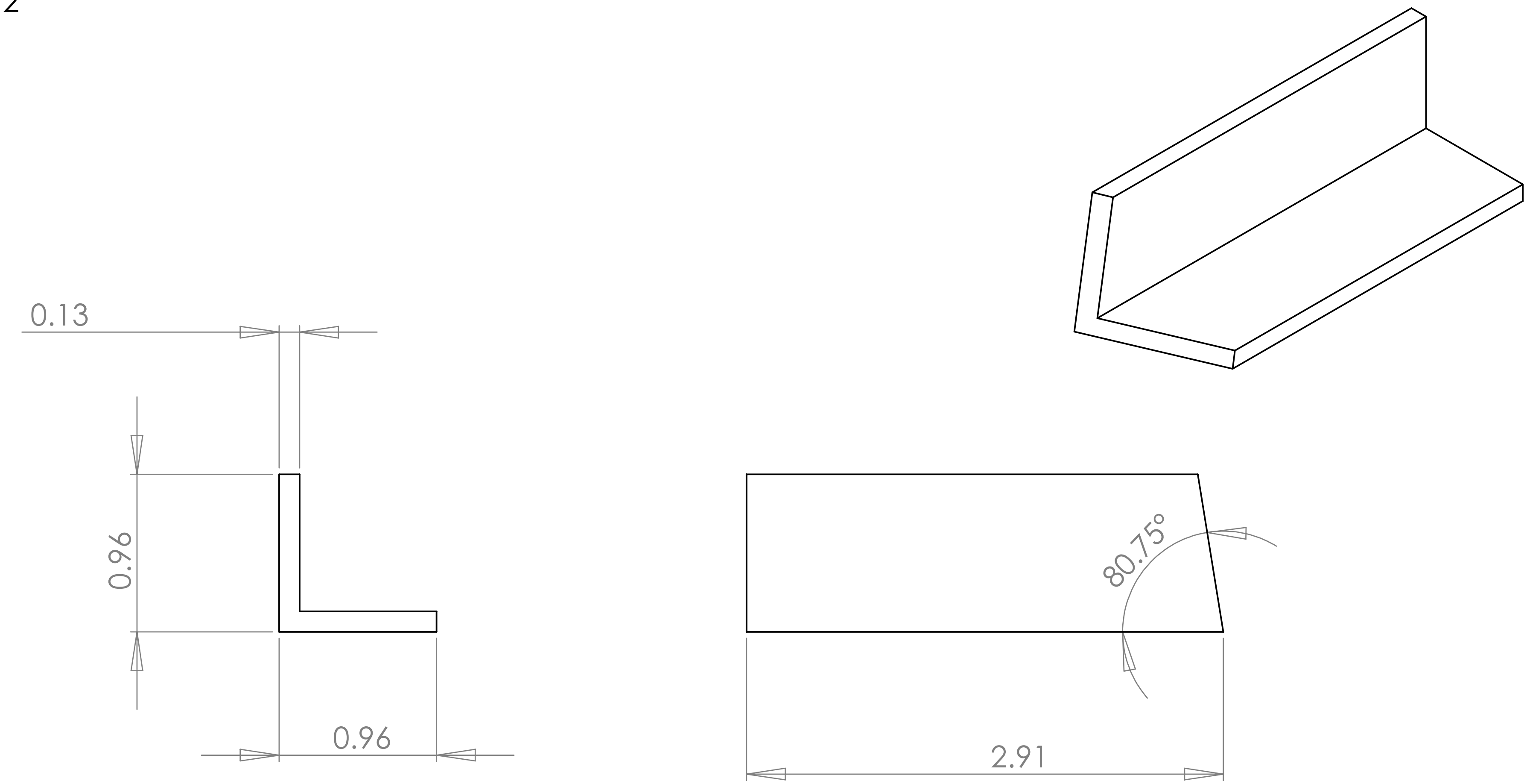
STEER TUBE

SIZE	DWG. NO.	REV
A	ST000-4	2

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

QTY: 2



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

SANTA CLARA UNIVERSITY

TITLE:

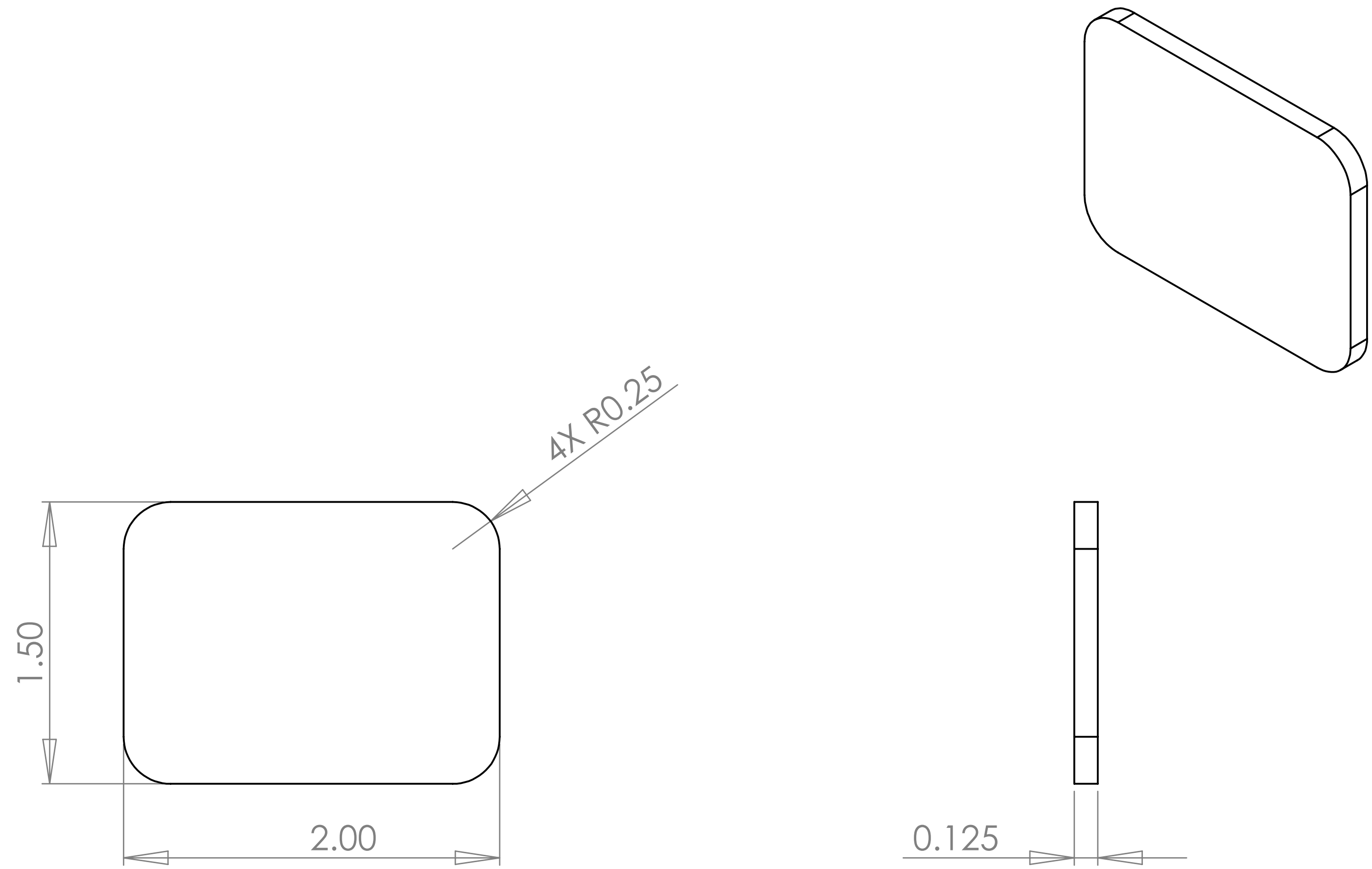
BRAKE BRACKET

SIZE A | DWG. NO. ST000-5 | REV 2

SCALE: 1:1

5 4 3 2 1

QTY: 2



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	5/27/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

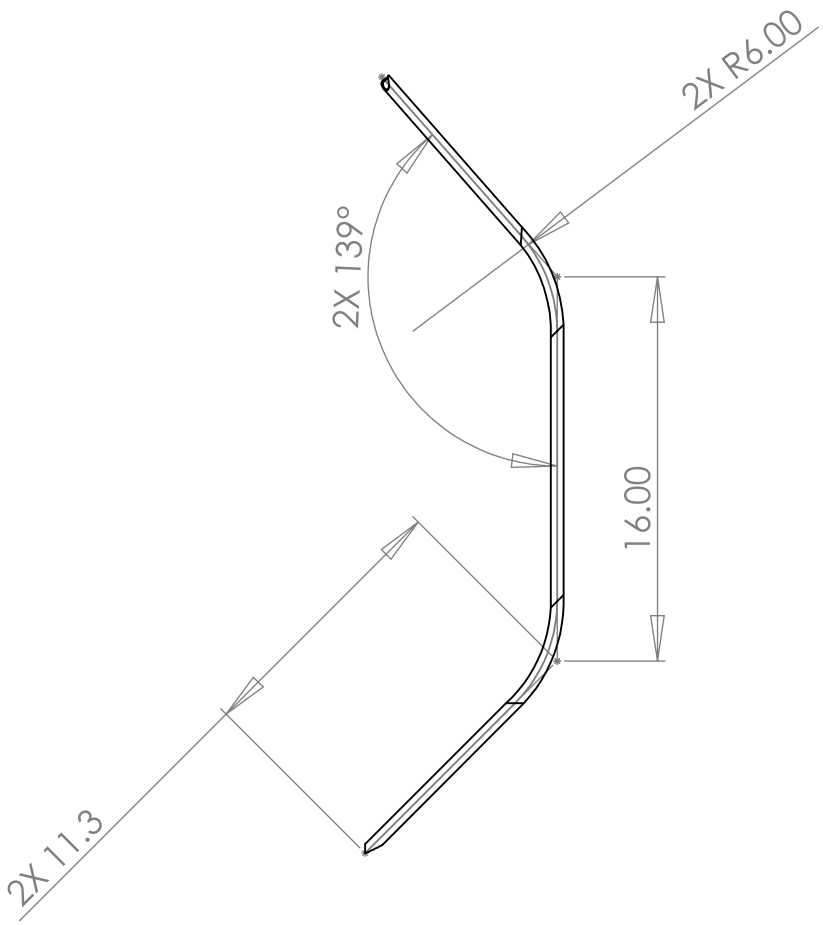
BRAKE TAB

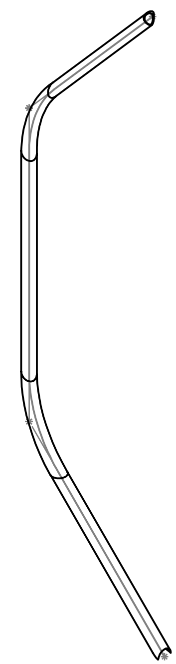
SIZE A | DWG. NO. ST000-6 | REV 2

SCALE: 2:1 | SHEET 1 OF 1

5 4 3 2 1

MADE FROM 3/4" X 0.065" MILD STEEL TUBING
QTY: 2



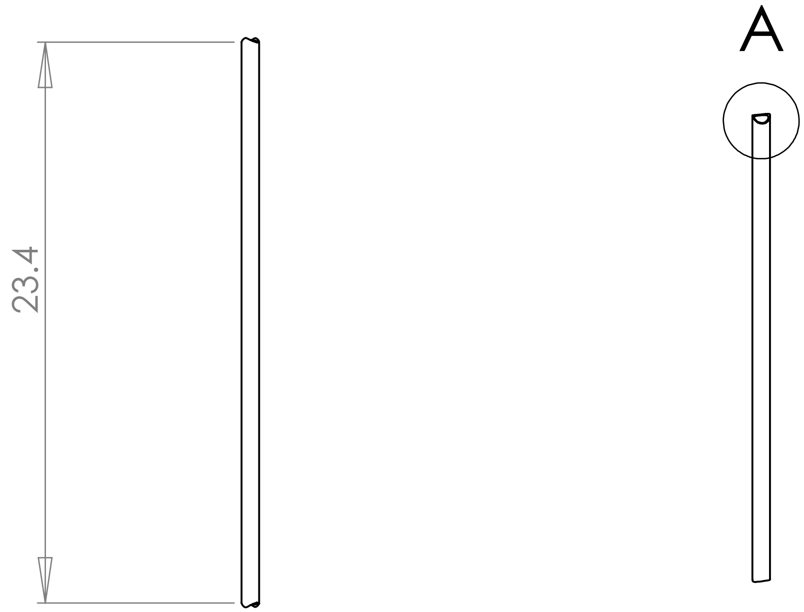


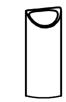
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	SANTA CLARA UNIVERSITY
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	MJG	6/2/13	TITLE:
			CHECKED			ROLL PROTECTION SIDE
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL MILD STEEL	COMMENTS:			SIZE A DWG. NO. RP001 REV 2
NEXT ASSY	USED ON	FINISH NONE				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:8 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1

MADE FROM 3/4" X 0.065" MILD STEEL TUBING





DETAIL A
SCALE 1 : 4

TUBES COPED AT 90 DEG WITH 3/4" DIA. END MILL, WITH CENTERLINE ON TUBE EDGE

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: MILD STEEL

FINISH: NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

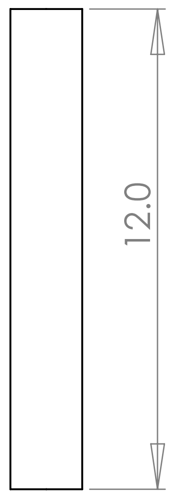
ROLL PROTECTION CROSS BAR

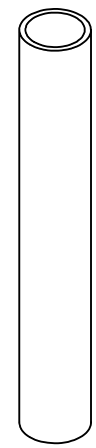
SIZE	DWG. NO.	REV
A	RP002	2

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

MADE FOMR 3/4" X 0.065" MILD STEEL TUBING





NEXT ASSY	USED ON	
APPLICATION		

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	MJG	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

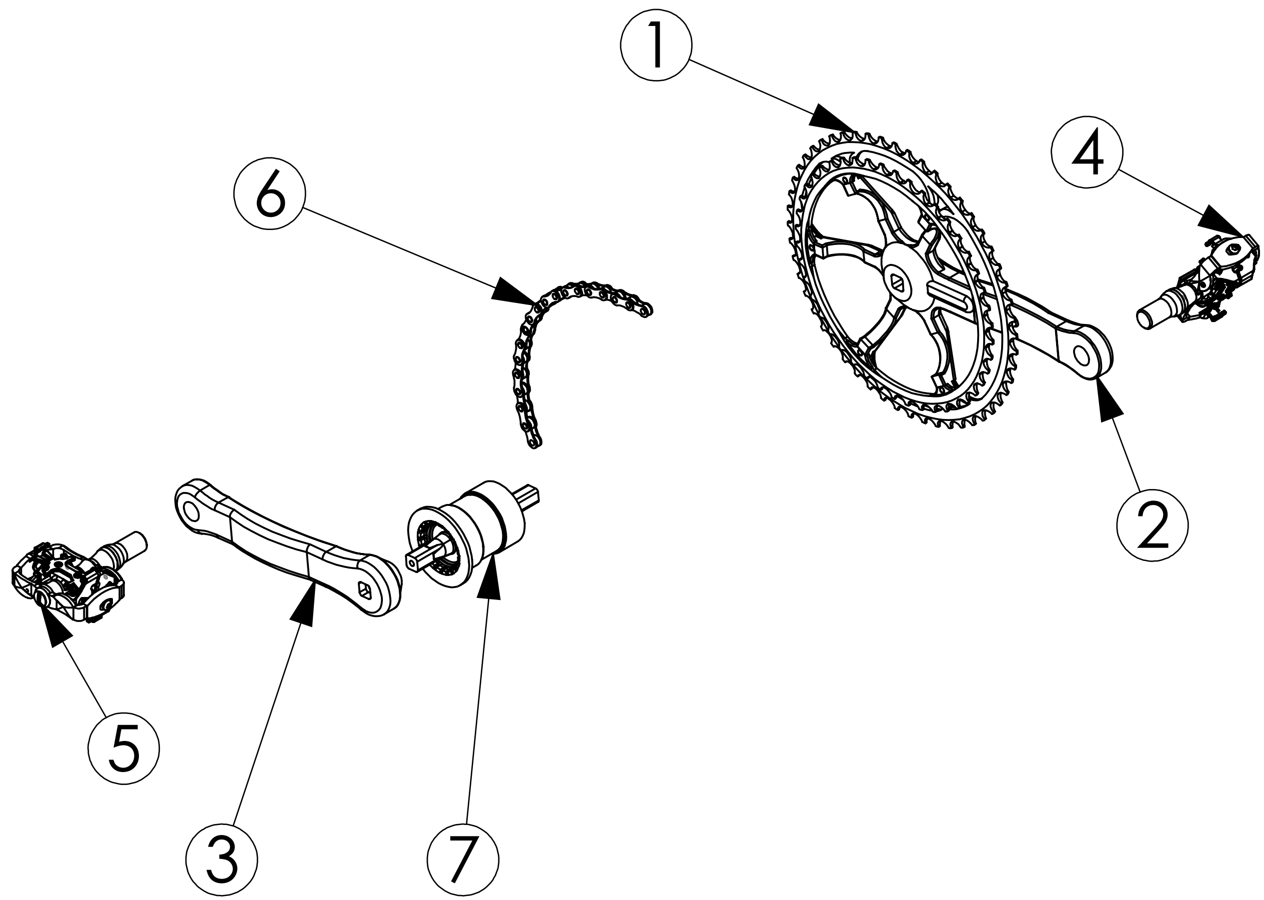
TITLE:

ROLL PROTECTION MATING PIECE

SIZE	DWG. NO.	REV
A	RP003	2

SCALE: 1: 2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT001	46-Tooth Cog	1
2	DT002	Right Pedal Crank	1
3	DT003	Left Pedal Crank	1
4	DT004	Right Pedal Crank	1
5	DT005	Left Pedal Crank	1
6	DT006	Chain	1
7	DT007	Bottom Bracket	1

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TP	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

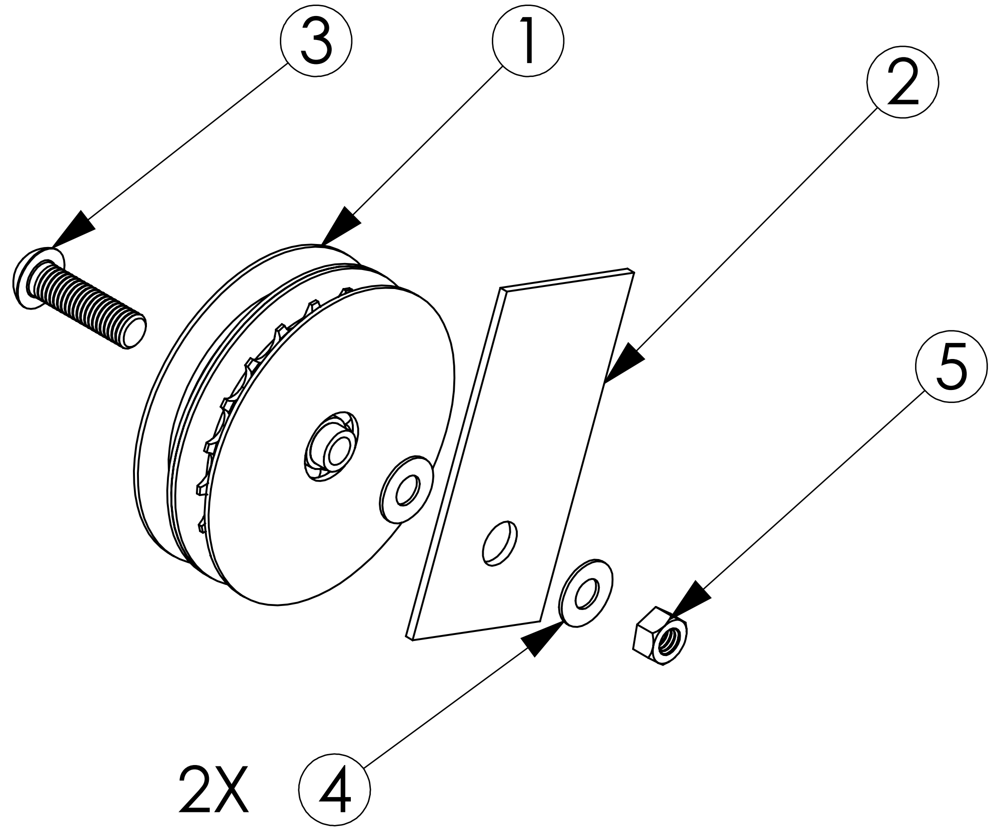
TITLE:

FRONT ASSEMBLY

SIZE	DWG. NO.	REV
A	DA001	2

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



12	PART NUMBER	DESCRIPTION	QTY.
1	DT008	Idler	1
2	FR010	Idler Tab	1
3	DT009	5/16'' Bolt	1
4	DT010	5/16'' Washer	2
5	DT011	5/16'' Nut	1

			NAME	DATE
		DRAWN	TP	6/2/13
NEXT ASSY	USED ON	CHECKED		
APPLICATION		ENG APPR.		
		MFG APPR.		
		Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH NONE

DO NOT SCALE DRAWING

PROPRIETARY AND CONFIDENTIAL

SANTA CLARA UNIVERSITY

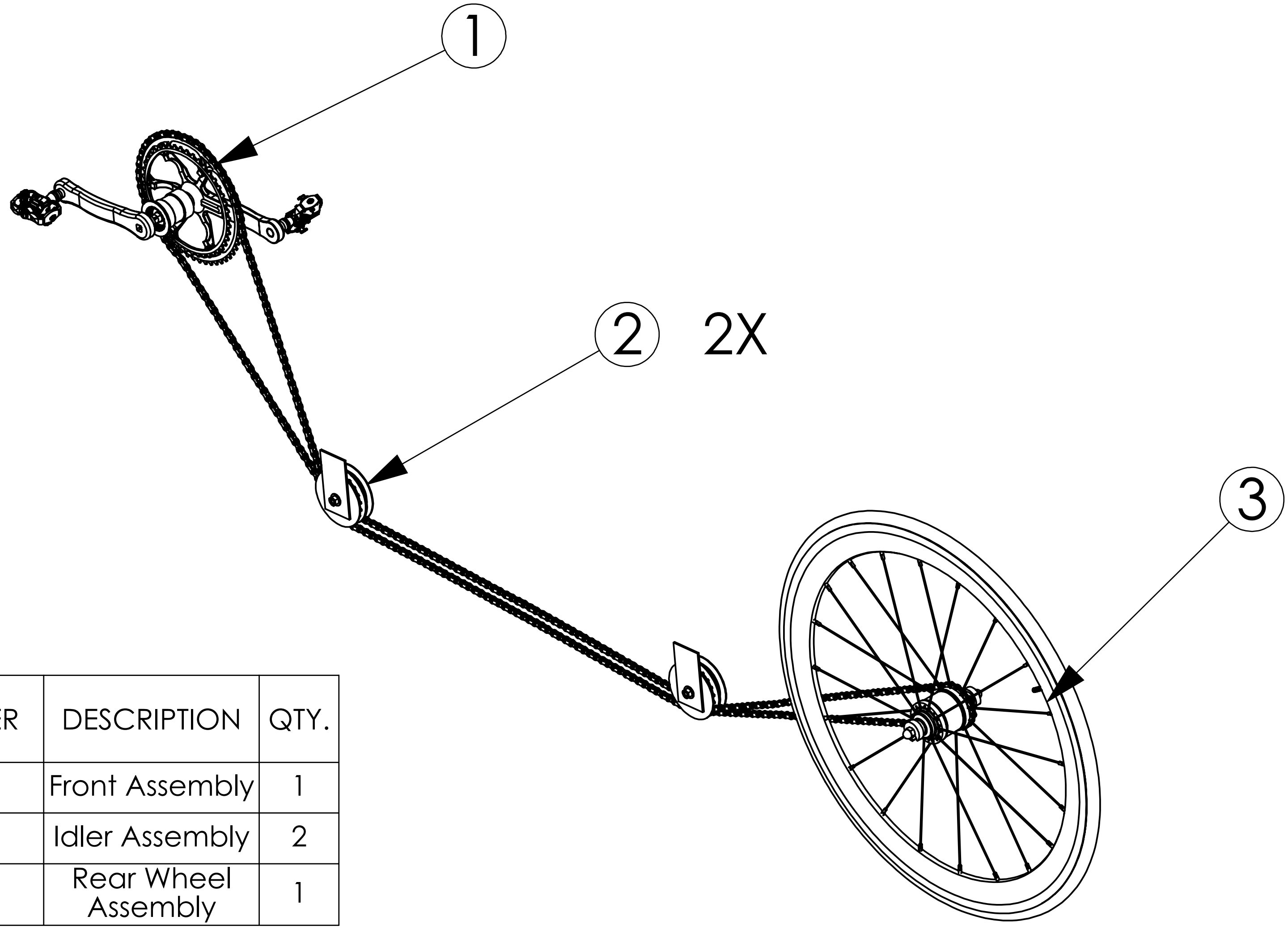
TITLE:

IDLER ASSEMBLY

SIZE A | DWG. NO. DA002 | REV 2

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

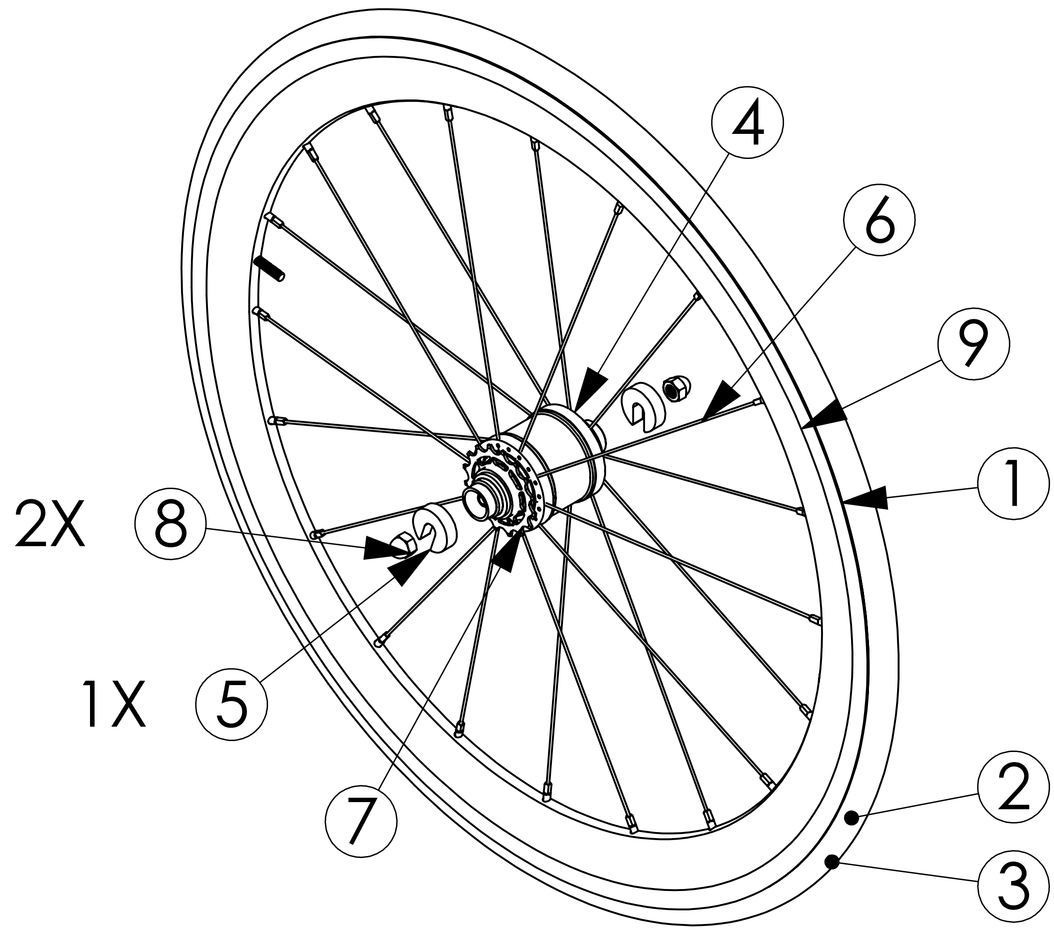


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DA001	Front Assembly	1
2	DA002	Idler Assembly	2
3	WA002	Rear Wheel Assembly	1

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	SANTA CLARA UNIVERSITY
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	TP	6/2/13	TITLE: FULL DRIVETRAIN ASSEMBLY
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. DA003 · REV 2
NEXT ASSY	USED ON	FINISH NONE				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:50 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	RW001	Rear Wheel Rim	1
2	RW002	700 c Tube	1
3	RW003	700 c Tire	1
4	RW004	Internal Hub	1
5	RW005	Slotted Washer	2
6	RW007	14-Guage Spokes	32
7	RW008	18-Tooth Cog	1
8	RW009	Dome Nut	2
9	W001	Rim Tape	1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TP	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

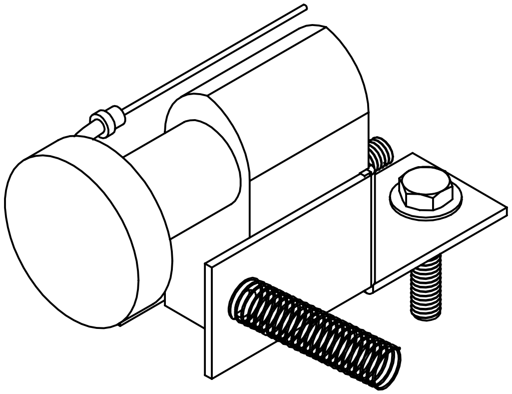
TITLE:

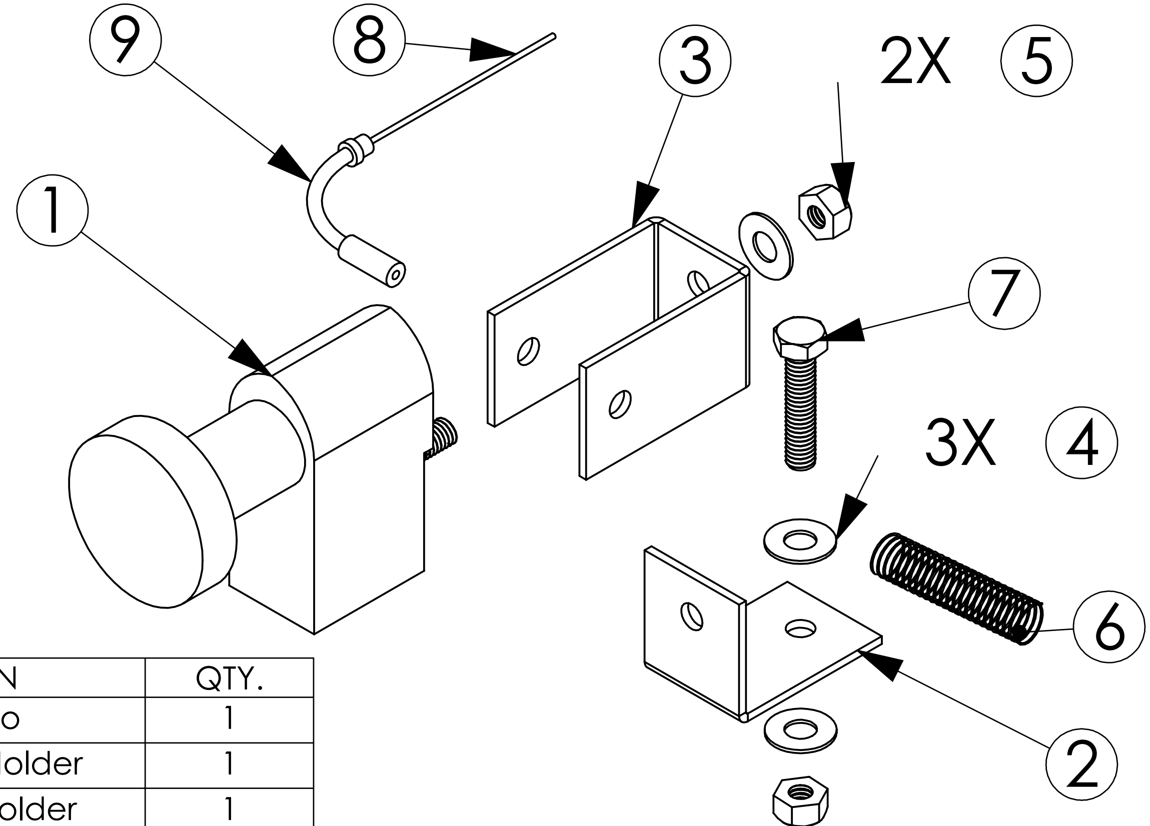
REAR WHEEL ASSEMBLY

SIZE **A** DWG. NO. WA002 REV 2

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ES001	A/C Dynamo	1
2	ES002	Back Dynamo Holder	1
3	ES003	Side Dynamo Holder	1
4	ES004	5/16" Washer	3
5	ES005	5/16" Nut	2
6	ES006	Spring	1
7	ES007	5/16" Bolt 1" Length	1
8	ES008	Brake Cable	6"
9	ES009	Brake Cable Housing	6"

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TP	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:

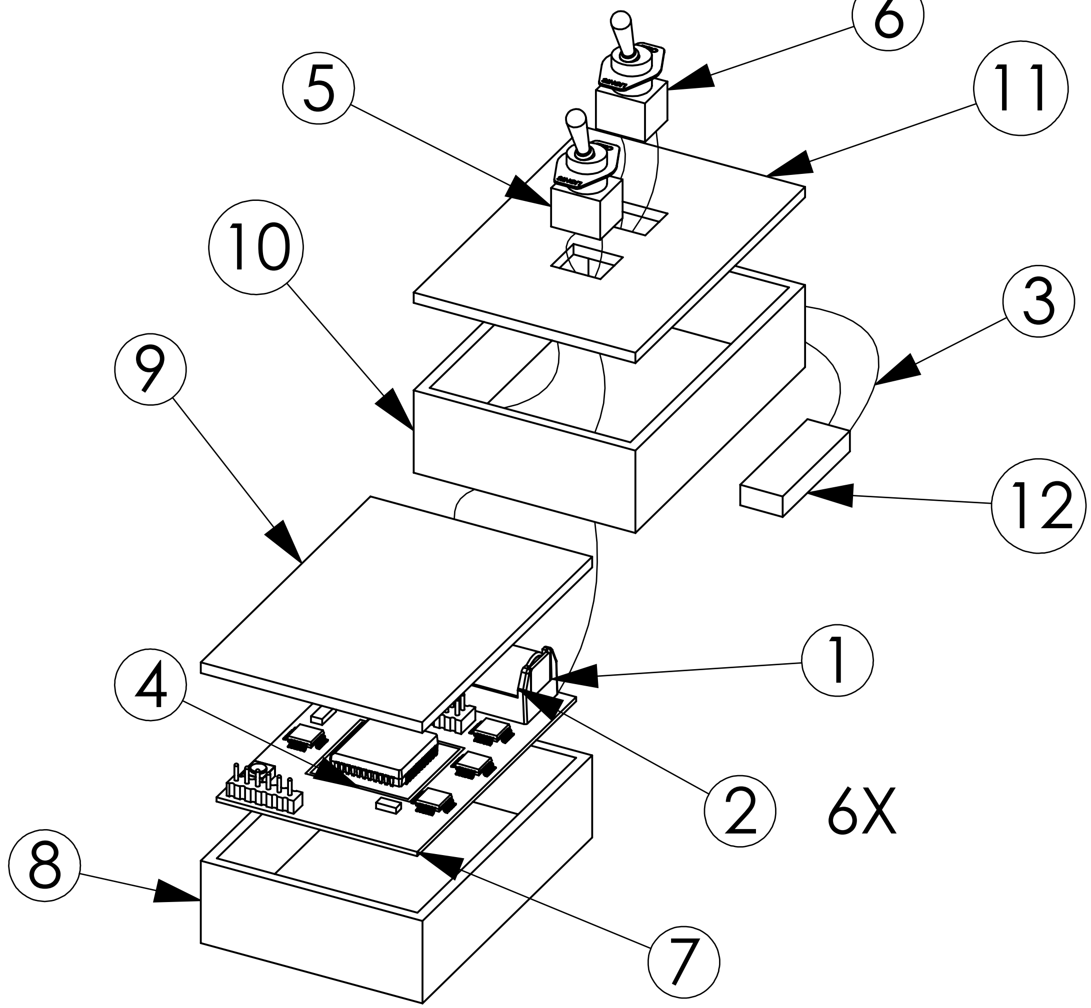
ENERGY STORAGE ASSEMBLY

SIZE A | DWG. NO. EA001 | REV 2

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

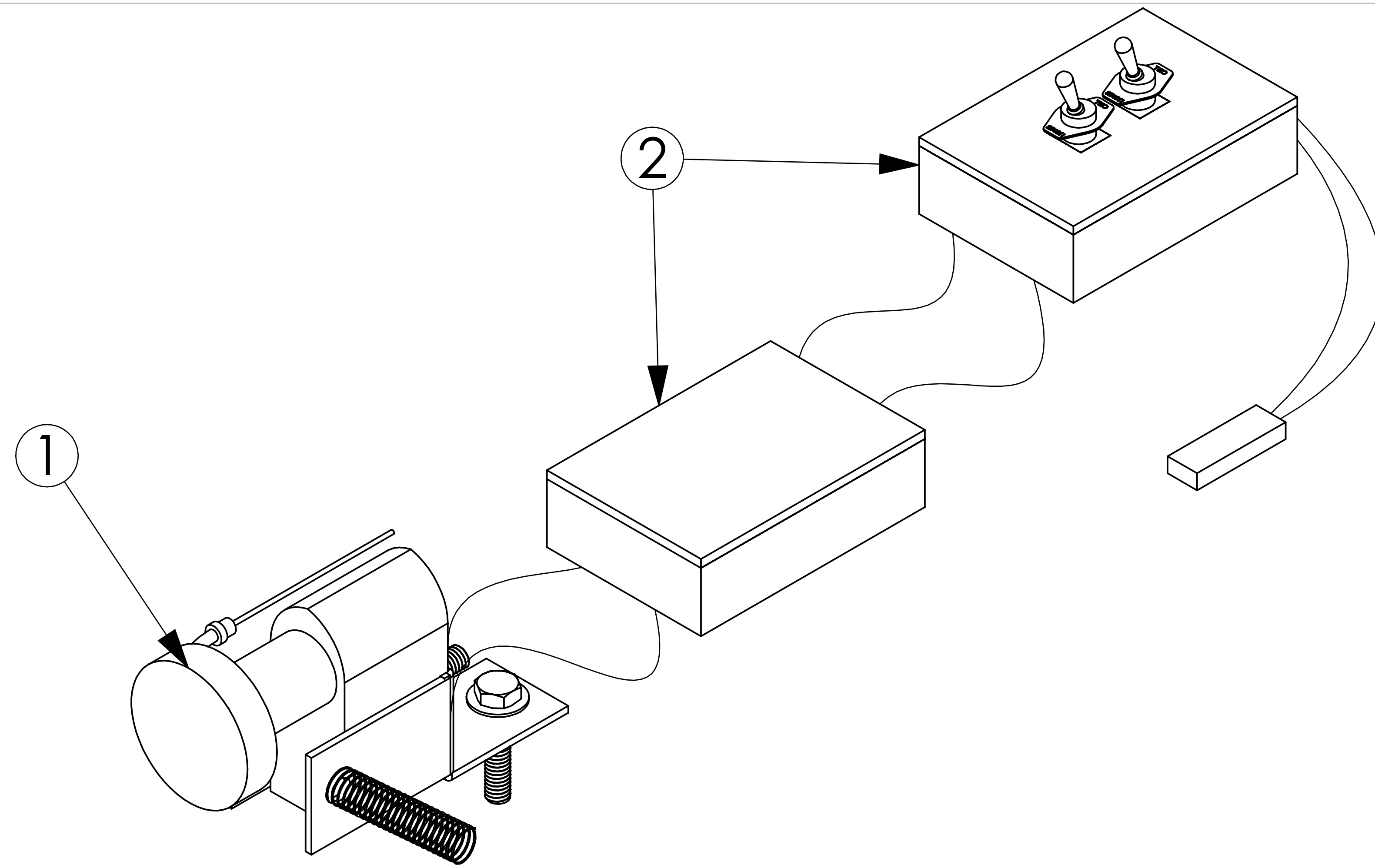
5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	ES010	Rechargeable Battery Pack	1
2	ES011	Rechargeable Batteries	6
3	ES012	Wiring	10'
4	ES013	MintyBoost Circuit	1
5	ES014	SPDT Switch	1
6	ES015	DPDT Switch	1
7	ES016	Bread Board	1
8	ES017	Energy Storage Box	1
9	ES018	Energy Storage Box Top	1
10	ES019	Switch Box	1
11	ES020	Switch Box Top	1
12	ES021	Reed Switch	1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	SANTA CLARA UNIVERSITY
		DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	TP	6/2/13	TITLE:
			CHECKED			ENERGY STORAGE CIRCUIT
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. EA002 · REV 2
NEXT ASSY	USED ON	FINISH NONE				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	EA001	Energy Storage Assembly	1
2	EA002	Energy Storage Circuit	1

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL MILD STEEL

FINISH NONE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TP	6/2/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

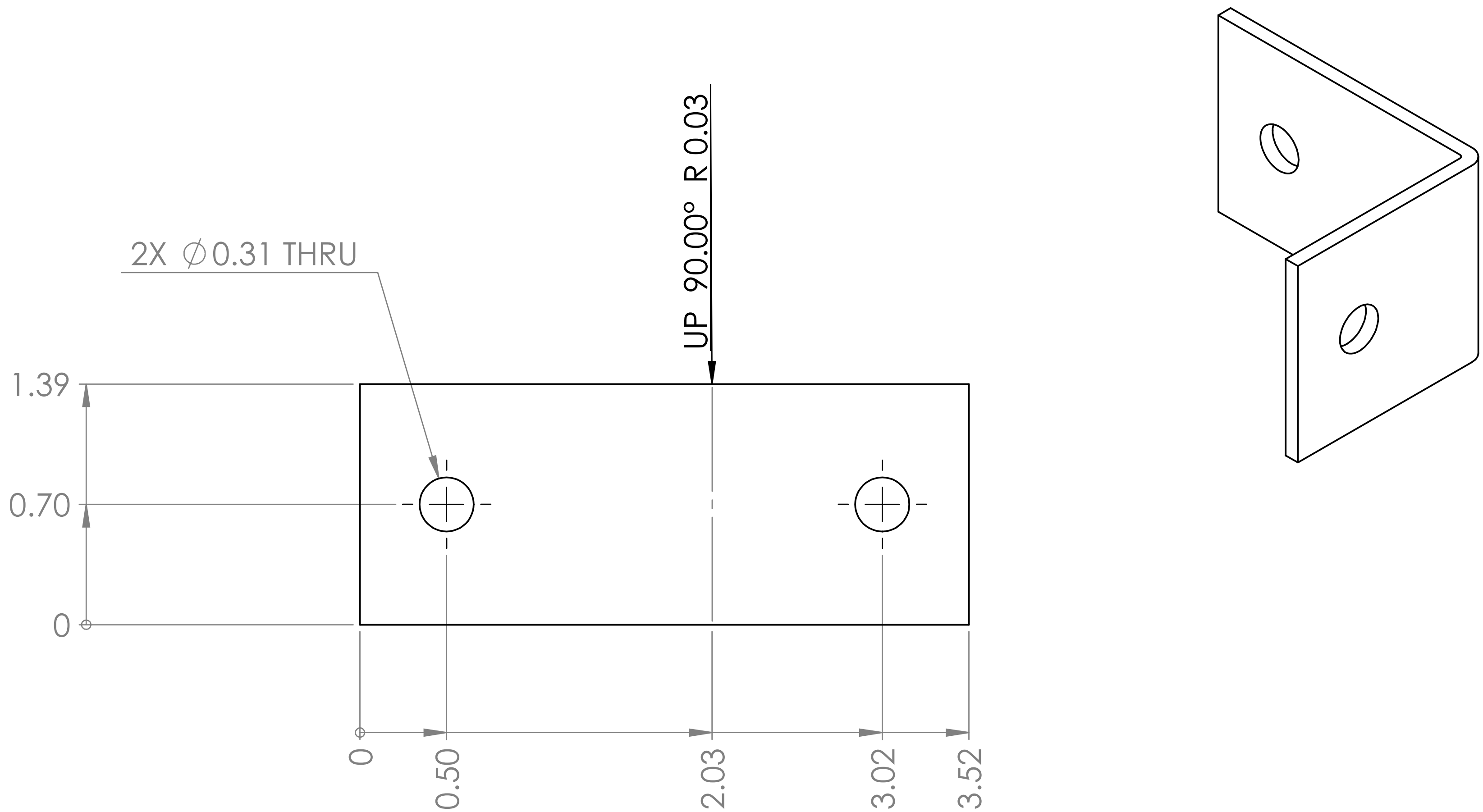
TITLE:

FULL ENERGY STORAGE ASSEMBLY

SIZE A | DWG. NO. EA003 | REV 2

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



NOTES:
1. THICKNESS OF STEEL IS 0.1 IN

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ± 0.5 BEND ± 0.5 TWO PLACE DECIMAL ± 0.1 THREE PLACE DECIMAL ± 0.005	DRAWN	SRS	5/29/13
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL MILD STEEL	COMMENTS:		
FINISH NONE			
DO NOT SCALE DRAWING			

NEXT ASSY | USED ON
APPLICATION

PROPRIETARY AND CONFIDENTIAL

SANTA CLARA UNIVERSITY

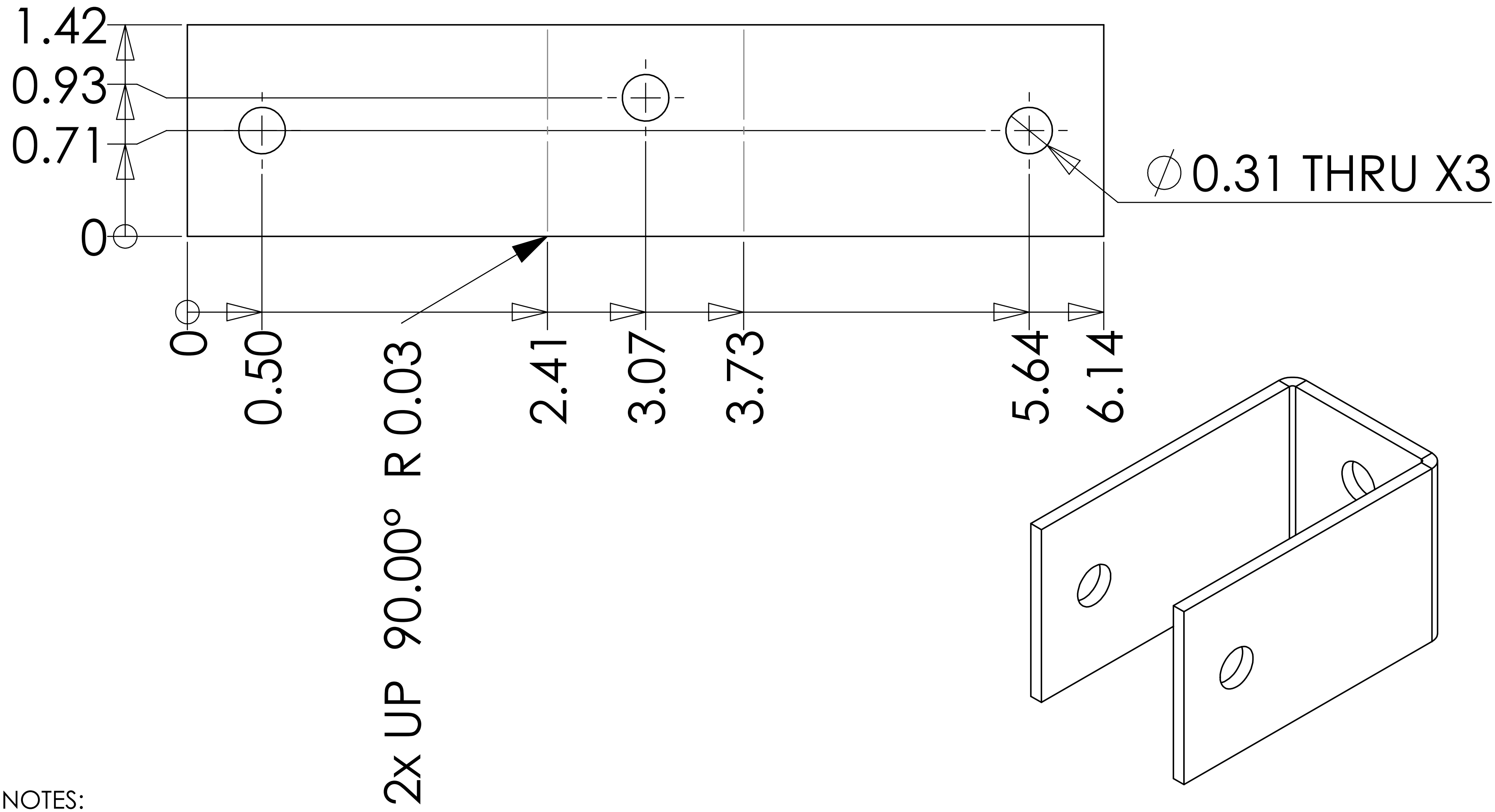
TITLE:

BACK DYNAMO HOLDER

SIZE	DWG. NO.	REV
A	ES002	2

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



NOTES:
1. THICKNESS OF STEEL 0.1IN

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGLE ± 0.5
BEND ± 0.5
TWO PLACE DECIMAL ± 0.1
THREE PLACE DECIMAL ± 0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL MILD STEEL
FINISH NONE
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	SRS	5/30/13
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SANTA CLARA UNIVERSITY

TITLE:
SIDE DYNAMO HOLDER

SIZE	DWG. NO.	REV
A	ES003	2

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

Appendix C: Bill of Materials

Subsystem	*Component Description*	*Part #*	*# of Items*	*Vendor*	*Unit Cost*	*Total Cost*
Frame	Assembly	FR000				
	Bottom Bracket Shell	FR001	1	Tread	$10.00	$10.87
	Front Fork	FR002	2	R.E. Borrmann's Steel Co.	$5.00	$ -
	Back Fork Tube 1	FR003	1	R.E. Borrmann's Steel Co.	$5.00	$ -
	Back Fork Tube 2	FR004	2	R.E. Borrmann's Steel Co.	$5.00	$ -
	Back Fork Tube 3	FR005	2	R.E. Borrmann's Steel Co.	$5.00	$ -
	Head Tube	FR006	2	R.E. Borrmann's Steel Co.	$10.00	$ -
	Crank Tube	FR007	1	R.E. Borrmann's Steel Co.	$8.34	$ -
	Main Tube	FR008	1	R.E. Borrmann's Steel Co.	$6.71	$ -
	Drop Down	FR009	2	R.E. Borrmann's Steel Co.	$3.00	$ -
	Idler Tab	FR010	2	R.E. Borrmann's Steel Co.	$12.03	$ -
	End Cap	FR011	3	R.E. Borrmann's Steel Co.	$18.05	$ -
	* Dash represents donated materials.				**Frame Subsystem Total:**	**$10.87**
Steering		ST000				
	Axle Tab	ST000-1	2	R.E. Borrmann's Steel Co.	$25.75	-
	Upper Control Arm	ST000-2	2	R.E. Borrmann's Steel Co.	$17.43	-
	Lower Control Arm	ST000-3	2	R.E. Borrmann's Steel Co.	$17.43	-
	Steer Tube	ST000-4	2	Tread	$10.00	$20.00
	Brake Bracket	ST000-5	2	R.E. Borrmann's Steel Co.	$8.72	-
	Brake Tab	ST000-6	2	R.E. Borrmann's Steel Co.	$12.43	-
	Headsets	ST003	2	Tread	$30.00	$60.00
	Steering Stems	FR006	2	Tread	$25.95	$51.90
	Wheel linkage	ST004	1	McMaster Carr	$20.00	$20.00
	Axles	ST005	2	McMaster Carr	$23.06	$46.12

	Ball joints	ST006	2	McMaster Carr	$9.92	$19.84
	Handlebars	ST007	2	Tread	$20.00	$32.66
	Grips	ST008	2	Tread	$17.00	$10.76
	Welded Joint	ST009	1	Welder's Heaven	$40.00	$40.00
					Steering Subsystem Total:	**$301.28**
Seat	*Component Description*	*Part #*	*# of Items*	*Vendor*	*Unit Cost*	*Total Cost*
	Machine Screw 1/4-20X1 bag of 3	SE001	2	Orchard Supply Hardware	$1.09	$2.56
	Washer SAE 5/16 Zinc bag of 8	SE002	1	Orchard Supply Hardware	$1.09	$1.09
	Washer SAE 1/4 Zinc bag of 8	SE003	1	Orchard Supply Hardware	$1.09	$1.09
	Carbon Fiber sheet	SE004	1	TAP Plastics	$40.00	$40.00
	Epoxy/Resin	SE005	1	TAP Plastics	$60.00	$60.00
					Seat Subsystem Total:	**$104.74**
Energy Storage	*Component Description*	*Part #*	*# of Items*	*Vendor*	*Unit Cost*	*Total Cost*
	Dynamo	ES001	1	TerraCycle	$52.66	$52.66
	Back Dynamo Holder	ES002	1	Home Depot	$13.52	$13.52
	Side Dynamo Holder	ES003	1	Home Depot	$5.00	$5.00
	5/16" Washer	ES004	3	Home Depot	$0.75	$2.25
	5/16" Nut	ES005	2	Home Depot	$0.60	$1.20
	Spring	ES006	1	Home Depot	$0.75	$0.75
	5/16" Bolt 1" length	ES007	1	Home Depot		$0.00
	Rechargable Battery Pack	ES008	1	Fry's	$1.00	$1.00
	Rechargable Batteries	ES009	6	Fry's	$5.33	$31.98
	Wiring	ES010	10	Fry's	$0.75	$7.50
	MintyBoost Circuit	ES011	1	adafruit	$20.00	$20.00
	SPDT Switch	ES012	2	Fry's	$1.30	$2.60

	Bread Board	ES013	1	Fry's	$15.25	$15.25
	Energy Storage Box	ES014	1	TAP Plastics	$8.45	$8.45
	Energy Storage Box Top	ES015	1	TAP Plastics	$2.50	$2.50
	Switch Box	ES016	1	RadioShack	$3.00	$3.00
	Diode (MURS120)	ES017	4	DigiKey	$2.16	$8.64
	Transistor (LT1021-5)	ES018	1	Sullivan UAV	$8.40	$8.40
	Capactiors (.1u)	ES019	2	DigiKey	$0.48	$0.96
	Capactiors (10u)	ES020	4	DigiKey	$1.36	$5.44
	Wiring	ES021	10	Panduit	$0.75	$7.50
	X Factor 3-Inch Bicycle Generator Llight Set	ES022	1	Amazon	$12.99	$12.99
	CatEye Strada Cadence Bicycle computer CC-RD200	ES023	1	Amazon	$33.13	$33.13
	Energy Storage Assembly	**EA001**				
	Energy Storage Circuit	**EA002**				
	Full Energy Storage Assembly	**EA003**				
					Energy Storage Subsystem Total:	**$244.72**
Wheels	*Component Description*	*Part #*	*# of Items*	*Vendor*	*Unit Cost*	*Total Cost*
	Front Wheel Frame	WH001	2	Tread	$155.00	$310.00
	Front Wheel Tube	WH002	6	Tread	$6.99	$41.94
	Front Wheel Tire	WH003	2	Tread	$19.00	$38.00
	14-Guage Spokes-FW	WH004	64	Tread	$0.40	$25.60
	Rear Wheel Frame	WH005	1	Tread	$250.00	$250.00
	Rear Wheel Tube	WH006	3	Tread	$8.99	$26.97
	Rear Wheel Tire	WH007	1	Tread	$25.00	$25.00
	Alfine Internal Hub	WH008	1	Tread	$675.00	$675.00
	Alfine Hub Small Parts Kit	WH009	1	Tread	$28.00	$28.00

	Hub Shifter	WH010	1	Tread	$95.00	$95.00
	14-Guage Spokes-RW	WH011	32	Tread	$0.40	$12.80
	18-Tooth Cog	WH012	1	Tread	$49.00	$49.00
	Rim Tape	WH013	3	Tread	$5.00	$15.00
	Front Wheel Assembly	**WA001**	1			
	Rear Wheel Assembly	**WA002**	1			
	Sun Ringle CR-10 20"	WH014	2	Tread	$35.00	$70.00
	Velox 17mm Cloth Rimtap	WH015	1	Tread	$10.00	$10.00
	Bicycle Tube	WH016	1	Tread	$6.00	$6.00
	Bicycle Tube	WH017	1	Tread	$6.00	$6.00
	Rim Tape	WH018	3	Tread	$5.00	$15.00
	Sun Ringle CR-18 700cm 32h	WH019	1	Tread	$35.00	$35.00
	Phil Wood Spokes 310m 14g Stainless Steel	WH020	1	Tread	$38.40	$38.40
					Wheels Subsystem Total:	**$1,772.71**
Brake System	*Component Description*	*Part #*	*# of Items*	*Vendor*	*Unit Cost*	*Total Cost*
	Avid Disk Brakes	BS001	2	Tread	$70.00	$140.00
	Brake Levers	BS002	2	Tread	$18.00	$36.00
	Brake Calipers	BS003	2	Tread	$13.98	$27.96
	Brake Cable	BS004	12	Tread	$7.19	$86.28
	Brake Cable Housing	BS005	10	Tread	$3.99	$39.90
	Brake Assembly	**BA001**	1			
	Brake Lever, Locking	BS006	1	WizWheelz	$14.95	$14.95
	Avid BB5 Break Levers (Set of 2)	BS007	1	Tread	$20.00	$20.00
	Shimano 5mm Brake Housing	BS008	1	Tread	$20.00	$20.00
	Tool Park BBT-19 BOT	BS009	1	Calmar Cycles	$23.99	$23.99
	Primo cable converter	BS010	1	Calabazas Cyclery	$9.99	$10.84

	Shimano Mountain Brake	BS011	1	Tread	$7.90	$4.51
	5mm 1-1/8 Headset Spacer	BS012	1	Tread	$4.00	$1.18
					Braking Subsystem Total:	**$425.61**
Drive Train	*Component Description*	*Part #*	*# of Items*	*Vendor*	*Unit Cost*	*Total Cost*
	46-Tooth Cog	DT001	1	Tread	$49.84	$49.84
	Pedal Cranks	DT002	2	Tread	$8.00	$16.00
	Pedals	DT003	2	Tread	$25.00	$50.00
	Clip-In for Pedals	DT004	2	Tread	$6.50	$13.00
	Chain	DT005	24	Tread	$1.25	$30.00
	Chain Tensioner	DT006	1	Tread	$9.60	$9.60
	Idlers	DT007	2	Tread	$8.50	$17.00
	Drive Train Assembly	**DA001**	1			
	Idler Tab	DT008	1	The Home Depot	$6.99	$6.99
	1/4" Hex Nut x25	DT009	1	The Home Depot	$1.57	$1.57
	1/4" Cut Washer x25	DT010	1	The Home Depot	$2.46	$2.46
	1/4 x 3-1/2 Hex Bolt	DT011	2	The Home Depot	$0.24	$0.48
	1/4-20" x 4" Hex Bolt	DT012	2	The Home Depot	$0.26	$0.52
	1/4 x 2-1/2 Hex Bolt	DT013	2	The Home Depot	$0.20	$0.40
	1/4 x 2 Hex Bolt	DT014	2	The Home Depot	$0.20	$0.40
	Lockwasher Med Split 1/4 Zinc	DT015	4	The Home Depot	$0.15	$0.60
	Over/Under Idler - Sport	DT016	2	TerraCycle	$59.95	$119.90
	Sport Return Idler	DT017	2	TerraCycle	$39.95	$79.90
	1/8 Chain	DT018	3	Tread	$10.00	$30.00
	Nexus 22T Cog	DT019	1	Tread	$6.00	$6.00
	Nexus 20T Cog	DT020	1	Tread	$5.00	$5.00

	Nexus 18T Cog	DT021	1	Tread	$5.00	$5.00
	Road Crankset	DT022	1	Tread	$60.00	$60.00
	Cont Sport Contact 700	DT023	1	Tread	$40.00	$40.00
	Front Assembly	**DA001**				
	Idler Assembly	**DA002**				
	Full Drivetrain Assembly	**DA003**				
					Drive Train Subsystem Total:	**$544.66**
Fairing	Front Fairing	FA001	1	Windwrap	$224.00	$224.00
					Fairing Subsystem Total:	**$224.00**
					System Totals:	**$3,628.59**

Appendix D: Experimental Results

Table D.1 Experimental results for vehicle preformance.

Criteria	Results
Top Speed	22 mph
Top Speed w/ Dynamo	17 mph
Turning Radius	5.75 ft
Stopping Distance	19.2 ft @ 17 mph
Stopping Distance w/ Dynamo	14.5 ft @ 17 mph
Weight	66 lb
Acceleration	4.2 ft/s^2
Max Power Output	5 watts
Battery Life: Lights	1 hr 50 minutes
Battery Life: Device to 65%	1 hr 15 minutes
Dynamo Drag	20%

Appendix E: Safety Rules for Prototype Vehicle

Rider Apparel to be worn while operating vehicle:

1. Helmet.
2. Gloves.
3. Elbow pads.
4. If platform pedals: Closed toed shoes.
5. If clip in pedals: Biking shoes with proper cleats.

Prior to Riding:

1. Ensure seatbelt is latched and tightened.
2. Check braking function.
3. Check that chain is not derailed, rusted, or broken.
4. Check that front and rear axle bolts are secure.
5. Check that speedometer has power and spin wheel to check function.
6. Inspect frame for damage or cracking.

Operating Rules:

1. Stay off of public roads, use sidewalks, paths, and campus roads.
2. Only one rider at a time.
3. Follow all applicable traffic laws.
4. Do not ride prototype off campus.
5. Stay below 30mph.
6. Only operate on level ground–no hills.
7. Yield to all pedestrian and vehicle traffic on campus.
8. Do not operate vehicle in crowded areas of campus–ex: mission church during class changes or the parking garage during sporting events.

Appendix F: Presentation Material

F.1 Frame and Fairing Presentation

The presentation materials for the Frame and Fairing team are attached on the following pages.

SANTA CLARA UNIVERSITY

SCU Human Powered Vehicle

Frame and Fairing

Colin Austin
Miles Graugnard
Max Herrmannsfeldt
Leif Kjos
Theodore Schapp

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Project overview

- Human powered vehicles
  - Inexpensive
  - Practical
  - A simple solution
- ASME Competition

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

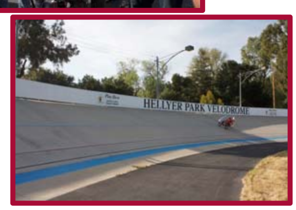
Presentation Plan

- ASME Competition
- Goals
- Timeline
- Engineering
- Results
- Lessons Learned
- Future Plans

SANTA CLARA UNIVERSITY

ASME Competition

- Four Events
  - Design
  - Innovation
  - Speed
  - Endurance



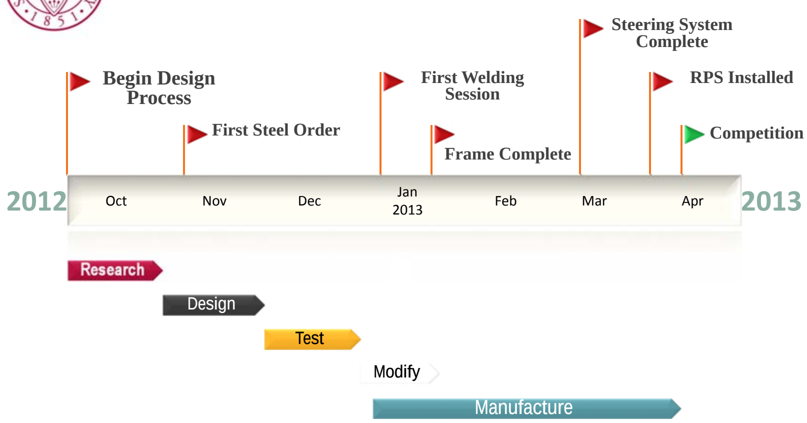
www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

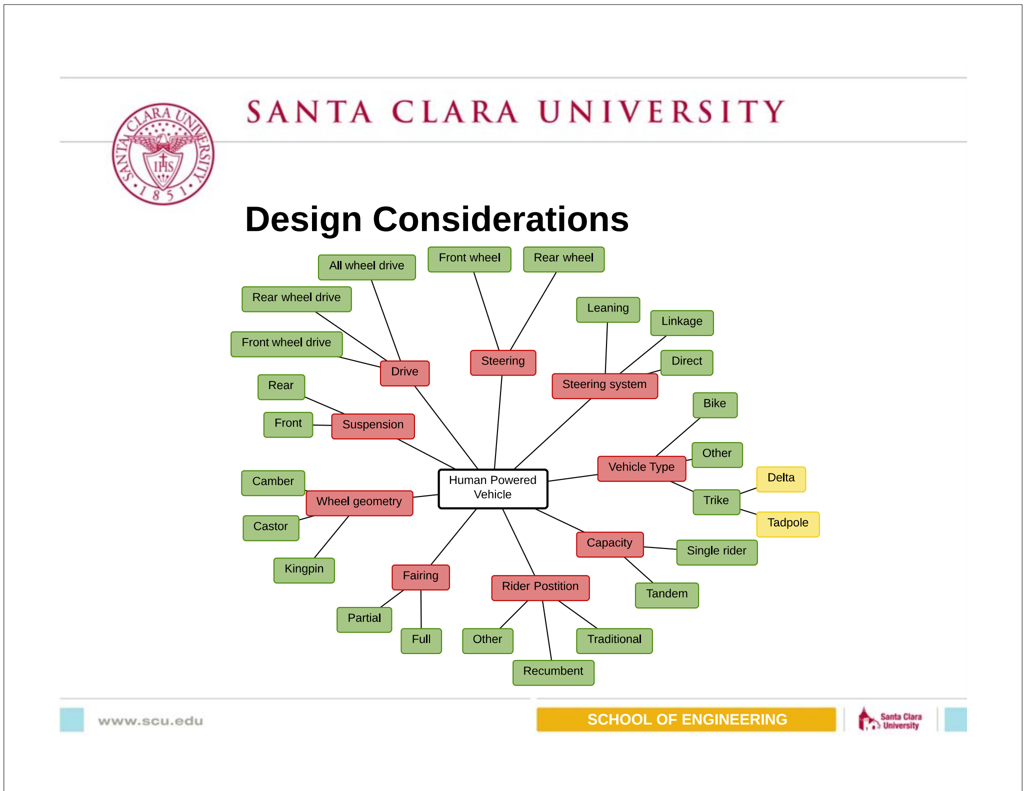
SANTA CLARA UNIVERSITY

Goals:

- Frugal
  - Simple
  - Easily Manufactured
- Practical
  - Rugged
  - Safe
  - Storage
- Competitive

SANTA CLARA UNIVERSITY




SANTA CLARA UNIVERSITY
Design Considerations
Human Powered Vehicle
Drive
All wheel drive
Rear wheel drive
Front wheel drive
Steering
Front wheel
Rear wheel
Steering system
Leaning
Linkage
Direct
Suspension
Rear
Front
Vehicle Type
Bike
Other
Trike
Delta
Tadpole
Wheel geometry
Camber
Castor
Kingpin
Capacity
Single rider
Tandem
Fairing
Partial
Full
Rider Postition
Other
Recumbent
Traditional
www.scu.edu
SCHOOL OF ENGINEERING


SANTA CLARA UNIVERSITY
Vehicle Design
www.scu.edu
SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Vehicle Cost

Category	Price
Components	$ 1,640
Raw material	$ 140
Development	$ 200
Fasteners	$ 50
Fairing	$ 250
TOTAL	$ 2,280

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Frame Features and Specs

- Size: 60”L x 25”W x 35”H
- Frame weight: ~ 12 lbs
- Total weight: 66 lbs
- Single axis cuts
- Bottom bracket stiffness: 1700 lb/in
- Effective RPS

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Frame sizing

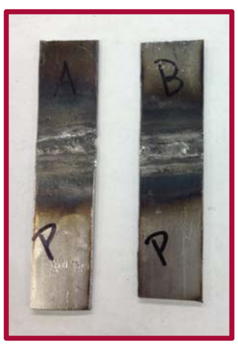
www.scu.edu

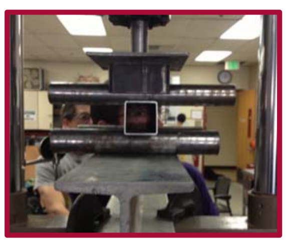
SCHOOL OF ENGINEERING

Santa Clara University

SANTA CLARA UNIVERSITY

Material and weld tests





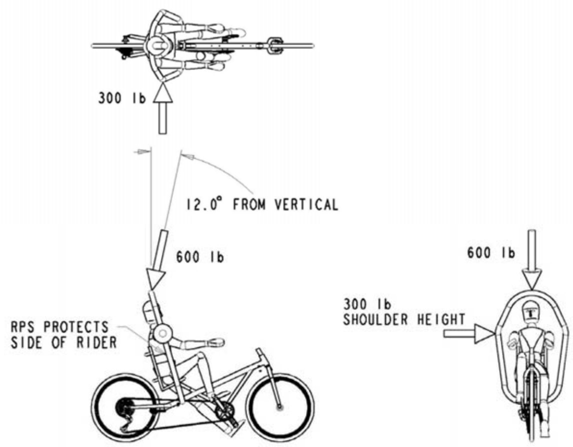
www.scu.edu

SCHOOL OF ENGINEERING

Santa Clara University

SANTA CLARA UNIVERSITY

RPS Requirements

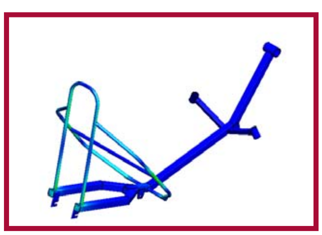


www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

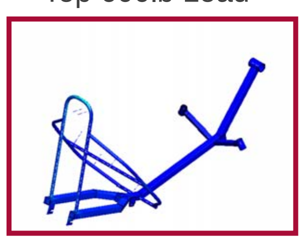
RPS Analysis

Side 300lb Load



Variable	Maximum
Max Displacement	.176 inches
Max Stress	31384 psi

Top 600lb Load

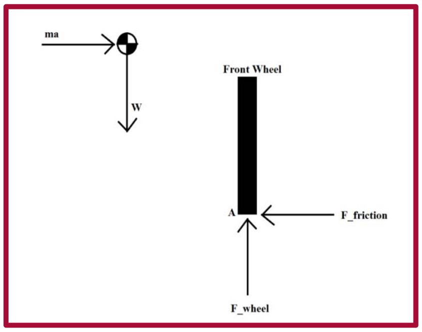


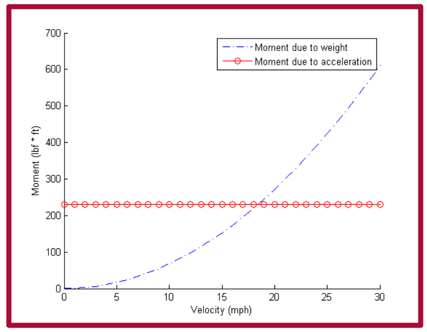
Variable	Maximum
Max Displacement	.0164 inches
Max Stress	37782 psi

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Roll speed analysis



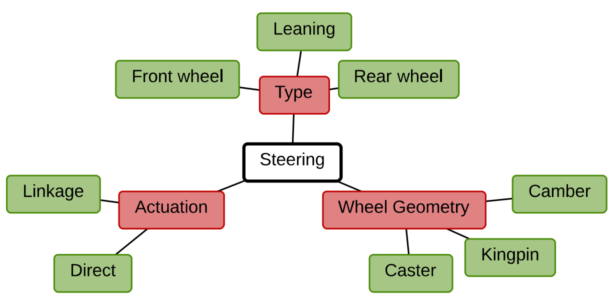


www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Steering Considerations



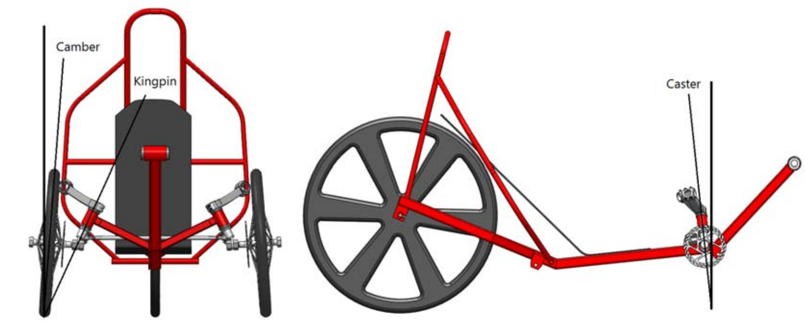
www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Steering Geometry

Kingpin, Camber, and Caster

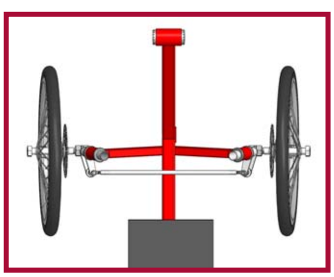


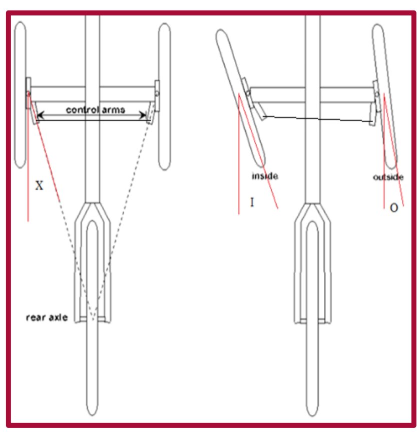
www.scu.edu SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

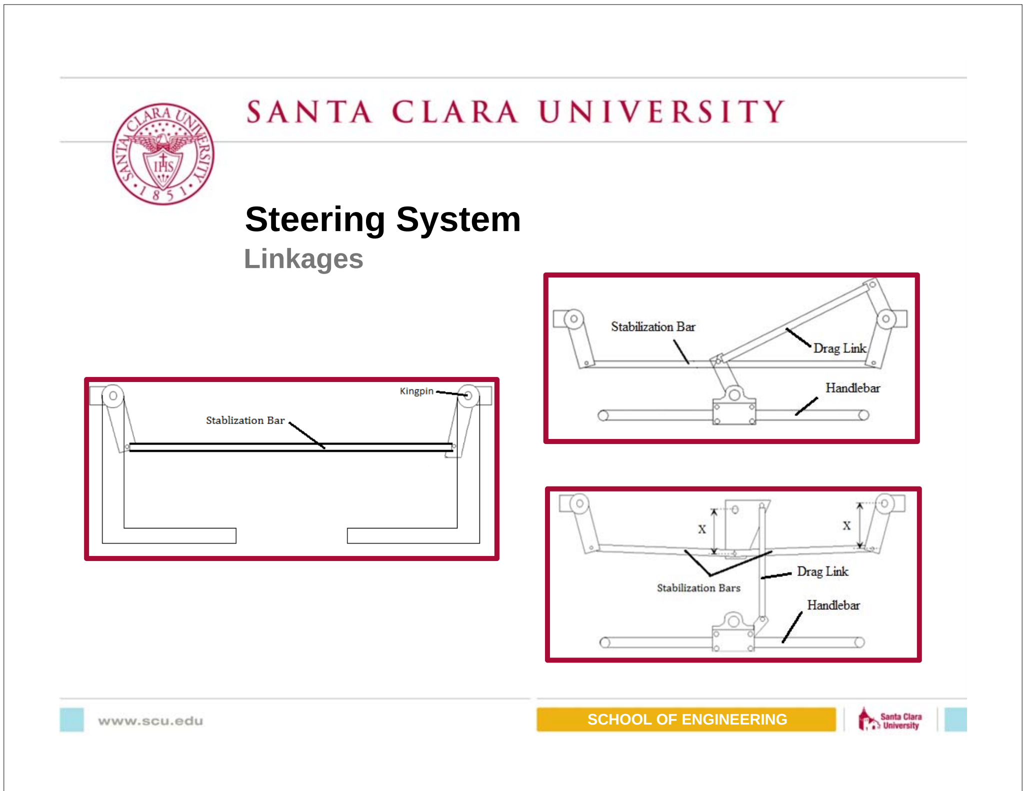
Steering Type

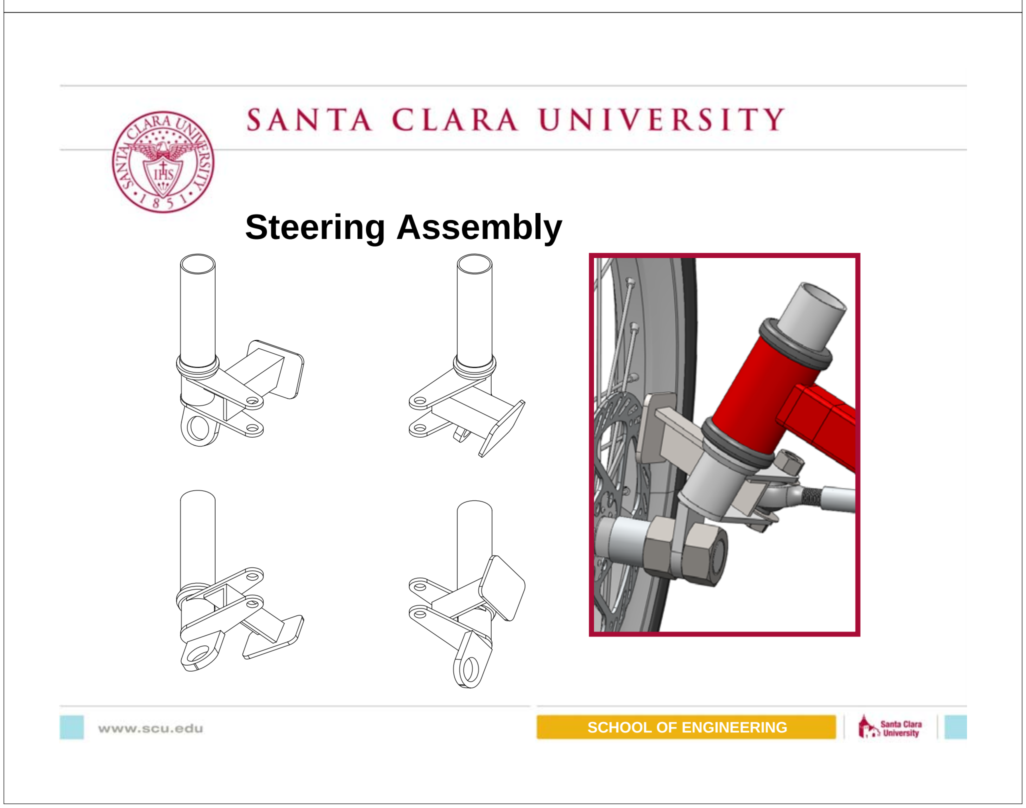
Ackerman





www.scu.edu SCHOOL OF ENGINEERING


SANTA CLARA UNIVERSITY
Steering System
Linkages
Kingpin
Stablization Bar
Stabilization Bar
Drag Link
Handlebar
X
X
Stabilization Bars
Drag Link
Handlebar
www.scu.edu
SCHOOL OF ENGINEERING
Santa Clara University


SANTA CLARA UNIVERSITY
Steering Assembly
www.scu.edu
SCHOOL OF ENGINEERING
Santa Clara University

SANTA CLARA UNIVERSITY

Fairing

- Low priority
- Impractical with respect to our project scope
- Needed for competition only

SANTA CLARA UNIVERSITY

Competition Results

Rose-Hulman
- 1st place overall
- 6+ years experience
- $10,000 budget

Colorado State
- 2nd place overall
- 10+ years experience

Missouri S&T
- 3rd place overall

www.scu.edu
SCHOOL OF ENGINEERING
Santa Clara University

SANTA CLARA UNIVERSITY

Competition Results

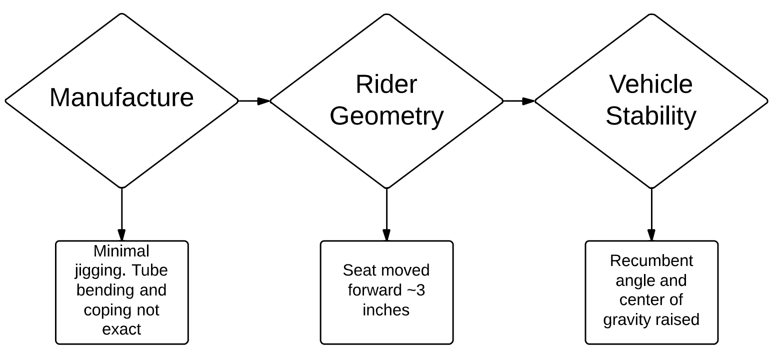
- 11th overall out of 29 teams
- 8th Innovation
- 9th Women's Speed
- 10th Endurance
- 12th Design
- 19th Men's Speed

www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Issues



www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Future Work

- Improve rider geometry
- Optimize stiffness
- Improve stability
- Built-in adjustability
- Fairing improvements

SANTA CLARA UNIVERSITY

Acknowledgments

- Santa Clara University, School of Engineering
  - Dr. Terry Shoup, Advisor
  - Don MacCubbin
  - Dr. Timothy Hight
  - Dr. Tonya Nilson
- R.E. Borrmann's Steel Co.
- Tread Bikes
- SCU Center for Science Technology & Society

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Thank You

SANTA CLARA UNIVERSITY

Contact Info

- Colin Austin

(925) 457-7395

colin91a@gmail.com

- Theodore Schapp

(408) 836-5697

theojschapp@gmail.com

- Miles Graugnard

(210) 836-7505

mjg9912@gmail.com

- Max Herrmannsfeldt

(206) 731-9490

Maxwell-h@comcast.com

- Leif Kjos

(206) 920-5467

Lekjos@gmail.com

F.2 Drivetrain and Energy Storage Presentation

The presentation materials for the Drive Train and Energy Storage team are attached on the following pages.

SANTA CLARA UNIVERSITY

HUMAN POWERED VEHICLE:
Drivetrain and Energy Storage

Dane Kornasiewicz
Terra Oldham
Toban Platt
Sean Smith

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Presentation Plan

- Objective & Needs
- Timeline
- System Sketch
- Design Specifications
- Budget
- Drivetrain
- Energy Storage
- Moving Forward

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Motivation

- Compete in ASME's Human Powered Vehicle Challenge
- Design an innovative energy generation & storage solution
  - Powerful lights
  - Battery charging device
- Create solution for commuting in urban communities & developing countries

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Project Objective

"The ultimate goal of this project is to design and build a safe, ergonomic, and high performance vehicle to be ***successful in the ASME Human Powered Vehicle Challenge*** *as well provide a feasible and sustainable solution for* ***transportation in urban communities and developing countries.***"

Santa Clara Human Powered Vehicle

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Customer Needs

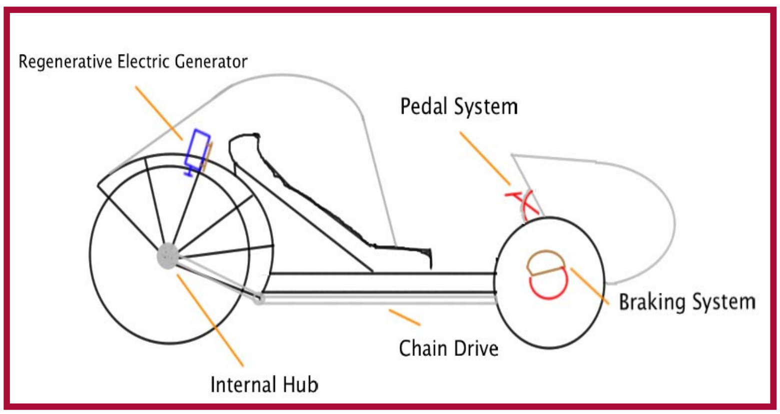
Weight factor was established by a controlled survey of those who commute daily via bicycle.

Customer Need	Weighting Factor
Safety	5.00
Variability of Speed	4.67
Energy Storage	4.67
Storage Space	4.67
Weight	4.00
Comfort	4.00
Durability	3.67
Maneuverability	3.33

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

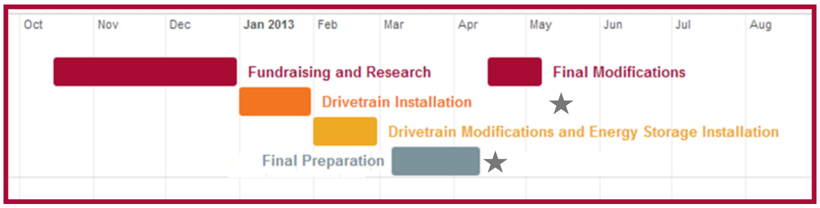
Initial System Sketch



www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Timeline



www.scu.edu

SCHOOL OF ENGINEERING

Santa Clara University

SANTA CLARA UNIVERSITY

Product Design Specifications

REQUIREMENTS/ELEMENTS	UNITS	DATUM	TARGET - RANGE
Top Speed	mph	~35	25
Weight	lbs	45	40-60
Stopping Distance	ft	20 from 15.5 mph	10-15 from 15.5 mph
Budget	Dollars	1000	x<4000
Max Allowable Torque	lb-ft	220	220
Chain Safety	N/A	Basic Gearing System	Covered Chain Track Internal Hub Shifting
Electrical Safety	N/A	Basic Electrical Motor System	Covered and Bound Wiring Weatherproof Casing
Maintenance	N/A	Bike Shop Repair	Removable Parts Personal Care
Durability	Mile	2000-5000	5000-6000
Battery Life	Minutes	N/A	45-75

www.scu.edu

SCHOOL OF ENGINEERING

Santa Clara University

SANTA CLARA UNIVERSITY

Budget & Fundraising

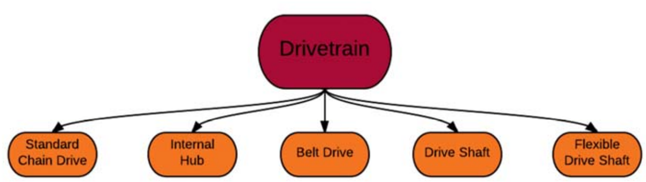
- Fundraising
  - Roelandts Grant
  - School of Engineering
- Total Cost
  - Rough Cost: $1,600
  - Budget Allowance: $2,500

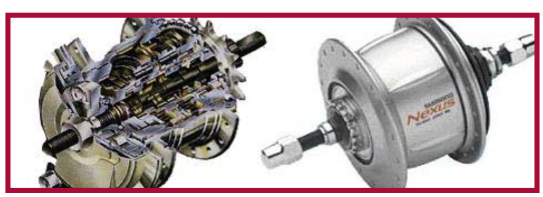
Component	Price
Rear Hub	$ 254.00
Crank Set	$ 70.00
Idler	$ 89.00
Chain	$ 90.00
Front Rim (2)	$ 188.00
Front Hub (2)	$ 160.00
Rear Rim	$ 94.00
Spokes	$ 100.00
Pedals	$ 110.00
Shifter	$ 90.00
Brake Lever	$ 20.00
Brakes (2)	$ 160.00
Dynamo	$ 50.00
Battery	$ 4.00
Friction Brakes	$ 80.00
Energy Storage Diodes/Wires	$ 120.00
TOTAL	$ 1,679.00

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Drivetrain Options





www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

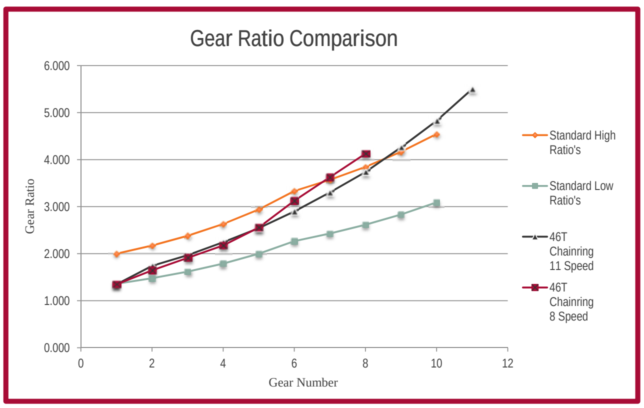
Drivetrain

- Internal hub shifting with chain drive
- Idler aligned chain track
- Rear wheel driven by single chain

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

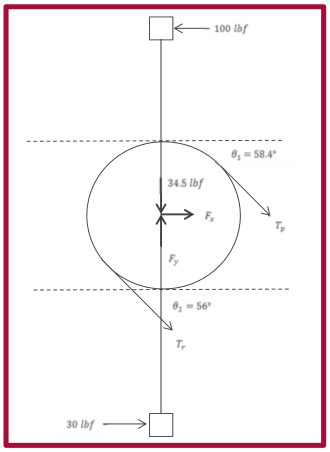
Drivetrain Calculations



www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Drivetrain Calculations



Front Chain Ring & Pedals

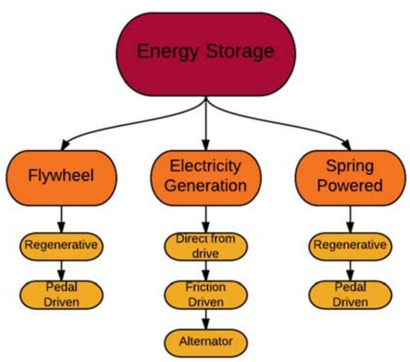
$$\sum F_x = 0 = 30\ lbf\ - 100 lbf + F_x + T_p \cos(58.4)$$
$$\sum F_y = 0 = T_r + F_y - 34.5 lbf$$
$$\sum M = 0 = 100(7\ in) + 30 lbf(7\ in) - T_D(1.375 in)$$

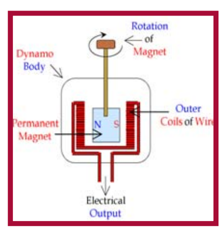
$$T_D = 331\ lbf$$
$$F_x = 4\ lbf$$
$$F_y = 316\ lbf$$

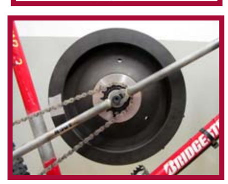
www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Energy Storage





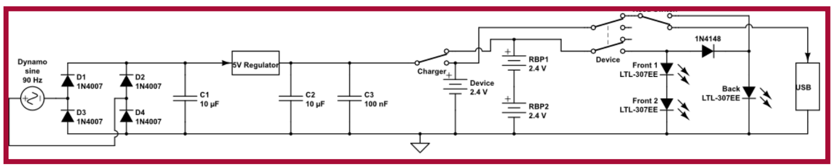


www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Energy Storage

- Variable friction driven electricity generation
- Regenerative braking
- Removable batteries
- Mounted vehicle lighting
- Accessory charging potential



www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

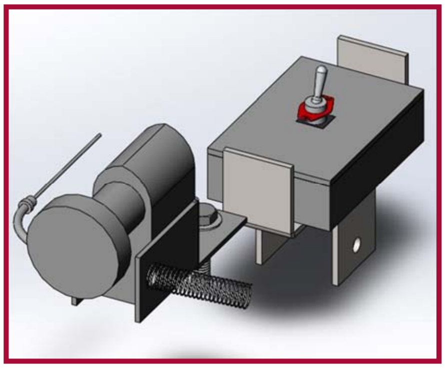
SANTA CLARA UNIVERSITY

Energy Storage System

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Energy Storage




www.scu.edu SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Energy Storage Results

	Charge Time (Hours)	
Current Generated (Amps)	Device Battery Pack	Removable Battery Pack
1.5	2.6	5.3
2.2	1.8	3.5

www.scu.edu SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

ASME Competition

- 8th Place Innovation
  - Energy storage device
  - Applications in developing countries
- 11th of 29 teams
- 2nd among rookie teams

www.scu.edu SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Design Modifications

Drivetrain

- Idler mounts reinforced with 1/8” galvanized steel
- Interchangeable front chain ring
- Optimized longitudinal chain line and tightness

www.scu.edu SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Design Modifications

Energy Generation & Storage

- Optimized locking hand brake cable length
- Personal electronics charging capabilities
- Permanent circuit connection box
- Improved circuit – flucuation allowances

www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Performance Results

Criteria	Results
Top Speed	22 mph
Top Speed w/ Dynamo	17 mph
Turning Radius	5.7 ft
Stopping Distance	19.2 ft @ 17 mph
Stopping Distance w/Dynamo	14.5 ft @ 17 mph
Weight	66 lbs
Acceleration	4.2 ft/s^2
Max Power Output	5 watts
Battery Life	2 hours
Dynamo Drag	~ 20 %

www.scu.edu

SCHOOL OF ENGINEERING

Moving Forward

- Design Goals
  - Improve top speed by optimizing drivetrain
  - Design a more efficient circuit
- Organizational Goals
  - Communicate design flaws and suggest improvements for future vehicles
  - Involve next years students to promote future entries into ASME's HPVC

SANTA CLARA UNIVERSITY

Acknowledgements

- Santa Clara University, School of Engineering
  - Dr. Terry Shoup, Advisor
  - Dr. Timothy Hight
  - Dr. Shoba Krishnan
  - Don MacCubbin
- R.E. Borrmann's Steel Co.
- Tread Bikes
- SCU Center For Science, Technology, & Society
  - Roelandts Family

www.scu.edu SCHOOL OF ENGINEERING Santa Clara University

SANTA CLARA UNIVERSITY

Questions?

www.scu.edu

SCHOOL OF ENGINEERING

Santa Clara University

SANTA CLARA UNIVERSITY

Detailed Options – Energy Storage

Design Project = HPVC

System= Energy Storage

CRITERIA	TARGET or FACTOR	DESIGN IDEAS: 1 = Baseline		Flywheel-regenerative		Flywheel-pedal power		Generator-regenerative		Spring-pedal power		Spring-regenerative	
Time – Design	3	3		10		9		5		3		6	
Time – Build	2	2		5		5		4		4		5	
Time – Test	1	1		2		2		1		1		1	
Time Score	10		10		26.11		25.00		15.56		13.33		18.33
Cost – Prototype	250	$ 250.00		$ 300.00		$300.00		$300.00		$200.00		$250.00	
Cost – Production	200	$ 200.00		$ 100.00		$150.00		$ 50.00		$150.00		$200.00	
Cost Score	10		10		8.50		9.75		7.25		7.75		10.00
Weight	4	3	12	1	4	1	4	3	12	2	8	2	8
Charge Time	5	3	15	3	15	2	10	3	15	2	10	2	10
Discharge Time	5	3	15	2	10	2	10	3	15	2	10	2	10
Cost	1	3	3	4	4	4	4	3	3	4	4	4	4
Weather Resistance	2	3	6	5	10	5	10	4	8	4	8	4	8
Efficiency	5	3	15	2	10	1	5	4	20	1	5	2	10
0	0	3	0		0		0	1	0		0		0
0	0	3	0		0		0	1	0		0		0
0	0	3	0		0		0	1	0		0		0
0	0	3	0		0		0	1	0		0		0
0	0	3	0		0		0	1	0		0		0
0	0	3	0		0		0	1	0		0		0
	TOTAL		66.0		38.4		28.3		70.2		43.9		41.7
	RANK												
	% MAX		94.0%		54.7%		40.2%		100.0%		62.6%		59.4%
	MAX	70.2											

NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = Generator-pedal power

www.scu.edu

SCHOOL OF ENGINEERING

Santa Clara University

SANTA CLARA UNIVERSITY

Detailed Options - Drivetrain

Design Project = HPVC   System= Drive Train

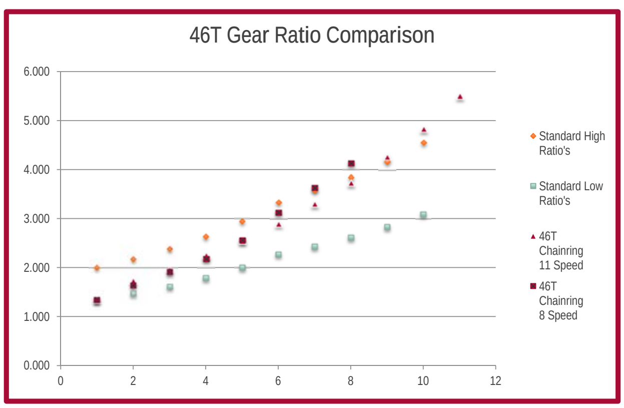
CRITERIA	TARGET or FACTOR	DESIGN IDEAS: 1 = Baseline		Internal Hub		Belt Drive		Drive Shaft		Flexible Drive Shaft	
Time – Design	3	3		1		4		8		8	
Time – Build	5	5		3		10		5		5	
Time – Test	1	1		2		2		3		3	
Time Score	10		10		9.78		17.78		22.22		22.22
Cost – Prototype	150	$ 150.00		$ 100.00		$300.00		$100.00		$200.00	
Cost – Production	600	$ 600.00		$1,000.00		$700.00		$400.00		$600.00	
Cost Score	10		10		11.67		15.83		6.67		11.67
Weight	4	3	12	1	4	4	16	2	8	4	16
Top Speed	3	3	9	3	9	2	6	2	6	2	6
Stopping Distance	3	3	9	3	9	3	9	3	9	3	9
Energy Storage	3	3	9	4	12	4	12	3	9	3	9
Budget	1	3	3	2	2	4	4	4	4	3	3
Max Torque	5	3	15	4	20	2	10	2	10	2	10
Ease of Gear Shifting	5	3	15	5	25	2	10	4	20	4	20
Resistance to Elements	2	3	6	5	10	4	8	4	8	4	8
0	0	3	0		0		0	1			0
0	0	3	0		0		0	1			0
0	0	3	0		0		0	1			0
0	0	3	0		0		0	1			0
	TOTAL		78.0		89.6		61.4		65.1		67.1
	RANK										
	% MAX		87.1%		100.0%		68.5%		72.7%		74.9%
	MAX	89.6									

NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = Standard Chain Drive System

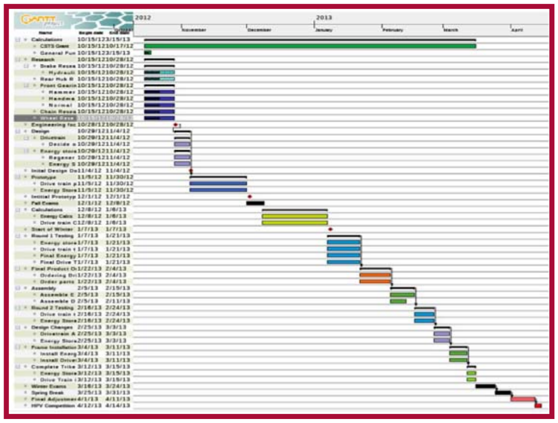
SANTA CLARA UNIVERSITY

Gearing Ratios



SANTA CLARA UNIVERSITY

Timeline

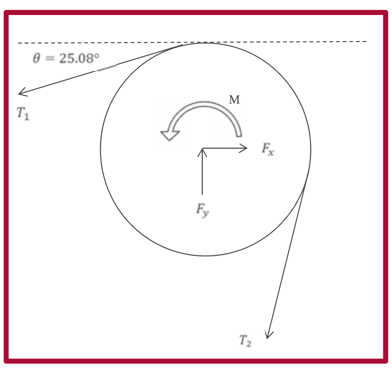


www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Drivetrain Calculations



Rear Cog

$$\sum F_x = 0 = F_x - \cos(25.08)T_1$$

$$\sum F_y = 0 = F_y - \sin(25.08)T_1$$

$$\sum M = 0 = T_1(1.375) + M_1$$

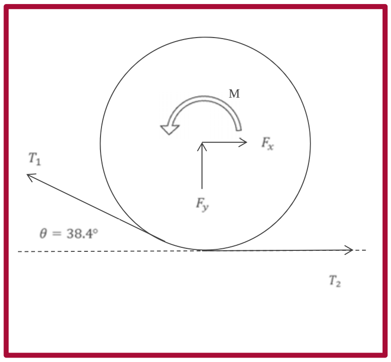
$$M_1 = -805\ lb.in$$
$$F_x = 530\ lbf$$
$$F_y = 248\ lbf$$

www.scu.edu

SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Drivetrain Calculations



Idler #1

$$\sum F_x = 0 = F_x + T(1 - \cos(38.4))$$

$$\sum F_y = 0 = F_y - T\sin(38.4)$$

$$\sum M = 0 = -T_1(1.375) + T_2$$

$$F_x = 127\ lbf$$
$$F_y = 364\ lbf$$

www.scu.edu SCHOOL OF ENGINEERING

SANTA CLARA UNIVERSITY

Patent Search

- Existing patents
  - Dynamos for bikes
  - Energy storage devices
- Create a patent profile
  - Differentiate design
  - Illustrate innovation and creativity
- Potentially establish business plan

www.scu.edu SCHOOL OF ENGINEERING

Appendix G: ASME Competition Results

The competition results as published by ASME can be found on the following page.

2013 HPVC West Results

ASME HPVC

		San Jose state university	California Polytechnic State University, San L	Rose-Hulman Institute of Technology	California State University Chico	California State University, Long Beach	Santa Clara University	University of Texas at Dallas	University of California Berkeley	Northern Arizona University	University of Utah	Colorado State University	Missousi University of Science and Technology	University of Arizona	Cal State University, Northridge	ITESM Campus Guadalajara	Arizona State University	Arizona State University	California State University Fresno	East Los Angeles College	LAMAR UNIVERSITY	Montana State University	PEC University of Technology	University of Miami	University of Montana	University of Nevada, Reno	University of Oklahoma	Utah State University	South Dakota School of Mines and Technology	Brigham Young University
		Spartacus/Apollo	Black Stallion	Celeritas	Caffeine	The Dark Knight	Cerberus	The Comet	PB&J	Axe	University of Utah	Donskoki	Colossus	Blue Steel	Pedal Slayer	Borregos GDA	Team Ramrod	Pedal to the Devil	Cerberus II	Laika	PIOLIN	Montana State University HPV	PEC	Hurricane	El Oso	Wolfie 1986	The Crimson Edge	Blue Bullet	Sparkle Motion	Cougar
Vehicle Count = 29	**№**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**23**	**24**	**26**	**29**	**34**	**37**	**38**	**45**	**46**	**49**	**50**	**56**	**67**	**68**	**71**	**74**	**87**	**89**	**90**
Design Event																														
General	**5**	5	5	5	5	1	5	0	5	5	5	5	5	5	5	2	0	0	5	3	5	5	0	0	5	0	5	5	4	4
Design	**15**	7.625	13.25	12.875	8.375	5.125	8.5	0	7.875	10.125	10.625	12.375	11.5	6.625	11.125	6.5	0	0	9.125	7.125	7.25	9.25	0	0	6.875	0	11.875	4	7.75	4.25
Analysis	**25**	18.875	22.75	20	4.875	5	12.75	0	15.75	17.25	18.5	22.625	19.125	7.625	19.875	6.25	0	0	11.875	13.5	10.375	9.625	0	0	5.75	0	19.75	1.25	4.625	8
Testing	**25**	3.875	14.375	12.125	3.375	5.75	5.875	0	9.125	6.375	14.875	18.25	13.875	4	11.375	2.75	0	0	12.625	9.5	6.25	6.875	0	0	7.375	0	11.375	8	2.375	6.125
Safety	**20**	14.25	15.875	17.25	15.5	6.5	16.25	0	12.875	11.125	12.75	17.125	17	8.25	13.125	8.75	0	0	15.75	13.75	12.25	9.25	0	0	14	0	17.125	10.5	8.75	10.75
Aesthetics	**10**	6.5	9.375	9.375	8.875	6.25	8.5	0	5.5	8.75	7.75	9.625	9.25	5.5	8.125	2.125	0	0	9.25	7	8	7.25	0	0	4.375	0	6.25	6.125	3.75	5.75
Design Event - Total	**100**	56.1	80.6	76.6	46.0	29.6	52.3	0.0	56.1	58.6	69.5	85.0	75.8	37.0	68.6	26.1	0.0	0.0	63.6	47.9	49.1	47.3	0.0	0.0	41.6	0.0	71.4	5.6	31.3	15.6
Report content largely non-original	100%																													
Late Report Submission (per day)	4%						8%									8%				8%					4%	4%		84%		60%
Late for Static Judging or Safety Check	10%																													
Over Page Limit (per page)	3%																			3%										
Report Does Not Conform to Outline	10%																													
Design - Rank		**10**	**2**	**3**	**16**	**20**	**12**	**24**	**10**	**9**	**6**	**1**	**4**	**18**	**7**	**21**	**24**	**24**	**8**	**14**	**13**	**15**	**24**	**24**	**17**	**24**	**5**	**23**	**19**	**22**
Innovation Event																														
Capability	**6**	5	5.25	5.5	4.25	4.75	4.625	0.625	4.875	4.375	5.25	5.25	5	3.75	4.625	4.625	0	0	4.75	3.5	0	0	0.25	0	4.125	0.5	4.75	2.5	5.25	4.375
Innovation	**9**	3.375	6.125	7.75	1.125	1.625	1.625	0.75	1.125	1.5	6.25	6.125	5.75	1.625	1.125	2.25	0	0	1.5	1.625	0	0	0	0	1.375	0	4.125	0	1.75	0.625
Effectiveness	**10**	6.6	6.3	9.5	6.1	3.4	6.5	0.0	5.4	4.8	8.0	7.8	7.6	5.0	6.8	5.1	0.0	0.0	6.5	2.9	0.0	0.0	0.0	0.0	5.4	0.0	4.5	1.3	5.6	4.6
Judge's Discretion	**5**	0.75	1	3.5	1.25	1	1	0	0.5	1.5	2	2.125	1.5	0.25	1	0.5	0	0	0.5	0.25	0	0	0	0	0.75	0	1.125	0	1	0.375
Innovation Event - Total	**30**	15.8	18.6	26.3	12.8	10.8	13.8	1.4	11.9	12.1	21.5	21.3	19.9	10.6	13.5	12.5	0.0	0.0	13.3	8.3	0.0	0.0	0.3	0.0	11.6	0.5	14.5	3.8	13.6	10.0
Innovation - Rank		**13**	**8**	**1**	**6**	**8**	**8**	**21**	**15**	**4**	**3**	**2**	**4**	**19**	**8**	**15**	**21**	**21**	**15**	**19**	**21**	**21**	**21**	**21**	**13**	**21**	**7**	**21**	**8**	**18**
Women's Speed Event - Total	**12.5**	4.7	9.6	12.5	7.9	8.7	8.6	0.4	9.9	11.4	0.4	10.0	12.4	6.1	8.3	5.5	0.4	9.4	7.3	6.4	0.4	8.3	0.4	0.4	0.4	0.4	8.2	10.0	0.4	0.4
Fastest Time (s)		7.70	3.77	2.90	4.59	4.17	4.23	99.00	3.68	3.19	99.00	3.63	2.93	5.99	4.39	6.54	99.00	3.85	4.96	5.64	99.00	4.35	99.00	99.00	99.00	99.00	4.44	3.63	99.00	99.00
Women's Speed- Rank		**19**	**7**	**1**	**14**	**9**	**10**	**20**	**6**	**3**	**20**	**4**	**2**	**17**	**12**	**18**	**20**	**8**	**15**	**16**	**20**	**11**	**20**	**20**	**20**	**20**	**13**	**4**	**20**	**20**
Men's Speed Event - Total	**12.5**	8.6	10.4	12.5	9.3	9.6	6.9	0.3	9.5	10.9	6.1	10.1	12.3	7.4	8.4	3.8	0.3	10.8	7.8	0.3	7.1	8.8	0.3	0.3	3.6	0.3	8.0	9.7	4.1	9.3
Fastest Time (s)		3.36	2.79	2.32	3.11	3.03	4.21	99.00	3.05	2.66	4.74	2.88	2.35	3.90	3.47	7.71	99.00	2.69	3.72	99.00	4.08	3.28	99.00	99.00	8.09	99.00	3.62	2.98	7.09	3.11
Men's Speed - Rank		**13**	**5**	**1**	**10**	**8**	**19**	**24**	**9**	**3**	**20**	**6**	**2**	**17**	**14**	**22**	**24**	**4**	**16**	**24**	**18**	**12**	**24**	**24**	**23**	**24**	**15**	**7**	**21**	**10**
Endurance Event - Total	**25**	20.3	21.8	19.8	25.0	21.1	20.6	0.0	24.6	22.2	0.0	23.0	21.8	0.0	15.3	14.1	0.0	18.2	17.7	19.0	19.0	21.8	0.0	0.0	8.1	0.0	19.0	21.4	12.5	0.0
Laps Completed		51.00	54.00	49.00	62.00	53.00	51.00	0.00	61.00	55.00	0.00	57.00	54.00	0.00	38.00	35.00	0.00	53.00	44.00	47.00	47.00	54.00	0.00	0.00	21.00	0.00	47.00	53.00	31.00	0.00
Finish time (hr)		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Lap Length (km)	0.9317																													
Total Distance Penalty (km)		0.5	0	0	0	0.7	0	0	0	0	0	0	0	0	0	0	0	7.4536	0	0	0	0	0	0	0.9317	0	0	0	0	0
Avg Speed Minus Penalties (km/h)		18.8	20.1	18.3	23.1	19.5	19.0	0.0	22.7	20.5	0.0	21.2	20.1	0.0	14.2	13.0	0.0	16.8	16.4	17.5	17.5	20.1	0.0	0.0	7.5	0.0	17.5	19.8	11.6	0.0
Avg Speed Minus Penalties (mph)		11.7	12.5	11.3	14.4	12.1	11.8	0.0	14.1	12.7	0.0	13.2	12.5	0.0	8.8	8.1	0.0	10.4	10.2	10.9	10.9	12.5	0.0	0.0	4.6	0.0	10.9	12.3	7.2	0.0
Illegeal Start Assistance (m)	500	500																												
Damage or Loss of Parcel (m)	up to 500					200																								
Failure to Stop at Stop Sign (m)	500					500																								
Safety Violation [Laps]	1 or more																													
Min Driver Lap Violation [Laps]	1																													
Max Driver Lap Violation [Laps]	1																	8							1					
Endurance - Rank		**11**	**6**	**12**	**1**	**9**	**10**	**22**	**2**	**4**	**22**	**3**	**6**	**22**	**18**	**19**	**22**	**16**	**17**	**14**	**13**	**5**	**22**	**22**	**21**	**22**	**14**	**8**	**20**	**22**
Overall - Total	**100**	61.02	78.38	85.25	64.52	55.39	60.88	1.58	68.71	70.12	41.67	82.70	82.46	31.67	61.52	39.58	0.66	38.37	60.77	45.55	41.18	53.13	0.83	0.66	32.28	0.99	66.20	45.26	35.41	21.02
Overall - Rank		**10**	**4**	**1**	**8**	**13**	**11**	**25**	**6**	**5**	**17**	**2**	**3**	**23**	**9**	**19**	**28**	**20**	**12**	**15**	**18**	**14**	**27**	**28**	**22**	**26**	**7**	**16**	**21**	**24**

Appendix H: Customer Needs Survey Results

The point of these questions is to highlight aspects of our design to see if they are relevant for an active population. These are the four questions asked:

A.) Pick two of the fallowing as the least attractive aspects of using a bicycle as transportation

- Safety
- Comfort (get dirty, sweat)
- Efficiency
- Minimal Storage
- Balance
- Other:

B.) If safety and comfort were vastly improved on a bicycle would you be more apt to ride?

C.) If you could commute on a bicycle without getting dirty or sweaty would you find this form of transportation more attractive? Do you feel this is an issue with infrastructure or the device itself?

D.) If there was a Human Powered Vehicle that was safer, faster, less dirty, and had more storage do you think it could revolutionize this forum of transportation? If so why?

Here are the responses:

Interview one	
Age	21
Gender	M
Activity (0-10)	7

A.)	Safety and Balance, being on the road is very scary with cars. It would be nice to be much safer when riding on the street.
B.)	Yes, definitely.
C.)	Yes, I am not sure this is possible though. It would be nice if more companies had showers to look more professional after riding to work.

D.) Yes, this could change the way we "get around" it would be nice if the infrastructure was set up better for it, roads ect...

Interview two

Age	22
Gender	M
Activity (0-10)	4

A.) Safety and comfort, if it was as nice to ride as it is to drive more people would ride. Bikes are just less comfortable.

B.) Yes.

C.) Yes, it is a problem with both, being enclosed could fix this. The infrastructure is there, people go work out at the gym before work and are fine. There needs to be more incentive.

D.) Yes, many people would rather get to work for free. This is hard with how far many people commute.

Interview three

Age	42
Gender	F
Activity (0-10)	8

A.) Efficiency and safety, if bikes were easier to ride more people would ride them, plain and simple.

B.) No, personally I have no problem with the bike the way it is. It is arguable that more people would ride if this were the case.

C.) It would be nice; my commute is not long enough for this to be a problem.

D.) Yes, I think one of the major problems is not the device itself but rather how it is supported. Bike lanes should be bigger and there should be incentive for riding.

Interview four

Age	19
Gender	M
Activity (0-10)	5

A.) Safety and comfort, riding on the road is just scary on a bike with the cars.
B.) Yes.
C.) Yes, there is a problem with the systems we have. Cars and bikes should not share roads, just like pedestrians don't need to walk in the street.
D.) No, I do not think that the device itself is the problem. Although these highlighted modifications would be a nice improvement I feel this is not the major problem.

Interview five

Age	20
Gender	F
Activity (0-10)	4 or 5

A.) Efficiency and storage, I think bikes are as safe as they are going to be. The problem is cars not bikes. It would be nice to make a bike more like a car, easy to use and easy to store things in.
B.) Yes.
C.) Yes, I do not think this is possible though because the simple nature of working causes your body to sweat.
D.) Yes, If this were the case there would be no reason to not use a bike.

Interview six

Age	32
Gender	M
Activity (0-10)	3

A.) Storage and Safety.
B.) No, why would you ride when you can easily take a car?
C.) No, the bicycle would need to be changed drastically for me to use one for commuting.
D.) No, I think that the people that would ride to work already do.

Interview seven

Age	21
Gender	M

Activity (0-10)	8

A.) Safety and comfort, If the bike was safer it would be much more popular.
B.) Yes, I would think most people would ride then.
C.) Yes, I would say the device. If it was safer and was easier to use more people would.
D.) Yes, of course.

Interview eight

Age	19
Gender	F
Activity (0-10)	8

A.) Efficiency and safety, if bikes were easy to ride then they would be super popular.
B.) No, I would ride either way to be honest.
C.) Yes, I think that is the main reason many do not use the bicycle to commute.
D.) Yes, because improvement on those traits could give people less of an excuse.

Appendix I: ASME Competition Rules

The competition rules as published by ASME are attached on the following pages.

energy | innovation | sustainability | engineering | design

RULES FOR THE 2013 HUMAN POWERED VEHICLE CHALLENGE

SETTING THE STANDARD

Rules for the
2013 Human Powered Vehicle Challenge
ASME

Table of Contents

I General Information

A) *Objective* To provide an opportunity for engineering students to demonstrate application of sound engineering principles toward the development of fast, efficient, sustainable, and practical human-powered vehicles.

B) *Superiority of Rules* These rules have been established by the ASME's Human Powered Vehicle Challenge (HPVC) Committee. Should any conflict arise between these rules and those of the ASME, the ASME rules shall dominate. Should any conflict arise between these rules and other information regarding the ASME HPVC, whether generated by the ASME or any other organization, these rules shall dominate.

C) *Location* Locations of all competitions (East and West North America and international) can be found on the official HPVC website. Teams wishing to participate should consult the HPVC website or the ASME HPVC Community on Facebook .

Official HPVC Website: http://www.asme.org/events/competitions/human-powered-vehicle-challenge-(hpvc)

HPVC Facebook Community: http://www.facebook.com/ASMEHPVC

D) *Schedule Summary & Host Information* The ASME HPVC web site shall specify all the important dates and contact information for the relevant competition.

E) *Competition Summary* The competition shall include four events: a design event, a speed event, a technology innovation event, and an endurance race. Scores from each event are totaled to obtain the overall score to determine the winner. The overall competition winner must compete in all four events.

F) *On-Site Schedule* On-site registration begins on Friday morning of the competition. All teams must register in person before the end of the registration period. Each team will be provided with a static judging/safety inspection time block at registration.

The design event shall consist of static judging by the Judging Team. The design event and a safety inspection will take place throughout the day on Friday. It is the responsibility of each team to be ready at the start of their assigned time block.

The speed event (a sprint or drag race) will take place on Saturday morning. The innovation event will occur on Saturday afternoon, and the endurance race will be held on Sunday morning. Prizes and trophies will be awarded in a ceremony after the endurance event, usually in conjunction with a banquet or meal.

II General Rules of Competition

A) *Minimum Number of Vehicles to Compete* There is no requirement for a minimum number of vehicles. However, should the number of vehicles entered be more than one but less than four, the number of awards granted for overall placement in that event shall be one less than the number of competing vehicles.

Further, no trophy or prize money will be awarded to the overall winner unless the vehicle completes and scores in all four competitions. In the endurance event, a vehicle must complete at least 10 kilometers in order to meet this requirement.

B) *Events of the Competition*
- Design Event: Teams are scored on their application of sound engineering principles and practices toward a vehicle design. This event includes a written report and static judging of their design.
- Men's and Women's Speed Event: Teams are scored on the speed of their vehicles, either in a flying start 100 meter sprint or a head-to-head drag race from a standing start. The ASME HPVC Committee will announce which event will be held well in advance of the competition. Separate scores for men and women are recorded for this event.
- Innovation Event: Teams are scored on the design and demonstration of a technical innovation related to their vehicle.
- Endurance Event: Teams are scored on speed, practicality, performance and reliability of their vehicles in a road race format with typical urban transportation obstacles.

C) *Energy Storage Device* Vehicles are encouraged to use energy storage devices. Energy must be stored while the vehicle is in motion, with human power as the sole external source of energy. Prior to each event, each team must demonstrate that their storage device has no initial energy stored. Combustion engines are excluded from the competition.

Energy storage devices are permitted in the Technology Innovation event, and may begin the demonstration with stored energy. All energy storage devices should be compatible with the spirit of the competition with respect to energy conservation and environmental stewardship.

During the safety inspection the team must be prepared to discuss the safety of the storage device, especially during a high-speed incident. Teams whose vehicles present an unacceptable risk in the perception of the judges will not be allowed to utilize the energy storage device in the competition.

D) *Modification of Vehicles* Modifications to the vehicle are allowed between events, as long as safety is not compromised. Vehicles must retain their main frame and general drivetrain configuration. Any vehicle deemed to have undergone changes in excess of this allowance will be permitted to compete if it does not present a safety risk; however, any scores achieved will not be credited to the original entry. Vehicles in which the basis of design involves changes to the main frame or drive train configuration for various racing events must submit a request for a waiver prior to the report due date.

E) *Aerodynamic Devices* Each vehicle shall include components, devices, or systems engineered specifically to reduce aerodynamic drag. Front fairings, tail sections, and full fairings are encouraged. Other devices may be permitted providing they clearly demonstrate that the device or system significantly reduces aerodynamic drag. The effectiveness of such devices must be justified in the design report.

Vehicles may compete in racing events without aerodynamic devices, but full design points shall not be awarded without analysis and testing of the aerodynamic device. Makeshift devices which are unrepresentative of the design, are crudely crafted, and/or present a clear safety concern will be prohibited, and must be removed prior to racing unless granted a waiver by the Chief Judge.

Fairing configurations may be changed between events in accordance with Section II.D provided that all safety requirements, including the seat belt and Rollover Protection System (RPS) rules, are not compromised by the change of configuration.

F) *Vehicle Number and Logos* ASME will assign each vehicle a number. The number "1" will be assigned to the overall winner from the prior year's competition. All other numbers will be assigned by ASME. At its discretion, ASME may consider requests for specific vehicle numbers, but no zero or triple digit numbers will be allowed.

<u>Decals</u> –ASME will provide two adhesive decals to each team during the on-site registration process. Each decal will display the assigned vehicle number as well as the ASME logo. Each vehicle shall provide sufficient space on either side for these stickers. This space may include fairings, cargo containers, or surfaces especially designed for this purpose. The decals shall be no larger than 35 x 30 cm.

<u>School Name</u> – All vehicles must display their school name or initials on each side of the vehicle in characters at least 10.1 cm (4 inch) high in a color that contrasts with the background.

If the ASME decal or displayed school name are lost, obscured, or difficult to see from either side of the vehicle, the vehicle shall be removed from the competition until they are restored. If a vehicle number is obscured during an endurance race, any laps run without a visible number will not be counted.

G) *Fairness of Competition* All participating teams will be assured an equal opportunity and a fair competition. Any participating team that, in the reasoned opinion of the judges, seeks to exert an unfair advantage over other competitors will be subject to a penalty in performance points or disqualification from the competition.

H) *Protests* Protests must be announced to a member of the judging staff either at the time of the incident or within a 15 minute period following the announcement of results of the event. Following the announcement of the intent to protest, a written protest must be presented within 30 minutes unless otherwise allowed by the Chief Judge. Oral protests will not be recognized.

Protests must be specific in nature and must include a factual account of the event being protested and the specific rules infraction, or the perceived error in the scoring of an event. ASME HPVC Form 7 may be used to file a protest. This form is available on the HPVC website or from HPVC officials.

Protests will be examined and resolved by the judges at their earliest convenience during the competition. Their decision will be final and without further appeal.

I) *Event Scoring* Scoring for each event and the overall scores will be based on a points system. The team with the most points wins the event.

III Safety

A) *General* The safety of participants, spectators, and the general public will override all other considerations during the competition. The judges will consider the safety features of the competition courses, as well as those of the competing vehicles, in permitting each event of the competition to begin or continue. Any event of the competition may be delayed, terminated prematurely, or canceled if the Chief Judge, in consultation with ASME and the Judging Team, determines that such action is necessary in the interest of safety.

B) *Performance Safety Requirements* Each vehicle must demonstrate that it can come to a stop from a speed of 25 km/hr (15.5 miles per hour) in a distance of 6.0 m (19.7 feet), can turn within an 8 m (26.2 ft) radius, and demonstrate stability by traveling for 30 m (98.4 feet) in a straight line at a speed of 5 to 8 km/hr (3-5 mph) (fast paced walking speed).

C) *Rollover Protection System* All vehicles must include a rollover protection system (RPS) that protects all drivers in the vehicle in the event of an accident. Functionally, the RPS must:

- Absorb sufficient energy in a severe accident to minimize risk of injury
- Prevent significant body contact with the ground in the event of a fall (vehicle resting on its side) or rollover (vehicle inverted)
- Provide adequate abrasion resistance to protect against sliding across the ground.

In addition, the RPS shall meet the top and side load requirements described below.

1) <u>RPS Load Cases:</u> The RPS system shall be evaluated based on two specific load cases – a top load representing an accident involving an inverted vehicle and a side load representing a vehicle fallen on its side. In all cases the applied load shall be reacted by constraints on the vehicle seat in an inverted or side position with drivers strapped in and clipped in to the pedals.

(a) Top Load: A load of 600 lb per driver/stoker shall be applied to the top of the roll bar(s), directed downward and aft (towards the rear of the vehicle) at an angle of 12° from the vertical. Note that there may be one roll bar for the driver and another roll bar for the stoker which will result in each RPS having an applied load of 600 lb, or the driver and stoker can both be protected by a single roll bar which will result in the RPS having an applied load of 1200 lb.

The roll bar is acceptable if 1) there is no indication of permanent deformation, fracture, or delamination on either the roll bar or the vehicle frame, 2) the maximum elastic deformation is less than 2.0 inches and shall not deform such that contact with the driver's helmet, head or body will occur.

(b) Side Load: A load of 300 lb per driver/stoker shall be applied horizontally to the side of the roll bar at shoulder height. Note that there may be one roll bar for the driver and another roll bar for the stoker which will result in each RPS having an applied load of 300 lb, or the driver and stoker can both be protected by a single roll bar which will result in the RPS having an applied load of 600 lb.

The roll bar is acceptable if 1) there is no indication of permanent deformation, fracture or delamination on either the roll bar or the vehicle frame, 2) the maximum elastic deformation is less than 1.5 inches and shall not deform such that contact with driver's helmet, head occurs.

2) RPS Attachment The RPS must be structurally attached and braced to the vehicle frame or fairing and, with the vehicle in the upright position, must extend above the helmeted head(s) of the driver(s) such that no part of any driver will touch the ground in a rollover or fall over condition. The RPS may be incorporated into the fairing, providing that that part of the fairing is used in all events. Teams must demonstrate that the RPS meets both functional requirements and loading requirements.

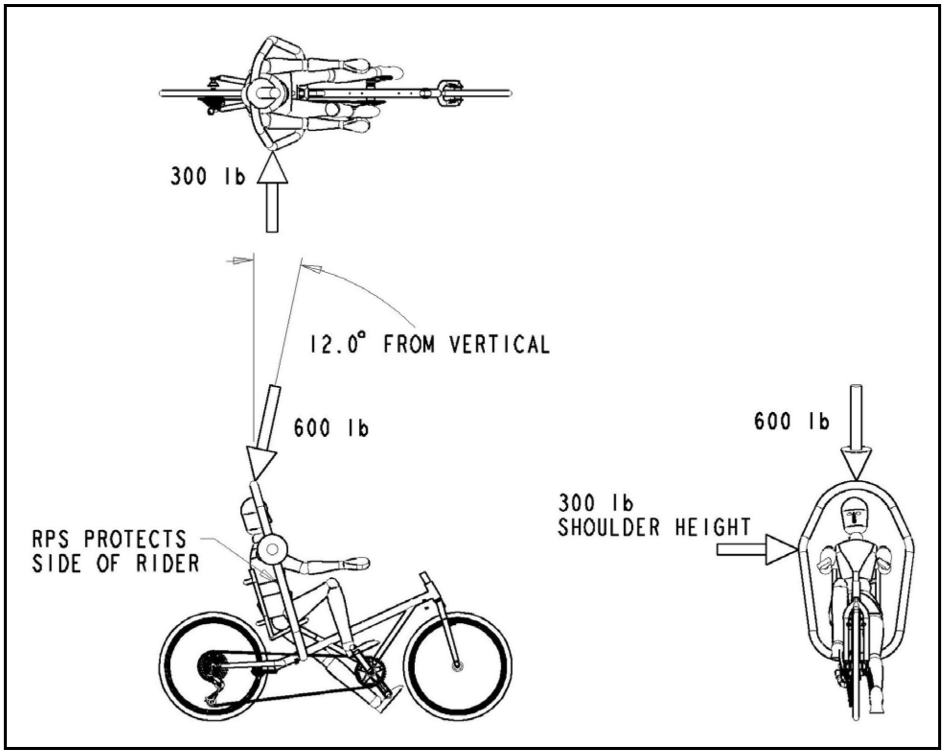


Figure 1: Example of Proper RPS Design and Side and Top Load Case Applications *(Note: Loads shown should not be applied concurrently in analysis and/or testing)*

D) *Safety Harness* All drivers of all vehicles in all events will be secured to their vehicle by safety belts and, where feasible, shoulder harnesses at all times that the vehicle is in motion. Commercially available seat belts and harnesses designed for automotive, aviation or racing applications will generally be accepted without test data for the straps and buckles. Test data for attachment points may still be required.

1) Custom Fabricated Harnesses If the harness is custom fabricated by the team or a commercial entity not in the business of producing harnesses or webbing products designed for use in life supporting application (i.e. climbing, racing, automotive), significant test data will be required, as defined below.
   - Hand stitching of webbing is not acceptable under any situation. Machine stitching will be acceptable with supporting test data.
   - Webbing connections secured with a properly tied water knot will be accepted without test data.
   - The minimum acceptable width for harness webbing is 1" (25mm).

2) Testing requirements for non-commercially produced harnesses

- Tensile test samples of a stitched joint must be prepared in an identical manner to the intended production method including: Base webbing material, thread, stitching pattern and quantity.
- Tensile tests performed on a minimum of 5 samples must show a 95% statistical confidence of an ultimate strength in excess of 750lb.

3) Testing requirements for off application buckles
   - Off application is defined as a buckle designed for anything other than a life supporting applications (automotive, aviation, climbing, etc.). Other buckles designed for life supporting applications will be accepted without testing documentation.
   - Plastic buckles of any type are not permitted.
   - Tensile tests performed on a minimum of 5 samples must show a 95% statistical confidence of an ultimate strength in excess of 750lb.

E) *Exemptions* Any team may request an exemption from rule **Section III.C** or **Section III.D** (HPVC Form 4). The request must be based on the safety of the driver or general public, and must be submitted in writing to the Chief Judge no later than the Entry Date. The request must convincingly argue that safety is enhanced by omitting the safety harness and/or the RPS. Waivers will generally not be granted for fully faired vehicles, recumbent vehicles, or vehicles with three wheels. Requests for waivers will be granted or denied by the judging committee, and their decision will be final and without appeal. The intent of the seat belt rule is to maximize safety, based primarily on the team's evaluation. It allows drivers of partially faired vehicles to operate those vehicles without safety harnesses and rollover protection, but only after a waiver is requested and granted.

F) *Vehicle Hazards:* All surfaces of the vehicle—both on the exterior and in the interior in the region of the driver(s) and in the access area—must be free from sharp edges and protrusions.

G) *Clothing and Protective Equipment* All participants must wear appropriate clothing and properly fitting helmets with fastened straps that meet CPSC Safety Standard for bicycle helmets (16 CFR Part 1203) or equivalent while:
   - Warming up or orienting themselves on any event course,
   - Riding in the Sprint or Drag Race, Endurance Event, and safety check, and
   - Riding any competing vehicle or other human powered vehicle on or in close proximity to an event course.

   Note that this requirement applies to all participants riding any HPV or bicycle, including personal vehicles.

H) *Required Safety Test of Energy Storage Devices* Vehicles that utilize energy storage devices shall specifically address the safety of the device or system in the design report and during the safety inspection. In particular, safety in the event of a high-speed accident shall be addressed. Teams whose vehicles present an unacceptable risk in the perception of the judges will not be allowed to utilize the energy storage device in the competition.

I) *Safety Certification* Participating teams must certify (HPVC Form 3) that:

- The design and construction of their respective vehicles have been carried out with due consideration of occupant and bystander safety.
- The specified safety tests will have been completed before arrival at the competition.
- All drivers and stokers will have had no less than 30 minutes of riding experience in their vehicle prior to the competition. Each team shall present a ride log at registration that clearly indicates the operator's name, date, duration in hours and minutes, and location for each ride or vehicle test used to satisfy the safety certification requirement.

J) *Safety Inspection and Demonstration* A competition official shall oversee tests of each vehicle's ability to meet the braking, turning and forward motion requirements. Each vehicle shall be visually inspected by the judges to ensure that no hazards exist that are likely to cause harm to the driver, passengers, competitors or spectators. Potential hazards include but are not limited to defects or play in the steering system, sharp edges, protruding bolts, open tube ends, and pinch points. In addition, the vehicle must provide the driver with a field of view of at least 90° to right and left of vehicle front and center.

The rollover protection system must appear substantial and correctly installed. The tallest driver on the team must sit in the vehicle and demonstrate the roll bar assembly extends beyond the driver's helmeted head and shoulders.

The safety check will take place during the scheduled safety inspection time block (within one hour of the end of the Static Judging time block.) No vehicle will be allowed to participate in any race unless it has successfully completed the safety check. Any team that fails the safety inspection may petition the safety judge for a re-inspection at a later time. Such re-inspection will be granted at the sole discretion of the safety official based on available time. If the re-inspection occurs after the designated inspection time block for that team, the team may be assessed a design score penalty up to 10%.

K) *Modifications Affecting Safety* Modifications to vehicles between events of the competition must not compromise the safety of the vehicle. If the competition officials determine that any modification has reduced the safety of the design to an unacceptable level, the vehicle will be disqualified from the affected event of the competition.

L) *Disqualification of Unsafe Vehicles* The competition officials reserve the right to remove from the competition any vehicle that is judged to be unsafe. This includes consideration of a vehicle's perceived performance under prevailing weather conditions.

IV Entry and Registration

A) *Team Eligibility* Entry in the Human Powered Vehicle Challenge is open to teams from any school with an engineering program.

B) *Team Member Eligibility and Certification* All members of the respective school's team must be enrolled as full-time students in an engineering program of study at that school.

Any individual that has been enrolled as a full-time student in an engineering program of study during the previous semester or quarter, but graduated no earlier than six months prior to the competition date, is eligible to fully participate in the ASME HPVC.

Entry submission must include names, ASME membership numbers, and academic majors of all team members. The final entry submission and must be received by the Entry Date using either the online registration site, or HPVC Form 2.

The team roster must clearly identify all designated drivers. Only those individuals thus identified and certified will be allowed to participate as vehicle drivers at any time during the competition. **No driver shall compete in multiple entries in any single racing event.**

C) *Verification of Team Rosters* Each team roster must be signed by the designated Team Leader. ASME may, at its discretion, submit a copy of any team's roster to the respective school's registrar's office for verification of enrollment and academic major.

D) *Vehicle Design, Analysis, and Construction* The research, analysis, and design of all vehicles entered by a school must be performed solely by current students at that school. All student team members shall be listed on the team's certified roster. Construction of the vehicle may include the assistance of outside vendors where the required capabilities exceed those available at the school.

E) *Driver Requirement Exceptions* All racing events require that teams have at least one complete crew of each gender. Significant penalties are incurred for teams that do not meet this requirement, as described in the rules for each event. An exception to the eligibility rule may be granted to allow drivers to compete for a school other than that in which they are enrolled, as described below. No other exceptions will be allowed.

If a participating school's roster cannot support at least one complete crew of each gender, that school may request the voluntary participation of one or more drivers from volunteers in attendance provided that the volunteer 1) meets all eligibility requirements from rule IV B and 2) will not participate in the same event for any other team. The requester must submit a written request for a waiver of the rules for this purpose to the Chief Judge for approval prior to the start of the applicable event. Scores derived in this manner will be credited to the requester.

F) *Submittal of Final Entries* Final entries must be received by the published entry date and must include the following:
- A completed entry form (HPVC Form 1)
- The registration fees
- Identification and certification of eligibility of team members (HPVC Form 2)
- A signed certification of vehicle safety (HPVC Form 3)
- If required, a Safety Exemption Request (HPVC Form 4)
- An acknowledgment of understanding of the rules, or requests for clarification or variance (HPVC Form 5)

- A description of the vehicle (HPVC Form 6; (Attached to design report)
- A top level 3-view engineering drawing of the vehicle (Attached to design report)

NOTE: Online registration satisfies all requirements for Forms 1, 2, 3 and 5, as well as the registration payment requirement.

G) *Late Entries* At its sole discretion, ASME may consider entries received after the entry date.

H) *Entry fees* The entry fees for the competition may differ depending on site. The specific fees will be outlined on the competition website.

I) *Refund of Entry Fees* If an entry is not accepted, all fees will be returned. If a school requests a cancellation of an entry and refund of the entry fee before the entry deadline, a full refund, less the non-refundable processing fee, will normally be made. No refunds of registration fees will normally be made after the entry deadline.

ASME may decline to refund any or all entry fees in the case of (1) cancellation of the Competition for reasons beyond its own control, (2) non-receipt of the full entry fee by the final entry deadline, or (3) submittal of an entry by an ineligible school.

J) *Notification of Acceptance* Notification of acceptance will be sent within one week of receipt of the final Entry Date.

K) *Competition Information* The following information, or a URL for a website that contains this information, shall be provided to each approved entrant at the time of notification of acceptance:

- A vehicle number
- On-site registration location and time
- A map showing the location of the various events
- A schedule of events
- Location and time for the Design event
- A course map for the Sprint or the Drag Race event, as appropriate
- A course map for the Endurance event

L) *On-Site Registration* All competitors must register on-site with ASME staff before participating in the competition. Registration location and time shall be provided to teams at the time of acceptance, or on the competition website.

During the on-site registration process teams may:

- Request changes in the team roster for verification
- Receive identification for each team driver (arm stamp, wrist bracelet, etc.)
- Receive two decals to display their assigned vehicle numbers and ASME logo
- Receive a final schedule, including times, locations and other event information.

M) *Late registration* Late registration will only be possible if prior arrangements have been made with ASME, at least one week in advance of the competition start date.

V Design Event

A) *Objective* To demonstrate the effective application of established principles and practices of design engineering to the development of the team's vehicle.

B) *Description* The Design Event includes three parts:
1) Design report submitted in advance of the competition
2) Static inspection by Judging Team
3) Safety inspection by competition official

Failure to submit a design report will result in a team not being scheduled for an inspection. If a team fails to complete any part of the design event, their vehicle will be judged as a non-participant. This condition will not affect the vehicle's participation in the other events, provided that the vehicle successfully completes the safety inspection.

C) *Time and Place* The Design Event will be held on Friday starting at approximately noon at a location specified by the host organization.

D) *Design Report* The report should concisely describe the vehicle design and document the design, analysis, and testing processes and results. The report should have the character of a professional engineering report and **<u>should be organized as described in Section V.E)</u>**.

Reports should emphasize clarity both in presentation and in the statement of results and conclusions. Photographs and drawings are encouraged where beneficial in documenting unique features of the design.

The design report must clearly display the vehicle number on the cover page.

Design reports shall use 12 point Times Roman font, single line spacing within paragraphs and double line spacing between paragraphs. Major headers shall be 14 point Times Roman Bold, left justified. Margins shall be 1 inch top, bottom, left, and right. All figures and tables shall include a caption in 10 point Times Roman italic font. Avoid watermarks and graphics that obscure text legibility.

Report writers should note that bulk is not a desirable feature; therefore, reports have a **30 page maximum limit.** (The limit includes the following sections: Design, Analysis, Testing, Safety, Aesthetics, and Conclusion. Required Form 6, the 3-view drawing, the abstract, and references will not be included in the page count. Penalties will be levied for exceeding the page limit (See Section V. M). Additionally, judges will not consider any page beyond the 30th.

A copy of the judges score sheet is included in Appendix 2 of these rules. Teams are strongly encouraged to carefully read the score sheet prior to writing the design report.

Teams are expected to comply with ASME's Code of Ethics in the creation of their reports.

E) *Design Report Organization* The design report shall be organized as follows:

1. ASME Form 6	No page number
2. Title Page	No page number
3. 3-View Drawing of Vehicle	No page number
4. Abstract	Page i
5. Table of Contents	Page ii
6. Design	**Page 1, First page that counts towards limit.**

   a. Objective
   b. Background
   c. Prior Work
   d. Design Specifications
   e. Concept Development and Selection Methods
   f. Innovation

7. Analysis
   a. RPS Analyses
   b. Structural Analyses
   c. Aerodynamic Analyses
   d. Cost Analyses
   e. Other Analyses
8. Testing
   a. RPS Testing
   b. Developmental Testing
   c. Performance Testing
9. Safety
   a. Design for Safety
   b. Hazard Analyses
10. Aesthetics
11. Conclusion
   a. Comparison – Design goals, analysis, and testing
   b. Evaluation
   c. Recommendations
   d. Conclusion **Last numbered page, Last page that counts towards limit.**
12. References

Appendix I –Innovation Event Report

F) *Design Report Content:* Content of each section should be in accordance with the design report score sheet (see Appendix 2).

1) ASME Form 6 The first page should be the completed Form 6, available on the HPVC web site.

2) Title Page The title page should include the report title, vehicle number (assigned by ASME), Names of team members including contact information for two designated team members, and the name and contact information of faculty advisor.

3) *3-View Drawing of Vehicle* Include a drawing of the complete vehicle with at least front, top, and side projections. Key dimensions such as wheelbase, track, overall length and overall width should be included.

4) Abstract The abstract should give a clear summary of the objectives, scope, and results of the vehicle design. It should be limited to no more than 300 words.

5) Design The Design section should include an overall description of the vehicle with appropriate background information, design objectives, design criteria, and design alternatives that were considered. It should clearly demonstrate that established design methodologies, including structured design methods and engineering principles, were effectively used during the vehicle design process. Sub-sections include:

   Objectives Clearly state the objectives and design mission of the vehicle

   Background Provide background information to justify your objectives, mission, design approaches, and design concepts. Cite references as appropriate.

   Prior Work Clearly document any design, fabrication, or testing that was not completed in the current academic year.

   Design Specifications Provide the design specifications for the vehicle. Tables and bullets may be used. Also provide rationale or justification for the specifications as appropriate. Document methods (such as QFD) used to develop the specifications.

   Concept Development and Selection Methods Document the use of established concept development and selection tools such as the Pugh's Concept Selection Technique, etc.

   Innovation Describe aspects of the vehicle design that are particularly innovative.

   Description Describe the final vehicle design, making generous use of drawings and figures. Describe how the vehicle can be practically used, what environmental conditions (weather, etc.) were addressed and how components and systems were selected or designed to meet the stated objectives.

6) Analysis The analysis section summarizes the engineering evaluation of the vehicle's performance and structural viability as related to the design criteria outlined in the description. For each analysis documented, the objective, modeling method and assumptions, results, and conclusions should be clearly indicated. Conclusions should

describe how the results were used to improve the vehicle, i.e. what changes were made as a result of the analysis.

Each sub-section should include a table summarizing all analyses completed in that section. The summary should include objectives, methods, and results. In addition, provide selected examples of specific analyses in sufficient depth to allow judges to evaluate the technical correctness of the analysis. The analysis section should include the following sub-sections

RPS Analyses Document the structural analysis of the rollover and side protection system. This section must convincingly demonstrate that the RPS is fully compliant with Section III.C of these rules in order to obtain full points.

Structural Analyses Document structural analyses conducted on the frame or mechanical components. Specify objectives, load cases, methods, and results. FEA is an appropriate tool, but not the only tool, used for structural analyses.

Aerodynamic Analyses Document aerodynamic analyses, including drag estimates, conducted on fairings, aerodynamic devices, or other components. CFD is an appropriate tool for aerodynamic analyses.

Cost Analysis Provide an estimate of production costs for the vehicle. Include a production cost estimate for the vehicle (1) as presented for the competition and (2) as estimated for a production run based on 10 vehicles per month. The production run cost estimate should include capital investment, tooling, parts and materials, labor, and overhead for a three (3) year production run.

Other Analyses Document other analyses conducted during the design process, including power/speed modeling, vehicle handling, stability, steering, suspension kinematics and dynamics, optimizations, etc.

7) Testing The testing section documents physical tests and/or experiments conducted to develop or verify the design. For each test, the objectives, methods, and results should be clearly described. Test results should be compared with design specifications and analytical predictions and should document design changes/validations driven by said results. Sufficient examples should be included to demonstrate the extent to which physical testing was used during the design process. This section should include the following sub-sections:

RPS Testing Physical testing of the RPS system should be documented, including methods, results, and conclusions.

Developmental Testing Document physical testing conducted to develop or optimize the vehicle design. Include objective, methods, results, and conclusions.

Performance Testing Document physical testing done to verify vehicle performance. Include objectives, methods, results, and conclusions.

8) Safety The safety section includes an analysis of potential hazards and **how the team addressed safety** of the 1) vehicle occupants, 2) bystanders, and 3) vehicle builders during the construction of the vehicle (i.e. shop safety).

   Features, components, and systems designed to mitigate hazards should be described. Of particular interest is how established engineering principles were used to design safety systems.

9) Aesthetics Document how aesthetics was addressed during the design of the vehicle.

10) Conclusions Demonstrate that the design team completed a substantive evaluation of the vehicle design. This section should include the following subsections:

    Comparison Use a table to compare the vehicle design specifications with analytical performance predictions and experimental results.

    Evaluation Describe how the final vehicle was evaluated with respect to the objectives and design specifications.

    Recommendations Document any recommendations for future work on the vehicle, including but not limited to modifications and improvements.

    Conclusion Clearly state your conclusions with respect to the vehicle. Were design objectives met?

G) *Prior Work* Design credit will only be given for work done during the current academic year. The report should clearly indicate if the documented design work is for a new vehicle design or improvements to a previous design. To be considered a new design, the vehicle must be substantially different from previous entries by that team or school. A substantially different vehicle has a significantly different objective, or has a significantly different design solution. It is acceptable to advance and refine the design of an existing vehicle, but the new developments must be clearly differentiated from prior work. In the event that the design is not a completely new design, the report must clearly identify which features of the design are new and what new analyses, tests, etc., were performed to verify the design changes. Scoring is based solely on the current year's work.

H) *Design Report Submittal* The design report must be submitted electronically to ASME no later than the report due date. The report due date is normally 32 days prior to the competition and will be announced by ASME well in advance. See the competition website for dates and instructions specific to each competition.

I) *Late Reports* Design reports will be accepted up to 25 days past the published Report Date, subject to a 4% penalty per day the report is late. Teams that do not submit reports within 25 days after the Report Date will not be eligible for participation in the design event.

J) *Design Report Update* During the static inspection, teams will provide the judges with an update summarizing the accomplishments made since design report submittal. The update is made orally to the judges, and shall not exceed five minutes duration.

Supporting material, though not required, is encouraged, and posters are preferred. Other acceptable mediums also include photographs, charts and other visuals. Live video links to short videos, photographs, and other digital visual media will be allowed, but teams are responsible for their own display equipment.

K) *Static Judging* Teams will be assigned time blocks to have their vehicles inspected at the on-site registration. Typically six teams will be assigned to each one hour block. Teams must be present with their vehicle at the beginning of their assigned time block in order to avoid penalties.

Teams will have a maximum of 10 minutes to display their vehicle to the judges, including the five minute oral update report.

Vehicles will be visually inspected based upon the following items:

- Physical characteristics
- Design features
- Consistency with report
- Safety
- Aesthetics

Teams should prepare a presentation board (typ. 36 x 48 in) to describe the design and construction of their vehicle and key innovative features.

L) *Vehicle Display* An area adjacent to the inspection site (see competition website) will be designated for static display of the vehicles. Teams should have the vehicle in the static display area while waiting for their inspection time block, or after completing required inspections. At least one team member must be present with the vehicle at all times.

During the static display time, it is expected that other participants, spectators and the competition officials will tour the display area. The judges may also review the display and inspect the design features of any vehicles for which a design report was not received.

M) *Design Scoring* Design scoring is based on the extent to which established engineering design principles were applied in the design process and effectiveness of those design practices used. Scores should also reflect the effectiveness of the report and presentation in communicating the design process and solution. Design teams must address each of the specified topics in order to receive a score for that topic. Design scoring for all vehicles shall be as follows:

Subject Area	Points
General	5
Design	15
Analysis	25
Testing	25
Safety	20
Aesthetics	10
Total	100

N) *Design Score Penalties* In addition to those previously described, penalties may be imposed by the Judging Team for failures to comply with the rules of the Design Event. Penalties will be assessed according to the following table in cases where an unfair advantage might have been gained or the Judges' ability to evaluate a design has been compromised.

Rules Infraction	Maximum Penalty
Report content largely non-original	Event Disqualification
Late report submittal	4% per day
Late for Static Judging or Safety Check	10%
Over Page Limit ("non-participant at 30 pgs over)	3% Per Page
Report does not conform to required outline	10%

O) *Overall Design Scoring* The judges will compile the design scores including any penalties on a total points basis. The event score is given by

$$\text{Points} = \left(\frac{\text{Team Design Score}}{\text{Maximum Possible Design Score}} \right) \times \text{Maximum Event Points}$$

Where the Maximum Possible Design Score is the maximum points possible according to the Judge's Score Sheet, and the Maximum Event Points are given in Part VIII.

VI Speed Event (Sprint or Drag Race)

The competition will include either a sprint or a drag race format. The type of race will be determined and announced well in advance of the competition at the discretion of the Judging Team and host school.

Separate speed events are held for men and women.

Sprint Race

A) *Objective* To provide teams the opportunity to demonstrate the top speed of their vehicles.

B) *Description* The Sprint Event is an individual, timed event with a flying start to achieve top speed on a closed course. Each team shall include multiple drivers with separate scoring categories for both genders. The male and female sprint races shall be run concurrently.

C) *Time and Place* The Sprint Event, a "flying start speed trial," will be held on Saturday morning at approximately 8:00 AM at a location specified by the host organization. The exact starting time may vary due to weather conditions or equipment readiness.

D) *Duration* The Sprint Event will normally continue for four hours. However, this time may be either extended or curtailed as deemed necessary by the Chief Judge.

E) *Sprint Course Description* The course will consist of a straight, smooth, and level (less than 1% slope over entire course) paved surface of suitable width and clear of obstacles, pits, cracks, or potholes. The timed portion of the course shall be 100 meters in length, preceded by a 400 to 600 meter "run-up" section and followed by a "run-down" section at least 200 meters in length. Where possible, the length of the “run-up” should be maximized.

The beginning of the run-up shall be marked by a starting line. All vehicles in line for a run shall remain in a marked staging area until directed by the start line official to move to the starting line. The course will include a separate route for returning vehicles from the "run down" end of the course to the starting area.

While the course should be designed to completely avoid collision hazards, this may not be possible in all cases. Hay bales or equivalent cushioning material will be used to protect vehicles and drivers from collision with any fixed obstacles located adjacent to the course. Such cushioning shall reflect proper safety design with due consideration to the estimated speed of passing vehicles and their direction along the course.

The course shall be clearly marked to indicate the following points:

- Staging area
- Starting line
- Release line
- 300 meters to time trap
- 200 meters to time trap
- 100 meters to time trap
- 50 meters to time trap
- Beginning of time trap
- End of time trap
- End of course

F) *Timing Area* The timing and scoring area, located at the end of the speed trap, will be off limits to spectators and all others except the competition officials and the event timing staff.

G) *Tally Board* Vehicle speeds and standings shall be posted in a timely manner on a "tally board" or display for the benefit of competitors. The "tally board" will be separated from the timing area.

H) *Drivers' Meeting* All drivers who will participate in the Sprint Event must attend the mandatory Drivers' Meeting at approximately 45 minutes prior to the scheduled start of the race. The meeting will clarify operating procedures and signals and will identify course features, hazards, and landmarks.

By the time of the meeting all team equipment, vehicles and other required items should be in place and clear of the track. Any team that is not represented at this meeting will not normally be permitted to participate in the event; in cases of unavoidable absence, the team may file an appeal with the Judging Team, whose decision regarding participation will be final.

I) *Starting Order* The first round of sprint attempts will be in the numerical order of the vehicles to the extent possible. Subsequent starts will be on a "first ready, first started" basis. Place holding in line is prohibited: a team is not considered ready unless both driver and vehicle are present and prepared to race. Teams will be notified of their staging order prior to the start.

J) *Line Position Forfeiture* Each successive vehicle will have 15 seconds to begin a sprint attempt after the start line official has determined that the course is ready and safe for the event to proceed. If a vehicle is not ready within the 15-second period, the vehicle must stand aside for others that are ready to proceed. In extreme cases, the vehicle will forfeit the run and must reenter at the end of the line.

K) *Start Assistance* Start assistance will be limited to holding the competing vehicle upright and stabilizing it as it begins its run; pushing the vehicle is only permitted as required to keep the vehicle stabilized and upright. No more than two individuals may assist in the starting process, and all assistance must end within the first 10m, which will be marked.

If the starting official determines that a vehicle has received start assistance in excess of that allowed by these rules, a mis-start may be declared. The mis-start shall be made known by a single blast of a horn or whistle, or as announced at the Driver's Meeting. This will occur before the vehicle reaches the "300 meters to time trap" marker.

L) *Number of Attempts* During the Sprint Event each vehicle will be allowed to make as many runs as time and conditions permit, and all vehicles will be provided an equal opportunity to compete.

Although all competitors will have an equal opportunity to compete, there will be no assurance of an equal number of runs for all vehicles. Teams may take advantage of every opportunity to maximize their number of runs, or selectively pass opportunities. Such strategies should consider that foregone opportunities may not be regained.

Under normal conditions, all present and competing teams will be notified before the final run is begun, and all teams will be allowed an opportunity to make a final attempt.

M) *Interruption and Termination* The Sprint Event will normally run continuously. However, circumstances such as equipment failures, an emergency or hazardous weather or wind conditions may require a delay or premature termination of the event. Delays or terminations will be determined by the Chief Judge with the help of the judging team and the Competition Director.

N) *Scoring* The Sprint Event is scored separately for each gender. Thus each vehicle will have two sprint scores: one for male drivers and one for female drivers.

The point score for each vehicle is based on the winning time for the event, that is, the fastest time of any vehicle in the event. Points are awarded based on the following formula:

$$\text{Points} = \frac{t_{\text{Winner}}}{t} \times (\text{Maximum Event Points})$$

Where t_{Winner} is the time of the winning vehicle, t is the fastest time of the event for a particular vehicle, and the Maximum Event Points is the point value for the event, specified in section VIII.

Drag Race

O) *Objective* To provide teams the opportunity to demonstrate the speed and reliability of their vehicles in a tournament format.

P) *Description* The Drag Event is a tournament style race where vehicles compete two at a time to be the first to cross a set finish line, from a standing start.

Q) *Time and Place* The Drag Race Event shall be held on Saturday morning at approximately 8:00 AM at a location specified by the host organization. The exact starting time may vary due to weather conditions or equipment readiness.

R) *Duration* The Drag Event ends when both the Men's and Women's events are complete and champions have been determined. However, this time may be curtailed as deemed necessary by the Chief Judge.

S) *Drag Course Description* The drag race course shall consist of a paved level course typically between 350 to 450 meters in length. The course shall be at least six (6) meters wide at all locations. The surface shall be smooth and free of potholes, cracks, and debris. Curves are permitted on the course, which may be a closed loop (although a closed loop is not required).

The course immediately following the start and immediately preceding the finish line shall be straight, unless separate and equal length lanes are provided for each vehicle. If the course is not a closed loop there shall be a return path to the staging area.

T) *Timing Area* The timing and scoring area shall be off limits to competitors, spectators, and all others except competition officials and the event timing staff.

U) *Tally Board* If the race venue can support it, race results shall be posted on a tally board or computer monitor throughout the race. Results should be updated after each individual race, and should indicate the winners' and losers' brackets and race times.

V) *Drivers' Meeting* All drivers who will participate in the Drag Race Event must attend the mandatory drivers' meeting for that event. The drivers' meeting shall take place approximately 45 minutes prior to the scheduled start of the race. The meeting will clarify operating procedures and signals and will identify course features, hazards, and landmarks.

W) *Race Description* The Drag Race Event allows two teams at a time to race each other side by side from stationary at a starting line to a predetermined finish line. The Drag Race Event is gender specific. Each driver shall compete against drivers of the same gender. Separate scores shall be kept for male and female drivers.

The drag race consists of two phases: qualifying and a double-elimination tournament drag race. All vehicles shall compete in the qualifying race. The 16 vehicles with the fastest qualifying times shall compete in the drag tournament.

X) *Qualifying Race* The event shall begin with the female driver qualifying race. After all female drivers have completed the qualifying race, the male qualifying race shall commence. In both male and female races, vehicles shall start in the order of vehicle number. The maximum number of vehicles racing in each heat shall be at the discretion of the Chief Judge, and will depend on the nature of the course and the available timing equipment (typically two). Each vehicle shall be timed separately. Qualifying race place is based on finish times.

Y) *Brackets And Seeding* The top 16 vehicles from the qualifying race will advance to the elimination rounds in each gender. If there are less than 16 vehicles, then the tournament shall consist of 8 vehicles.

After the first round of eliminations, the event is split into two brackets: the winner's bracket and the loser's bracket. At the end of each round, the losers in the winner's bracket move into the loser's bracket. The losers of the loser's bracket are eliminated from the competition. The championship race determines the winner of the event. In the event that neither championship contestant has two losses after the round, an extra race will determine the winner.

Seeding shall be based on qualifying time. That is, the first race shall take place between the vehicles with the first and last qualifying times, the second race between the second and next to last qualifying places, and so on.

Tournament seeding and sequencing may be modified by the Chief Judge to account for event-specific circumstances.

Z) *Drag Race* All races in the drag tournament shall be between two vehicles. Vehicles will be instructed at the starting line of the race by a flagman. When both competitors indicate they are ready the flagman will start the race by waving the flag. No verbal command is required therefore the drivers must be able to clearly see the flagman. There will be a finish line judge (if not a closed loop) who will determine the winner of the race.

Following the completion of the race competitors must return to the staging area for succeeding elimination rounds. Once there teams will be instructed by the staging area coordinator.

Event and race sequencing will be determined by the Chief Judge and announced at the drivers' meeting.

Disabled vehicles at the start or during the race will have no more than 20 seconds to make repairs or they will forfeit the race. Disabled vehicles must clear the course as rapidly as possible.

AA) *Race Forfeiture* Vehicles must be in line and ready to start in turn. If a vehicle is not ready to start at their turn, they forfeit the race and either move to the loser's bracket or are eliminated from the race. If a vehicle is unable to start within 20 seconds of the start signal it must forfeit the race. Forfeiture in the qualifying race makes the vehicle ineligible to compete in the drag tournament.

BB) *Start Assistance* Start assistance will be limited to holding the competing vehicle upright and stabilizing it as it begins its run; pushing the vehicle is only permitted as required to keep the vehicle stabilized and upright. No more than two individuals may assist in the starting process, and all assistance must end within the first 10 meters, which will be marked.

CC) *Interruption and Termination* The Drag Race Event will normally run continuously. However, circumstances such as equipment failures, an emergency, hazardous weather, or wind conditions may require a delay. Delays will be determined by the Chief Judge with the help of the Judging Team and the Competition Director. The Drag Race Event will end with the completion of the championship rounds for both genders.

DD) *Scoring* The top (16) (or 8 in the event of an 8-vehicle tournament) places shall be determined by the round in which the vehicle was eliminated. The place order for all remaining vehicles shall be determined by qualifying speed. Separate scores shall be maintained for each gender.

Scoring for teams that qualify in the tournament depends on the round in which they are eliminated from the tournament. See Table 1.

Table 1 Drag Tournament Scoring

	Elimination Match															
Eliminated in Round:	Champion	30, 31	29	28	25	26	25	24	23	22	21	20	19	18	17	16
Place	1	2	3	4	5	5	7	7	9	9	9	9	13	13	13	13
Points	12.5	11.5	10.5	9.5	8.5	8.5	7.8	7.8	7.1	7.1	7.1	7.1	6.5	6.5	6.5	6.5

Teams that do not qualify for the tournament will be scored based on time obtained in the qualifying round, in accordance with the following formula:

$$\text{Points} = \frac{t_{\text{Fastest Non-Qualifying Time}}}{t} \times \left(6.0 \text{ Points}\right)$$

VII Innovation Event

A) *Objective*
1) To encourage innovation that advances the state of the art in human-powered vehicles.
2) To provide teams an opportunity to demonstrate significant innovations.

B) *Description* This event provides teams an opportunity to complete a functional demonstration of a key innovative feature of the design that advances the technology of human powered vehicles. Innovation may be related to vehicle systems, performance, manufacturing methods, safety or other vehicle areas. Teams provide a detailed description of their innovation in Appendix 1 of the design report. During the Innovation Event, teams will have 5 minutes to demonstrate the effectiveness of the innovation and answer the judges' questions. The innovation will be scored on capability, innovativeness, and effectiveness.

C) *Definition of Innovation*
1) Innovation is the introduction of a previously unknown, unusual, or unfamiliar product, process, material or method, or the alteration of an established product, process, material or method by introducing new elements, forms or processes.

2) Innovations related to any aspect of human-powered vehicles are encouraged, including vehicle performance, manufacturing and materials, human physiology, safety, and ergonomics.

D) *Target Innovation Areas* Each year, ASME will suggest several target areas for innovation. Teams are encouraged – but not required – to develop innovations in the target areas.

1) *2013 HPVC Innovation Event Target Areas:*

Type of Vehicle	Description	Areas
Bicycles	Provide bicycles with zero-speed and low-speed stability, ensuring that a bicycle can come to a full stop or ride at very low speeds without risk of overturning.	Performance and Safety A practical velomobile must be able to stop and start unassisted and without falling.
All	Provide a means for rapid unassisted ingress and egress, including opening/closing door or hatch and securing safety belt or harness.	Performance Ingress/egress ease is important in the endurance event and in the real world.
All	Provide a means of packing a faired recumbent in a case not exceeding 62 linear inches (x+y+z). Several folding production bicycles have this capability, but relatively few recumbents particularly with packable fairing.	Usability (This would be a real boon for international teams and teams that travel great distances.)

E) *Report* Teams shall submit an Innovation Report. The Innovation Report is due on the same date as the Design Report, and should be attached as Appendix 1. (<u>Note: This report will **not** count toward the 30 page limit for the Design Event.</u>) The report should be no more than 3 pages in length, and should contain the following sections:

1) *Objective* – Clearly state the objective of the innovation.
2) *Need* – Describe the need addressed by this innovation. Why is it significant?
3) *Description* – Describe the innovation, including principles of operation, unique elements, and implementation. Be sure to provide clear, but brief, answers to the following questions:
   (a) How is the state-of-the-art of human-powered vehicles advanced with this innovation?
   (b) What additional capabilities are provided by this innovation?
   (c) Is the innovation a new concept or an improvement/new implementation?
   (d) How does the innovation improve your vehicle?
4) *Literature review* – Summarize the results of a literature search to find related work. What similar ideas have been attempted in the past? How is your idea different?
   (a) *Patent search* – Include a patent search in the literature review.
   (b) *Patentability* – Based on the literature review, is this innovation patentable?
5) *Testing and Evaluation* – Describe how the innovation was tested or evaluated for functionality and for evaluating the benefit of the innovation. Clearly indicate if the innovation functions as intended.
6) *Market Analysis* – Include a brief analysis of the marketability of the innovation, considering costs, benefits, markets, and customer acceptance.

7) *Conclusions and recommendations* – Provide clear and concise conclusion regarding the capability, novelty, and effectiveness of the innovation. Include recommendations for future development or additional implementations.
8) *References* – List all references and patents cited in the literature review.

F) *Time and Place* The Innovation Event will take place on Saturday, beginning at approximately 1:30 PM at a location specified by the host organization.

G) *Demonstration Area* The Innovation Event shall take place on a paved area suitable for demonstrating human-powered vehicles. The size, configuration, and grade will be posted on the HPVC website. Any team that cannot demonstrate their innovation within the limits of the published area must contact the chief judge no later than the report due date to arrange for an alternative site or alternative evaluation method.

H) *Demonstration Order and Scheduling* Teams will demonstrate their innovation in order of vehicle number. Teams will be scheduled in blocks of ten vehicles per hour time block. Teams must check in with the judging team at the beginning of their time block. Any team that is late for check-in will be considered a non-participant.

I) *Demonstration* When called for a demonstration by the judges, each team shall provide the judges with the following information in addition to a functional demonstration of the innovation:

Objective of the demonstration
Need addressed by innovation
Brief description of innovation, including principles of operation
How is the state-of-the-art advanced with this innovation?
What additional capabilities are provided by this innovation?
Is the innovation a new concept or an improvement/new implementation?
Does the innovation function as designed?
How does the innovation improve your vehicle?
Describe how the innovation was tested or evaluated for function and benefit.
Conclusions and recommendations

Teams proposing innovations that cannot be conveniently demonstrated on-site (such as manufacturing methods, etc.) should provide documented evidence of the effectiveness of the innovative design.

J) *Energy Storage Devices* Energy storage devices that meet the requirements of II.C may be used in the demonstration and may start the demo with stored energy. Judges shall be advised if stored energy is used during the demonstration.

K) *Judging Area* The judging area will be adjacent to the demonstration area. It will be off limits to all participants and spectators except the team currently performing a demonstration.

L) *Team Check-in* Teams must check in with the judging staff ten minutes prior to the start of their time block.

M) *Disabled Vehicles* In the event of an accident during a demonstration, the first concern is the safety of the driver. Once it has been determined that the driver is not injured, the demonstration may continue if time permits. In the event the vehicle is disabled, it must be removed from the demonstration area by the team in a timely manner. In no event will additional time be granted due to an equipment malfunction or driver error.

N) *Scoring* Teams will be scored out of 30 possible points, based on the following criteria:

1) Points are awarded based on the following three areas
   (a) Capability 6 points
   (b) Innovation 9 points
   (c) Effectiveness 10 points
   (d) Judge's Discretion 5 points

2) Vehicle score in the Innovation Event is the total points earned divided by the total possible points, expressed as a percentage:

$$\text{Points} = \left(\frac{\text{Team Raw Score}}{\text{Maximum Possible Raw Score}}\right) \times \text{Maximum Event Points}$$

Where the Maximum Possible Raw Score is the maximum possible according to the Judge's Score Sheet, and the Maximum Event Points are given in Part IX.

VIII Endurance Event

A) *Objective* To provide teams the ability to demonstrate the functionality, agility, and durability of their vehicles.

B) *Description* The Endurance Event is a 2.5 hour, timed relay race with multiple laps around a closed course. Each team shall include multiple drivers of both genders.

C) *Time and Place* The Endurance Event will take place on Sunday, beginning at approximately 8:30 AM at a location specified by the host organization.

D) *Endurance Course* The Endurance Event shall take place on a closed-loop course at least 1.5 kilometers in length.
   (a) The course shall be continuously paved with occasional patches of rough pavement or gravel typical of a public roadway.
   (b) The course shall include turns in both directions and straight sections designed to demonstrate the advantage of the vehicles' aerodynamic features.

(c) Up and down grades shall be included if possible, with maximum grades on the course to not exceed 5 % uphill or 7% downhill. The maximum vertical distance climbed in one lap shall not exceed 30 meters.
(d) The course shall include a paved section with no obstacles that is at least 1.0 kilometers long.
(e) Individual laps should be approximately two (2) kilometers in length, again to the extent that the event site permits; in no case, however, may the lap length be less than 1.5 kilometer.

E) *Start* The start of the race will be an unassisted LeMans style start
(a) *Start Area* The start area shall accommodate a LeMans style start that includes a broad, straight section immediately preceding the start line. This area shall be wide enough to ensure a safe start. The start area will include a designated driver start area at least 10 meters away from the vehicles parked in preparation for the start.
(b) *Start Process* Start of the Endurance Event shall begin with all vehicles parked diagonally on one or both sides of the race course. Drivers will be positioned at least 10 meters from their vehicle with a parcel of groceries positioned in front of the driver. At the start signal, all drivers shall pick up the parcel, run to their vehicles, enter and buckle in, and then take off.
(c) *Cargo* Start will include the pick-up and stowage of a grocery parcel that must be carried until the first grocery stop.
(d) *Starting Order* Vehicles shall start each endurance race in the order of finish for the women's sprint or women's drag race. Vehicles with no women's sprint or drag race score shall be placed at the end of the starting line-up.
(e) *Starting Driver* The starting driver may be of either gender and is subject to the minimum, maximum and single ride limits (below). In other words, teams may start the race with their fastest driver regardless of gender, if desired.
(f) *Single-Gender Teams* Vehicles without drivers of both genders shall be held at the start line for 15 minutes, after which they may proceed with the competition as usual.
(g) *Mechanical Malfunctions at Start* Any vehicle that requires mechanical assistance at the time of the start must forfeit its starting position and safely exit to the side of the course; it may rejoin the event at the rear of the field of competitors when ready. Repair work that interferes with the safe and orderly start of an event may result in a penalty against the responsible team.
(h) *Caution* Drivers shall use caution during the start to avoid accidents.

F) *Pits* The course layout must include pit work areas, including safe entry and exit; room for the starting line-up; and a straight run of at least 100 meters between the starting line and the first turn.
(a) *Pit Location* The pit area shall be located in an area adjacent to the course and shall begin not less than 30 meters and not more than 50 meters after the finish line. The pit area shall be located after, but in relatively close proximity to the start line.

(b) *Pit Crews* Due to space limitations, no more than eight crew members (excluding drivers) will be allowed in the pit area for each team. Crew members may not be in another team's pit area without permission.

(c) *Pit Stalls* Prior to the drivers' meeting, teams shall select their pit stalls on a first come first serve basis. All equipment must be placed in the selected pit area prior to the drivers' meeting. During the race, all work in the pit area must take place within the selected pit stall and not in the pit lane. (Failure to observe this rule will result in black flag penalties as described in VII Q.)

(d) *Right of Way in the Pit Area* Competing vehicles have the right of way on the course and in the pit areas at all times during an event. Vehicles entering the pit area from the course shall have the right-of way over those returning from the pits to the course. Interfering with a competing vehicle in any way may result in a penalty assessment against the responsible team.

G) *Start Assistance* No assistance shall be provided to any driver except in the pit area (except in emergencies). This includes picking up or launching a fallen vehicle. The penalty for receiving assistance will be 500 meters deducted from the total race distance for each occurrence.

In the event that assistance is provided to a vehicle after a fall or accident, if the condition of the rider is questionable a judge or course marshal may hold the vehicle for 60 seconds in lieu of the 500 meter penalty. During the 60 second wait, the judge or marshal shall ascertain that the driver is mentally and physical prepared to continue the race.

Note: This rule does not prohibit team members or spectators from checking on the condition of the rider after an accident. If necessary, assistance may be provided to extract an injured or disabled driver or move a disabled vehicle off the course.

H) *Obstacles* Course obstacles shall include:

- A speed bump typical of a city street speed control device
- **A stop sign, requiring a vehicle to come to a complete stop and to hold that stop for at least five (5) seconds**
- Up/down grades (hills) (if local terrain permits.)
- A tight hairpin turn of approximately 180 degrees with a radius that does not exceed 8 meters. Double hairpin turns are acceptable and encouraged if facilities permit.
- A slalom section consisting of a series of tight turns
- A section of rough pavement or gravel surface

All obstacles shall be located on the course such that at least one continuous kilometer is obstacle-free.

I) *Parcel Pickup and Delivery* A parcel pickup and delivery station shall be provided on the course. Each team is required to deliver or pick up a parcel five times during the race. At least two drivers must make a pickup or delivery. Teams start the race with a parcel. At the first parcel stop, the initial parcel is deposited with a parcel clerk who will record the time and vehicle number. Subsequently, parcels are alternatively picked up or dropped off. After dropping the parcel on the fifth stop, the parcel pickup/delivery requirement has been met. Teams may choose when to stop, and stops are permitted throughout the event. Note that delays due to a waiting queue are possible. Teams are encouraged to plan stops accordingly.

Failure to complete five stops with at least two drivers shall result in a one lap penalty for each missed stop. If all five stops are made by the same driver the team will be penalized one lap. Damage to parcels will be assessed at the completion of the 5 drop offs and appropriate penalties will be made at that time.

The parcel will be a standard sized 38x33x20 cm (15"h x 13"w x 8"d) reusable grocery bag containing items determined by the host school (weight not to exceed 12 lbs).

J) Lap *Counting Process* Laps will be counted by the Judging Team and an Assistant Lap Counter provided by each team.
   (a) The Judging Team will record laps of all teams in sequence as the official record of the race.
   (b) *Assistant Lap Counters* Each competing team must provide one assistant lap counter as a scoring assistant to count and record laps. This record will serve as a back-up to correlate the official lap count. Lap counters will be provided with a lap counting sheet on which to record:
      (i) The time-of-day each lap is completed using time from their own watch; counters need not be synchronized between teams
      (ii) The driver's gender and identity
      (iii) The times of driver changes
      (iv) Any other substantive data

   No score will be tabulated for any school that does not provide an assistant lap counter.

K) Driver/Stoker Requirements
   (a) Minimum distance for any driver: the number of laps nearest 5 km or 30 minutes (whichever occurs first)
   (b) Maximum distance for any driver: the number of laps nearest 20 km.
   (c) For multi-driver vehicles, the minimum distance also applies to same-gender crews, i.e. at least one male-only crew and one female-only crew must complete the minimum distance. Otherwise, mixed-gender crews are permitted and each individual driver must complete minimum distance. A complete crew swap may not be required however each individual driver must complete the minimum. In the event that the multi driver vehicle may be propelled by a single female this would qualify as a female-only crew.
   (d) A team may include any number of drivers as long as the distance-per-driver requirements are met.
   (e) All laps by an individual driver must be continuous – that is, all drivers must complete their laps in sequence, uninterrupted by any other driver, and may not ride in that event further.

(f) A driver's distance or time may be cut short due to injury, vehicle disablement, or end of scheduled race time. There will be no penalty as a result of scheduled race ending prior to present occupant's completion of minimum distance. Otherwise the Chief Judge must rule that the driver is indeed unable to continue in order to avoid penalty.

L) *Judging Area* The lap counting and judging area will be adjacent to the start/finish area. It will be off limits to everyone except competition officials and the assistant lap counters.

M) *Drivers' Meeting* All drivers who will participate in the Endurance Event must attend the mandatory Drivers' Meeting for that event. Drivers' meetings will take place approximately 45 minutes prior to the scheduled start of the race. The meeting will clarify operating procedures and signals and will identify course features, hazards, and landmarks.

N) *Course Practice* The road course will be opened by the Chief Judge for practice and will remain open at his/her sole discretion. All vehicles practicing on the course must be operated in a safe manner and with extreme caution, particularly when entering the pit area or any other areas congested with participants, officials, or spectators.

All drivers operating a vehicle on or adjacent to the course, on competing vehicles or otherwise must wear helmets meeting the approved standards for the competition.

O) *Signals* Flags will be used by competition officials as follows:

Flag Color	Usage
▪ Green	Start event
▪ Red	Stop event
▪ Yellow	Proceed with caution, beware of hazards, no passing
▪ Black	Proceed directly to pits: problem with vehicle, rule infringement, or penalty assessment
▪ White	Less than 10 minutes remaining in the race
▪ Black/white	Event completed, proceed to pit area

Each Course Marshal will be supplied with a yellow flag with which to signal caution in the event of an accident. All other flags will be held in the judging area. As described, a green flag will signal that the event is underway. A red flag displayed at the race start will indicate that a restart is necessary, and all vehicles should proceed by their most direct path to the starting area. A red during the event requires that all vehicles stop at the earliest safe opportunity. At the end of the race a 'clean up vehicle' will display a red flag to indicate that the race has ended and is not to be overtaken. The vehicles should then return to the pit area as the course will then be closed.

P) *Disabled Vehicles* The first concern following any accident is the safety of the driver. Once it has been determined that the driver is not injured, disabled vehicles must be removed from the course as soon as possible. In the event of an injury, no person should take any action that might increase the risk associated with the injury. In the case of injury, only on-site paramedics, ambulance workers or licensed medical professionals should tend to the injured.

Disabled vehicles must be removed from the course at the nearest safe exit; drivers may not move disabled vehicles along the course other than to reach a point of removal. Disabled vehicles may be returned to the pit area by the driver and/or team members by safely removing the vehicle from the course and wheeling or carrying it to the pit area.

Course workers will assist with the removal of vehicles from the course, as necessary in the interest of safety. Primary responsibility, however, remains with the respective team. Non-emergency blockage of the course by a disabled vehicle may result in the assessment of a penalty.

Traffic will be controlled in the area of a disabled vehicle by the Course Marshals or by other competition officials, who will oversee the clearing of the course and signal the resumption of normal competition.

Disabled vehicles that have been removed from the course and repaired must reenter the course either at the point of removal or at some point that it had passed between that point and the starting line on that same lap. That is, no vehicle will advance its position on the course as the result of a disablement. Reentering vehicles must yield the right-of-way to vehicles on the course.

Q) *Fouls and Penalties* The Chief Judge or the Judging Team will determine whether a foul has occurred and the extent of any assessed penalty (which may include disqualification from the event or from the competition). The responsible team will be notified immediately of an infraction and any resultant penalty by the Judging Team.

Fouls will include—but will not be limited to—the following:

- Failure to meet equipment requirements, including the proper display of vehicle numbers;
- Safety violations, such as entering the course without a proper helmet or seat belt;
- Obstruction of a vehicle by a competing team or by a spectator;
- Foul driving, whether intentional or unintentional;
- Poor sportsmanship or an activity that fosters unfair competition; and
- Failure to meet driver lap requirements or limitations.

Drafting is expressly permitted as long as there is no interference with other vehicles.

Penalties will be assessed as follows:

- Equipment violations: Require a pit stop to remedy the violation.
- Safety violations: Subtraction of one or more laps from the team's total lap count.
- Lap requirement violations: deduction of one lap for each improper lap.
- Illegal start assistance on course: Deduction of 500 meters from total distance

- Damaging or loss of parcel: Deduction of a maximum of 500 meters from total distance depending on severity of damage
- Failure to stop at stop sign: Deduction of 500 meters from total distance
- Conduct violations:
    - First violation: A minimum of a 15-second delay in the pit area. No work may be performed and no driver changes may be made during this stop.
    - Second violation: A minimum of a 60-second delay, with the same stipulations;
    - Third violation: Disqualification

Violations and penalties will be at the sole discretion of the Chief Judge and the Judging Team. Penalty appeals may be filed in accordance with specified protest procedures.

R) *Interruptions* The Endurance Event will normally run continuously. However, obstruction of the course, an emergency, hazardous weather, or other conditions may require a delay or premature termination of the event. The need for—and extent of—any such delay or termination will be evaluated by the Judging Team, with the Chief Judge making the final determination.

If the event is interrupted and a restart is required, the restart order will recreate, as nearly as possible, the order of vehicles at the time of the interruption.

S) *Termination* The endurance event shall be run for 2.5 hours. At that time, all vehicles still in the competition will be permitted to finish the lap they are currently on. A "sweep" vehicle will enter the course and complete one lap. The sweep vehicle shall not pass any operable competing vehicles on the course, nor shall any competing vehicles pass the sweep vehicle. At the completion of the lap by the sweep vehicle, the event will be declared complete.

When the official race clock reads 2:20, the white flag shall be placed on prominent display near the judge’s area, and will remain there until a race time of 2:30. At that time, the white flag shall be replaced with the black and white checkered flag.

T) *Scoring* Vehicle rank in the endurance event is based on total distance travelled and average speed.

Average speed is computed after penalties have been assessed. The formula for average speed is:

$$V_{\text{Average}} = \frac{(\text{Number of Laps Completed}) \times (\text{Lap Length}) - (\text{Distance Penalties})}{\text{Actual Finish Time}}$$

The raw score for each vehicle is found by

$$\text{Raw Score} = \text{Distance Travelled} + 0.95\left(\frac{V_{\text{Average}}}{V_{\text{Maximum Average}}}\right)$$

Points are awarded based on the raw score by

$$\text{Points} = \left(\frac{\text{Team Raw Score}}{\text{Maximum Possible Raw Score}}\right) \times \text{Maximum Event Points}$$

Where the Maximum Event Points is the point value for the event, specified in section VIII.

IX Overall Scoring

Overall Score Scores from Design Event, Speed Event and Endurance Events scores will be combined to determine the overall standing of the competition.

The formula for combining the scores is:

$$\text{Overall Score} = \sum \text{Event Scores}$$

The maximum event points are:

Competition Event	Maximum Points
Design Event	30
Male Speed Event	12.5
Female Speed Event	12.5
Innovation Event	20
Endurance Event	25
Total Score	100

In the case of a tie in the overall point count, the order of finish in the Design Event will determine the overall finish for all vehicles.

X Announcement of Results and Awards

A) *Announcement of Results* The judges will post the results of each event of the competition as soon as possible after the completion of the respective event and validation of the collected data.

B) *Presentation of Awards* The awards presentation will be held after the completion of the competition's final event.

C) *Competition Awards* Competition awards shall be given as follows:

Overall 1st Place:	Trophy and $800 to team
Overall 2nd Place:	Trophy and $500 to team
Overall 3rd Place:	Trophy and $300 to team

Design Event	1st + $200, 2nd and 3rd place trophies
Men's Speed Event	1st + $200, 2nd and 3rd place trophies
Women's Speed Event	1st + $200, 2nd and 3rd place trophies
Innovation Event	1st + $200, 2nd and 3rd place trophies
Endurance Event	1st + $200, 2nd and 3rd place trophies

The winner of the Innovation event will receive the Novelty Award for Innovation.

Overall winner must participate, complete minimum requirements and score points in all events to be eligible for monetary awards.

Minimum requirements are valid non-zero scores in the design event, male sprint or drag event, female sprint or drag event, Technology Innovation Event and endurance event.

D) *Other Awards* Judges may recognize significant achievements by one or more teams during the course of the Competition. Judges awards may include—but are not limited to the following:

Sportsmanship	Novelty Award for Innovation
Team Spirit	Special Achievement

Additional awards may be suggested or provided by the host, the teams involved, or others. Such awards are encouraged in the spirit of the competition; however all such awards must be approved by the ASME Judging Team prior to the event.

XI Clarification and Modification of Rules

A) *Clarification and Modification of the Rules* These rules will be modified by the Competition Judges as necessary to maintain the competition as a challenging and rewarding experience for engineering students. No changes by any party shall be made without the written consent of the Chief Judge. Questions or recommended changes should be referred to the Chief Judge.

B) *Chief Judge* The Chief Judge of the ASME Human Powered Vehicle Challenge serves a three year term and maintains the competition rules.

The current Chief Judge is:
Chris Wlezien, Chicago, IL

Questions about the rules may be sent to:
E-mail: hpv@asme.org

XII Appendix 1
Registration and Documentation Submittal

The following documentation is required for registration and participation in the ASME Human Powered Vehicle Challenge. The required materials should be submitted to the parties indicated in accordance with the schedule as noted.

For reference, the following lead times establish the deadlines:

Entry Date	8 weeks before Registration Date
Report Date	32 days before Registration Date
Update Date	Friday of competition during static vehicle judging
Registration Date	The initial day of competition (on-site)

Document	**HPVC Form**	**Notes**	**Date Due**
Entry Registration	Form 1		Entry Date
Certification of Eligibility	Form 2		Entry Date
Safety Certification	Form 3		Entry Date
Safety Ride Log	Form 3a		Registration Date
Safety Exemption Request	Form 4	▪ Submit only if a exemption is requested ▪ Submit to Chief Judge	Entry Date
Acknowledgment of Rules	Form 5		Entry date
Design Reports		ASME electronic submission	Report Date
Report Update		ASME electronic submission	Update Date
Vehicle Description	Form 6		Entry Date
Protests	Form 7	Submit to Chief Judge only if required	In accordance with II.J
Evaluation	Form 8	Form provided by ASME at the end of the competition	End of competition

Please refer to the ASME HPVC website for dates, registrations fees, and registration instructions.

http://www.asme.org/events/competitions/human-powered-vehicle-challenge-(hpvc)

XIII Appendix 2
Design Event Judge's Score Sheet