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Peter Chester
Santa Clara University

Luis Flores
Santa Clara University

Ian Jones
Santa Clara University

Ryan Nakamura
Santa Clara University

Dylan Porter
Santa Clara University

See next page for additional authors

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Author

Peter Chester, Luis Flores, Ian Jones, Ryan Nakamura, Dylan Porter, and Peter Stephens

Date: June 11, 2014

Santa Clara University
DEPARTMENT OF MECHANICAL ENGINEERING

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Peter Chester, Luis Flores, Ian Jones, Ryan Nakamura, Dylan Porter, and Peter Stephens

ENTITLED
2013-2014 Santa Clara Human-Powered Vehicle Team

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

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

THESIS ADVISOR, Dr. Calvin Tzeng

DEPARTMENT CHAIR, Dr. Drazen Fabris

Santa Clara University Human Powered Vehicle 2013-2014

by

Dylan Porter, Peter Chester, Peter Stephens, Luis Flores, Ian Jones, and Ryan Nakamura

SENIOR DESIGN PROJECT REPORT

Submitted in partial fulfillment of the requirements
for the degree of
Bachelor of Science in Mechanical Engineering
School of Engineering
Santa Clara University

Santa Clara, California
June 11, 2014

Santa Clara Human Powered Vehicle 2013-2014

Dylan Porter, Peter Chester, Peter Stephens, Luis Flores, Ian Jones, and Ryan Nakamura

Department of Mechanical Engineering
Santa Clara University
2014

ABSTRACT

This document discusses the conceptual design for the 2013-2014 Santa Clara University Human Powered Vehicle. The objective of the Santa Clara University Human Powered Vehicle team is to design and manufacture a human powered vehicle that is practical, sustainable, and efficient. Key design features include a partial body fairing, tilt and ackermann steering, and cargo space. Ultimately we had to block out the tilt steering because its operation conflicted with the Ackermann steering. This vehicle's design satisfies the primary needs of a commuter and ultimately serves as a practical alternative to an automobile. Finally, this design complies with the requirements set by the American Society of Mechanical Engineers for the 2014 Human Powered Vehicle Challenge West Competition.

Acknowledgements

The Santa Clara University Human-Powered Vehicle Team would like to extend their sincere appreciation to Santa Clara University and the Santa Clara University School of Engineering for their educational guidance and financial support. The team would also like to acknowledge Dr. Drazen Fabris and Dr. Calvin Tzeng, two of the project advisors, for their guidance and advice during the design and testing stages of the project. Additionally, our team would like to thank Dr. Robert Marks, our inspirational professor, Mr. Don MacCubbin, our shop instructor, and Wesley Rooney, an ASME Human Powered Vehicle Challenge Judge, for assisting us in addressing and implementing customer needs into our design as well as helping us understand all of the rules for the HPV competition. We would also like Chavez welding for their generosity in helping our team greatly in the manufacturing process of our vehicle. Lastly, our team would like to express the utmost gratitude to our family and friends who have supported us these last four years at Santa Clara University; without their hard work and dedication, this endeavor could never be realized.

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Variable Definitions:

a_b	Braking deceleration
a_y	Centripetal acceleration
C_F	Cornering stiffness of front wheels
C_R	Cornering stiffness of rear wheel
F_b	Braking force
F	Force
F_c	Force due to centripetal acceleration
F_T	Force at which the vehicle tips over
g	Acceleration due to gravity
HG	Height of center of gravity
LG	Distance of center of gravity from front wheels
m	Mass
R	Radius of turn
T	Torque
TR	Wheel track (distance between front wheels)
V,v	Velocity
W	Weight
W_B	Wheelbase (distance between front and rear wheel axles)
W_F, F_F	Reaction force on front wheels
W_R, F_R	Reaction force on rear wheel
δ	Angle that the vehicle needs to turn at to make a given radius of turn
θ	Angle
μ_c	Coefficient of friction

1 Introduction

1.1 Background and Motivation

The Santa Clara University Human Powered Vehicle (HPV) team is composed of six senior mechanical engineering students with a desire to build a vehicle that will be a practical alternative to a motorized vehicle. Currently, gas powered vehicles are the main form of transportation for Americans; this dependence on vehicles has a negative impact on our global environment due to the large-scale consumption of fossil fuels and greenhouse gas emissions. In recent years, the rise in demand for renewable energy power sources has increased tremendously even as the demand for gasoline continues to grow. HPVs, such as bicycles, are some of the purest forms of sustainable transportation. Our goal was to design and fabricate a well-engineered human powered vehicle that would be an aesthetically attractive, practical, sustainable, and efficient alternative to the modern commuter car. Our design is a tadpole-style recumbent tricycle with rear-wheel drive and a partial fairing for a single rider. The SCU team has placed priority on the implementation of a protective roll cage system as well as stable steering, an efficient drivetrain system and an aerodynamic fairing. Emphasis was also placed on manufacturing a tricycle that is stable, easy-to-ride, and most importantly safe. The unique innovation pertaining to our design was the use of both tilt and Ackermann steering. However, after the vehicle was assembled and testing was conducted, we noticed that the design in its current state would not function correctly. It was decided to block out the tilt-steering portion of our vehicle for the American Society of Mechanical Engineers (ASME) West Coast Competition. The reasoning behind this is explained in more detail in the steering section of this report. The tricycle was constructed from Aluminum 6061 T6 for its desirable properties such as lightweight, high-strength, and resistance to corrosion. This vehicle’s design satisfies the primary needs of a commuter traveling approximately 20 miles round-trip, ultimately serving as a practical alternative to an automobile. Finally, this design complies with the requirements set forth by the ASME members for the 2014 Human Powered Vehicle Challenge West Competition. A rendering of the final vehicle prototype, nicknamed Pegasus, can be seen below in Figure 1:

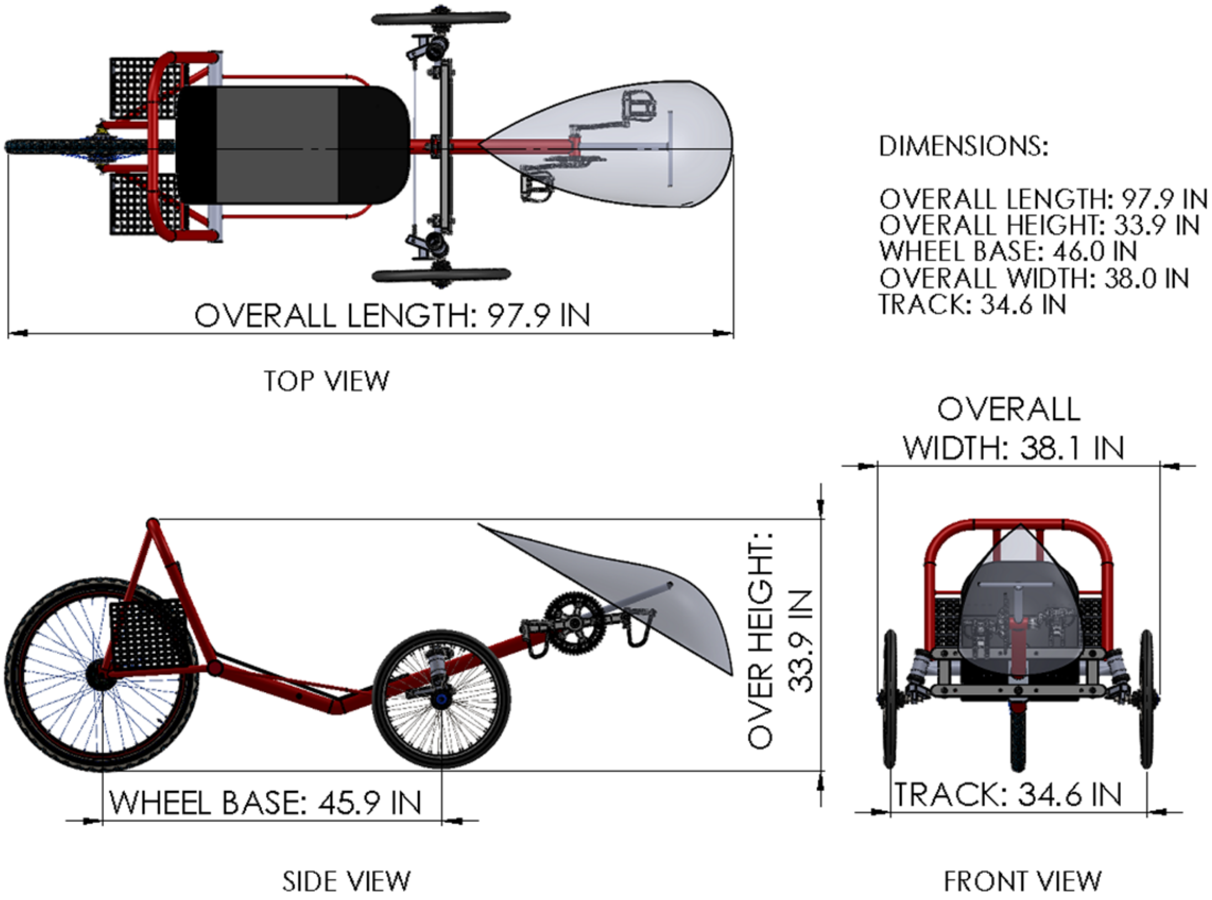


Figure 1: The final design model used to construct the vehicle.

1.2 Brief Literature Overview

Cerberus: A human powered vehicle
Document 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."

The Cerberus document is the thesis written for the human powered vehicle project at SCU in 2013.This document covers the design process and specifications of the Cerberus model HPV entered in last year's ASME HPV competition. This document has been referenced for benchmark values and a comparison of current design ideas to implemented ones for the Cerberus. This includes the consideration of what design ideas were successful and implemented into the design, as well as which design ideas were unsuccessful or disregarded. References to the competition have been noted as well. Indications as to how the vehicle performed in the competition provided motivation for design parameters to succeed in the categories of the ASME competition.

Vehicle Aerodynamics

Text Preface:

"This volume is primarily an assemblage of published papers selected to illustrate current activity in the field of vehicle aerodynamics. In its broadest sense, vehicle aerodynamics encompasses many different and interesting aspects of the airflow around and through a vehicle. Many of these aspects are addressed, including wind tunnel testing, on-road testing, computational simulations, and selected examples of aerodynamic development in a vehicle's design and development process. This collection of papers does not purport to represent either a comprehensive coverage or a critical assessment of road-vehicle aerodynamic technology. It is limited by what is available and there are consequent gaps in the technical coverage. Furthermore, in the highly competitive and commercial auto industry, where proprietary considerations are important, current publications may not represent state-of-the-art technology."

As stated above, the vehicle aerodynamics text is an assembly of published papers on the behavior of airflow over vehicles in testing. Each section of the text discussed the variation of testing for aerodynamic analysis and the results and observations of each test. These observations were made on air flow behavior, factors of vehicle design contributing to drag, and more. This text was referenced for design considerations in the fairing selection of the vehicle. In addition, the analyses made in the published papers provided insight to successful body stylings of the vehicle.

Human Powered Vehicles

Text Preface:

"This book reviews the history of human-powered water, land, and air vehicles and concentrates on the significant developments that have led to spectacular improvements in performance during the past two decades. This is the first comprehensive and up-to-date scientific and practical overview of all types of human-powered vehicles.”

This book provided valuable insight on innovative mechanisms we wanted to incorporate in our vehicle. The sections that addressed drive-train design, steering design, and suspension design were of particular relevance to the scope of the project. Specific engineering analysis was done in these sections and has been incorporated in our vehicle design. Various figures were included in the sections to visually depict the engineering principles that were helpful during the research and design phase. Specific crank rotation angles were discussed and included for the drive-train design of the vehicle.

Different Strokes

Document Abstract:

“The article presents information related to the new speed record made by human powered vehicles. A new record for the longest hour-long ride in a human powered vehicle was set by Freddy Markham. He rode 53.34 miles in one hour. In human-powered vehicle history, Greg Kolodziejzyk put more miles under his tires in 24 hours than anyone else. He rode 650.5 miles in the span of 24 hours.”

This article discusses some of the world’s fastest HPVs and what considerations went into the design phase. In designing the vehicles, Solidworks was utilized to determine the most optimal aerodynamic shape of the vehicle. However, it was interesting to find that the most aerodynamic designs were not always used in order to make the driver more comfortable when operating the vehicle. This directly correlates back to the design of Santa Clara University’s HPV. As a team, Santa Clara has had to balance different objectives of the vehicle design. For example, in order to make the vehicle more stable and provide storage space, *Pegasus* has three wheels, creating a negative effect on the overall speed of the vehicle. There are other considerations and compromises that were made in order to satisfy different needs. Another important aspect that this article discusses is the use of computer programs to model and help in the design of a vehicle. This concept can make -- and ultimately made -- the finished product more efficient and reduced expenses required for prototyping.

Human-Powered Vehicles-Aerodynamics of Cycling

This article was written by an applied physics professor at Universidad de Salamanca in Spain. The article analyzed the different types of human powered vehicles spanning from aerial to water to land. More specifically, the article focuses on the aerodynamics and fluid mechanics of cycling in the wind. The article demonstrated well thought-out, in-depth calculations of different aerodynamic drag forces and the effects of wind on cycling speeds. This article was mainly referenced to analyze data that has already been calculated and to determine the different aerodynamic effects of wind on bicycles. One sentence that stood out was the following: “The effect of the position and geometry of the rider (prone or supine) and bicycle is extraordinary, but the use of high technology full fairings in recumbent bicycles is astonishing.” Due to the fact that our vehicle has a recumbent design and included a partial, frontal fairing, the recorded data in this article proved to be extremely advantageous to the scope of the project.

1.3 Problem Statement

As the consumption of fossil fuels and greenhouse gases continue to escalate, the motivation to develop sustainable, alternative forms of transportation have steadily increased. According to Commuting Statistics, if 5% of the United States population utilized a HPV, roughly 3 billion gallons of gasoline would be conserved each year. In addition, most motorized vehicles have high expenses including the initial purchasing price, cost of fuel, and routine vehicle maintenance. Currently, there are four primary alternatives for petroleum-powered vehicles: electric powered vehicles, walking, regional transit, and human-powered vehicles. Although these alternatives protect the environment, most of these alternatives have significant issues that make them less viable than petroleum vehicles. For the human-powered vehicle, several key problems that are commonly encountered include: low speed, portability, minimal storage space, personal exhaustion, and minimal safety features. We hope that our work will help to further the ability of human powered vehicles to address these concerns.

1.4 ASME HPVC Requirements

In order to gauge our vehicle's performance, we participated in the 2014 ASME West Coast Human Powered Vehicle Challenge. The challenge took place from April 25, 2014 through April 27, 2014 and was split up into four specific sections:

The Design Event

- Design report detailing design, analysis, and testing submitted in advance of the competition
- Design presentation and safety and static presentation

The Speed Event

- Time trials were conducted at the Santa Clara velodrome
- A one lap run

The Innovation Event

- A presentation to the ASME judges that showcased our unique innovation incorporated into the design of the vehicle

The Endurance Event

- A two and a half-hour race with various obstacles in which we completed as many 1.3km laps as possible

Mandatory Safety Requirements

All quoted text in this section comes directly from the Rules for the 2014 Human Powered Vehicle Challenge (https://community.asme.org/hpvc/m/default.aspx).

- General
    - "The safety of participants, spectators, and the general public will override all other considerations during the competition."
- Performance Safety Requirements
    - Vehicle "can come to a stop from a speed of 25 km/hr in a distance of 6.0 m."
    - Vehicle "can turn within an 8.0 m radius."
    - Vehicle "can demonstrate stability by traveling for 30 m in a straight line at a speed of 5 to 8 km/hr"

- Rollover Protection System

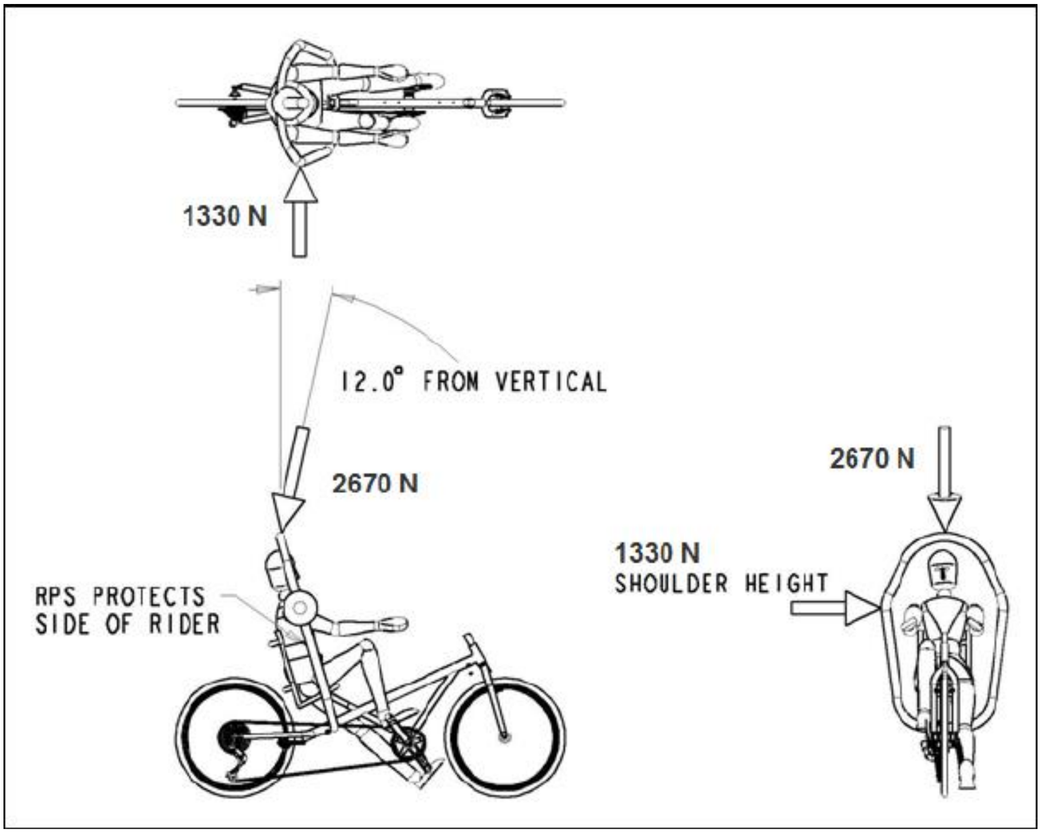


Figure 2 : ASME HPVC roll cage requirements for competing vehicles

  - "Top Load: A load of 2670 N 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, and the reactant force must be applied to the roll bar attachment point and not the bottom of the roll bar (unless the bottom is the attachment point). 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 2670 N, 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 5340 N."
  - "Side Load: A load of 1330 N per driver/stoker shall be applied horizontally to the side of the roll bar at shoulder height, and the reactant force must be applied to the roll bar attachment point and not the other side of the roll bar. 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 1330 N, 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 2670 N."

Some important dates include the following

- Entry/Registration Deadline: March 2, 2014
- Design Reports Due: March 24, 2014
- Report Update Due: April 25, 2014
- On-Site Registration: April 25, 2014

The motivating factor behind the Human Powered Vehicle project yields a multitude of valuable aspects which pertain to many organizations and goals. The primary objective, as stated earlier, is to design and manufacture a commuter vehicle that would compete with the car as an alternative form of transportation. We will also be competing and representing the University at a National American Society of Mechanical Engineers competition.

The importance of this project is to create a better environment for those who want to use human powered transportation. The project is aimed towards using alternative methods of transportation instead of relying on transportation powered by our natural resources. In addition to improving the environment we live in it will improve health, reduce hydrocarbon pollution and of course will be less expensive.

2 Systems Level Considerations

2.1 System Level Overview

Our team built a vehicle that aims to replace the commuter car; all of the features included in the vehicle were designed with that idea in mind. Some of these features are represented in Figure 1. In order to be a viable commuter vehicle the HPV had to make use of current infrastructure, protect the rider and have space for storage among a variety of other considerations.

In order to work more efficiently and create a better overall vehicle, it was broken down into several different subsystems, including: Fairing, Frame, Seating, Steering and Drivetrain. Figure 3 shows the vehicle and its subsystems.

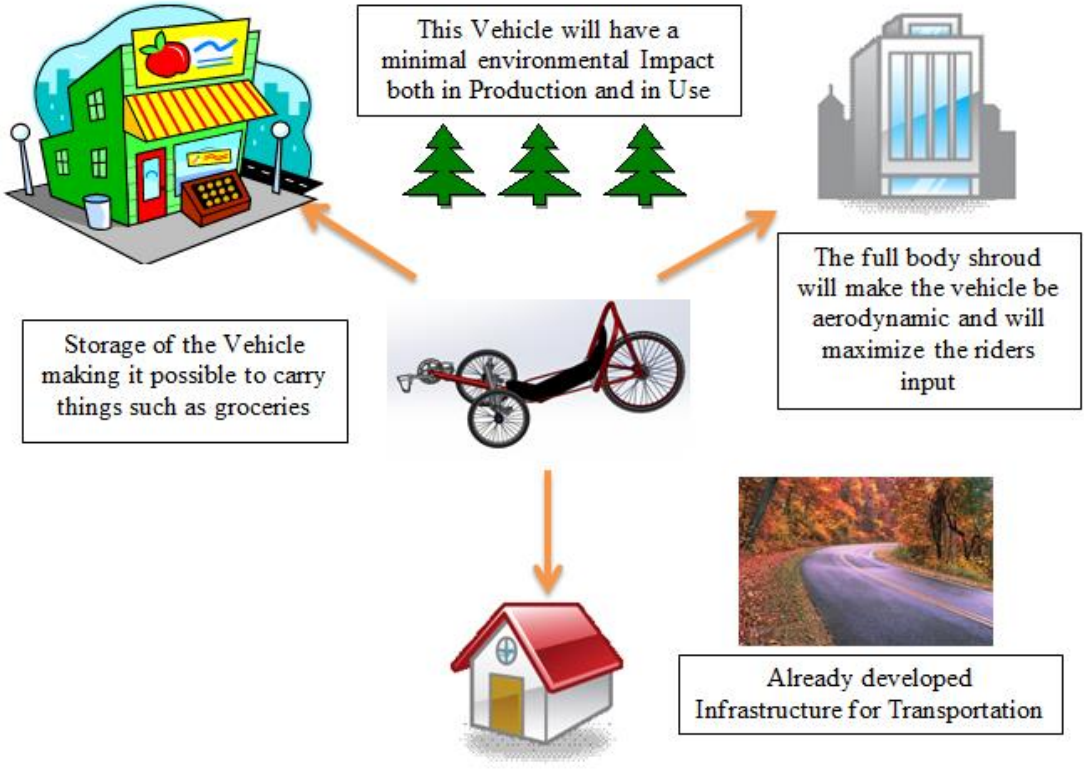


Figure 3: This is a system overview of the SCU HPV design.

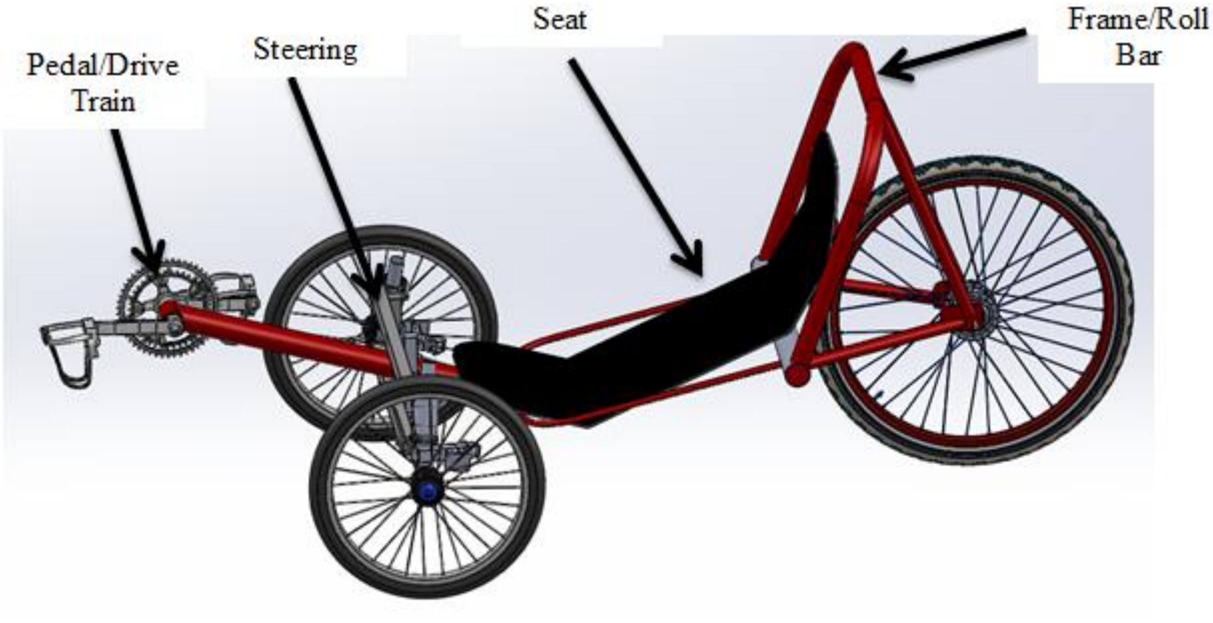


Figure 4: The vehicle without the fairing and storage included.

2.2 Customer Definitions and Needs

Design Criteria/PDS

In conjunction with the brainstorming and research and development phases, the team evaluated various designs that would result in a competitive vehicle. The finalized product design specifications are available in Appendix C. Many of the specifications established by the team pertained to the ASME regulations and are denoted by the "Competition" category in the ASME HPVC requirements. The measurements (top speed, etc.) that our prototype achieved are also included.

In order to prioritize and establish a correlation between customer and functional requirements, the team constructed a House of Quality (HoQ) for our human powered vehicle "The Pegasus" (Lowe). Our design was benchmarked against SCU's entry from last year (Cerberus) and the production Catrike 700. The HoQ is located in Appendix C. With the help of the HoQ, different design alternatives were evaluated for the potential benefits and drawbacks of each design option based on engineering knowledge, customer feedback, and common sense and ultimately settled on our current design

City/Communities

The primary customers were commuters traveling short distances in urban areas where bike lanes are available. These primary customers are part of the 51% of the population that travels 20 miles or less each day as part of their commute (Statistician Brain). Our concept addressed the needs of an environmentally conscious society, including current automobile drivers as well as cyclists who might be intrigued by the potential of greater speed and storage capability.

ASME Judges

Our primary design goal was to meet the needs of the customer. However, we also designed our vehicle to meet the requirements of the ASME competition judges and the specific challenges of the competition.

SCU Judges/ Advisors

Our next group of potential customers was the Santa Clara University judges' panel at the senior design presentations. This audience was more extensive in the sense that we competed against different senior design projects rather than different designs of the same project. Thus, we set out to convince the panel that our idea had future market potential and was well engineered. The judges who participated in the senior design presentations are experts in the manufacturing and fabrication fields, so we considered the viability of our design as if it were to enter the vehicular market.

2.3 Primary Needs

The primary customer for Pegasus is a commuter who averages 20 miles roundtrip or less on a daily basis. We wanted to design and manufacture our vehicle to be fast enough to be an appealing alternative to a car, at an economic and reasonable price. Moreover, our final design was sufficiently light and easy to transport.

From an ethical and safety standpoint, one essential requirement set forth by the team was to design a safe vehicle that protects the rider under all circumstances. This protection spans from physical harm to exposure to harsh elemental conditions such as rain and hail. The rider of our vehicle is secured by a four-point harness to a cushioned seat to simultaneously provide comfort and safety. Pegasus was designed to have minimal chances of flipping over, but we also designed and installed a rollover protection system (RPS) to protect the rider in the event of a roll-over.

Our HPV is practical in the sense that it can store cargo for the operator's convenience and lifestyle. This storage was motivated by the consumer need for storage in everyday commutes. This includes room for groceries, supplies for work, or other commute accessories such as backpacks and laptops. This is a crucial component for making our vehicle a practical alternative to a car, since a distinguished feature of gasoline powered vehicles is large, convenient storage space.

2.4 Customer Survey

When creating a product, it is one thing to design something that meets the team's requirements; however, it is an entirely different task to create a product that customers are satisfied with. With this in mind, we interviewed two cycling experts and conducted a survey to gain a better understanding of our potential customers and what features they would like to have incorporated in a human-powered vehicle. The first person interviewed was Dr. Robert Marks, an avid biker who commutes to and from work on his bicycle on a daily basis. The second individual interviewed was Dainuri Rott, founder and CTO of Good Life Mobility and Lightning Marine Drives. Mr. Rott is also a bicyclist who designs and manufactures tricycles with electric pedal assist for the elderly. Dr. Marks offered his insights as a bike enthusiast, whereas Dainuri Rott lent us his industry and market expertise to compare current recumbent tricycle costs, materials, features, and manufacturing methods.

Both these expert sources shared unique perspectives on the pedal assist feature that we presented. Dr. Marks indicated that part of the overall reward from cycling lies in the struggle and pride one has when biking distances with one's own power. Dainuri Rott articulated that for his target audience of elderly riders, exercise is important and thus pedal assist should only be implemented when the physical activity from cycling begins to stress the rider. Based on their responses, our team concluded that the pedal assist feature should be something that can be turned on and off as an option rather than constantly assisting the rider. However, we ultimately decided to omit the pedal assist feature in our final prototype due to time and budget limitations.

In addition to these interviews, our team also conducted a survey on Survey Monkey that questioned respondents on bicycle use and what features their ideal bike might have. This survey proved to be an extremely successful resource, generating approximately 110 responses. Of the 110 participants, 81% were between the ages of 18 and 24 and 66% of all respondents utilized bicycles, skateboards, and other human-powered transportation on a daily basis. Many respondents mentioned that a pedal assist system option would be desired. There was a consensus that additional technologies such as electronic device charging or GPS systems would be admirable features. Feedback suggested that the comfort and ergonomics of our design were very important for long-term rider contentment. Analysis of the results determined that the average, feasible commuting distance would range from 0 to 10 miles in radius. Generally, our feedback showed a desire for vehicle speeds that ranged between 20-30 miles per hour. One of our surveyors' most prevalent concerns was for the safety of the vehicle. The responses regarding safety encompassed a variety of safety methods, such as stability to prevent tipping over, a mechanism to lock the wheels and vehicle to prevent theft, and turning signals and brake lights to warn drivers and pedestrians for increased visibility. Respondents articulated that they would desire a full-body or frontal fairing that could help protect the user from weather and -- in extreme instances -- crashes. Protection from the elements, as well as storage space for small/medium packages, would encourage riders to utilize an innovative and efficient HPV.

2.5 System Requirements

The Santa Clara HPV has placed requirements on the vehicle beyond what is required of the vehicle which can be seen in Appendix C. The requirements that they placed on the vehicle were derived from talking with customers and determining what was deemed practical to include in the design.

Max Speed Unassisted:

- Greater or equal to 30 mph on level ground

Dimensions:

- Maximum size 4' (width) by 5' (height) by 6' (length).
- Minimum of 4 cubic feet of storage space

Weight

- Less than 30 lbs (without rider)

Additional:

- 3 wheels, recumbent trike
- Tilt assist turning
- Single Driver
- An external full-body fairing
- Carbon fiber seat and tail box

2.6 System Level Requirements

2.6.1 Functional Analysis

Our project has been broken into four major components:

- Steering
  - We plan to implement tilt steering and Ackermann steering into the vehicle.
- Frame
  - The frame will build in a way that the rider is safely secured and the center of gravity will be as low as possible to minimize risk of tipping.
- Drivetrain
  - The drive train will be designed to maximize the speed of the rider.
- Fairing
  - The fairing will be will be built to minimize drag and to protect the rider from the elements.

All of these subsystems are interconnected and cannot be designed independently.

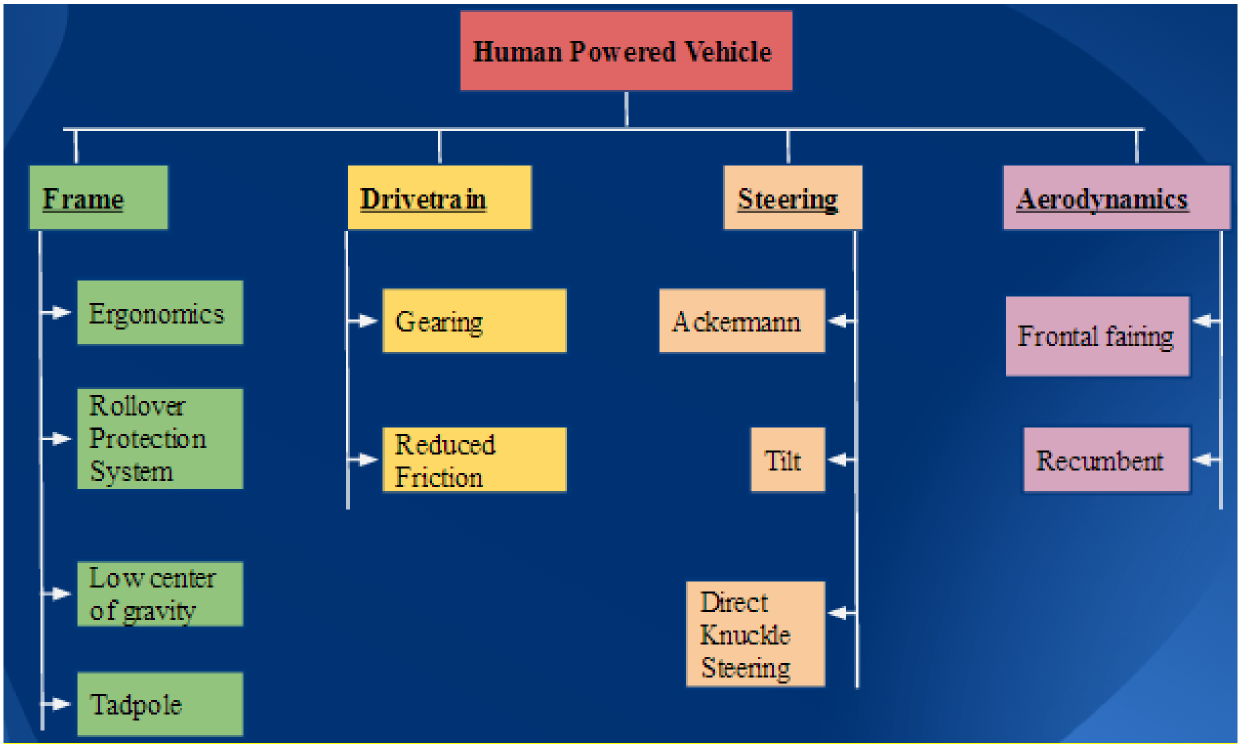
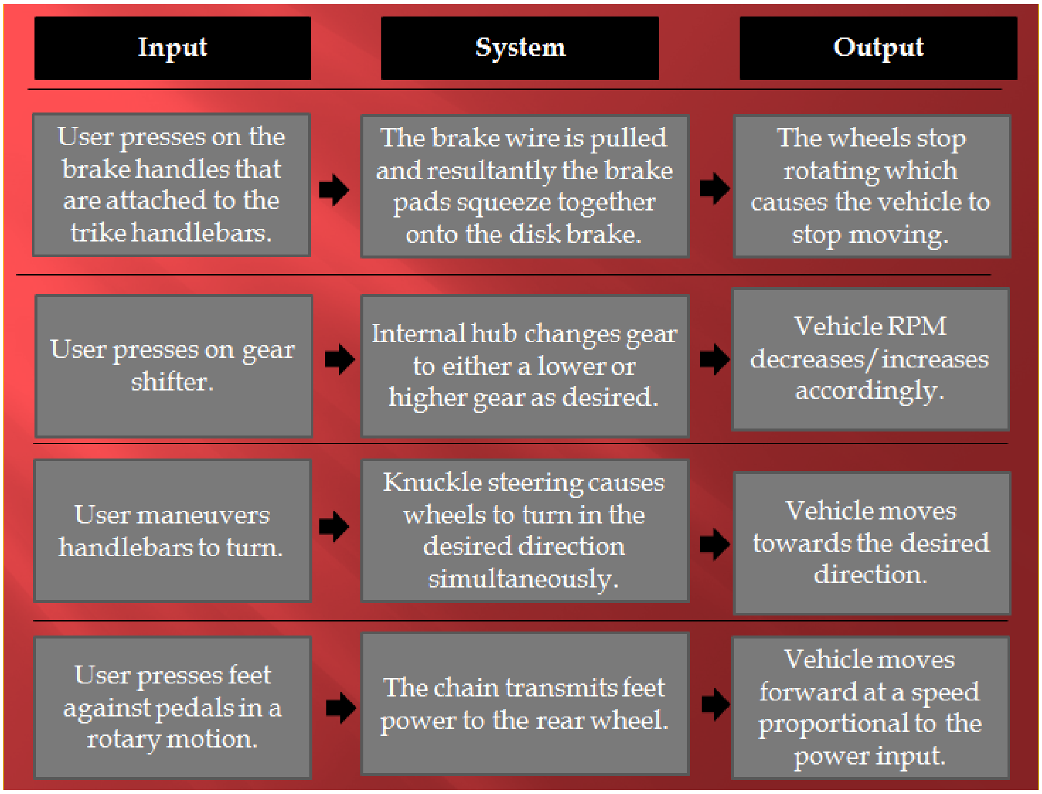


Figure 5: The figure depicts a functional decomposition of all four major components of our project.

Each of the major subsystems can be broken down into smaller subsystems that were designed individually then brought together in the end. During the research and design phase of the project, we realized that how a user interacts and controls the vehicle is very important in the design of each of these subsystems. The four main ways that the user interfaces with the vehicle are shown in the input-output diagram in Figure 6 below:



Input	System	Output
User presses on the brake handles that are attached to the trike handlebars.	The brake wire is pulled and resultantly the brake pads squeeze together onto the disk brake.	The wheels stop rotating which causes the vehicle to stop moving.
User presses on gear shifter.	Internal hub changes gear to either a lower or higher gear as desired.	Vehicle RPM decreases/increases accordingly.
User maneuvers handlebars to turn.	Knuckle steering causes wheels to turn in the desired direction simultaneously.	Vehicle moves towards the desired direction.
User presses feet against pedals in a rotary motion.	The chain transmits feet power to the rear wheel.	Vehicle moves forward at a speed proportional to the power input.

Figure 6: The figure above illustrates an input and output diagram of all major rider interfaces that the rider is capable of controlling. These features include braking, shifting, steering, and pedaling.

The user interacts with the vehicle in a variety of ways. One of the most essential considerations in our design was the steering of the vehicle. Throughout the design phase, we placed utmost priority on building a vehicle that is simple to operate and has extremely responsive handling. The way that the user interfaces with our vehicle influenced the design ideas we ultimately went forward with.

2.6.2 Considered Design Ideas

- *Bamboo Frame*
    - Our primary way to address the sustainable aspect of the design requirements and our mission statement. We haven't completely disregarded the idea, but we have realized that none of us have experience with bamboo and an entire bamboo frame would be difficult to fabricate. Our new frame design will primarily

    incorporate recycled aluminum and steel. Time permitting we would like to include some bamboo into our final frame design.

- *Flywheel*
    - The competition calls for some sort of energy storage capability. The group initially thought to use a flywheel. Energy could be stored while coming to a stop and used as a pedal assist out of the stop by engaging the flywheel. The idea was thrown out due to some of the physical effects that a flywheel would have on our vehicle. The flywheel needs to be large enough to store the energy coming to a stop. The flywheel would have inertia that that wants to continue forward as our vehicle is attempting turns. Thus, our vehicle would be much heavier with a flywheel and it would not fare well during turns.
- *Spring Energy Storage*
    - A large spring was a design consideration to store the energy during the ride. However, the same problem arises with a heavy spring. Currently, there are no bicycles that effectively harness the spring power as a method of energy storage. The main challenge here would be the spring stores power in one direction and in order to utilize the energy the direction would have to be reversed.
- *Two Wheel Design*
    - Other design teams in the competition have fared well with a two wheel design. A three wheeled design was agreed upon due to our target customers. As a team, the design of the vehicle is catered toward our overall goal of an alternative to a car. Stability is the reason why a three wheeled design was chosen.
- *Two Person Design*
    - A passenger or dual operator design was initially considered. A solo rider human powered vehicle was decided upon due to some of the challenges that a two seater human powered vehicle would provide. Specifically, differing rates of pedal speed would be hard to translate into our drivetrain design.

2.6.3 Team and Project Management

Some of the most significant challenges that were faced over the course of the project were meeting deadlines for the project and competition, accessing funds to manufacture the vehicle, construction of the design, and having the subsystems of the design be fully integrated with one another for the system as a whole. This required quarterly goals to be set early in the design process to ensure deadlines for the project were accomplished. In order to obtain the funds needed for this project, the team applied to every applicable grant offered by the university, as well as searching for potential sponsors for the project. The budget for the project is shown in Appendix D. Minor difficulties during the construction and manufacturing of the vehicle were encountered due to limited access to machining, as well as researching companies to manufacture parts of the design we could not. A substantial amount of time was allotted for trial and error of the subsystem design and interaction with the system as a whole because of the number of subsystems incorporated in the design of the vehicle.

Issues with the budget were seen while obtaining funds for the project, as well as planning for potential replacement materials and parts for the design when needed. The goal was to have enough funds to be able to replace the more expensive components of the design if needed. Another issue encountered for the team was planning for certain deadlines on our project timeline. This was satisfied by creating a Gantt chart, as well as having weekly deadlines to satisfy goals set with advisors. The initial design process planned out specifications required for the final design. Following this, calculations were executed to determine how specifications were incorporated and defined for the final vehicle.

The team was self-managed by each individual as a leader of the essential subsystems for the designs. Assigning a leader to each subsystem provided an individual focus and responsibility on the subsystem. The leader of his respective subsystem also worked cohesively with the other teammates who were leaders of different subsystems directly to ensure that all components and features would function properly. This confirmed design constraints from one subsystem for the design adhered to the constraints of the other subsystems.

An overview of the design process our team followed is referenced in Figure 7 below. The crucial steps of the design portion are illustrated from the beginning of the design process to the ASME HPV competition.

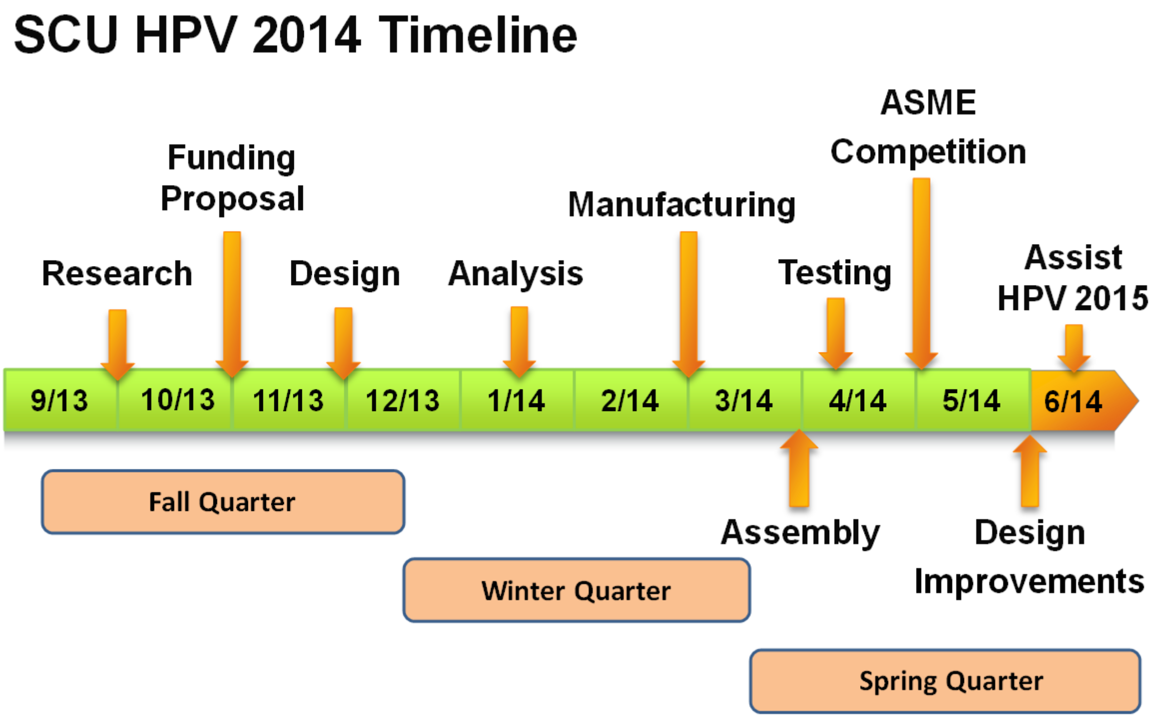


Figure 7: An overview timeline indicating when the major design steps took place for the SCU HPV Team 2013-2014

2.7 Engineering Standards and Realistic Constraints

2.7.1 Economic

As engineers, it is imperative to think about what contributes to the functionality of a product, while maintaining budget considerations. Our design needed to be efficient and usable. The team also had to focus on the economic effects that the vehicle would potentially have on the market. The law of supply and demand is directly related to prices in economics. Thus, if the supply of recumbent tricycles is increased in the market, the market price of recumbent tricycles would inevitably be reduced because there are more options for consumers and prices fluctuate to remain competitive. The team strove to design a vehicle that was as cost efficient as possible to create as big of a positive impact on the market as we can.

Currently, there are various recumbent bicycles available in the market. Our design focused on the functionality of our product at a less expensive cost to the customer. Due to the fact that our HPV was designed to be purchased by a consumer, we needed to incorporate an aesthetic design. There is a difference between designing the highest performing bike and designing a successful bicycle that customers will purchase. Therefore, an efficient and effective marketing scheme that satisfies the customer was absolutely essential for the scope of this project.

2.7.2 Sustainability

Not only must engineers design functional products in today's market, they must also design sustainable systems. An ingenious and attentive engineer will contemplate designs that harness energy and resources at a rate that does not compromise the natural environment or ability of future generations to meet their own societal needs. Through multiple design iterations, our HPV incorporated sustainable components wherever possible. Healthy ecosystems and environments are necessary to the survival and preservation of the world, and the design supporting our HPV is no exception.

In the last few years, the sustainable energy movement has provided a multitude of solutions to serve as alternatives for gas-powered vehicles. HPVs, such as bicycles or tricycles, are some of the purest forms of sustainable energy that can be used as an alternative method of transportation to a car. Based on an experiment conducted by Commute Statistics, studies showed that 80%-98% of the energy delivered by the rider into bicycle pedals is directly transmitted to the wheels. In addition, Commuting Statistics revealed that if only 5% of the United States population utilized a human-powered vehicle, roughly 3 billion gallons of gasoline would be conserved each year. With nearly 51% of commutes encompassing 20 miles or less per round trip, the 2014 Santa Clara University HPV team decided to fabricate an innovative, sustainable HPV that can help achieve a healthier environment for present and future generations.

Environmental Impact

In order to quantify the impact our project will have on the environment, some assumptions were made on how human powered vehicles and motorized vehicles are operated:

Assumptions:

In order to quantify the impact our project had on the environment, some assumptions were made on how human powered vehicles and motorized vehicles are operated:

- There are 128.3 million commuters in the U.S.
- 51% of those commutes are eligible for being replaced by bikes.
- 11% of bicycle trips are for commuting.
- 12% of trips are already made by bicycles.
- CO2 emissions per gallon=19.6 lb CO2/gallon (http://www.epa.gov/otaq/climate/documents/420f11041.pdf)
- A passenger vehicle is defined as a 4-tire vehicle including passenger cars, vans, pickup trucks, sport/utility vehicles with 2-axles.
- Weighted average combined fuel economy of cars and light trucks: 21.4 mpg (FHWA 2013)
- Average vehicle miles traveled per year: 11,318 miles (FHWA 2011)
- Ratio of carbon dioxide emissions to total greenhouse gas emissions for passenger vehicles: 0.988 (EPA 2013a)

Based on the above assumptions, 5.33 kg of CO2 would be saved per commuter per 15 mile commute. Taking into account the number of eligible commuters (those with commutes of 20 miles or less) who could feasibly switch to human powered transportation, this adds up to ***340 million kg of CO2*** emitted per work day over the entire United States that could be avoided if people switched to human powered transportation.

Another measure of the effectiveness of the human powered vehicle is the metric tons of carbon dioxide emissions per motor vehicle per year:

$$\frac{19.6\ lbs\ CO_2}{gallon\ of\ gasoline} \times 11{,}318\ AVMT \times \frac{1\ gallon}{21.4\ miles}(average) \times \frac{1\ g\ emissions}{0.988\ g\ CO_2} = 10{,}472\ lbs\ CO_2 \frac{emissions}{vehicle}/year \tag{1}$$

On top of this is the sheer amount of fuel consumed by motorized vehicles. The U.S. Energy Information Administration has determined that 134 billion gallons of gas are consumed just by the United States each year (or 365 million gallons each day). American Energy Independence adds on by stating that 45% of total oil consumption for the United States is for gasoline. To quantify these values further:

- United States uses 6.89 billion barrels of petroleum each year (EIA 2013)
- 45% of this petroleum is used for gasoline production, which equates to 3.1 billion barrels (WSG)
- 1 Barrel (42 gallons) produces 19 gallons of gasoline, yielding 58.9 billion gallons of gasoline produced by the United States (EIA 2013)
- This means the United States only produces 43% of the total gasoline we use (134 billion gallons of gasoline). This means that imports are needed
- Estimate: 600 gallons of gas used each year per car on average based on average gas mileage for cars
- This means if 128 million HPVs replaced cars in the US permanently, then the United States would only need the gasoline it produces\
- With 254 million registered vehicles in the US (US Bureau of 2007), then the switch from cars to HPV would have to be 50.3% of the total cars that are registered and active on the road

As can be seen from this approach, human-powered vehicles have a significant impact on the environment in terms of oil and gasoline usage. If slightly over half of all motor vehicles in the United States were replaced by HPVs, then there would be no need to foreign import fuel.

Not only are HPVs able make an impact based on reduced emissions, they are also less resource intensive to build, maintain, and recycle than traditional automobiles. According to a study by the Argonne National Laboratory, it takes the equivalent of 260 gallons of gasoline to make a typical 3,000 lb car. (Sierra Club) Further, the production and shipment of a bicycle can be assumed to be a fraction of that required for a car. This is due to the bicycle’s drastically smaller use of material (20lbs vs 3,000 lbs) and reduced size allowing for reduced shipping costs. Also, a simpler design would make the local manufacture of an HPV more feasible than for a car.

Overall, human-powered vehicles create a much smaller environmental impact than the automobile.

2.7.3 Manufacturability

Manufacturability plays a vital role in the design of the vehicle. When the complexity and number of parts used in a design increases, the cost and time of manufacturing the vehicle increases, as does the probability the product will fail.

To reduce complexity and simplify manufacturing, we used off-the-shelf parts where possible. We discussed our designs and drawings with instructors experienced in manufacturing and understand the capabilities of Santa Clara's machine shop. Our goal was to build a vehicle that met our project goals in the simplest way possible in order to make our finished project relatively cheap and easy to assemble.

An example of this manufacturing mindset can be seen in the design of the wheel axle assembly. Figures 8 and 9 detail the changes made over the course of design to make the part easier to manufacture.

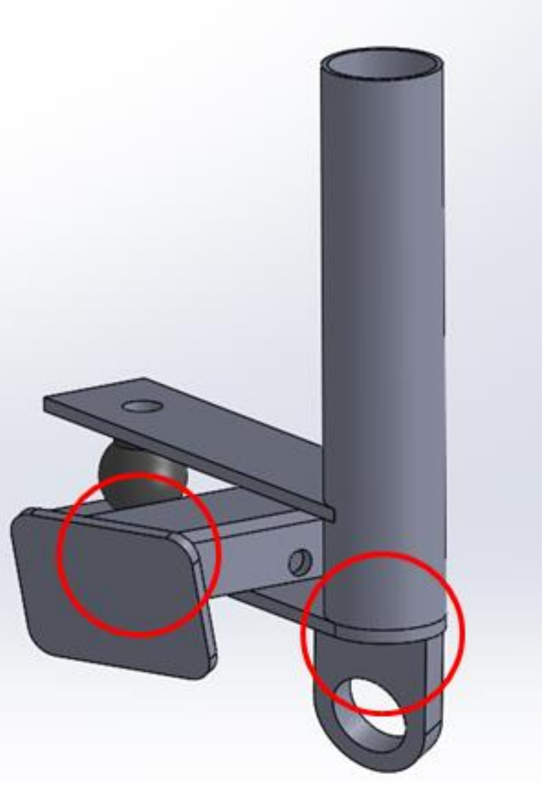


Figure 8: An initial design idea for the wheel axle and Ackermann connection. The red circles show parts that had complex angles; i.e. parts that had two different angles that had to be machined onto the same surface.

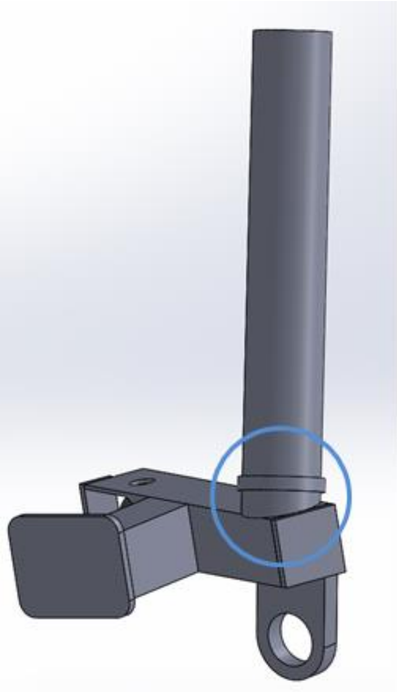


Figure 9: The final design for the wheel axle assembly. The blue circle shows the change made from the initial design that allowed for the removal of all complex angles from the design.

By cutting the steering tube at an angle and adding in a rectangular tube, we were able to get rid of the complex angles in the design and thus greatly reduce manufacturing time and difficulty. In turn this reduces the likelihood of failure of the part due to the simpler geometry.

2.7.4 Ethical

The current transportation system is unsustainable in the long run due to a growing population and globalization. We cannot just provide doomsday prophecies without providing a solution. As engineers, we must come up with sufficiently viable solutions so that humans, out of their own free will, are willing to switch away from an unsustainable way of life. According to the Markkula Center, this approach involves "the belief that humans have a dignity based on their human nature per se or on their ability to choose freely what they do with their lives." We as a senior design team do not believe that the bicycle in its current form is capable of causing such a switch from the automobile. The solution will have to include some of the benefits that make automobiles so attractive to consumers: storage space, protection from the elements, and speed to name a few. These thoughts guided many of our design decisions.

The question then becomes: Why should we strive to achieve a healthier environment and a more sustainable way of life? There are two major answers to this question. The first is that the Earth should be protected and treated with care because it provides us with the raw material we need to survive. If we continue our unsustainable lifestyles, then a point will arrive when the Earth is simply incapable of keeping up with our resource-intensive lifestyles. Similar to this argument is another ethical perspective, titled the “Common Good Approach,” that states that each individual’s actions concerning resource use will not only have an effect during our lifetime but on the lives of those for generations to come. Hence, our design needs to consider the longer-term impact of our choices in material and construction on society and the environment.

The second answer to this question is that the Earth itself is inherently valuable outside of the value that we ourselves place onto it. The value that we place onto the Earth is due to both our need for its resources as well as for the beauty that we see in it, such as in a colorful sunset. However, even if we see the planet as something beautiful outside of its ability to provide us with resources, we are still assuming that the Earth is valuable because we have placed value onto it. The idea of intrinsic value means that whether we intelligent beings were around to appreciate the Earth’s beauty or not, it would still have value. A believer might see this as a thing having value because it was designed by the hand of God.

It is the job of the engineer to take scientific knowledge and build useful technology that improves the situation of mankind. As such we as a team hold that the purpose of the engineer is to use his or her knowledge to improve quality of life. The ASME code of ethics states that engineers have certain personal responsibilities: they look for the enhancement of human welfare; are honest, impartial and professional; hold paramount the safety, health and welfare of the public; do not compete unfairly; and are objective and truthful. As we pursued the design of our Pegasus vehicle, we put utmost importance on following these principles.

In “The Good Engineer: Giving Virtue Its Due in Engineering Ethics,” Charles Harris emphasized certain habits that a virtuous engineer ought to have. As a team we have gained experience in each of these habits:

Techno-social Sensitivity

The first habit is “techno-social sensitivity” which is the idea that technology changes society while at the same time social forces affect how technology evolves. This idea is readily apparent in the direction that human powered vehicles have taken over the last few decades. Many rightly view HPVs as contraptions meant to push the limits of speed at which someone can go under their own power. However, there seems to have been a shift in recent years towards a vehicle that is not only fast, but also practical for the average commuter. Practicality would include such criteria as stability, ease of entry and exit, safety, and storage capability. At the recent ASME HPV competition we noticed that a number of vehicles there were focused on this practicality aspect, and we know that our design was itself also influenced by this social push.

Respect for Nature

The second is “respect for nature.” The connection of our project to this ethical value is obvious in our desire to reduce the consumption and impact of fossil fuels. But from a broader perspective, it is also important for engineers working on any project to have a respect for nature; not just those working on “environmental” projects. Every project has impact on the environment, from material choice to energy requirements, and thus every project should be undertaken with respect for our world. At one point we were committed to building our bicycle out of bamboo because we believed this to be a “green” material. However, after further investigation we found that bamboo would be harder to work with than we previously thought. Further, aluminum was “greener” than we initially thought because it is easily recyclable. This really highlighted for us that a project doesn’t need to be an environmentally trendy design to be green, it can just as easily be environmentally responsible through small choices made through the design process.

Commitment to the Public Good

The third is “commitment to the public good.” This habit is similar to the respect for nature habit in that many things that are good for nature end up being good for the public in the long run. Throughout the work on our project we were intent on providing for the public good not only in general environmental terms but also in terms of safety. We realized that as a dynamic vehicle containing a rider, Pegasus needed to be safe for both the rider and those around the vehicle as well. This meant designing a vehicle that not only met the basic safety requirements of the ASME competition, but that was designed and built to provide a reasonable assurance of safety. For us, this meant building a strong yet lightweight roll-bar and a predictable and responsive steering system so that the rider might be safe in a crash and in control of the vehicle at all times. We realized that it was insufficient to follow the letter of the law concerning safety regulations; we also needed to follow the intent. As a bonus to the commitment to the public good, cycling is an excellent form of exercise that encourages a healthy lifestyle.

Teamwork

The fourth habit is "teamwork." We found through the duration of the project that being a good team member helps the project to run smoothly. Sometimes this means you are willing to take a larger workload to help out someone, and other times it requires you to step back and let others do the work. This means it's important to take initiative on needed tasks for the project. If one person is stretched too thin handling multiple tasks, then the final quality of the overall project suffers. The opposite also holds true. If a teammate has taken the lead on a task, then it is imperative to support his or her efforts, rather than take charge of their task. In all cases, teamwork requires a sense of generosity, sacrifice, and humility. One has to realize that one's own ideas are not always the best. Support is the key to teamwork.

Courage

The final habit discussed by Harris was that of "courage." We realized as our project got into full swing that courage is something that every professional engineer needs to develop. We as a team have come to realize this personally when part of our design failed. Although we still produced a fully functioning tricycle, a large part of our design was to incorporate both tilt and Ackermann steering into one package. However, as we began testing, we realized that the design would not work and that the tilt steering would have to be removed. It took courage to come to the conclusion that our design would not work, and even more courage to admit that to others, such as at the senior design presentation, that that part of our design that we spent so long on did not work. But this kind of courage is required of an engineer because if a faulty design ends up in the public, lives can be at risk. It is much better to catch the mistakes early and address them. Similarly, an engineer should know the point at which a project interferes with his or her ethical concerns and have the courage to walk away from it.

The Pegasus project was initially shaped by our ideas of ethics and an engineer's obligation to human welfare. However, the project shaped these ideas further and gave us examples of what it actually means to put engineering ethics into practice.

The Impact of Ethics on Design

There were many engineering ethics challenges specifically related to the construction and implementation of our Pegasus human powered vehicle.

A main concern of ours heading into the project was the trade-off between vehicle performance and rider safety. We obviously wanted to produce a vehicle that could accelerate quickly, have a high top speed, and maneuver agilely. However, we also wanted to keep the rider not just safe, but able to depend on the vehicle's long-term reliability. A conceptual model of the Pegasus was first constructed in Solidworks to provide a rough idea of our final design. To find that line between performance and safety, we then proceeded to analyze the frame design using finite element analysis. This analysis allowed us to iteratively change our design until we arrived at a design we believed would handle any loads the vehicle might encounter with an adequate factor of safety, while keeping the frame light weight. Our final design had a frame that weighed 8 lbs and could theoretically hold a vertical weight incident on the top roll bar of over 4000 lbs.

When welding of the frame was finished, we wanted to verify our calculations by testing a load on top of the roll-over protection system, or RPS. The frame was tested by placing a squat bar on top of the frame that had 610 lbs of weight, and a squat bar on the side of the RPS with a load of 320 lbs. The frame ended up having no noticeable deflection. Physically testing the frame was the ethical thing to do because often, in theoretical analysis, it is difficult to predict all of the different factors that might go into a real-world build. In addition, physical testing gives us and the customer a greater sense of security knowing that the frame can hold the theoretical weight.

A roll protection system was included on our vehicle as part of the ASME competition requirements. We took the design of the RPS seriously in our design, knowing that a faulty design could lead to serious neck injuries to a rider if a high speed crash occurred during a lap around a velodrome. Velodromes have very steep angles at the turns that make it easy to tip over. The robust design of our RPS came into play once during the competition, when one of our riders rolled over during a sprint race. Thankfully our attention to safety allowed the rider to escape with only a few scratches, and the vehicle itself remained undamaged.

Knowing the vehicle was designed with safety as a priority, we wanted operation of the vehicle to be intrinsic, in the sense that once the rider entered the vehicle, the ergonomics and interface of the vehicle would not only ensure easy use, but also motivate safe operation for our design. This included multiple design revisions of the vehicle's brakes and handle systems. Throughout the design we encountered multiple issues with the disc brakes of our vehicle rubbing as well as not generating the necessary braking force required to stop. At this point in the design, making the brakes function safely became our primary focus. In the end we perfected the brakes and designed the handle system of our vehicle to grant maximum braking easily for the rider. This success in the design showed that this design of the brake system guaranteed safe operation for any inexperienced rider.

Aesthetics is not merely a matter of how an object looks. How an object feels to a user during operation is also critical. We might build the fastest bicycle in the world, but if the user does not trust the vehicle, then he or she will not be willing to operate it. Our final design has to make the customer feel just as safe and secure when they are bombing down a mountain road as when they are stopped at a stoplight. For this reason, we are placing special concern on the design of the steering system for our vehicle. The user has to be confident that the vehicle will respond in a consistently stable and predictable manner. A poorly designed steering geometry can lead to high amounts of wheel wobble at high speeds and can result in the tipping of the vehicle on sharp turns. The steering for our vehicle must be light and responsive while being stable and controllable at all times. This is one reason why we decided to use the three-wheeled design: the vehicle will be much more stable, especially at low speeds, when compared to the typical two-wheeled human powered vehicle. For these same reasons, the frame must be rigid to provide a sense of stability.

It is the Santa Clara Human Powered Vehicle design team's responsibility to design a vehicle that protects the rider from harm and that does not endanger others on the road. At a certain point safety designs would reduce the utility of our vehicle to the point where it becomes impractical for the customer. Thus, we have to give the responsibility of safe operation to the user. We cannot control where all of our customers will use our vehicle, nor can we make sure that every user is practicing safe operation of our vehicle. The customer has an ethical responsibility to operate our vehicle in a safe manner.

2.7.5 Health and Safety

According to the engineering handbook under the health and safety chapter, "Engineering is the application of the laws of nature and the goods of the world through the development of products and systems for the betterment of the human condition" (Santa Clara Engineering Handbook). A human powered vehicle provides the opportunity to physically "better the human condition," by providing an opportunity for users to exercise where they cannot in a car. Our design requirements along with the requirements of the ASME HPV challenge ensured that this vehicle was safe as well.

Safety in Design

The way the vehicle was designed gave it inherent safety features. Besides the RPS, the use of a three-wheeled recumbent body increases the stability of the vehicle, especially at low speeds or when carrying heavy loads (e.g. a week's worth of groceries). The inclusion of a tilt steering system also counteracts the tendency of the three-wheeled vehicle to tip during hard cornering due to the lowering of the center of gravity into the turn (however, as discussed later our tilt steering system was ultimately removed from the final design for other reasons). In our design, we kept in mind the distance of the center of gravity from the front wheel axle so that our vehicle can safely come to a stop in the required distance without experiencing forward weight transfer. Finally, we included gas springs in the tilt steering system so that any steering wobble would be dampened and the rider would be assisted by a spring force to right him or herself after a turn.

Safety in Material Choice

The material chosen for the vehicle was Aluminum 6061 T6 due to its lighter weight and stiffness than Chromoly 4043 high strength steel. Aluminum 6061 has been successfully used in many production bicycles and has strength close to that of Chromoly steel while having a lower density. In choosing this material, we realized that the welding process for aluminum is more difficult to accomplish correctly than for steel. For this reason, we hired an outside contractor to weld the frame as well as machine critical parts.

Safety in Manufacturing Process

In the manufacturing of our vehicle, it was crucial that we had a solid design before we began construction. Each part drawing was reviewed by the machine shop manager prior to construction to ensure that proper design techniques were being followed. For the parts being manufactured and welded by the outside contractor, we handed them a detailed set of drawings and remained in contact with them throughout the build process to confirm that the design was being implemented successfully. For in-house construction, we checked with the shop manager for proper machining technique and spindle speed before beginning manufacturing of parts. All construction that produced fumes (painting and epoxy) was done outside for maximum ventilation and safety.

2.7.6 Social

The benefits of cycling are not only environmental; they can also benefit low-income communities:

> “Simple, sustainable bicycle transportation multiplies an individual’s efficiency. Compared to walking, bikes improve access to education, healthcare and economic opportunity. They increase carrying capacity and accessible travel distance while decreasing the time it takes to commute to schools, clinics and markets.” (World Bicycle Relief)

The bicycle can drastically change the way that someone in a third-world country is able to interact with the world. However, it can have an equally large impact in America where a disproportionately large amount of the world’s resources are used. The bicycle can have a massive environmental impact for the better; however, its larger scale adoption is hindered by the fact that bicycle riding is often seen as for workers of lower class. This is a huge social problem that has to be addressed: for large scale adoption of the bicycle those who pedal to work must be seen on the same social status as those who drive to work.

Paul K. Simpson, a practicing physician of internal medicine, wrote a paper titled: “The Bicycle: Vehicle to Health and Social Equality” that explores these ideas of social equality and transportation. He writes that the “fight or flight” stress response can be constantly activated in people low on the social ladder; these high levels of stress over time can create a multitude of health problems. In fact, a study of British civil servants shows that health is directly related to one’s social status, with the healthiest group on top (Simpson). Note that these findings were made after accounting for factors such as diet, exercise, etc. Currently the transportation system in America is set up so that the motor vehicle is at the top of the ladder: those who use public transportation, walk, or bike are seen as inferior. Naturally then people are more inclined to want to be at the top of the social ladder and use an automobile. (onestreet.org)

The continued improvement of human powered vehicle technology, such as our Pegasus project, will help to improve the social status of cycling. Combining this with political action can create a more sustainable transportation system in the future.

2.7.7 Aesthetics

As engineers, we need to think about what contributes to the functionality of our product while maintaining our budget considerations. Balance and symmetry are important in the design of our vehicle. We sought to enhance the elegance and simplicity of the design by making the vehicle intuitive to control. Cut pieces and other extruding parts were sanded down for safety purposes as well as aesthetic appeal. Our design plans called for a human-powered vehicle that is fast, agile, and comfortable. The aesthetics of the design needed to reflect these design considerations. For example, in choosing Aluminum tubes for the frame, one might want to use circular tubes versus rectangular tubes since these provide a sleeker design, even if the structural differences are negligible.

We also submitted our frame materials to an outside contractor (Chavez Welding) that cut, bent, and welded our frame; the professionalism enhanced the aesthetic look of our vehicle.

3. Detailed Design

In designing the HPV, the SCU team placed priority on the implementation of a protective roll cage system, stable steering, an efficient drivetrain system, and an aerodynamic fairing. The recumbent frame is fabricated from Aluminum 6061 T6; chosen to reduce the weight of the bicycle when compared to high strength steel. The design featured direct knuckle steering that was intended to control a combined tilt steering and Ackermann steering mechanism; however due to unforeseen problems using both steering systems the tilt steering system was blocked out. The vehicle utilized an 11-speed internal-shifting hub motor for the rear-wheel drivetrain to reduce chances of chain derailment. Disc brakes were located on each of the two front wheels. The SCU HPV team used a Lexan polycarbonate fairing to minimize air drag and optimize vehicle speed. The seat was fabricated from carbon fiber with foam cushioning, and storage compartments were located on the rear of the frame.

3.1 Frame

3.1.1 Frame Background

In a recumbent-style vehicle, the rider operates the vehicle at a reclined angle which allows for the center of gravity to migrate closer to the surface of the ground. When progressing through the brainstorming process for the frame, the team considered two possible designs: the delta frame and the tadpole frame configuration. The delta tricycle geometry operates with a single wheel in the front and two wheels in the back. Although the delta design is ideal for shorter distances due to its upright seating, the geometry lacks stability at high speeds. Alternatively, the tadpole tricycle configuration utilizes two frontal wheels and a rear wheel. Incorporating a recumbent, tadpole tricycle arrangement yields many desired features, such as increased stability, enhanced ergonomics for longer distances, and superior handling at high-speeds. See the trade-off matrices in the Appendix C for more information. We desired to build a lightweight (under 10 lb) frame that could hold the weight of a rider plus cargo (~250lbs) while maintaining sufficient stiffness so that most of the force into the pedals was translated into forward motion. The design of our vehicle, which met all of these requirements, is detailed below.

3.1.2 Frame Design

The center of gravity was kept low, near the height of the wheel axles, to reduce both aerodynamic drag and tendency to tip. Reduction of aerodynamic drag is a key element in having the bike be able to perform at excess of 30 mph. The reclined seat design also improved the overall ergonomics of the vehicle. When last year's vehicle (2013 Cerberus) was tested, we noticed that the steeper seat angle was uncomfortable to ride during long commutes. A lower angle is not only more comfortable for long commutes, but it also reduces the cross-sectional area of the vehicle, yielding a small drag coefficient. When sizing the frame of the vehicle, the physical characteristics of all six members of the team were considered to ensure that each of our riders could reach the pedals of the vehicle comfortably and to confirm that the roll cage would cover and protect the head of our tallest rider in the event of a flip.

The frame design has two wheelstays and two framestays extending down from the roll bar to the rear axle. This creates a triangulated geometry that keeps the rear wheel rigid. When designing performance vehicles, stiffness of the frame is crucial because sway in the vehicle arrests forward motion. The roll bar is incorporated into the frame such that the amount of material used is reduced. A 3D view of the frame is shown in Figure 10 below:

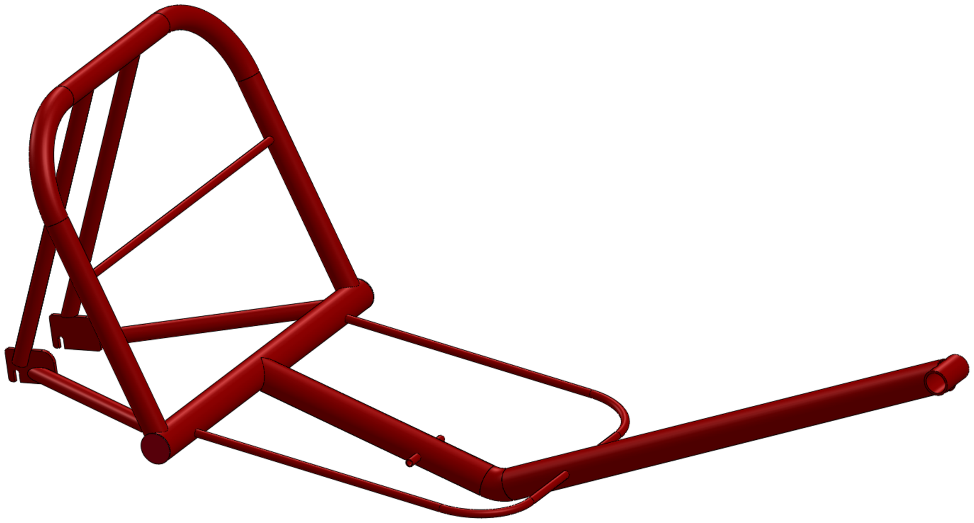


Figure 10: A CAD rendering of the main vehicle frame detailing the construction of the roll bar.

Material Choice

Although the frame geometry plays a vital role in vehicle performance, it is imperative to select efficient and appropriate materials. During the frame design, we decided that we wanted a material based on four requirements: weight, manufacturability, cost, and repairability. With these design constraints in mind, our team researched the material properties of common materials utilized in bicycle frames, including Carbon Steel, Titanium, Aluminum, and Carbon Composites.

Chromoly 4130 steel is a low-cost material and is a common choice for bicycle frames. If optimizing performance and weight is of interest, Titanium is an excellent material to incorporate into bicycle frames; however, it is difficult to manufacture and is expensive, which outweighs the benefits of its rigid frame structure. Similar to Titanium, Aluminum is lightweight and is relatively easy to machine but is difficult to weld. Carbon Composites are typically lightweight in structure and resist fatigue; however, they are relatively expensive and can shatter under hard impact.

After further research and collaboration, it was determined that Aluminum 6061 T6 best met our team's desired material properties for our frame. Aluminum 6061 T6 is a strong, lightweight aluminum alloy composed of silicon and magnesium, making it easy for TIG welding. Table 1 compares the material properties of these materials we considered for design.

Table 1: Material properties for commonly used frame design materials. (sheldonbrown.com)

Material	Elastic Modulus (psi)	Yield Stress (psi)	Density (lb/ft3)
Aluminum 6061 T6	10 to 11 x 10^6	11 to 59 x 10^3	168.5
Chromoly 4130 Steel	30 x 10^6	46 to 162 x 10^3	490
Titanium	15 to 16.5 x 10^6	40 to 120 x 10^3	280

Although aluminum has the lowest elastic modulus and yield stress, it is also the lightest material. This allows for the aluminum to be formed into wider, thicker tubes (which increases stiffness) while still maintaining a lower weight than steel and a lower cost than titanium.

3.1.3 Frame Analysis:

Tipping Analysis:

The objective of calculating the tipping point of our vehicle was to ensure that the design would be safe when cornering at high speeds.

In order to determine the tipping point, the vehicle can be represented as a simple wireframe model. A representation of the vehicle is shown in Figure 11 below:

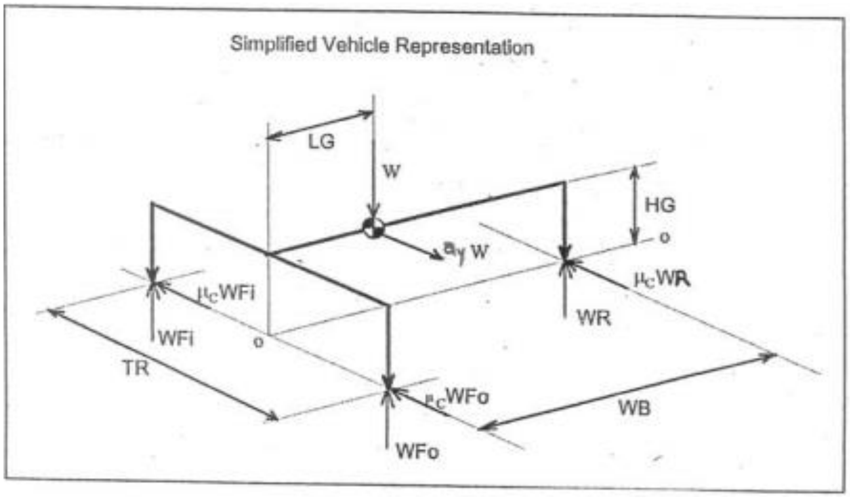


Figure 11: A simplified representation of our vehicle, defining the important lengths and static forces. (Gillespie)

As last year's entry had a lot of issues with tipping during cornering (Schapp and Smith), we wanted to focus on preventing this issue. The physics of a turning, three-wheeled vehicle were derived as shown in Appendix A. By summing the moments due to centripetal acceleration about an imaginary tilt axis, one can arrive at the equation below to determine at what velocity and radius of turn the vehicle will tip at (Starr).

$$F_c = \frac{V^2}{Rg} = \frac{TR(WB - LG)}{2(HG)\sqrt{\left(\frac{TR}{2}\right)^2 + WB^2}} \qquad (1)$$

Ideally, this desired value would be made as large as possible. This can be achieved by decreasing the height of the center of gravity in addition to decreasing the horizontal distance of the center of gravity from the front wheel axle. The allowable cornering force for our vehicle was found from Equation ###### to be 0.813 g prior to tipping. The vehicle measurements used in this calculation can be found in Table 2 below:

Table 2: The measurements for our final design. The definitions for each measurement are detailed in Figure 11 above.

TR (in)	WB (in)	LG (in)	HG (in)
35	46	14	14

Note that these dimensions were calculated without the added reduction in the height of the center of gravity due to tilt steering. This means that our vehicle should be able to approach 17.9 mph when traveling around the ASME competition required minimum turn radius of 26 ft.

Weight Transfer Analysis:

Another important aspect to consider in dynamic vehicle frame design is the amount of weight transfer during braking. Too much forward weight transfer can cause the vehicle to flip over the front axle. A simplified representation of the vehicle under braking deceleration is shown in Figure 12:

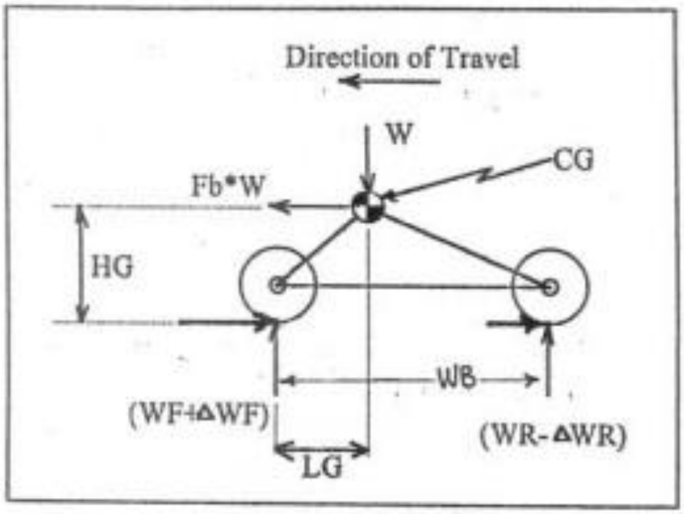


Figure 12: A simplified representation of the vehicle under dynamic braking deceleration. The vehicle is shown from the side view. (Gillespie)

From this sketch the change in weight over the rear wheel can be solved using moments (Starr).

$$\frac{\Delta WR}{WR} = \frac{(HG)(a_b)}{(LG)(g)} \leq F_T \tag{2}$$

The derivation for this equation can be found in the Appendix A. By decreasing the height of the center of gravity and increasing the distance of the center of gravity from the front axle the weight transfer can be reduced. Notice that increasing the distance from the front axle improves braking performance but is detrimental to tilting during cornering. The theoretical maximum allowable braking deceleration of our vehicle is -32.2 ft/s^2 prior to forward tipping. This value is over twice that of the ASME required braking deceleration of -13.2 ft/s^2 (making a stop from 15.5 mph in 20 ft).

Steering Response Analysis:

The placement of the center of gravity also affects whether a vehicle handles with understeer, oversteer, or neutral steer. Ideally a vehicle will have either neutral or understeer. Neutral steer occurs when a lateral force on the vehicle (such as the friction force on tires during a turn) causes no shift in the vehicle's direction. All of the lateral force goes directly into sideslip. Understeer occurs when a side force on the vehicle causes the vehicle to turn away from the direction of the force. With understeer, the greater the velocity of the turn, the more the operator will have to move the steering. What the operator does not want is oversteer, which causes the vehicle to turn more sharply as velocity increases, potentially causing a crash or tip-over.

Static margin is a term that helps to define the steering response of a vehicle, and is shown in Equation 5 below (Gillespie):

$$SM = \left[\frac{C_R}{2C_F + C_R} - \frac{LG}{WB}\right] \tag{3}$$

This term defines the effect of the distance between the center of gravity and the neutral steer point (the point at which a side force causes no change in heading). A zero or positive value of the static margin is desired, which corresponds to understeer. Our vehicle design has a static margin of 0.029, which gives us the desired understeer result and which provides a predictable steering response. Another important term in vehicle handling is the understeer gradient, given by Equation 6 below (Gillespie):

$$K = \left[\frac{W_F}{2C_F} - \frac{W_R}{C_R}\right] \tag{4}$$

For understeer one wants a value of zero to positive. This term defines the effect of the separation of weight between the front and rear wheels on steering stability. Our design has an understeer gradient of 0.05, again a desirable result.

Finite Element Analysis

Abaqus/CAE was used to perform finite element analysis of the vehicle. A few assumptions were made to simplify the computations. Simplifying assumptions included:

- Elements were assumed to be beam elements
- Computations were performed using cubic formulations
- Point loads were applied versus loads over a surface area
- Mount points, such as holes in the frame, were not included in the analysis
- The frame was illustrated using a “connect the dot” method, so interfaces between frame parts are not ideal but assumed to be accurate.

- The frame has uniform composition, meaning structural weakness from welds was not accounted for.
- Forces and weights incident on the frame were doubled to account for uncertainties (e.g. dynamic motion, impact, etc.)
- All parts modeled were assumed to be Aluminum 6061 T6.

Table 3 outlines the physical properties for Aluminum 6061 T6 subjected to FEA analysis. Table 4 displays the modeling methods for Top loading and side loading in the FEA analysis.

Table 3: The physical properties of Aluminum 6061 T6 used in the FEA analysis: (asm.matweb.com)

Density	0.0975 lb/in^3
Young's Modulus	9,993 ksi
Poisson's Ratio	0.33
Yield Stress	40.03 ksi

The free body diagram of the frame is shown in Figure 13 below. The weight (W) of the rider was assumed to be incident on the lower crux of the main beam as a point load.

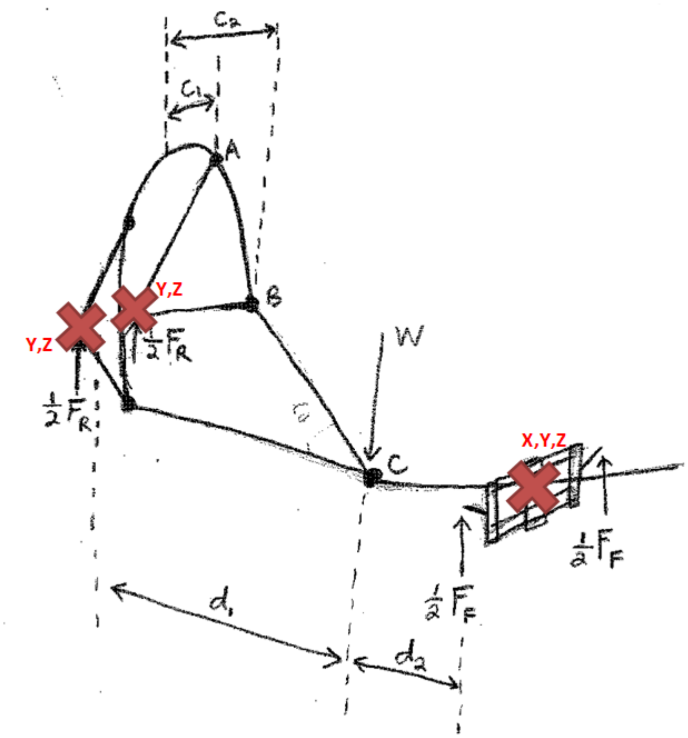


Figure 13: A free body diagram of the frame showing the forces on a frame due to the static weight of a rider. The constrained degrees of freedom are shown in red.

The reaction forces at the wheels were found using the following equation derived from the free body diagram:

$$F_F = \frac{\frac{d_1}{d_2}W}{1 + \frac{d_1}{d_2}} \tag{5}$$

These reaction forces were used in the hand calculations detailed in Appendix A. The max stress found at the crux of the main tube due to a rider weight of 200 lbs was found to be 256 ksi by hand calculation.

The expected mode of failure was high stress from bending in some facet of the frame. The critical points of failure were expected to occur at the major bend at the bottom of the frame, and at the interface points between different pieces of the frame where welds would need to be applied. These critical points are shown in Figure 14 below:

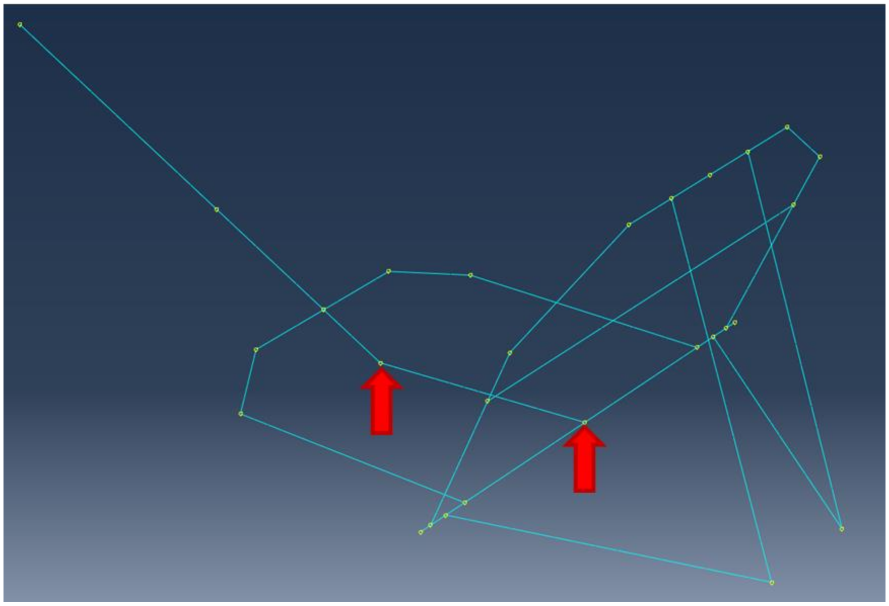


Figure 14: This is an image of the critical points for expected failure due to excessive stress.

Static Load Analysis

The ability of the frame to handle the static top and side loads to the RPS as required by the ASME competition was analyzed through FEA. The constraints listed in Table 4 were used to model the system:

Table 4: The modeling methods utilized for the top and side loads

Top Load Modeling	***Side Load Modeling***
The top load on the RPS was modeled per the ASME requirements: ● A 1,200 lb load at an angle of 12 degrees off of the vertical in the direction of the front wheels. ● Rear constraints: y and z ● Front constraints: x, y, and z ● The full frame was modeled rather than just the RPS	The side loads on the RPS were modeled per the ASME requirements: ● Two loads of 600 lbs were modeled on each side of the frame. They were incident horizontally at the point where the RPS went from straight to curved tubing. ● Rear constraints: y and z ● Front constraints: x, y, and z ● The full frame was modeled rather than just the RPS

The Abaqus CAE results for the final iteration of the frame design are shown in Figure 15 below:

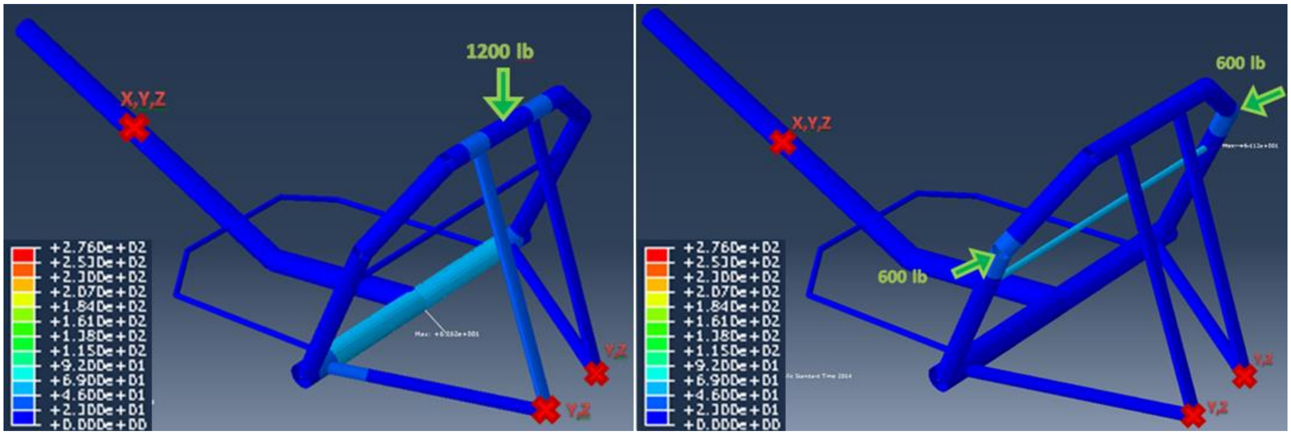


Figure 15: The FEA results for a 1,200 lb load applied to the top of the roll bar is on the left and the results for the 600 lb loads on the sides is on the right. The constraints of the system are detailed in red.

The frame passed the benchmark as the highest stress modeled in the final design was 23% of the yield stress of Aluminum 6061. This means that, for a 600 lb load, the frame currently has a factor of safety of 8.8, showing that the design is over engineered. However, due to the multiple assumptions made at the beginning of the analysis we have deemed this factor of safety acceptable to account for these assumptions. The maximum stresses that were computed are shown in Table 5 below:

Table 5: The von Mises and maximum principal stresses for the frame due to a top load of 1200 lb and side loads of 600 lbs are tabulated below.

	von Mises Stress	Max Principal Stress	Yield Stress of AL 6061 T6	Ultimate Tensile Strength
Top Load (1,200 lb)	9.06 ksi	7.40 ksi	40.03 ksi	44.96 ksi
Side Load (2 X 600 lb)	7.41 ksi	0.0087 ksi	40.03 ksi	44.96 ksi

Rider Pedal Load Analysis

The frame was also analyzed for performance under the stress that a rider would impart while sitting in the vehicle and placing maximum force onto the pedals.

This case was simplified as a 600 lb weight load on the center of gravity of the vehicle due to the rider's weight and a force of 300 lb applied to the pedals. This force on the pedals was then applied through the rest of the drivetrain due to the tension on the chain. The loads in this case were set as these magnitudes to ensure maximum confidence in design.

Table 6: The modeling method utilized for the rider generated load.

Rider at Maximum Load Output

The maximum load on the frame was modeled as:

- A 600 lb load at the major bend of the main frame tube with a 300 lb load being generated at the pedals, translating to various forces along the frame
- Rear constraints: y and z
- Front constraints: x, y, and z

The maximum force that a rider could impart to the vehicle was estimated as the force that a rider places onto the drivetrain when accelerating from a dead stop. The Abaqus/CAE results for the rider starting from a dead start are shown in Figure 16 below:

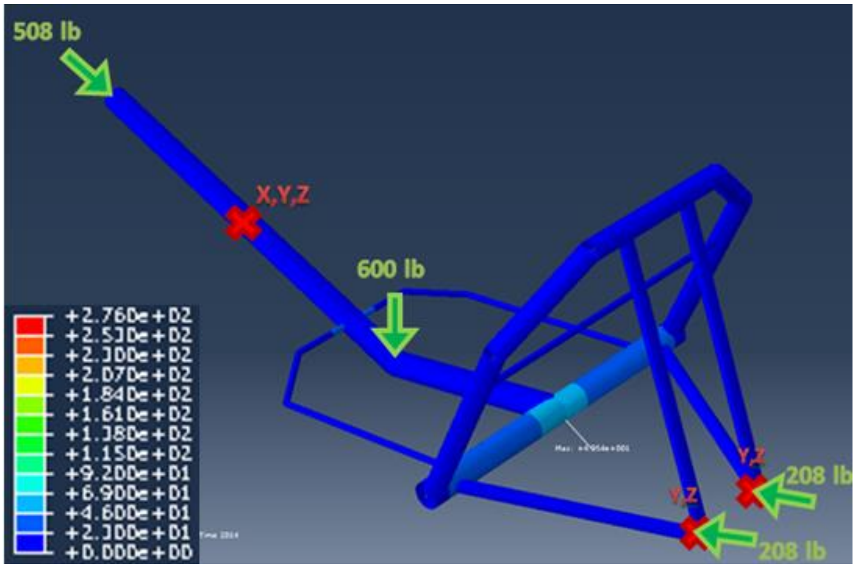


Figure 16: The FEA results for a 600 lb rider applying a force of 300 lb to the drivetrain. The constraints of the system are detailed in red. A factor of safety of 2 was used in the analysis.

The final iteration of the frame passed the benchmark as the highest stress modeled in the final design was 18% of the yield stress 6061 T6 Aluminum. This means that for a 300 lb rider generating 150 lbs of force at the pedals, the vehicle had a factor of safety of 9.3, showing that the frame is over engineered. However, in this case we have deemed the over-engineering acceptable due to the assumptions made in the analysis as well as the desire to strengthen the bottom beam of the RPS. The maximum stresses that were computed are tabled in Table 7 below:

Table 7: The Mises and max principal stresses for the frame due to a top load of 600 lb.

	Mises Stress	Max Principal Stress	Yield Stress of AL 6061 T6
Rider Pedaling (300 lb +150 lb)	7.19 ksi	6.03 ksi	40.03 ksi

We concluded that this frame easily handled the loading cases; therefore, we reduced the wall thickness of some of the tubes as described in the next section.

Design Modifications

Initial FEA analysis indicated that the weakest point on the frame was formed by the connection of the main frame bar and the horizontal piece of the RPS. The size of the lower RPS tube was increased from a diameter of 1.5” to 2”. This modification both increased the strength of the tube and reduced the stress concentration at that point due to a greater weld area. The attachment of the upper RPS tube to the lower RPS tube was also simplified to reduce the shear forces on the weld shown in Figure 17 below:

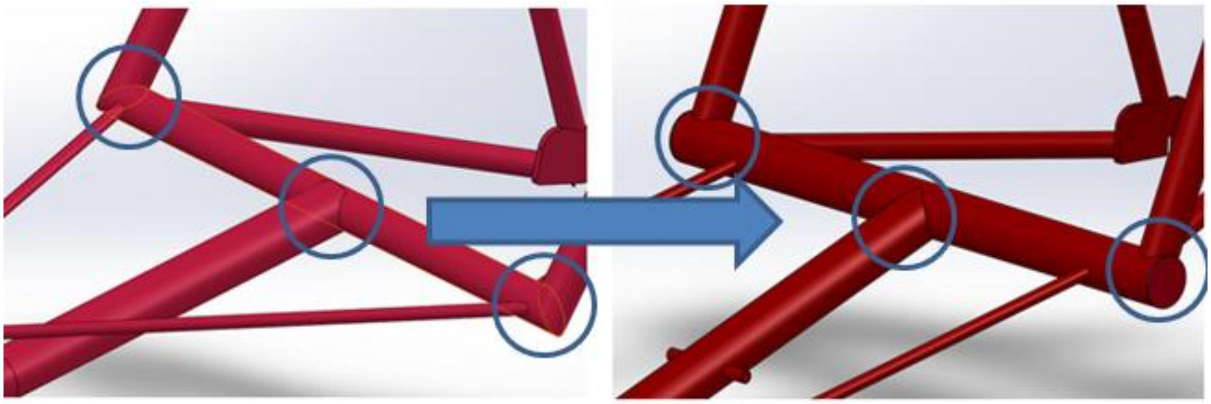


Figure 17: Design changes made after running FEA analysis of the frame. The initial design is shown on the left and the final design is on the right.

The thickness of the main tube and RPS were decreased from 0.083” to 0.065” to save weight. Finally, the side support struts were re-designed so that they follow the curve of the seat in order to better support the rider. These struts were initially designed to help support the bending moment incident on the bend of the main tube, but the FEA analysis showed that the main tube was stiff enough to handle the loads on its own. Thus we could redesign the side supports to increase the ergonomics for the rider without sacrificing other performance criteria. The FEA results described earlier in this report describe the final design that was produced. A comparison of the FEA results for the old and new designs are shown in Figure 18 below:

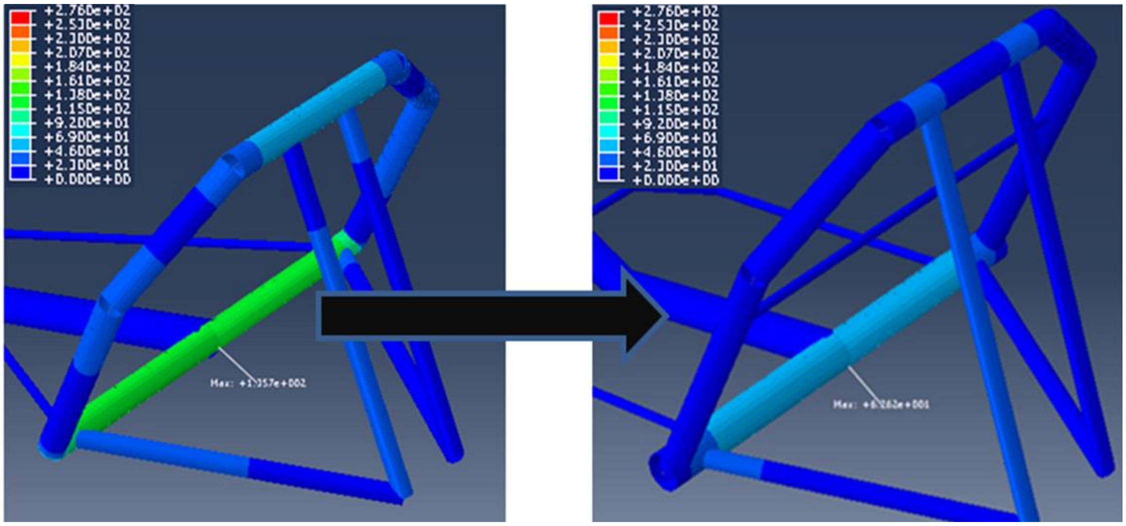


Figure 18: The reduction in stresses in the RPS due to the design changes. On the left is the old design and on the right is the new design. The load modeled was the top load.

The old design had a von Mises stress of 19.6 ksi while the final design had a von Mises stress of 9.06 ksi for the same top load, a reduction of 47% in the von Mises stress. The new design is thus both lighter and stronger than the original, and we built this final design as shown in the section below.

3.1.4 Frame Mechanical Description

The frame was fabricated at Chavez welding and machining using MIG welding This choice was made since the machine shop at Santa Clara University did not have aluminum welding capabilities at this time. The cutting and welding of the aluminum tubes was also beyond the expertise of any of our team members, so for safety concerns we wanted to have the frame done by a professional. The finished frame can be seen in Figure 19 below:

Figure 19: A photo of the finished frame.

The central piece of the frame is the roll protection system. Extending from the RPS is the front boom, with a single 12 degree bend in the middle. A rectangular attachment for the tilt steering is located towards the front of the boom, and an attachment for the pedals is at the end. A connection piece for the seatbelt is also shown on the boom. Two tube stays extend from the RPS to the front boom at a 90 degree angle; the purpose of these is to stabilize the seat. Four wheel stays extend from the back of the RPS to the rear wheel.

The seat was constructed with carbon fiber, Styrofoam, and plumber's tape. This was done by creating a thin layer of carbon fiber that was then coated with epoxy. The epoxying was done on a waxed surface so that the carbon fiber did not become stuck. Next the Styrofoam was placed onto the carbon fiber layer with plumbers tape used to connect the separate seat sections. A final layer of carbon fiber was then placed onto the Styrofoam and epoxied and the edges were finished up to complete the seat.

3.1.5 Frame Test and Verification Data

The finished frame was weighed on a scale and found to be 8.5 lbs. This is well below our desired weight of 10 lbs. The rollover protection system was then loaded with weights to ensure that the system would meet the requirements specified by the competition. The testing consisted of placing the frame under a squat rack and oriented accordingly with jack stands. Once the frame was positioned in the squat rack, a squat bar was oriented on the frame to simulate a point load. Pictures of this process can be seen in Figure 20 below:

Figure 20: On the left is the frame loaded from the top at an angle of 12 degrees. On the right the frame is loaded from the side

Weights were added to the squat bar until the desired weight was achieved. This process was done for a 600 lb load on the top of the rollover protection system 12 degrees from the vertical, and a 300 lb load applied to the side of the rollover protection system. The goal of this testing was to ensure that the RPS met the requirements of the competition. The testing results showed that neither load case had any visible deformation or deflection, and would meet the requirements set by the ASME competition. The frame did experience one roll-over during the

ASME competition.

During the testing of the fully assembled vehicle, we noticed that after a few hours of riding the front boom had begun to bend inwards due to the pull of the chain. After further consideration we realized that the cause of this problem was due to not representing the tension in the chain correctly. In our analysis we had the chain tension as incident directly through the center of the tube rather than offset to the side a few inches as it is in actuality. This offset created a bending moment, which combined with the high tension in the chain, served to bend the front boom. The ideal solution would be to redesign the frame with a thicker front boom based on a corrected finite element model. However, we did not have the budget to build a new frame and thus we attached a steel angle iron to the front boom on the compressive side of the bending. This fix solved the issue and the frame had no other problems afterwards. A picture of our fix to the front boom is shown below in Figure 21 below:

Figure 21: The angle iron that was attached to the front boom to increase stiffness.

Overall, however, the frame performed to our expectations of being light and strong, and the one problem with the front boom was easily solved.

3.2 Steering

3.2.1 Background

The objective of designing the steering system was to provide stable high speed performance and low speed maneuverability. We found steering stability to be important for both vehicle safety and performance. A well-designed steering geometry can make the bike fast and responsive, while a poor design can cause instability and a tendency for the vehicle to tip. The ASME competition guidelines required that the vehicle be able to make a turn under a 26.25 foot radius. Given that we designed a performance vehicle, we wanted it to turn within a radius of under 10 feet. Furthermore, the steering had to be stable in a straight line with no steering wobble. The vehicle also had to turn smoothly and in control at high speeds, but was also be able to make tight turns at low speed. We wanted the steering to be intuitive for the driver, and not interfere with the other subsystems in the design in a negative manner. Finally, the wheels and steering arms could not bump into the rider or frame during vehicle operation, so sufficient clearance had to be allowed.

Combined tilt and Ackermann steering is not a new concept. However, the way we implemented the combination in the design of our vehicle has never been done before. A steering design for trikes that incorporates the benefits of both Tilt and Ackerman was patented in 2002 by Alan Maurer (Maurer). For more information on Maurer's patent see Appendix H. Our design was different than Maurer's patent in multiple respects.

3.2.2 Steering Design

In contrast to how Maurer accomplished the system, we were able to combine the two geometries by using universal joints on the Ackermann control arms. The benefits of using both systems is that Ackermann steering provides solid performance at low speeds by reducing scrub friction, while tilt steering performs well at high speeds by placing lateral forces radially through the tires and by shifting the height of the center of gravity lower into the turn. However, the two systems ended up conflicting and we had to block out the tilt steering portion, as explained in the next section.

Ackerman Steering Design

The first aspect of our steering design was the incorporation of Ackermann steering. The importance of Ackermann steering is that for two-wheeled steering, as in the trike design for this project, the inner wheel on a turn has a smaller turn radius than the outer wheel. Thus, in order to avoid unnecessarily large amounts of friction during turning, it is necessary to have the inside wheel turn at a slightly greater angle than the outer wheel. The necessary geometry to achieve this Ackermann steering principle can be derived from the turn radius equation (Steering Dynamics):

$$\delta = \tan^{-1}\frac{WB}{R} \tag{6}$$

The angles that the inner and outer front wheels need to be at for a given turn radius can be calculated using this equation. A properly sized Ackermann rod can then be sized to create the desired angles of the wheels at any given radius of turn.

Ackermann geometry includes two control arms, one attached to each front wheel at an initial angle. These control arms are connected by a rod so that when one wheel turns the other wheel turns at an angle that is slightly different. An illustration of how the turn radius is a result of the Ackermann design can be seen in Figure 22 below:

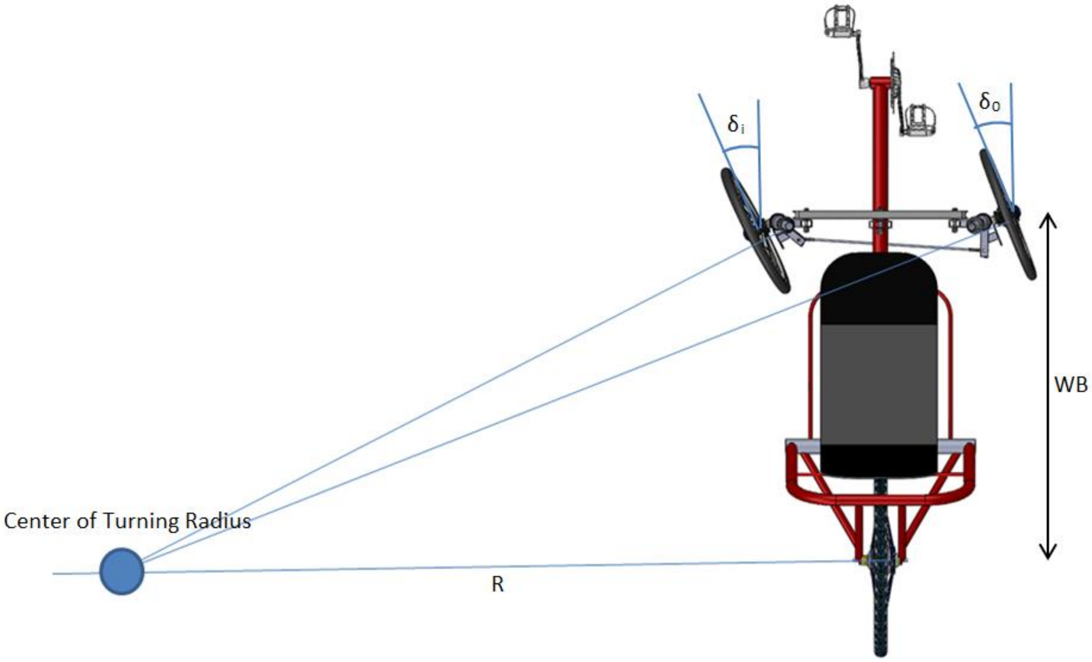


Figure 22: An illustration of how the turn radius is formed by Ackermann Steering, with the inside wheel turning at a greater angle than the outside.

With the help of Ackermann design spreadsheets from Peter Eland’s webpage (Eland), we were able to design a steering geometry that was only a 3.6% error off of the ideal Ackermann geometry. The design spreadsheets ultimately led us to use Ackermann control arms of 3.94” in length with an initial angle of 68 degrees, as shown in the spreadsheet calculations in Appendix A. A schematic of this design is shown in Figure 23 below:

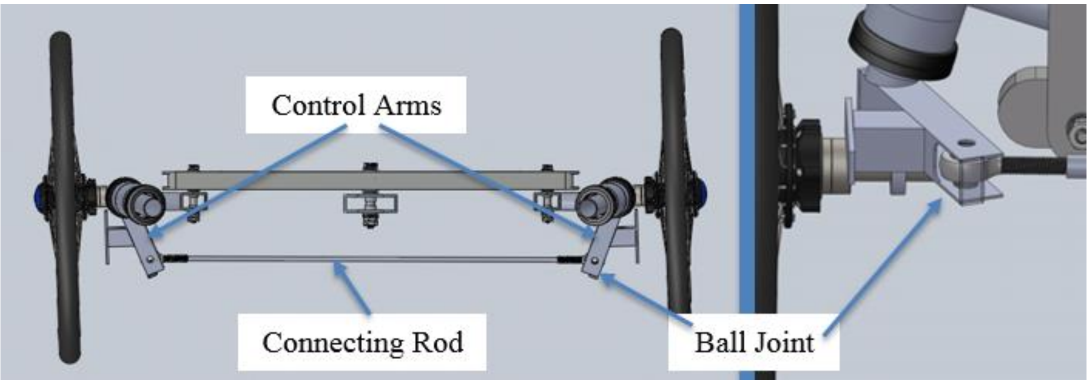


Figure 23: The control arms, the connecting rod, and the ball joint that enables the Ackermann steering system to be able to tilt.

Kingpin Axle Design

Also important in designing performance steering is the placement of the kingpin axle in the design. The kingpin axle is the axle about which the wheel pivots in order to make a turn. For proper steering geometry, it is important to have the kingpin axle angled slightly ahead of the wheel axle. When a vehicle is turning, centrifugal forces pull the vehicle towards the outside of the turn. A reaction force counters this centrifugal force, and is the result of friction between the wheel and the ground. When the kingpin axis is placed in front of the wheel axle, there is a resulting torque which is the product of the perpendicular distance between the axles and the reaction force. There are two ways of placing the kingpin axis ahead of the wheel axle: placing the kingpin horizontally in front of the wheel axle and angling the kingpin away from the axle at what is known as a caster angle. (www.eng.uah.edu) These geometries are described in Figure 24 below:

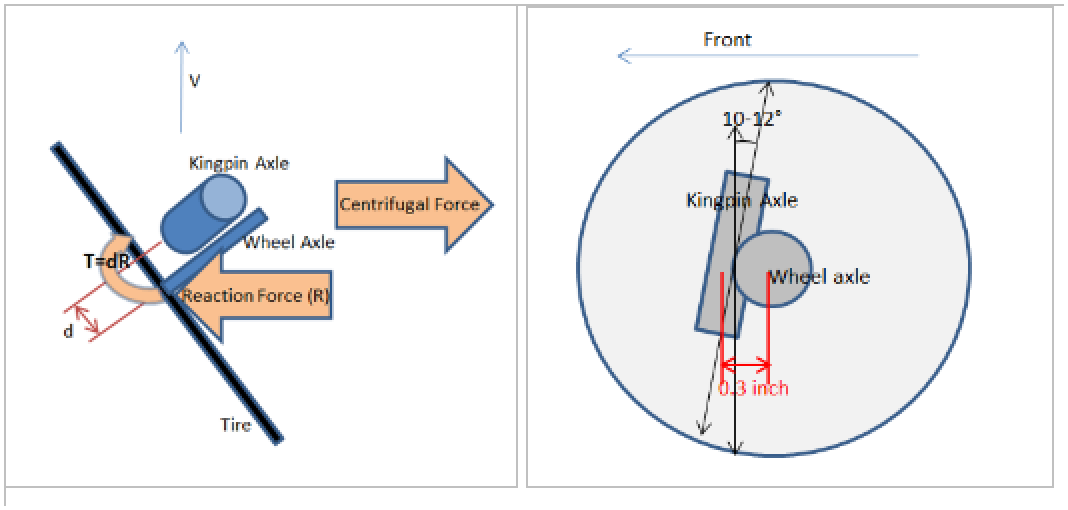


Figure 24: The diagram on the left represents the placement of the kingpin in front of the wheel axle and the stabilizing torque created while the wheel turns around a corner. The diagram on the right demonstrates the positive caster angle. (www.eng.uah.edu)

The importance of this torque is that it pulls the wheel back towards center during turning. This creates a stable steering setup that gives the user firm control over how much the vehicle turns. For our design, we ended up using a horizontal displacement of 0.3 inches and a caster angle of 12 degrees.

Besides the caster angle, the angle of the kingpin axle as viewed from the front of the vehicle is important in reducing friction. A wheel rotating about a kingpin creates a large amount of friction (known as scrub) at low speeds. By placing the kingpin such that the distance the tire must move to make a turn is minimized, this friction can be greatly reduced. (Horwitz) Angling the kingpin to reduce this low-speed turn friction is shown in Figure 25 below:

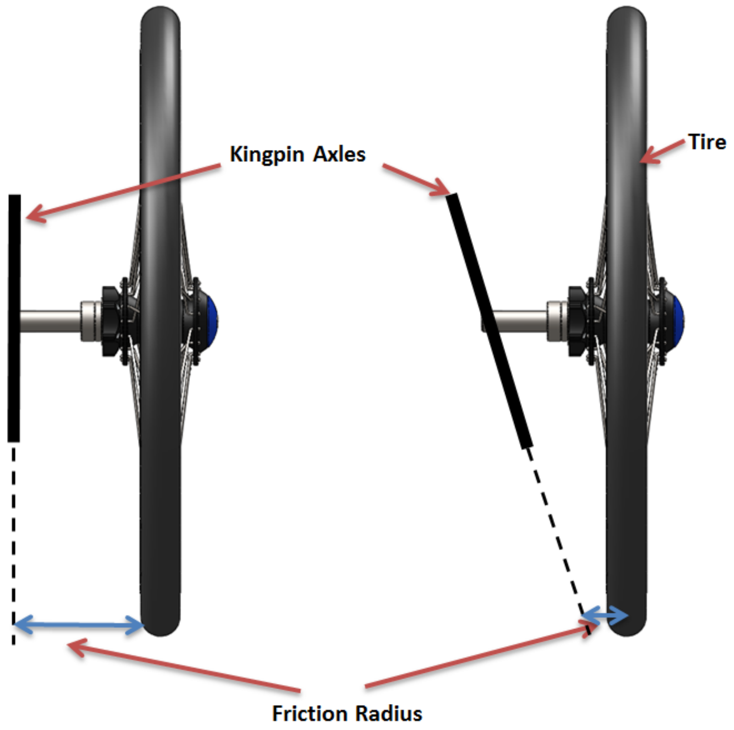


Figure 25: The figure above shows a diagram of two kingpin angles. The left diagram shows a vertical angle and the large amount of friction radius that results. The right diagram shows an angled kingpin and the reduced friction radius.

For our design, we used a kingpin angle that intersects the point where the front tires touch the ground. This leads to a friction radius of approximately zero (there is still a small amount of scrub due to the wheel pivoting about the point).

Tilt Steering Design

The idea of our tilt steering system, although it did not pan out, was accomplished by a collapsible parallelogram with the wheel axles attached to the short sides of the rectangle. Tilting into a turn can be accomplished by either leaning the body of the rider into the turn, or by shifting the handlebars to cause the tilt system to rotate. The design of this tilt system can be seen in Figure 26 below.

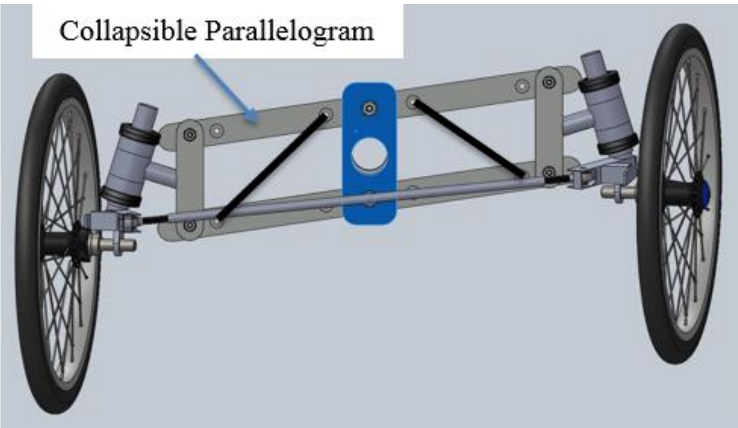


Figure 26: The Tilt steering design with labeled gas springs and parallelogram geometry.

There are two major benefits to tilt steering. The first is that leaning one’s body into a turn reduces the height of the center of gravity of the vehicle by a factor of cosine, with being the tilt angle of the wheels from vertical. The height of the center of gravity is the main factor in determining at what turning force the vehicle will flip over. The second benefit is that the wheels are angled in such a way that the resultant force on the wheel from the lateral friction force and the vertical weight reaction force is placed directly in line through the wheel axle (Starr), as shown in Figure 27 below:

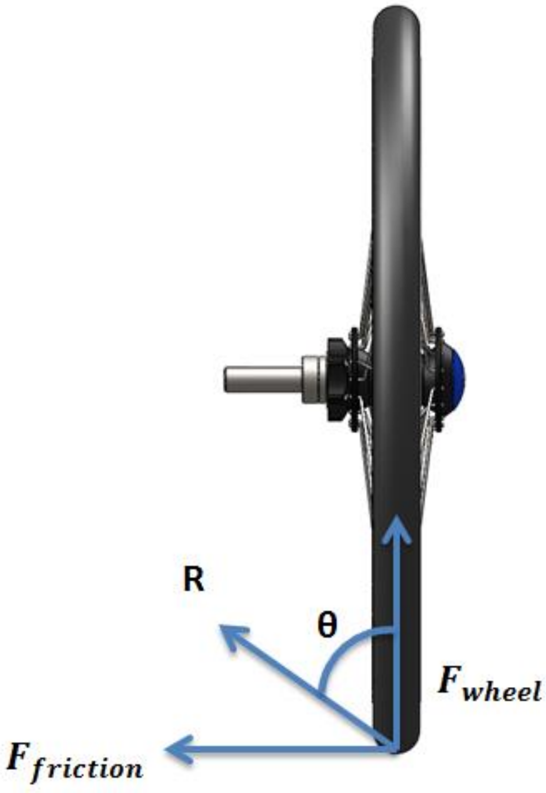


Figure 27: The resultant force vector on a wheel due to centripetal acceleration and vehicle weight. (Starr) In this case, the vehicle is making a turn to the right.

If the vehicle is making a turn, there will be a friction force that is equal and opposite to the centripetal force pushing the vehicle outwards. The only time when this is not the case is when the vehicle experiences a loss of traction due to friction forces being too low to counteract high velocity turns. There is also a vertical force on the wheel, which is simply the reaction force to the vehicle's weight. The resultant of this lateral friction force and vertical weight force can be calculated, and the angle of this resultant is found as shown in Equation #### below.

$$\theta = \tan^{-1}\frac{\frac{mv^2}{3R}}{F_{wheel}} \qquad (\$\$\$\$)$$

The resultant angle is dependent on the vehicle's weight, velocity, and radius of turn. If a tire is set at this angle, then all of the force will be directed straight through the axis of the wheel. This improves performance because forces that are perpendicular to the wheel, such as the friction force in Figure 27 above, cause the wheel to deflect. This reduces the wheel stiffness and thus the performance of that wheel as well. Thus having the wheels tilt enhances performance by increasing the stiffness of the tires while also reducing the height of the center of gravity.

3.2.3 Steering Analysis

Steering FEA Analysis

The objective for this analysis was to determine the strength of the tilt steering assembly while a rider was sitting on the vehicle. A load case for a rider creating a 600 lb weight load was simplified as two forces split between the two axle supports on the assembly. A rider was assumed to have a weight of up to 300 lbs, and then this force was doubled to account for unforeseen circumstances. During the FEA analysis, it was found to be easier to split this weight load between the two ends of the steering assembly and fix the central column rather than have the load incident on the central column.

Abaqus/CAE analysis of the assembly was simplified by treating the entire assembly as one part and varying the geometry of the individual parts using beam profiles. A constraint was specified along the central bar in the x, y, and z directions, since we knew that the design of this piece was to be welded to the main frame. The ends of the steering assembly were constrained in the x direction. The tilt steering bars were defined with Aluminum 6061 T6 properties, and the fastener rods were defined with stainless steel properties.

Results of Tilt Steering Analysis

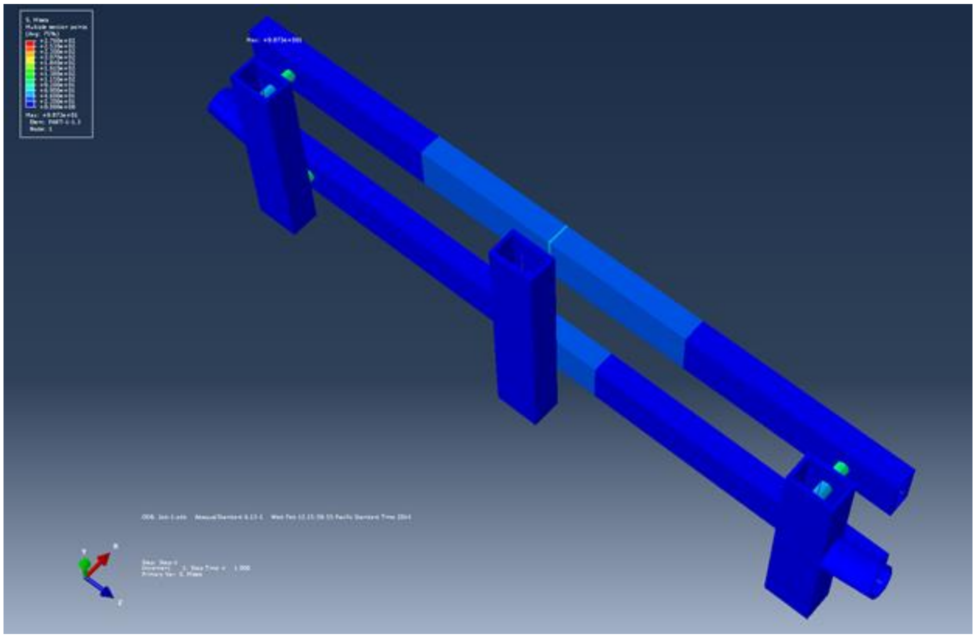


Figure 28: The FEA results for a 600 lb rider applied on the tilt steering mechanism.

Table 8: The Mises and max principal stresses for the tilt steering due to a rider load of 600 lb.

	Mises Stress	Max Principal Stress	Yield Stress of Stainless Steel
Seated Rider (600 lb)	14.21 ksi	13.49 ksi	31.18 ksi

The results of the analysis concluded that the maximum stresses in the assembly would occur in the fasteners and bearings that held the tilt steering bars together. This maximum stress in the fasteners came out to be 45% of the yield stress for stainless steel, showing that in the case of a 300 lb rider the steering mechanism has a factor of safety of 4.3. This suggests that the tilt steering mechanism is structurally sound. Our design team concluded that this stress is acceptable in our design. The only notable stresses in the Aluminum beams occurred in the top and bottom lateral bars in their mid-sections.

Design Modifications

From these results, it was concluded that smaller fasteners could be used in the design. This helped reduce the weight of the components in the steering assembly.

3.2.4 Steering Mechanical Description

The tilt steer system was built using four rectangular tubes formed into a parallelogram. A central rectangle was used to connect this parallelogram to the main frame. At each connection point a pivot was created by running a stainless steel shoulder bolt through press-fit bushings. Two gas springs were positioned in the parallelogram to keep the assembly stable at low speed. On each side of this parallelogram the kingpins were attached. The steering columns were allowed to rotate by the placement of bicycle headsets on the top and bottom of the kingpin outer shell. The Ackermann steering was accomplished by an aluminum rod linking the two steering axes. The connection was allowed to rotate due to a high clearance rod end bearing at each end of the Ackermann rod. The Ackermann steering and kingpin mechanisms are shown in Figure 29 below:

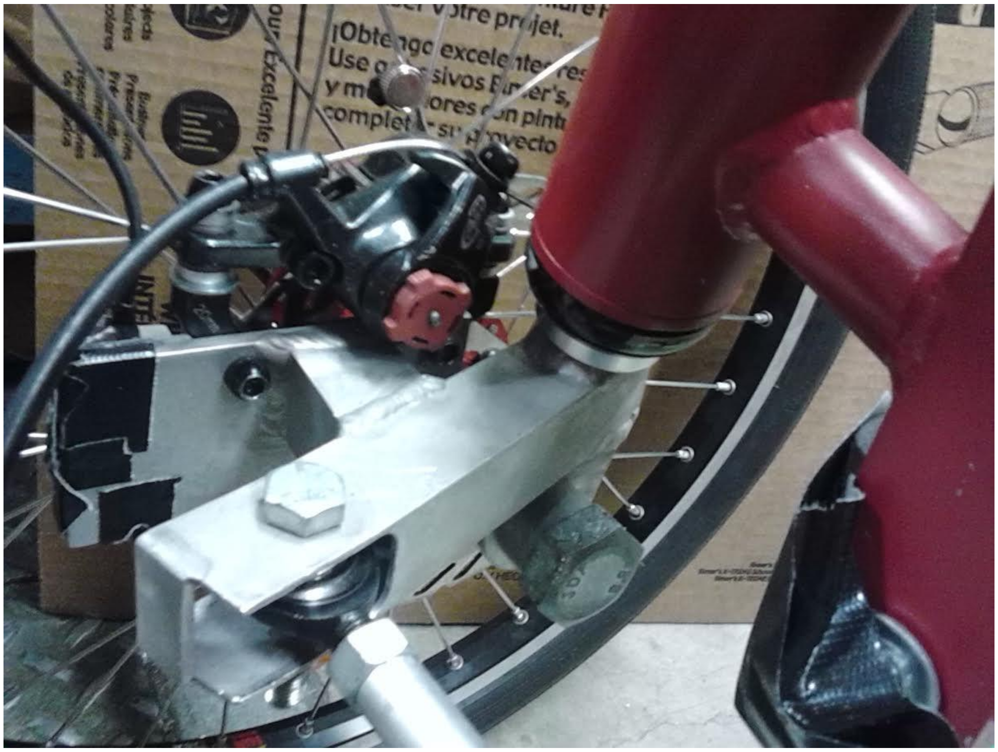


Figure 29: The Ackermann steering and kingpin axle mechanisms

3.2.5 Steering Test and Verification

However, as mentioned earlier, the team decided to block out the tilt steering by wedging wood blocks into the parallelogram during the ASME competition. This decision was ultimately made because after initial testing we found that the Ackermann steering and tilt steering would conflict with each other. This is due to the need for wheels to be parallel with each other while turning for tilt steering but for Ackermann steering the angle of each wheel has to be slightly different. This difference in angles caused a great deal of scrub friction as the rider attempted to make a turn. This scrub friction caused the front wheels to "skitter" or temporarily lose traction making the vehicle hard to control. Besides the scrub friction problem, the riders found it difficult to control both steering systems; the tilt would occasionally lean in the opposite direction that the Ackermann steering was pointed. Due to these unforeseen difficulties we had to immobilize the tilt steering so that our vehicle would still be fully functional for the competition, as shown in Figure 30 below:

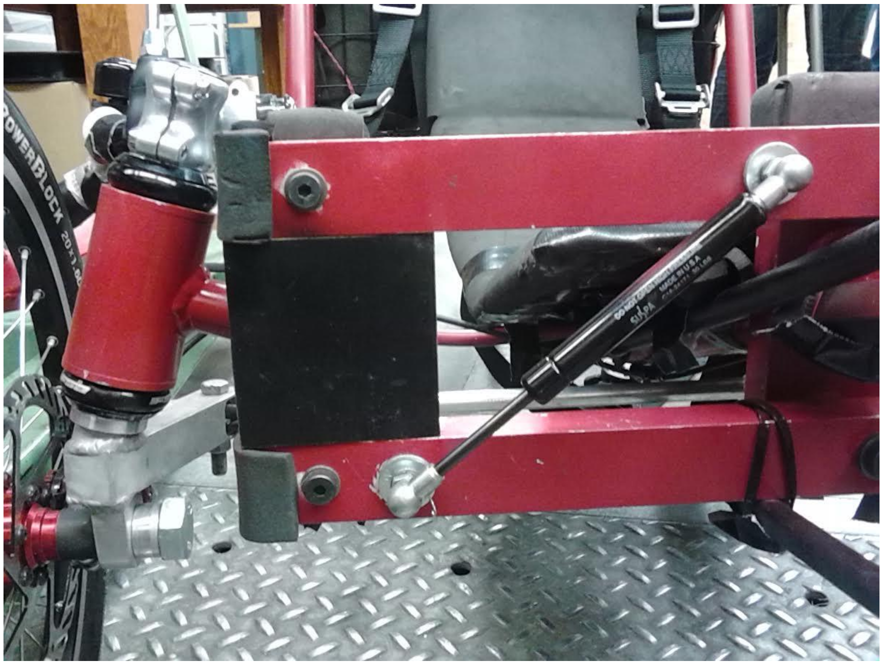


Figure 30: A picture of the tilt steering system, with the tilt blocked out.

Looking ahead there are a few ways that we could improve our design so that it would function properly. One way would be to create a mechanism that would immobilize one steering system while the other was in use. This way the user could choose either Ackermann or tilt steering depending on the speed of the turn. A second possibility would be to create a mechanism that would linearly couple the two mechanisms so that they would be equally engaged and allow the user greater control. We hope to implement one of these mechanisms in the future.

3.3 Aerodynamic Design

3.3.1 Aerodynamic Background

The fairing for our human-powered vehicle provided both a method to protect the rider from the elements as well as a way to reduce the vehicle's aerodynamic drag. During the research and design phases, it was evident that the fairing design was extremely flexible in regard to requirements, specifications, and variable geometries.

3.3.2 Aerodynamic Design

For the aerodynamic device requirement of the competition, our team decided to incorporate a frontal fairing. The concept of using a fairing is to sweep air around the vehicle, ultimately cutting through the air in the front and reducing the aerodynamic drag. The front fairing that we chose was an elongated teardrop fairing made of LEXAN polycarbonate. The fairing has overall dimensions of 17 inches at the widest point by 40 inches long with a depth of blow of 9 inches. The fairing is held in place with an attachment at the end of the bottom bracket. The frontal fairing attached to the finalized frame design is depicted in Figure 31 below:

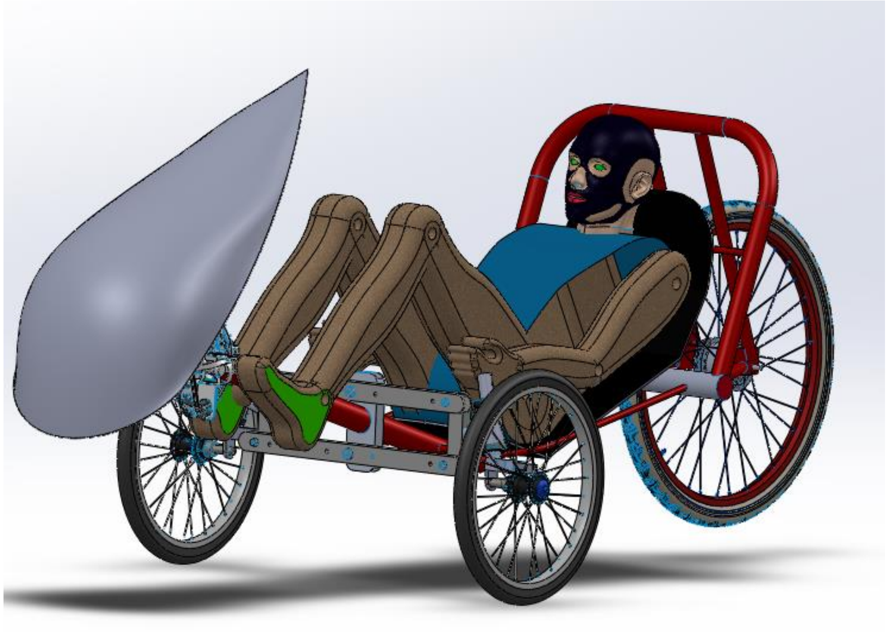


Figure 31: Placement of the fairing on the vehicle. This Solidworks model was used to perform CFD analysis.

Initially, our plan was to use a full body fairing. However, we ultimately decided to go with solely the frontal fairing due to limited manufacturing processes and budget constraints. This choice allowed us to take the most important piece of the full body fairing for aerodynamic purposes while not requiring the full expense, weight, and difficulty of manufacturing for a full body fairing. Given that we designed our vehicle for a commuter, we believe that our solution is more practical for entering and exiting the vehicle.

3.3.3 Aerodynamic Analysis

Computational Fluid Dynamic (CFD) analysis was performed on the front fairing, vehicle, and rider assembly using STAR CCM+ software. The objective of this analysis was to determine the drag coefficient of the full frame assembly to determine its viability (in terms of top speed, a criteria we considered important for a commuter vehicle). It was assumed that the fluid velocity was 30 mph, a good estimate for the top speed of the vehicle. Two different potential fairing choices from our supplier, Zzipper Road Fairings, were analyzed to compare their effectiveness in improving the vehicle's aerodynamics:

Table 9: The dimensions of the two fairings analyzed with CFD

Fairing Type	Length (in)	Width (in)	Depth (in)	Images (provided by Zzipper)
Maximum width rectangular	44	21	12	
Large Teardrop	40	17	9	

The resulting solution for the coefficient of drag using STAR CCM+ is shown in Figure 32 below for the 21” by 44” fairing.

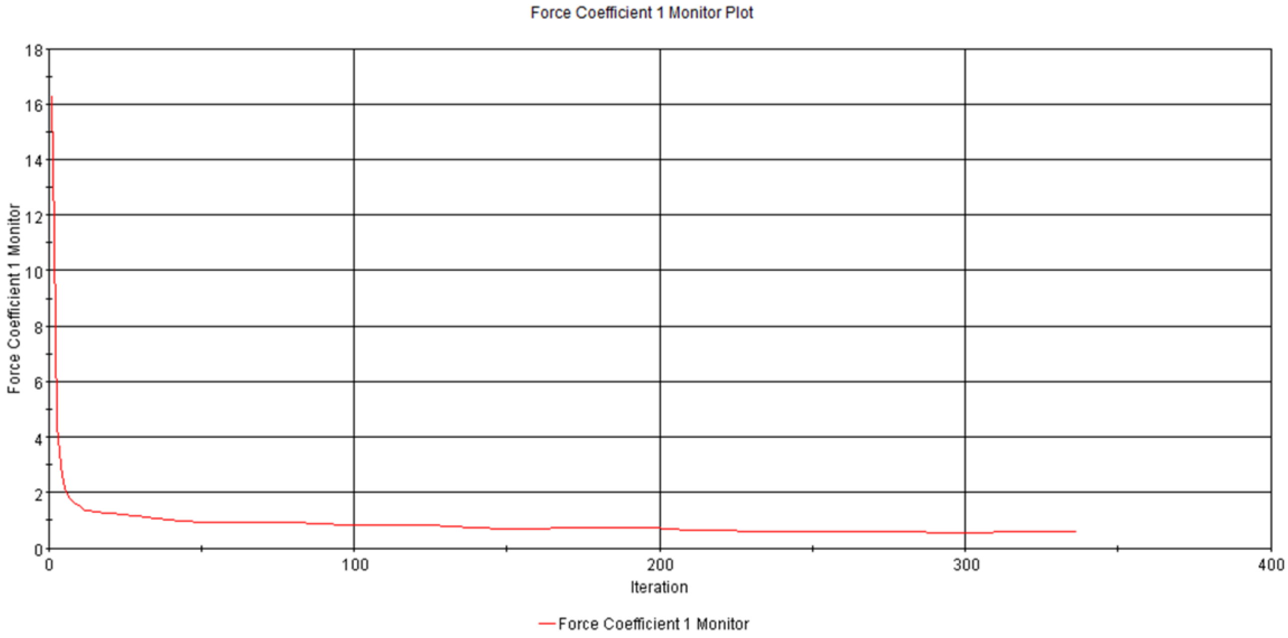


Figure 32: Iteration in CFD for the coefficient of drag of the maximum width rectangular fairing. The drag coefficient was found to be 0.595.

The final coefficient of drag for our vehicle with the maximum width rectangular fairing was 0.595. This value was obtained over approximately 350 iterations. The program used a model imported from Solidworks of the vehicle with fairing and rider. From this model, a rough surface mesh was created to define where the air would move about. A wind velocity of 30 mph was defined as coming head-on at the vehicle. These assumptions allowed us to arrive at an approximate drag coefficient for the vehicle.

For comparison, a CFD solution was also obtained for the vehicle with the teardrop shaped fairing. The result of this analysis is shown below in Figure 33.

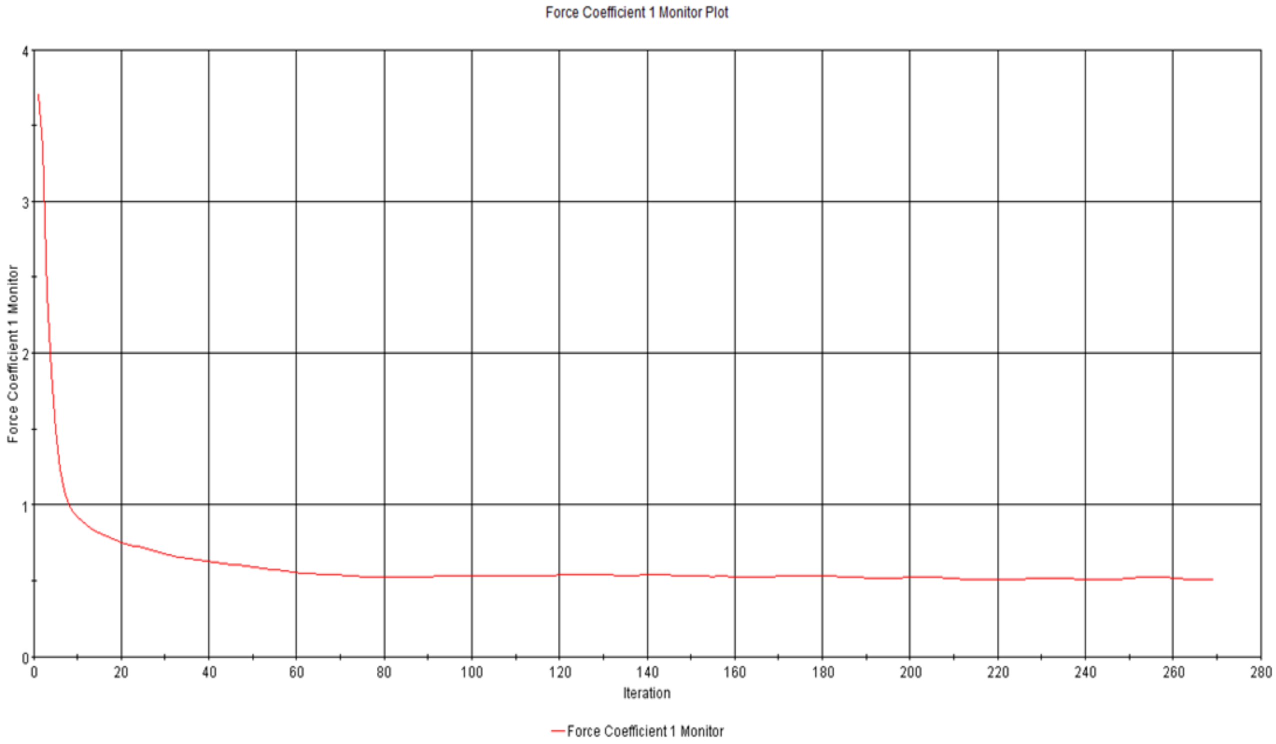


Figure 33: Iteration in CFD for the coefficient of drag of the teardrop shaped fairing. The drag coefficient was found to be 0.506.

The final coefficient of drag for our vehicle with the teardrop shaped fairing was 0.506.

Our final vehicle design used the teardrop shaped fairing due to its reduced drag coefficient when compared to the rectangular fairing. For comparison, the typical upright bicycle has a coefficient of drag of 1.1 while a typical recumbent tricycle without a fairing has a coefficient of drag of 0.77 (FloCycling). This shows that the inclusion of a fairing provides a significant improvement in aerodynamic drag. This frontal fairing helped our team to reach the top speed of 22.5 mph.

3.3.4 Aerodynamic Mechanical Description

The aerodynamic device used for our vehicle was a teardrop shaped frontal fairing made of LEXAN polycarbonate. This fairing was attached to the vehicle using Aluminum fixtures at two points: one off of the front of the boom and one off of the top of the boom. These fixtures were held in place using hose clamps tightened with a screwdriver. The fairing setup is shown in Figure 34 below:

Figure 34: The aerodynamic device used for the competition

3.4 Drivetrain

3.4.1 Drivetrain Background

The drivetrain for our HPV is the system that transfers the human power of the rider into motion for the vehicle. Most drivetrain systems implement gearing to grant a larger speed range with minimal effort. During the design phase, the drivetrain was the last subsystem we focused on for the vehicle due to the time spent on the redesign work for the axle tabs. Initially, we wanted our drivetrain to grant us a top speed in the range of 25 to 30 mph. The design and implementation of the drivetrain was functional for the competition; however, this design did not meet our expectations during competition due to issues with friction and derailment of the drivetrain. After the competition, these issues were modified and resolved in the final design.

3.4.2 Drivetrain Design

The initial design of our drivetrain included a bike chain, a front gear, a rear internal hub, Teflon tubes to guide the chain, and an idler to guide the chain at an angle. The bike chain needed to be long enough to reach from the front gear to the rear internal hub while simultaneously providing the right amount of tension in the chain. Drivetrains for bikes have a tendency to stretch over extended use, decreasing the amount of tension in the chain and increases the chance of derailment. Shifting gears in the internal hub also varies the tension in the drivetrain. To resolve this issue, a recycled chain tensioner was added to the design at the rear wheel. Bungee cords were added to the tensioner to add more tension in the chain. This tensioner created the necessary tension required in the drivetrain as the slack in the chain varied from shifting gears from the internal hub, as seen in Figure 35 below. However, during the competition, this recycled chain tensioner added unwanted friction in the drivetrain. As a result, changes were made post-competition to the drivetrain.

Figure 35: Images of how the chain tensioner was set up in the SCU HPV.

The sizing of the front gear of the vehicle is an important consideration for top speed. In bike design, a larger front gear with more teeth with a smaller rear gear equals higher speeds. Our team wanted to use a rear internal hub combined with a single front gear. In last year's bike, the vehicle used a 34 tooth front gear and achieved a top speed of 21 mph. Knowing that a larger gear grants a higher top speed, we decided to implement a 52 tooth front gear. If the 52 tooth gear was incorporated into last year's design, the gearing ratios would have theoretically granted a top speed of 26 mph. An image of the front gear can be seen below in Figure 36:

Figure 36: An image of the 52 tooth front gear for the SCU HPV

The rear internal hub is a system on a bike that can shift gears without the need for a derailleur because all of the gearing and shifting is done internally within the hub. Our team wanted to use an internal hub to avoid potential derailments with a conventional bike derailleur due to the issues discussed in our drivetrain. Not only did this system address the issues with derailment, but it was also easy to implement into our design. A conventional bike derailleur system requires a tensioner, a derailleur, and a rear hub with multiple gears, which would have made the design difficult and taken more time to implement than an internal hub.

The Teflon tube for our drivetrain was used to guide the chain through the tilt steering assembly. The Teflon tube prevented the chain from rubbing on the tilt bars when the tilt was active, meaning the chain would rub against the inside of the Teflon rather than the tilt bars themselves. However, once it was decided that the tilt steering of our vehicle would be locked, we realized the Teflon tube was creating unnecessary friction as well as issues with derailment when the drivetrain went in reverse. An image of the Teflon tube implementation can be seen below in Figure 37:

Figure 37: An image of the Teflon tube guides through the tilt steering assembly of the SCU HPV

The idler is a pulley system that helps guide the tension in the drivetrain at an angle while minimizing friction. An idler was needed at the bend at the base of the frame to guide the chain from the front crank to the rear internal hub. During the competition, issues were encountered where the chain made no contact with the idler. This meant that not only was the tension in the drivetrain loose, but the chain was making undesired contact with other sections in the drivetrain, creating much more friction than there would be with the chain just in contact with the idler. The idler used during the competition had the return and drive sides of the idler spin the same direction. This created unnecessary friction and prompted us to buy a different idler with independently rotating sides. An image of the initial idler set up can be seen in Figure 38 below:

Figure 38: This is an image of the idler used on the SCU HPV.

3.4.3 Drivetrain Analysis

Due to the time spent on the redesign work for the axle tabs, the analysis for the drivetrain was limited. The first round of analysis consisted of calculating the force of tension throughout the drivetrain based on a rider applying a 150 lb force on the pedals at 90 rpm. This analysis concluded that the majority of the losses would occur at the idler due to the normal force generated by the idler on the chain. Forces in the drivetrain were calculated for a 34 tooth front gear and a 52 tooth front gear. Some assumptions for this analysis included….. These results were used to determine the top speed of the vehicle for each front gear size. An image of these calculations can be seen in Appendix A.

The speed at each gear for the rear internal hub was calculated for both the 34 tooth gear and a 52 tooth gear. The goal of this was to determine the top speed for each front gear to decide which front gear to use. For each front gear the assumption was made that the rider was applying 150 lb force at the pedals at a speed of 90 rpm. These assumptions were used to determine the power generated by the rider at each gear. With these results, we calculated and compiled the speed based on the gear ratios of the internal hub. Loses due to air drag and wheel friction were incorporated into the calculation. The top speed for the 34 tooth gear was calculated to be 21 mph, which is consistent with last year's vehicle. The top speed for the 52 tooth gear was calculated to be 26 mph, verifying that the larger front gear would yield higher top speed. This calculation also determined the benchmark value for our top speed.

3.4.4 Drivetrain Mechanical Description

As discussed in the design section, the major drivetrain subsystems were the bike chain, the front gear, the rear internal hub, the Teflon tube, and the idler. The only changes to the design were the addition of a new idler, the removal of the chain tensioner, and reorientation of the Teflon tube. All of these redesigns were done to reduce the friction in the drivetrain. Replacing the old idler with the new idler allowed for the removal of the chain tensioner due to the new idler's chain-stay. With this chain-stay, the chain is kept close to the idler and prevents derailment of the system while reducing the amount of friction. The readjustment of the Teflon tube reduced the amount of internal rub the chain had with the Teflon, reducing friction as well as potential derailment in reverse. These final design changes can be seen in Figure 39 below.

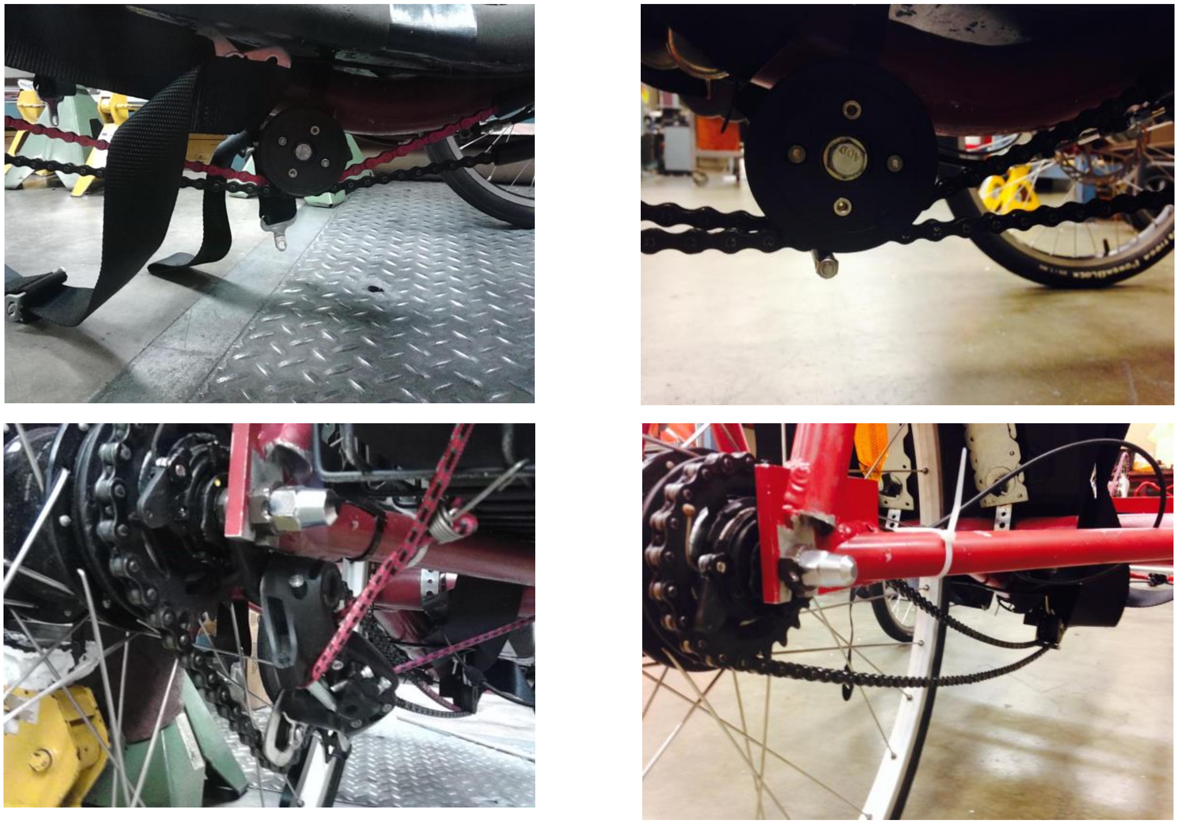


Figure 39: An image of the redesign work done on the drive train following the competition. The left images show the idler and chain tensioner set up going into the competition. The right images show the results of the redesign with the addition of the new idler with the chain stay.

3.4.5 Drivetrain Test and Verification

The drivetrain test before the redesign showed multiple spots were friction happened in the chain tensioner, the idler, and the Teflon tube. With these frictional losses the vehicle was able to achieve a top speed of 21 mph. As discussed earlier, multiple redesigns were made to the drivetrain to reduce friction. However, due to time constraints a full re-test of the vehicle with re-designed drivetrain was not able to be completed by the time of this report.

4. System Integration

4.1 System Integration and Test Prototype

To test some of the subsystems of our vehicle we decided to create a simple HPV prototype made out of PVC pipe. The PVC pipe prototype modeled both the steering and the frame of the vehicle. The prototype included approximate steering sizing of both Ackermann steering and tilt steering. In this PVC model the tilt steering mechanism that we created was able to tilt the entire frame of the vehicle which was helpful in illustrating how the steering axles will respond to changes in tilt. Additionally, the Ackermann steering mechanism was also implemented to verify its design. To model the Ackerman and tilt steering, 2”x4” wooden planks were cut to the right dimensions and then screwed together in such a way as to represent what the final steering geometry will look like. Duct tape was used mainly to make the connections of the design at the necessary angle, and to allow the dynamics of the Ackermann steering to be illustrated. Figure 40 shows a couple of different images of our prototype.

Besides testing the steering of the vehicle, the PVC prototype was used to verify the sizing of the vehicles seat, roll protection system and the distance of the rider to the pedals. The prototype was a full scale model of our design and was compared against all of the riders to ensure their comfort and safety.

At this stage of the design it seemed that incorporating both tilt and Ackermann steering would be possible. We learned later from the final prototype that the two systems could not be used in the design as intended. This issue was only determined after the weight of the rider was in the vehicle. The PVC model was able to show how both the tilt and Ackermann steering moved but because it could not hold a rider the steering design issue could not be observed. Even with the limited scope of the PVC prototype, it was a good way for our team to visualize and check the sizing of the vehicle before continuing to manufacturing our final prototype.

Figure 40: HPV PVC prototype illustrating Ackermann/tilt steering and frame geometry.

4.2 Axle tab redesign

One important design feature in the design of our vehicle was the axle tab. The axle tab is the tab connected to the steering handle assembly that holds the front wheel axle. In the first round of testing with a rider operating the tilt, these axle tabs began to show signs of yielding by warping. An image of what the axle tabs design before and after yielding can be seen in Figure 41 below:

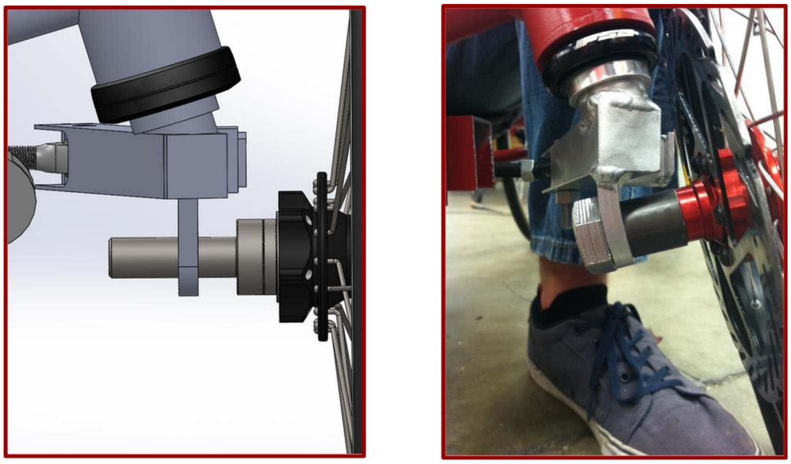
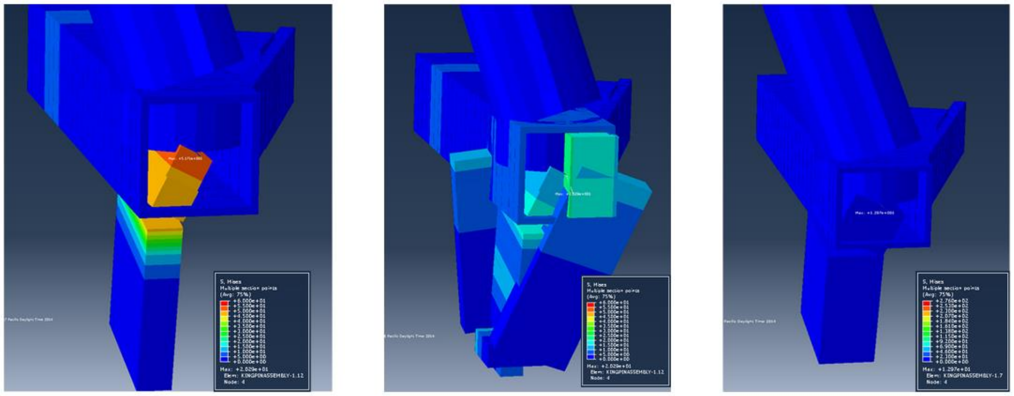


Figure 41: This is an image illustrating the failure of the initial axle tab design. The image on the left shows the axle tab design before failure. The image on the right shows the axle tab warping from the tilt steering testing of the vehicle.

This failure was a result of the unforeseen bending stresses in the axle tab. Further analysis showed that these bending stresses exceeded the yield strength of the aluminum after welding. Two redesigns were considered as replacements. The first redesign was a gusset tab design suggested by our welder. The design was similar to the first; the only difference was the addition of gussets to the tab's sides. These gussets act as a wedge between the steering assembly and the tab, distributing the bending stress from the vehicles tilt throughout the gusset. The second redesign was a thickened axle tab, which had double the thickness. This design increases the area moment of inertia, which decreases the bending stress throughout the entire tab. The analysis of these designs can be seen in Figure 42 below:



Initial Axle Tab Design

- Aluminum 6061-0
- Factor of Safety .95
- No Heat Treatment

Gusset Tab Design

- Aluminum 6061-0
- Factor of Safety 2.75
- No Heat Treatment

Thickened Axle Tab Design

- Aluminum 6061-T6
- Factor of Safety 21.4
- Heat Treatment

Figure 42: This is a figure showing the various designs for the axle tab

At first we went with the gusset tab design since we were short on time and our contract welder said it could be done in a day. However, testing with this design showed signs of cracking at the welds even though the tabs did not yield when the part was submitted to the tilt steering test. After observing this we decided to go with the thickened axle tab and heat treat the whole assembly, which would strengthen the tab as well as the welds. This final design proved to be successful.

4.3 Experimental Protocol and Results

In Table 10 below lists the tested braking distance, turning radius, top speed, and endurance of the vehicle are listed.

Table 10: The tested braking distance, turning radius, top speed, and endurance of the vehicle are listed.

Test	Measure
Braking Distance	9.84 ft from 15mph
Turning Radius	7.71 ft
Top Speed	21.5 mph
Endurance	21.7 miles in 2.5 hrs

Braking Distance

The vehicle came to a stop in 10 ft during the ASME competition safety test. This was done while traveling at 15 mph. For comparison, the required minimum stopping distance was 20 ft.

Turning Radius

The vehicle had a turning radius of 7.71 ft, which was well below the ASME requirement of 26.25 ft. This was measured by passing a cone then turning around it and measuring off of the inside wheel of the trike.

Top Speed

The top speed of the vehicle was 21.5 mph, as measured on the velodrome during the competition. The speed was achieved by taking a half lap on the velodrome to get up to speed and then measuring the time it took to cover the second half of the lap to get the top speed. A half lap on the velodrome was approximately 541 ft. Our final men's speed at the competition was 21.5 mph and the final women's speed was 14.3 mph.

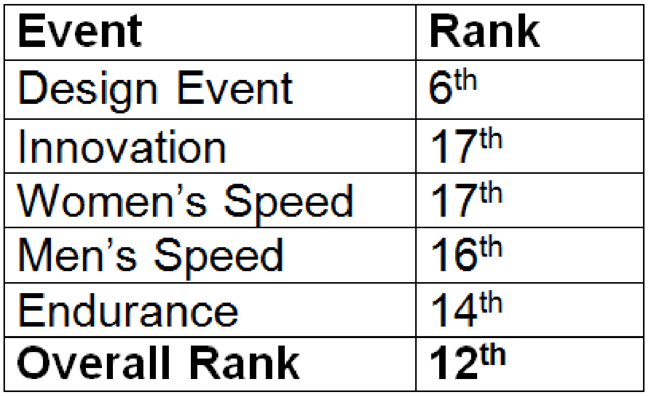
Endurance

The ability of our vehicle to travel efficiently over long periods of time was tested during the endurance competition. This portion of the races had various obstacles such as speed bumps and slaloms along the way. It also required multiple rider change-outs. We ended up traveling 21.7 miles in the allotted 2.5 hours.

4.4 Race Results

The overall results for all teams that entered in the ASME competition can be seen in the Appendix F. Our team achieved an overall rank of 12th out of 26 teams. The scores in each of the individual events can be seen in Table 11 below:

Table 11: The rankings for the SCU team in each of the ASME competition categories.



Event	**Rank**
Design Event	6th
Innovation	17th
Women’s Speed	17th
Men’s Speed	16th
Endurance	14th
Overall Rank	**12th**

Our top speed on the velodrome of 21.5 mph placed 16th in the men’s speed event and our top women’s speed of 14.3 mph placed 17th in the women’s speed event. In the endurance event our team placed 14th with our team doing the best in the design event with a 6th place finish. Our team is pleased with our placing in the design event as this event was the event we wanted to do the best. We believe that the scores in the different racing events would have been greatly improved with some slight changes made to the drivetrain.

5. Cost Analysis

For this project, balancing the budget of the design was crucial to its success. It was essential we maintained detailed records of all expenses for the project to ensure the funding that was generously given to us was enough. After applying for a series of grants we were able to obtain $4000 to design our vehicle from the Center of Science, Technology and Society grant as well as the Undergraduate Engineering grant.

The majority of our expenses were categorized into four main sections: Welding and Manufacturing, Fairing, Competition Costs, Components and Materials. Our welding, cutting and tube bending was done at Chavez Welding for $1,468. The reason why we decided to go with an outside contractor was because we were not able to train our members to weld Aluminum in time to manufacture and we did not have the shop capabilities to cut and bend some of the portions of the frame components. We decided to go to an outside contractor Zzipper for our frontal fairing and mounting system. The cost of these aerodynamic components came out to be $571. Some of the costs that we incurred were from the attempts to fabricate a carbon fiber tail box. We were unable to make a carbon fiber tail box that would be light enough to actually improve the aerodynamics of our vehicle. The competition costs were a team entry cost, a member entry cost, and the HPVC awards banquet ticket costs for a total of $385. The rest of the components and materials that we purchased came out to $1,430 this does not include the cost of components that we recycled from last year. Our total budget came out to be $3,854 which was under our budget of $4,000. The full detailed budget can be seen in Appendix D.

6. Business Plan

Introduction

It is one task to design a product that analytically excels on paper; however, it is a completely different task to engineer a product that thrives in the market for customers. Our team has already engineered an excellent product with promising potential, but it requires a systematized business plan to encourage consumers to buy our product. First of all, we must listen to the needs of the consumer. We accomplished this by sending out a customer survey, as well as interview a few experts in the field. This gave us a general idea as to what people want in terms of bicycles and commuter vehicles and how to transform their necessities into a working product. Through the implementation of our market analysis, we were able to determine that a GPS system, pedal assist, and vehicle safety were primary concerns and features that our target audience desire in a human powered vehicle.

Goals

- Reach a market share of 1.5% of the 2% market share that recumbent bicycles have in the total bicycle industry
- Reach our calculated Return On Investment of 30%
- Reach our calculated Internal Rate of Return of 15.3%

Objectives

- Broaden our manufacturing capabilities through purchasing the Capital needed for large scale manufacturing
- Hire a Project Manager with expertise in large scale manufacturing projects
- Hire contractors for Analysis and designers to assist the design and redesign of our vehicle.

Product Description

The product attempts to become a realistic alternative to a car. Thus, it is paramount that we cut our costs to the consumer while producing a reliable and worthwhile product for the consumer. We can limit our costs through our manufacturing process of smaller quantities and with less machining. Usually bicycles have to be fitted to a certain sized rider. Our HPV will be able to accommodate a more broad range of riders and will essentially cut down on the cost of machining different sized models. Our design team is determined to target multiple customers by incorporating many features that would be easy to implement, but also specifics that would make our product more consumer friendly. Through our market analysis we were able to determine that GPS system, and Safety were all main concerns that our target audience would have.

The potential markets for our vehicle would be for customers that frequently commute an average of 20 miles daily. Our company would start at a smaller scale calculated based upon the manufacturing time and costs for our vehicle this year. We would then like to broaden our company to reach most of the West coast through purchasing the capital required to start a manufacturing plant.

Our primary competition would be Catrike and similar three wheeled recumbent tricycle vehicles. Their company has multiple models for customers to choose from and has distributers all over the USA, parts of Europe, Australia, Indonesia, Korea and Japan. This company model is one that our company Pegasus Industries would like to emulate in the future. The Catrike has won multiple awards for Trike of the year by BentRider Online.

Sales and Marketing Strategies

To amplify publicity for our potential customers, we would have to launch some form of public relations campaign. If our product is to compete with names such as Schwinn, Trek, and Mongoose, our business plan must incorporate a recognizable brand name and logo that will motivate customers to purchase our vehicle design. We have decided to name our company Pegasus Industries. A rough initial sketch of our logo (which will be displayed on our prototype vehicle for the competition) can be seen in Figure 43 below:

Figure 43: A sketch-up of the logo that will be used for our bicycle company.

We believe that the name Pegasus represents our product, goals, and aspirations well. A Pegasus is a mythological creature that resembles a horse with wings. Our vehicle resembles the mythological creature Pegasus in numerous ways. The Pegasus is a majestic, powerful beast capable of carrying a single rider at high speed. The design of our logo is meant to catch the eye with its simplicity and symmetry.

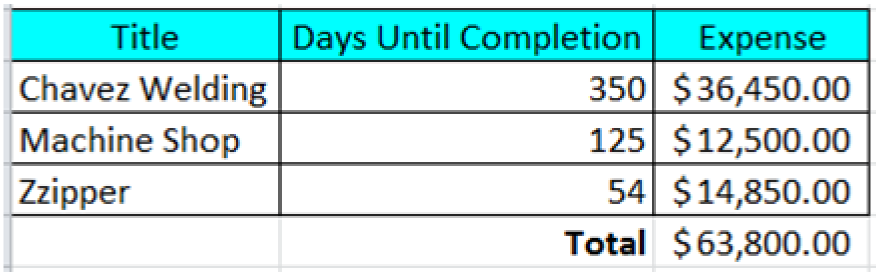
Our customers were identified in the earlier sections of this report. Their needs from our human powered vehicle were taken into account during the design of the vehicle. Pegasus industries will need to pique the interest of these potential customers through a business model that would take our product from our manufacturing location straight to the customer. We would maximize our profits by cutting out the distributer and thus lowering the overall price for the customer. Through ads and appearances at Human Powered Vehicle Challenges around the country we will be able to generate a demand for our vehicle by active involvement within the Biking community.

Manufacturing Plans

Product Cost and Price Summary [Preliminary at Santa Clara University]

Our cost analysis table in Appendix D includes the amount of expenditures for our vehicle this year. The analysis takes into account some of the parts that were recycled from last year's vehicle, but for the purposes of the production costs, we included the costs of all recycled parts into the total cost of materials. For production, the number of human powered vehicles that could be produced was calculated based upon the quote from our outside contractor for one human powered vehicle. It was estimated that 27 HPVs could be fabricated in one year. The steering pieces would be manufactured in the Machine Shop at Santa Clara University. The initial time frame was based upon how long it took our team to fabricate our steering. The fairing and mounting was calculated for 27 vehicles and the timeframe for Zzipper to make and install each fairing would be about two days per fairing. The subsequent calculations were performed based upon the fabrication time our vehicle took this year.

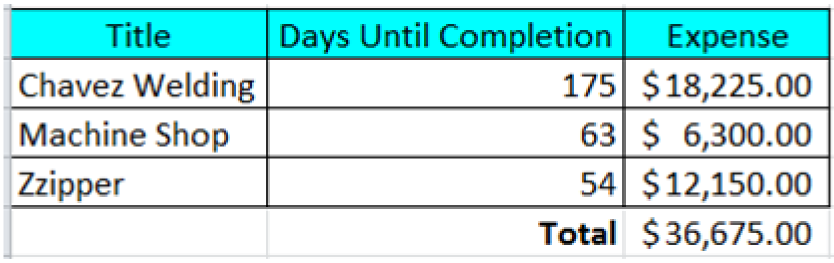
Table 12: Extended production expense for our first year of building for Machine shop steering manufacturing, cutting, bending, and welding at Chavez Welding, and fairing production and installation costs for 27 vehicles.



Title	Days Until Completion	Expense
Chavez Welding	350	$ 36,450.00
Machine Shop	125	$ 12,500.00
Zzipper	54	$ 14,850.00
	Total	$ 63,800.00

The decrease in the yearly costs for production is attributed to familiarity with SCU HPV 2014's design and fabrication process. A reduction in time for our outside contractor, as well as at SCU, is attributed to faster tooling setups and increased speed of production. This would lower our expense for the year per vehicle. Additionally, Zzipper, our fairing contractor may be able to give us a discount due to the size of our order.

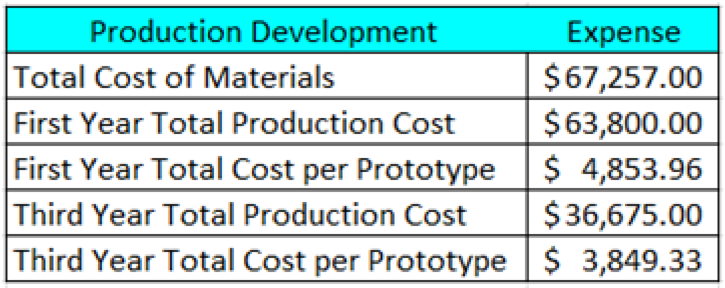
Table 13: Future production cost summary. Due to familiarity reductions in time and costs are projected for the production of 27 SCU human powered vehicles.



Title	Days Until Completion	Expense
Chavez Welding	175	$ 18,225.00
Machine Shop	63	$ 6,300.00
Zzipper	54	$ 12,150.00
	Total	$ 36,675.00

A total cost of materials was assumed to remain the same due to the fact that we priced all of our parts at relatively competitive rates. This is the next area in which our group could reduce costs if we purchased materials in bulk. Table 14 below displays our calculated costs for the first year of production, the cost per prototype for the first year, the costs for the third year of production and the cost per prototype based upon the reduced third year production cost. There is a downward trend in the cost per vehicle due to experience and increased efficiencies. The trend would continue into the future and would eventually allow our vehicle to be much more competitive in the market.

Table 14: Total parts cost for our vehicle applied to the first year production cost and to the future production cost.



Production Development	Expense
Total Cost of Materials	$67,257.00
First Year Total Production Cost	$63,800.00
First Year Total Cost per Prototype	$ 4,853.96
Third Year Total Production Cost	$36,675.00
Third Year Total Cost per Prototype	$ 3,849.33

Our vehicle is designed to provide the customer with the best experience as possible. The vehicle will incorporate an adjustable seat in order to reduce the cost of production and machining of different parts.

Product Cost and Price Summary [Large Scale Manufacturing]

Table 15 and Figures 44 through 46 display the methodology that was utilized in scaling up our business model from our machine shop at Santa Clara University into a large scale manufacturing plant.

Table 15: The table displays the data utilized to calculate a large scale manufacturing development costs and a financial model for a company.

Yearly Data		
Market Size	$6,000	Million
Market Units	18.7	Million Units
Average Price	$321	Average Price
Market Share	2%	
Number of Units	0.374	Million/Year
Market Share	1.5%	Approximation
Net Units	5610	Units/year
Marketing	5%	
Warranty	5%	

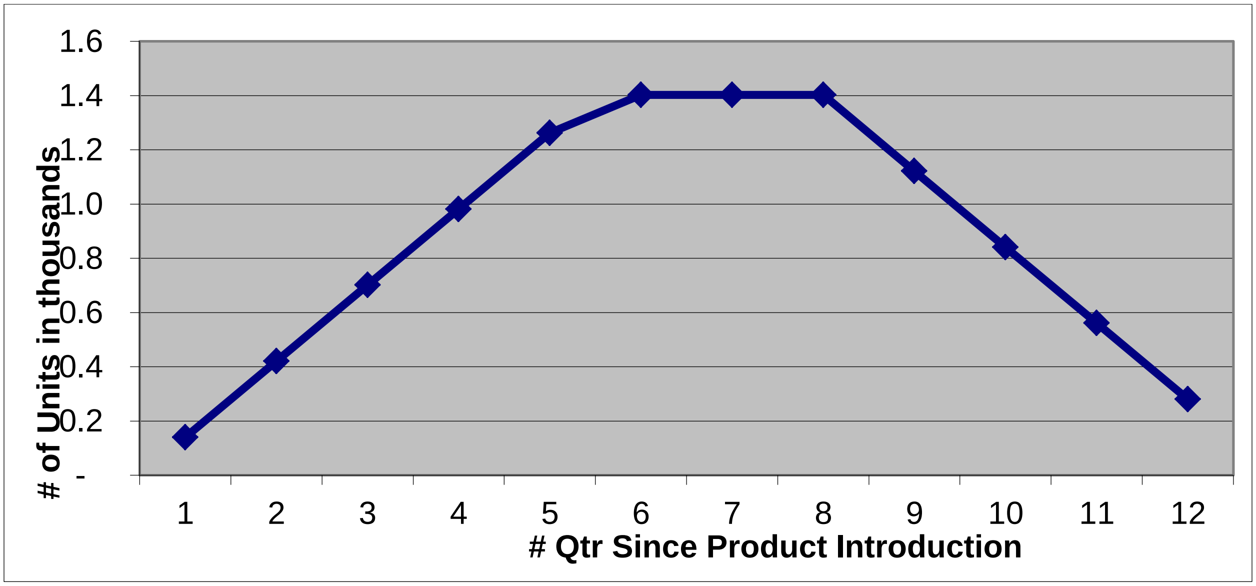
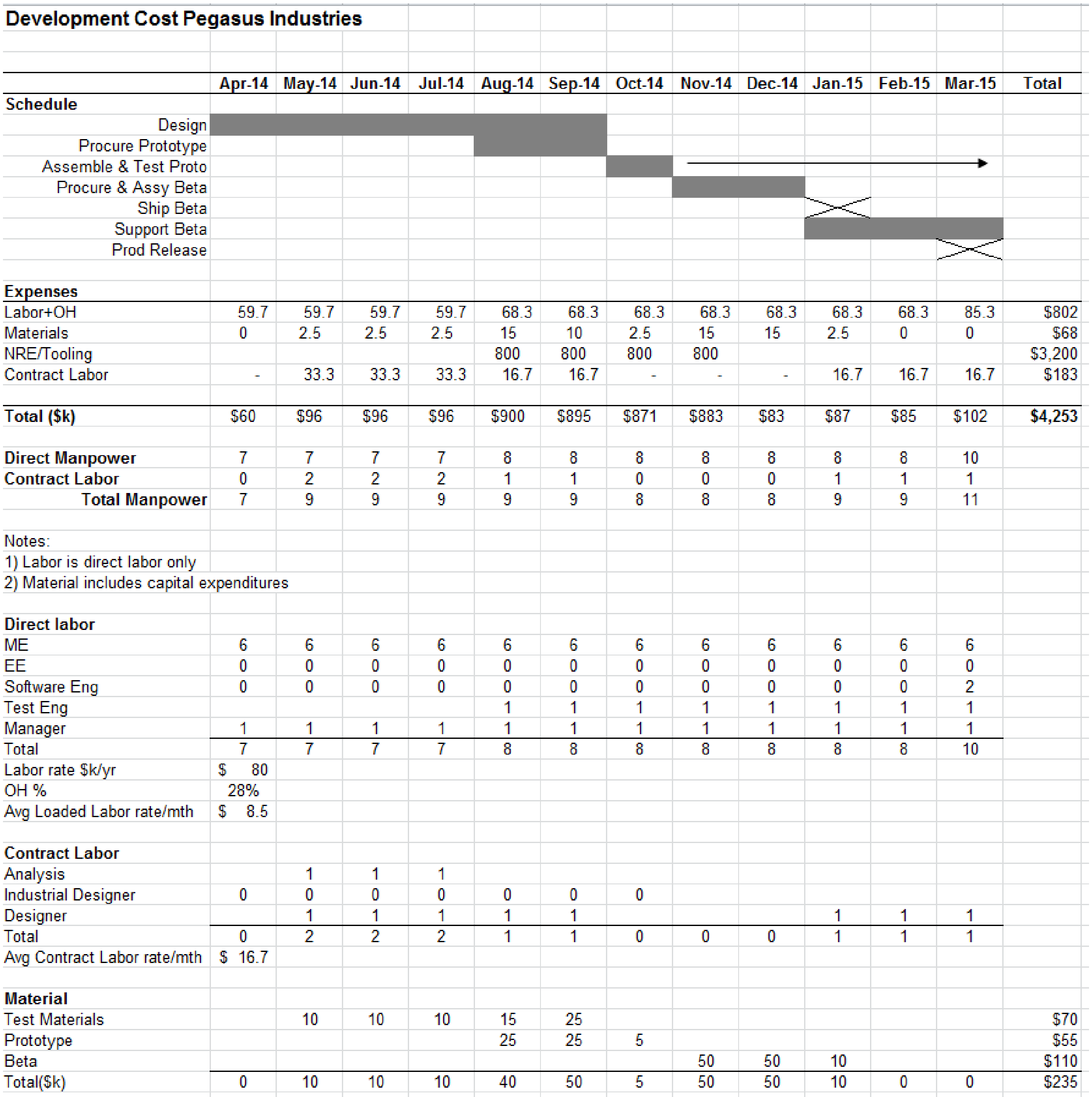


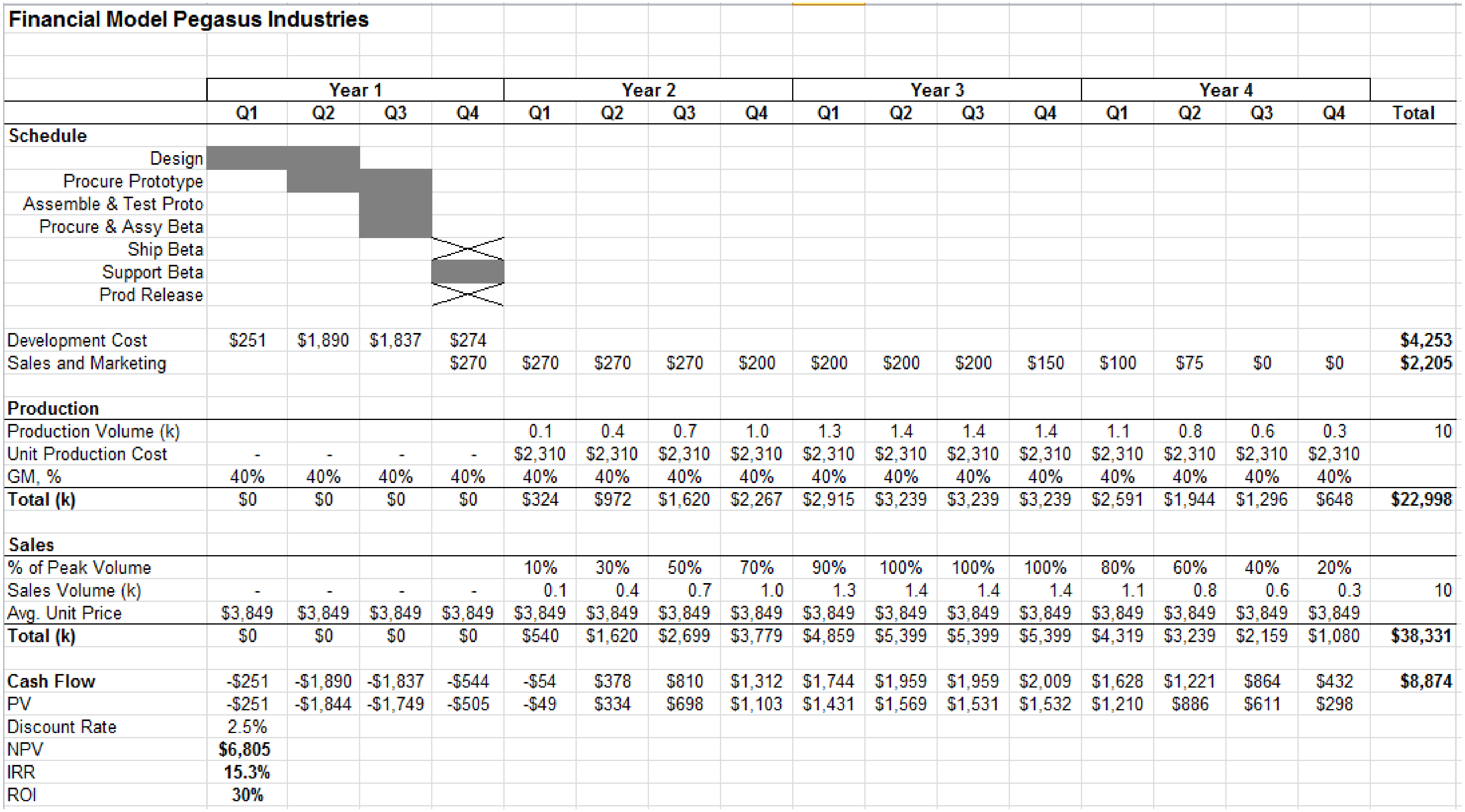
Figure 44: The plot of the number of units produced versus the number of quarters since product introduction of Pegasus Industry Human Powered Vehicles.



Development Cost Pegasus Industries

	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Total
Schedule													
Design	▨	▨	▨	▨	▨	▨							
Procure Prototype					▨	▨							
Assemble & Test Proto							▨	→	→	→	→	→	
Procure & Assy Beta								▨	▨				
Ship Beta										✕			
Support Beta										▨	▨	▨	
Prod Release												✕	
Expenses													
Labor+OH	59.7	59.7	59.7	59.7	68.3	68.3	68.3	68.3	68.3	68.3	68.3	85.3	$802
Materials	0	2.5	2.5	2.5	15	10	2.5	15	15	2.5	0	0	$68
NRE/Tooling					800	800	800	800					$3,200
Contract Labor	-	33.3	33.3	33.3	16.7	16.7	-	-	-	16.7	16.7	16.7	$183
Total ($k)	$60	$96	$96	$96	$900	$895	$871	$883	$83	$87	$85	$102	**$4,253**
Direct Manpower	7	7	7	7	8	8	8	8	8	8	8	10	
Contract Labor	0	2	2	2	1	1	0	0	0	1	1	1	
Total Manpower	7	9	9	9	9	9	8	8	8	9	9	11	
Notes:													
1) Labor is direct labor only													
2) Material includes capital expenditures													
Direct labor													
ME	6	6	6	6	6	6	6	6	6	6	6	6	
EE	0	0	0	0	0	0	0	0	0	0	0	0	
Software Eng	0	0	0	0	0	0	0	0	0	0	0	2	
Test Eng					1	1	1	1	1	1	1	1	
Manager	1	1	1	1	1	1	1	1	1	1	1	1	
Total	7	7	7	7	8	8	8	8	8	8	8	10	
Labor rate $k/yr	$ 80												
OH %	28%												
Avg Loaded Labor rate/mth	$ 8.5												
Contract Labor													
Analysis		1	1	1									
Industrial Designer	0	0	0	0	0	0	0						
Designer		1	1	1	1	1				1	1	1	
Total	0	2	2	2	1	1	0	0	0	1	1	1	
Avg Contract Labor rate/mth	$ 16.7												
Material													
Test Materials		10	10	10	15	25							$70
Prototype					25	25	5						$55
Beta								50	50	10			$110
Total($k)	0	10	10	10	40	50	5	50	50	10	0	0	$235

Figure 45: The developmental costs are shown above for establishing a manufacturing plant.



Financial Model Pegasus Industries

	Year 1				Year 2				Year 3				Year 4				
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Total
Schedule																	
Design	▨	▨															
Procure Prototype		▨	▨														
Assemble & Test Proto			▨														
Procure & Assy Beta			▨														
Ship Beta				☒													
Support Beta				▨													
Prod Release				☒													
Development Cost	$251	$1,890	$1,837	$274													**$4,253**
Sales and Marketing				$270	$270	$270	$270	$200	$200	$200	$200	$150	$100	$75	$0	$0	**$2,205**
Production																	
Production Volume (k)					0.1	0.4	0.7	1.0	1.3	1.4	1.4	1.4	1.1	0.8	0.6	0.3	10
Unit Production Cost	-	-	-	-	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	$2,310	
GM, %	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	
Total (k)	$0	$0	$0	$0	$324	$972	$1,620	$2,267	$2,915	$3,239	$3,239	$3,239	$2,591	$1,944	$1,296	$648	**$22,998**
Sales																	
% of Peak Volume					10%	30%	50%	70%	90%	100%	100%	100%	80%	60%	40%	20%	
Sales Volume (k)	-	-	-	-	0.1	0.4	0.7	1.0	1.3	1.4	1.4	1.4	1.1	0.8	0.6	0.3	10
Avg. Unit Price	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	$3,849	
Total (k)	$0	$0	$0	$0	$540	$1,620	$2,699	$3,779	$4,859	$5,399	$5,399	$5,399	$4,319	$3,239	$2,159	$1,080	**$38,331**
Cash Flow	-$251	-$1,890	-$1,837	-$544	-$54	$378	$810	$1,312	$1,744	$1,959	$1,959	$2,009	$1,628	$1,221	$864	$432	**$8,874**
PV	-$251	-$1,844	-$1,749	-$505	-$49	$334	$698	$1,103	$1,431	$1,569	$1,531	$1,532	$1,210	$886	$611	$298	
Discount Rate	2.5%																
NPV	**$6,805**																
IRR	**15.3%**																
ROI	**30%**																

Figure 46: The financial model used to calculate the Pegasus Industries rate of return on investment over a four year period.

7. Summary and Conclusion

Future Improvements

-Peter Chester

When looking back over the project our team did many things well. However, there were areas in hindsight could have done better. When looking forward to next year's team, some of the suggestions I have come from both our team's strengths and weaknesses.

One area in which our team could have done better was in team organization. At the beginning of the year we split our group into different sub teams. We decided that we did not need a team leader because of how we organized the team. As time went into the school year those sub-teams dissolved and our team worked as a cohesive unit. For future teams it would advisable to have a person who oversaw the sub-teams and kept track of their progress. Having a team leader would allow the group to work in a more efficient manner.

Throughout the process something that our team did well was document our design process. In the beginning it may seem cumbersome to save all the different iterations of the design and keep track of calculations. However, it provides helpful when you need to reference those iterations or equations in the future.

It is important to allow sufficient time for fine tuning of the vehicle. Our team did have a timeline that did help us keep on track but when our vehicle had issues with its axle tabs it set our team back several weeks and really limited the time we had to make our vehicle as efficient as possible. I would suggest that if at all possible have the vehicle design completed by the end of fall quarter and allow the frame to be built over winter break or in the first two weeks of winter quarter. This would allow more time to solve issues that arise (which they will).

-Ian Jones

Senior design has a phenomenal way of revealing all of the material one has retained while simultaneously exposing work-ethic, determination, and drive within an individual and team; the Human Powered Vehicle is no exception. An imperative aspect of senior design is the teammates you collaborate with. It is inevitable that you will spend an immense amount of time with your team, so creating a team that is not only diverse, but also one that has minimal conflicts helps the dynamics of the team in so many positive ways. Another improvement I would strongly suggest is to “divide and conquer”; that is, split up major tasks amongst teammates. Although we had team leads for various components (i.e. Drive Chain, Frame, Budget, etc.), we had a tendency to all work on the same task together. For example, when we worked on the frame assembly, we all focused on that single component to execute the task efficiently and effectively, but other components such as drive train were placed lower on our priority list. Because we did not have a team-member or two focusing on the drive train whilst the frame members executed the assembly, it resulted in a drive train that wasn’t very efficient.

Another thing I would stalwartly recommend for next year’s team is to physically visit the velodrome: the venue in which the sprint event was held. Our team had a general idea as to what a velodrome looked like and how we would need to operated the vehicle; however, we were surprised by how steep the incline was on the track which made it difficult for our vehicle to reach its optimal performance. Had we physically seen the track, I strongly believe that our team could have implemented a more efficient steering/handling mechanism that would have allowed us to reach a much faster speed.

Finally, the last piece of advice I would offer is in regard to the timeline of the project. It is imperative to plan ahead and to allocate enough extra time in case something goes awry. We encountered some significant problems with our axle tabs because they kept bending and cracks were propagating through them. Luckily for us, we budgeted two weeks of “buffer time” in case something was to go wrong. If I could reimplement this senior design project over again, what I would offer is this: get ALL of the designing completed by the end of Fall Quarter, strive to have the entire vehicle assembled by the end of Winter Quarter, and use the remaining three/four weeks before the competition to conduct testing and fine-tune the vehicle. This suggestion is extremely challenging to stick with, but I can ensure that if this is done, you will save a lot of stress, money, and time.

-Ryan Nakamura

Participating in the Human Powered Vehicle Challenge helped me to grow tremendously as an engineer. As part of a group we each learned the inner workings of a full scale engineering project from the design phase until completion. Our team learned a great deal from working together throughout this past year and through participating in the competition. For the remainder of this year our team has decided to improve the drivetrain of our vehicle. To do this we have purchased additional parts such as a new idler and a chain tensioner. Initially, our design had implemented Teflon tubing to inhibit the chain rubbing on our tilt steering. However, due to the fact that we decided to lock out our steering, we do not need to implement this feature. Eliminating some if not all of the Teflon tubing will greatly improve the friction that we experienced during competition. Due to monetary limitations we were forced to reuse a lot of last year's parts. If next year's team could get additional funds and more corporate sponsorships that would be ideal.

-Dylan Porter

After going through the senior design process and competition, I learned a lot about what it means to work on a design project, what is required for the success of a project, as well as what it means to work on a project with a team. With these learning processes came a great deal of struggle, which I felt took time and focus away from the project. My hope is my perspective and experience can hopefully shed light on the success of future projects, not only for the Santa Clara University Human Powered Vehicle Teams, but the general design process as well.

1. Taking Initiative

During the design process, there was an exceptional amount of work that was needed to be done for the completion of the design as well as work that needed to be done for the classes concerning the project. This meant multiple tasks needed to be accomplished in order to satisfy the design and classes. In order to make this happen, our team eventually got into the rhythm of taking initiative on certain tasks. This initiative meant taking lead on tasks that we felt interest in, where our strengths were well suited, or tasks that needed to be done to meet a deadline. This realization I felt was extremely important for the success of the project overall. For example, one of our teammates had extended experience and interest in the 3D rendering of our vehicle through the CAD software, SolidWorks. He took the initiative to lead the design through the program, which helped immensely. His strengths using the program and interest in the software helped motivate the design move more smoothly and quickly. With this being said, I feel a major improvement that can be made to the project is that team members take initiative on tasks that they feel interest in, experience in, or have the time and focus to put it in. Taking initiative sooner rather than later will help complete objectives quickly and effectively.

2. Analysis

As stated earlier, taking initiative is important for the completion of the project. One of the leads I took initiative on was the analysis of the human powered vehicles design using Finite Element Analysis, or FEA. I took this lead because I had an interest in how the software worked, developing the skill using the software as a future job skill, and I had the time to do the analysis where some of my teammates did not due to other work that had to be done.

A major improvement for the analysis process of the project is to ask for help. For our undergraduate education here at Santa Clara, we have no courses directed towards finite element method or the software that uses it. This meant I had to teach myself how to use the software, ABAQUS CAE through countless amounts of trial and error. If I had the education and experience that I had now back when I was learning the software, days would have been saved for other design objectives. That is why I am willing to offer my help and guidance on using ABAQUS CAE or SolidWorks FEA for the SCU HPV Team of 2014-2015. Hopefully my input on the analysis portion of the project will be helpful.

Another thing about the analysis of a project is to do analysis on every design feature you can. When we did the first round of testing on our design, the axle tab on our kingpin steering assembly yielded when we tested the tilt of our vehicle. Looking back we realized the axle tab was a design feature that we did no analysis on, and was based on the prior year’s design which used steel instead of aluminum. Since the axle tab was based on last years design we felt it was sound, however when we altered the design and changed the material, we changed the strength of the tab. We also did not account for the forces that would occur on the tab while our vehicle was tilting. This lack of analysis resulted in the failure of the tab, and set us back 2 weeks in the project, which could have been spent on other parts of the design, such as the drivetrain. If we had done the analysis on the axle tab, we could have redesigned it to handle these unforeseen stresses. As a future improvement, I would recommend that every design feature have some analysis done on it. It takes much less time to redesign something, than to see it fail in real life and fix it.

3. Competition

The ASME Human Powered Competition was something familiar to us, but looking back we really did not understand how the competition worked. Luckily, one of our teammates took the lead in communicating with one of the ASME judges for the competition. Since our teammate was in constant communication with the judge, we were able to do very well in the design portion of the competition since we knew what we needed to report on to earn the maximum amount of credit. A future improvement on this would be providing this contact to next years team earlier than we had, as well as offering our input.

A major improvement that can be made for the competition is informing next years team on how the competition events worked. If we had an awareness of how the speed and endurance events worked, we would have put a great deal of focus into the design of the vehicle for these two events. In hindsight it would have been helpful to take the vehicle to the competition areas and testing the vehicle, or even to see the courses during the designing process for our vehicle to ensure the design would work well on the courses. The speed event was conducted on a 15 degree angled velodrome track. Our team had no experience with a velodrome until the competition. While riding on the course, we realized that riders were having an issue with keeping stability while operating the vehicle on the incline, which affected our top speed. It would have helped if the design was better fitted for a velodrome, the seat provided better support for the incline, and if our team members had more experience riding on the course. Our goal is to inform next year's team on where and how the competitions work, helping them be better prepared for the events.

-Peter Stephens

Well I must say I am surprised you read all the way down to this page. This is a really long thesis. Props to you.

A lot has been said about the good and bad things that we did. I agree with them.

One thing I would suggest is that you will probably have a lot of awesome ideas about what to build. The thing is you won't have a lot of time to do all of them; pick one or two of your favorite and do them well. Also putting time into analysis work such as FEA can really help to get you a light but strong frame. When you run into problems, as I'm sure you will, don't let them get to you too much. Allow yourself a minute to freak out and then sit down and figure out how to fix it. This is the only reason we had an operational vehicle by the time of the ASME competition, since the axle tab failed twice and we had to redo it each time.

Build off of the work from this and past theses, and use our references to get you a head start. A lot of the steering and frame research can be put towards any design.

Finally enjoy the project. At times it can be a lot of work and many long nights, but you’re putting everything you’ve learned the past four years to work designing a real thing that you will ride. That’s pretty cool. I had fun with the design process and I’m sure as an engineer you will too.

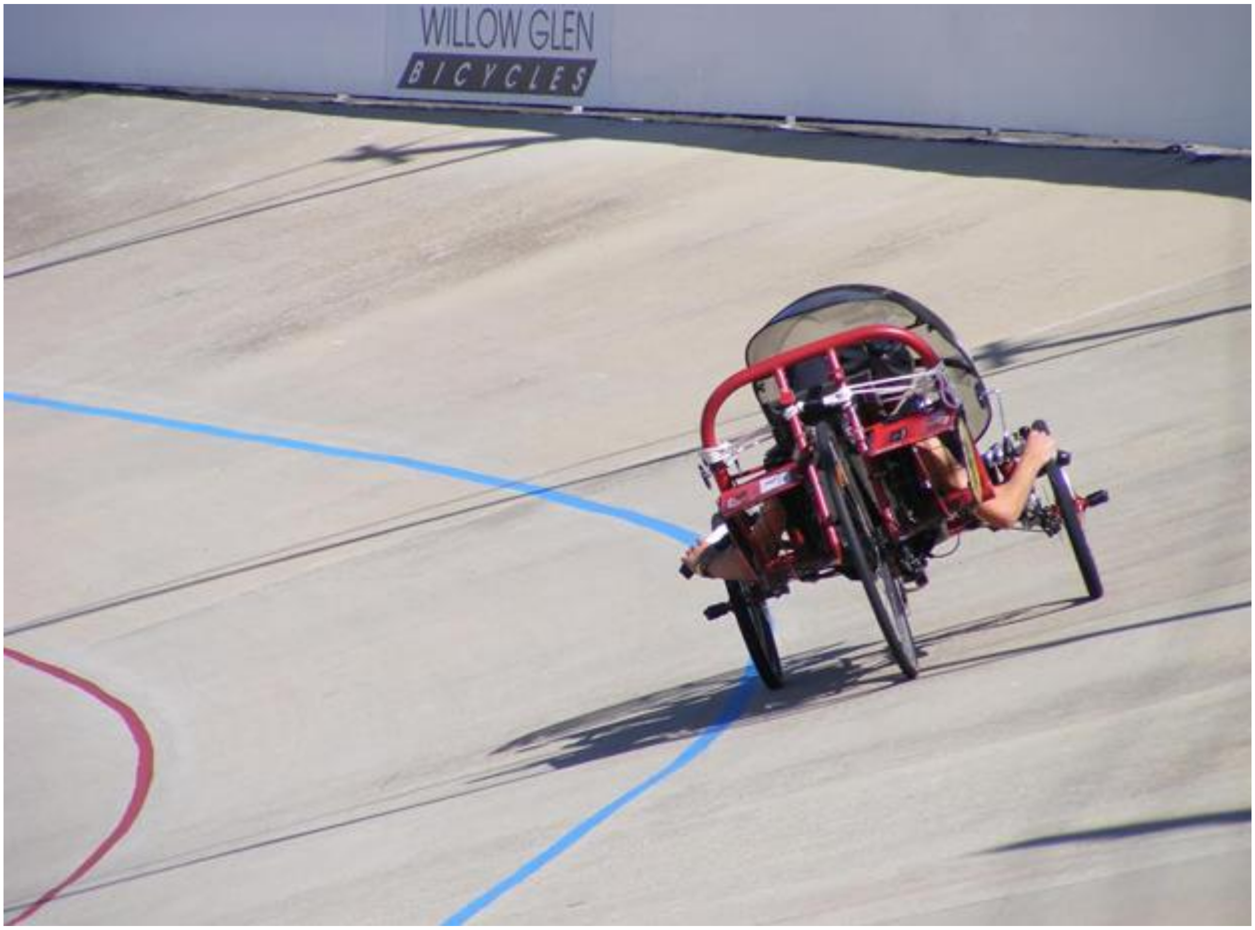
Conclusion

The objective of this project was to design and manufacture a human powered vehicle that was practical, sustainable, and efficient. The vehicle was designed to compete successfully in the 2014 Human Powered Vehicle West challenge hosted by the American Society of Mechanical Engineers in San Jose, CA on April 25th 2014.

Based on preliminary research, our team decided to design a vehicle that implemented both tilt and Ackermann steering to improve cornering and stability when operating the vehicle under high speeds. After initial testing however, our team realized that tilt and Ackermann steering would not be able to function properly the way we had initially designed it to so we decided to block out the tilt steering during the ASME competition. Our frame was designed as a recumbent tadpole tricycle; with two wheels in the front and one in the back, this ensures that the ergonomics and stability meet the rider's needs. A frontal fairing was also implemented into the design to enhance the aerodynamics of the vehicle to amplify overall speed while protecting the rider from natural elements, serving as a safety feature for weather and accidents/crashes.

When fully assembled, the Pegasus trike weighed a total of 55 lbs. The frame was made of 2" Aluminum 6061 T6 circular tubing that incorporated a roll protection system to protect the rider in the event of a flip. The RPS successfully underwent a series of tests for strength in accordance with ASME competition guidelines, it was able to support a 600 lb vertical load applied 12 degrees from the vertical and a 300 lb side load. 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 9.8 ft from a speed of 15 mph. An Ackerman steering system was chosen because of its ease of manufacturing and because it has the capability to maintain a tight turning radius. The minimum turning radius of the trike was 7.7 feet. Pegasus operates using a single line chain drivetrain system linked from a 36 tooth front chain ring and pedal system along the length of the trike to an 11-speed internal hub that operates the rear wheel. The maximum speed achieved was 21.5 mph, though this can be improved with additional drivetrain work to reduce the friction of the system.

At the ASME competition our team placed 12th overall out of 26 schools ranging from India, Canada, Mexico, and across the United States. To amplify publicity for our potential customers, our team has implemented a business plan for Pegasus industries, a company that would design and manufacture human powered vehicles that can serve as a practical alternative to the commuter car. For a price of $3,849 you too can ride a Pegasus trike today.



WILLOW GLEN
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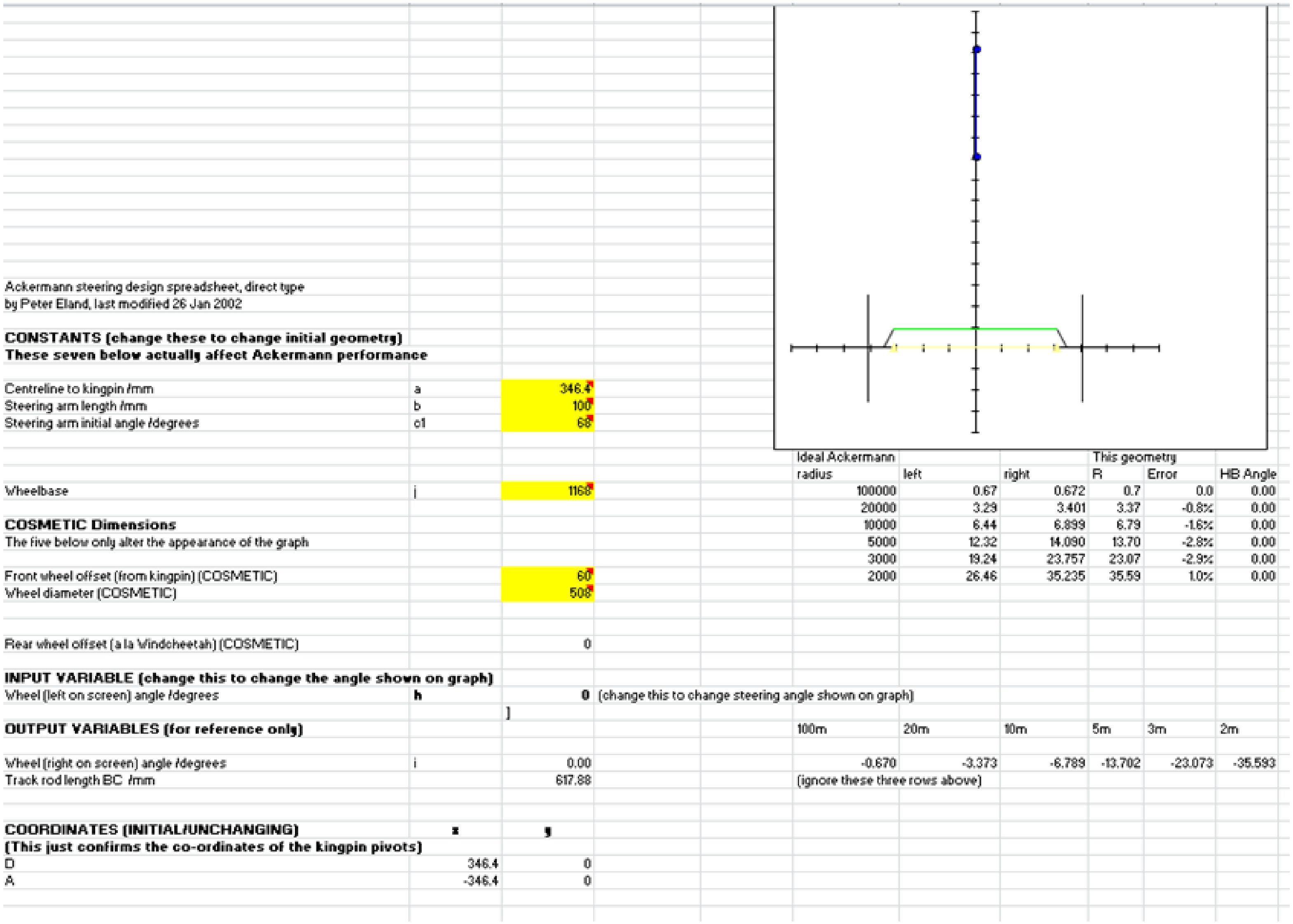
Appendix A: Detailed Calculations



Ackermann steering design spreadsheet, direct type
by Peter Eland, last modified 26 Jan 2002

CONSTANTS (change these to change initial geometry)
These seven below actually affect Ackermann performance

Centreline to kingpin /mm	a	346.4
Steering arm length /mm	b	100
Steering arm initial angle /degrees	c1	68
Wheelbase	j	1168

COSMETIC Dimensions
The five below only alter the appearance of the graph

Front wheel offset (from kingpin) (COSMETIC)		60
Wheel diameter (COSMETIC)		508
Rear wheel offset (a la Windcheetah) (COSMETIC)		0

INPUT VARIABLE (change this to change the angle shown on graph)

Wheel (left on screen) angle /degrees	h	0	(change this to change steering angle shown on graph)

OUTPUT VARIABLES (for reference only)

Wheel (right on screen) angle /degrees	i	0.00
Track rod length BC /mm		617.88

Ideal Ackermann			This geometry		
radius	left	right	R	Error	HB Angle
100000	0.67	0.672	0.7	0.0	0.00
20000	3.29	3.401	3.37	-0.8%	0.00
10000	6.44	6.899	6.79	-1.6%	0.00
5000	12.32	14.090	13.70	-2.8%	0.00
3000	19.24	23.757	23.07	-2.9%	0.00
2000	26.46	35.235	35.59	1.0%	0.00

100m	20m	10m	5m	3m	2m
-0.670	-3.373	-6.789	-13.702	-23.073	-35.593

(ignore these three rows above)

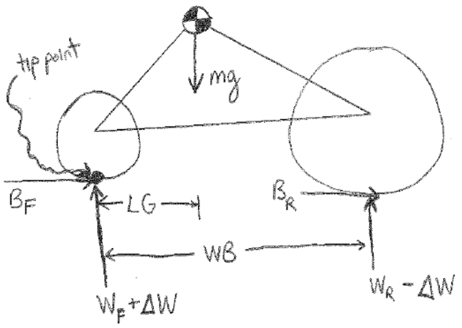
COORDINATES (INITIAL/UNCHANGING)
(This just confirms the co-ordinates of the kingpin pivots)

	x	y
D	346.4	0
A	-346.4	0

Figure A.1: The Figure above shows the Ackerman calculations used to calculate steering geometry for a human powered vehicle.

BRAKING WEIGHT TRANSFER CALCULATIONS

SIDE VIEW, DYNAMIC BRAKING



When braking, a weight ΔW is shifted from the rear of the trike to the front

B_F & B_R are braking friction on tires

total braking force: $B = B_F + B_R$

$B = m a_b$

for a static trike:

$(\Delta W = B_F = B_R = 0)$

$$\Sigma M_F = W_R \, WB - mg \, LG = 0$$

$$W_R = \frac{mg \, LG}{WB}$$

for decelerating trike:

$$\Sigma M_{CG} = (B)(HG) + (-\Delta W)(WB - LG) - (\Delta W)(LG) = 0$$

torque due to W_F & W_R ignored since these must balance under static conditons.

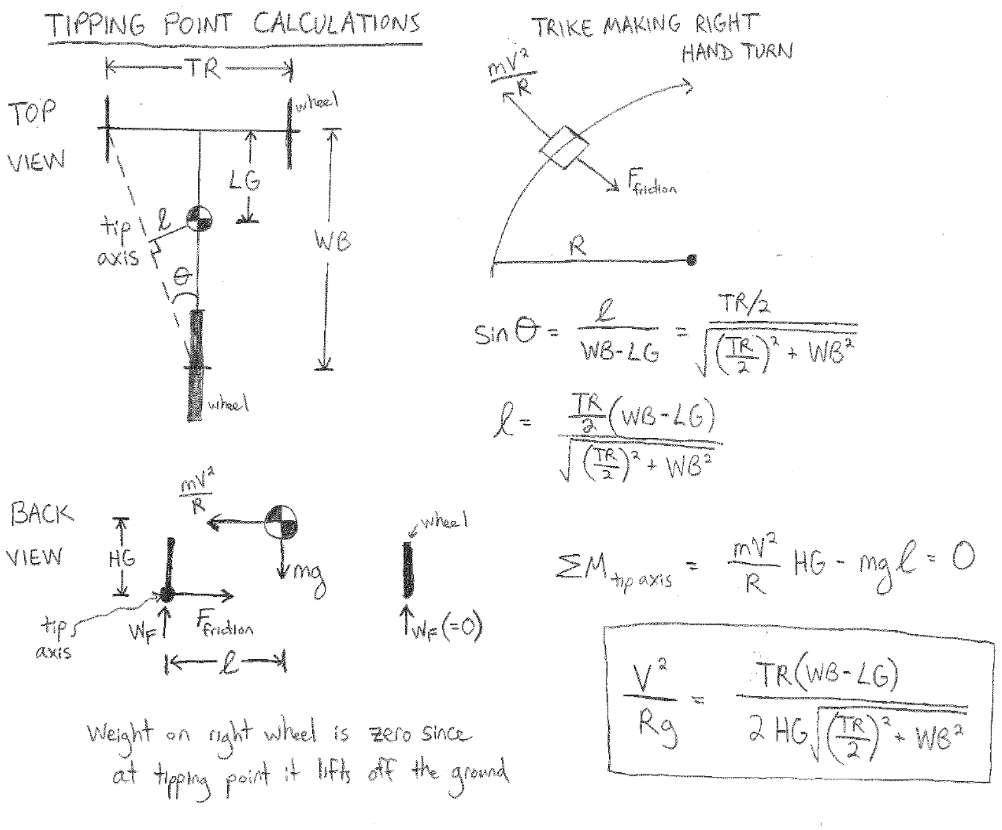
$$\Delta W = \frac{m a_b \, HG}{WB}$$

$$\boxed{\frac{\Delta W}{W_R} = \frac{a_b \, HG}{g \, LG}}$$

tipping occurs when $\Delta W = W_R$

(force on rear wheel = 0)

Figure A.2: The figure shown above displays the braking weight transfer calculations and equations used in design analysis of a human powered Vehicle.



$$\sin\theta = \frac{\ell}{WB-LG} = \frac{TR/2}{\sqrt{\left(\frac{TR}{2}\right)^2 + WB^2}}$$

$$\ell = \frac{\frac{TR}{2}(WB-LG)}{\sqrt{\left(\frac{TR}{2}\right)^2 + WB^2}}$$

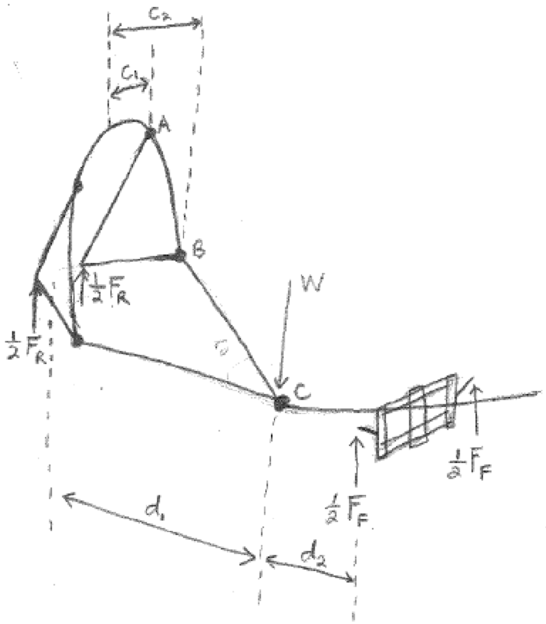
$$\Sigma M_{tip\ axis} = \frac{mV^2}{R} HG - mg\ell = 0$$

$$\boxed{\frac{V^2}{Rg} = \frac{TR(WB-LG)}{2\,HG\sqrt{\left(\frac{TR}{2}\right)^2 + WB^2}}}$$

Weight on right wheel is zero since at tipping point it lifts off the ground

Figure A.3: The figure shown above displays the tipping point calculations and equations for design analysis.

Weld Stress Hand Calculations



$$F_F = \frac{d_1}{d_2} F_R$$

$$F_R + F_F = W$$

$$F_R = W - F_F$$

$$F_F = \frac{d_1}{d_2}(W - F_F)$$

$$F_F + \frac{d_1}{d_2} F_F = \frac{d_1}{d_2} W$$

$$F_F = \frac{\frac{d_1}{d_2} W}{1 + \frac{d_1}{d_2}}$$

Figure A.4: The free body diagram of the frame with corresponding calculations for the reaction forces at the wheel axles.

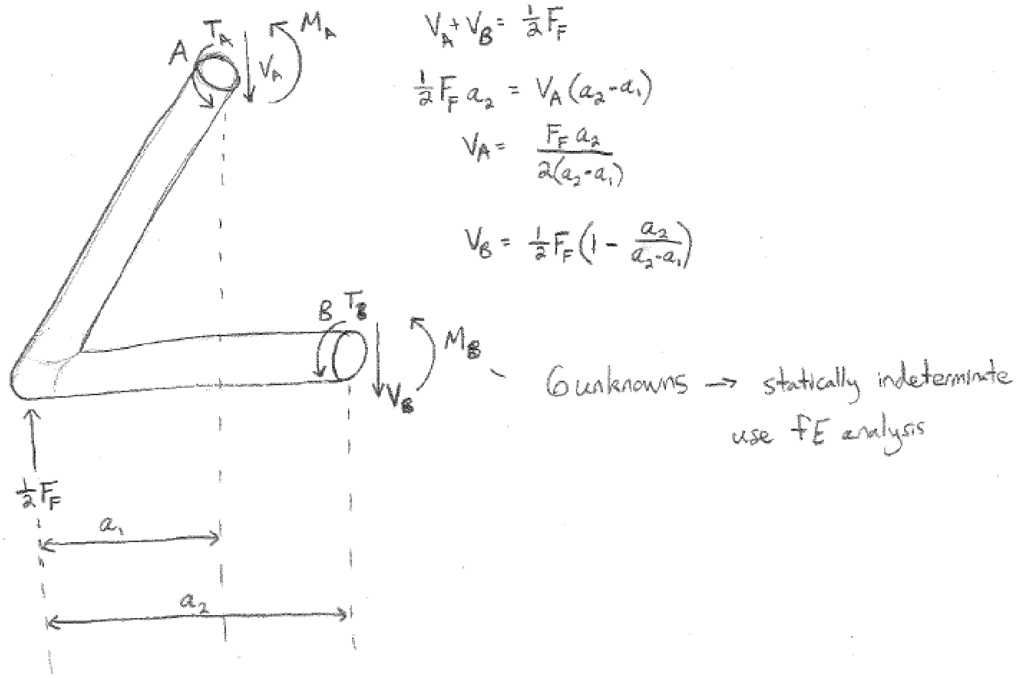
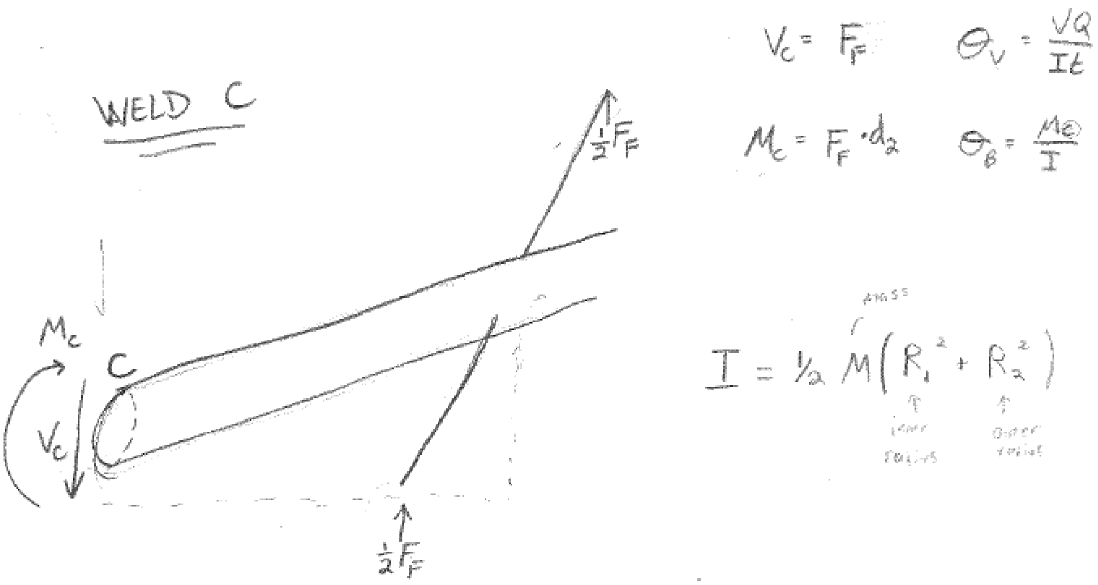


Figure A.5: Calculations for the stresses at welds A and B due to the reaction force at the rear axle. The model was determined to be statically indeterminate.

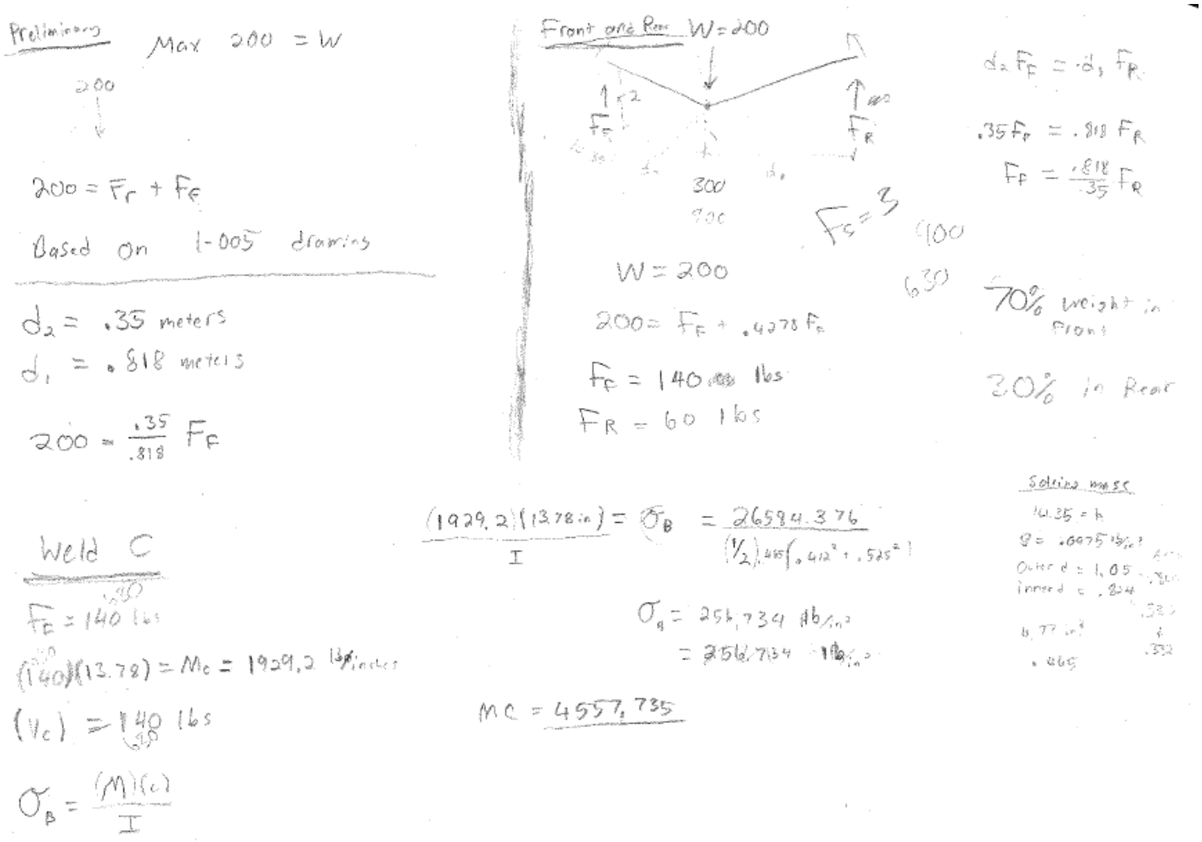


$$V_C = F_F \qquad \Theta_V = \frac{VQ}{It}$$

$$M_C = F_F \cdot d_2 \qquad \Theta_B = \frac{Mc}{I}$$

$$I = \tfrac{1}{2} M \left(R_1^2 + R_2^2 \right)$$

Figure A.6: Calculations for the stresses at weld C due to the reaction forces on the front wheels.



Preliminary Max 200 = W

$200 = F_r + F_F$

Based on 1-005 drawings

$d_2 = .35$ meters

$d_1 = .818$ meters

$200 = \frac{.35}{.818} F_F$

Front and Rear W = 200

300

900

$F_S = 3$

900

630

W = 200

$200 = F_F + .4278 F_F$

$F_F = 140$ lbs

$F_R = 60$ lbs

$d_2 F_F = d_1 F_R$

$.35 F_F = .818 F_R$

$F_F = \frac{.818}{.35} F_R$

70% weight in Front

30% in Rear

Solving mass

14.35 = h

$\rho = .0975$ lb/in³

Outer d = 1.05

Inner d = .824

6.77 in³

.465

.525

.412

.332

Weld C

$F_F = 140$ lbs

$(140)(13.78) = M_C = 1929.2$ lb/inches

$(V_C) = 140$ lbs

$\sigma_B = \frac{(M)(c)}{I}$

$\frac{(1929.2)(13.78\text{ in})}{I} = \sigma_B = \frac{26584.376}{(1/2).465(.412^2 + .525^2)}$

$\sigma_B = 256,734$ lb/in²

$= 256,734$ lb/in²

MC = 4557,735

Figure A.7: Calculations for the stress at the crux of the main tube (Weld C) for a rider weighing 200 lbs. The max stress was found to be 256,734 psi.

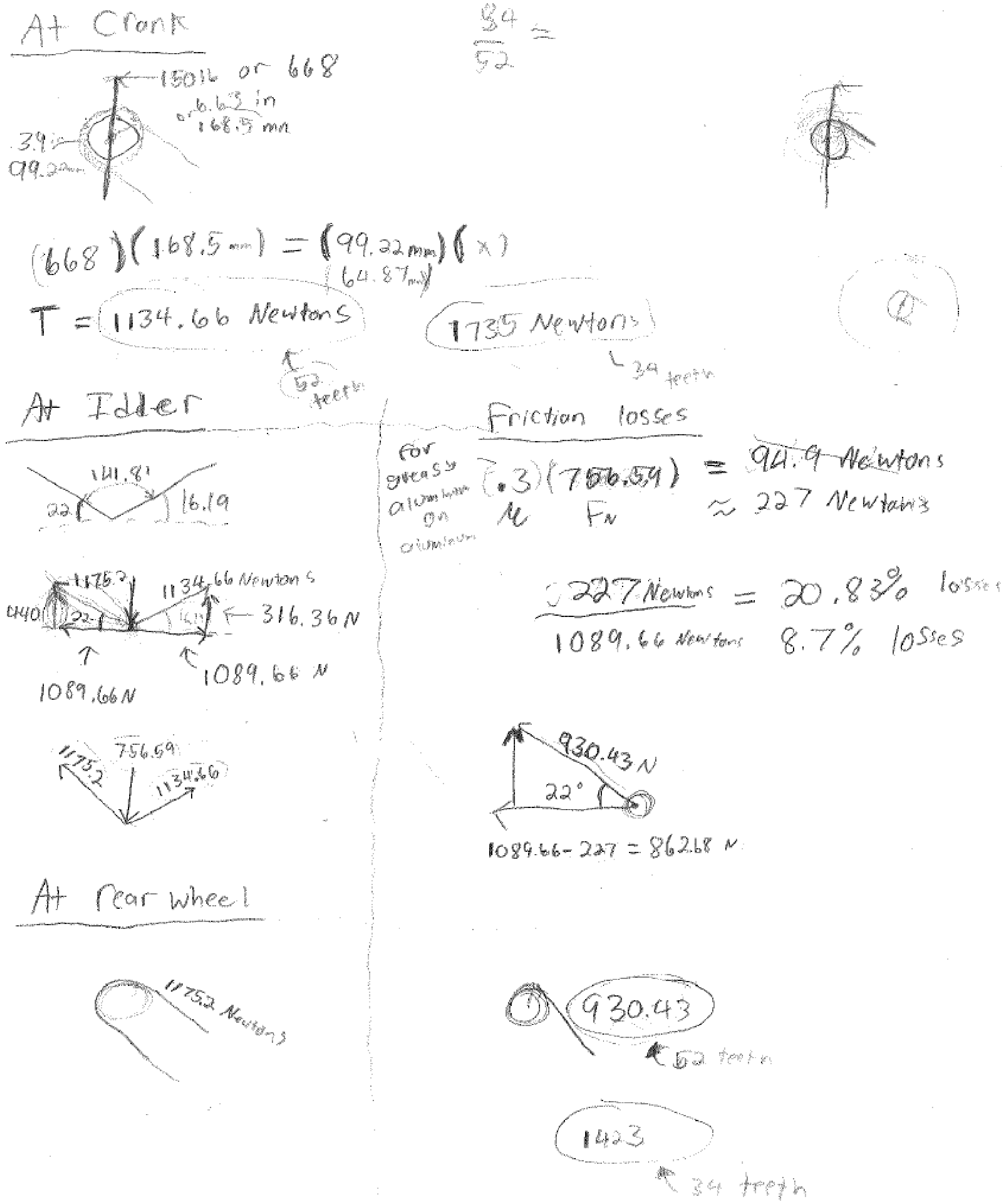
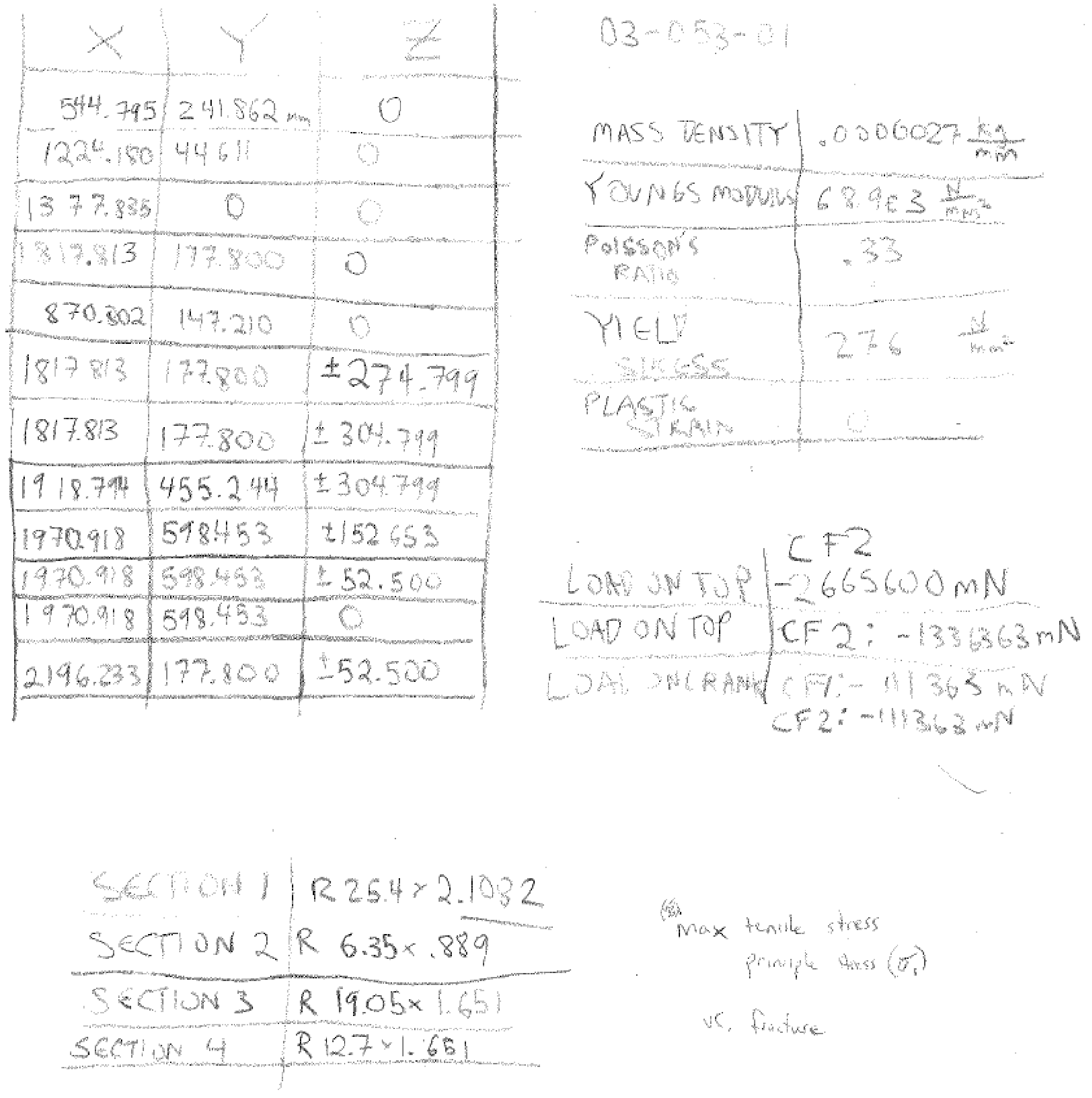


Figure A.8: The calculations to determine the forces incident through the drivetrain due to a 150 lb force input by the driver at the crankset. These forces were used in the ABAQUS FEA model.



X	Y	Z
544.795	241.862 mm	0
1224.180	44611	0
1377.835	0	0
1817.813	177.800	0
870.302	147.210	0
1817.813	177.800	±274.799
1817.813	177.800	±304.799
1918.794	455.244	±304.799
1970.918	598453	±152 653
1970.918	598.453	±52.500
1970.918	598.453	0
2196.233	177.800	±52.500

03-053-01

MASS DENSITY	.0000027 $\frac{kg}{mm}$
YOUNGS MODULUS	68.9E3 $\frac{N}{mm^2}$
POISSON'S RATIO	.33
YIELD STRESS	276 $\frac{N}{mm^2}$
PLASTIC STRAIN	0

	CF2
LOAD ON TOP	-2665600 mN
LOAD ON TOP	CF2: -133363 mN
LOAD ON CRANK	CF1: -111363 mN CF2: -111363 mN

SECTION 1	R 25.4 × 2.1082
SECTION 2	R 6.35 × .889
SECTION 3	R 19.05 × 1.651
SECTION 4	R 12.7 × 1.651

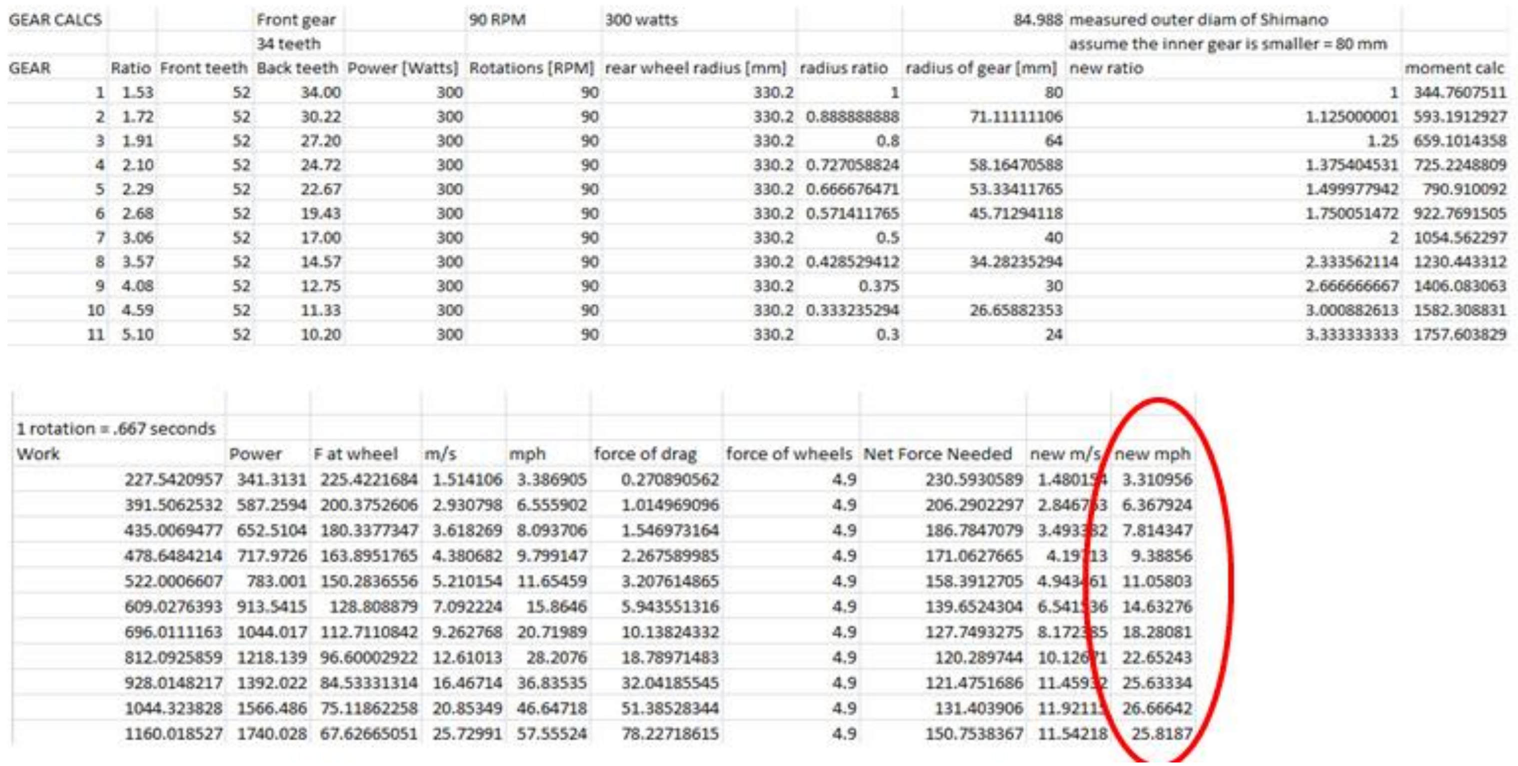
max tensile stress
principle stress (σ_1)

vs. fracture

Figure A.9: This is the handwritten information used as reference to enter the necessary data for Abaqus.

Gearing Calculations for Drivetrain

Table A.1: The Gearing calculations for speed of the vehicle with varying rear gear changes.



GEAR CALCS			Front gear		90 RPM	300 watts		84.988	measured outer diam of Shimano	
			34 teeth						assume the inner gear is smaller = 80 mm	
GEAR	Ratio	Front teeth	Back teeth	Power [Watts]	Rotations [RPM]	rear wheel radius [mm]	radius ratio	radius of gear [mm]	new ratio	moment calc
1	1.53	52	34.00	300	90	330.2	1	80	1	344.7607511
2	1.72	52	30.22	300	90	330.2	0.888888888	71.11111106	1.125000001	593.1912927
3	1.91	52	27.20	300	90	330.2	0.8	64	1.25	659.1014358
4	2.10	52	24.72	300	90	330.2	0.727058824	58.16470588	1.375404531	725.2248809
5	2.29	52	22.67	300	90	330.2	0.666676471	53.33411765	1.499977942	790.910092
6	2.68	52	19.43	300	90	330.2	0.571411765	45.71294118	1.750051472	922.7691505
7	3.06	52	17.00	300	90	330.2	0.5	40	2	1054.562297
8	3.57	52	14.57	300	90	330.2	0.428529412	34.28235294	2.333562114	1230.443312
9	4.08	52	12.75	300	90	330.2	0.375	30	2.666666667	1406.083063
10	4.59	52	11.33	300	90	330.2	0.333235294	26.65882353	3.000882613	1582.308831
11	5.10	52	10.20	300	90	330.2	0.3	24	3.333333333	1757.603829

1 rotation = .667 seconds									
Work	Power	F at wheel	m/s	mph	force of drag	force of wheels	Net Force Needed	new m/s	new mph
227.5420957	341.3131	225.4221684	1.514106	3.386905	0.270890562	4.9	230.5930589	1.4801[illegible]4	3.310956
391.5062532	587.2594	200.3752606	2.930798	6.555902	1.014969096	4.9	206.2902297	2.8467[illegible]3	6.367924
435.0069477	652.5104	180.3377347	3.618269	8.093706	1.546973164	4.9	186.7847079	3.493[illegible]2	7.814347
478.6484214	717.9726	163.8951765	4.380682	9.799147	2.267589985	4.9	171.0627665	4.19[illegible]13	9.38856
522.0006607	783.001	150.2836556	5.210154	11.65459	3.207614865	4.9	158.3912705	4.943[illegible]61	11.05803
609.0276393	913.5415	128.808879	7.092224	15.8646	5.943551316	4.9	139.6524304	6.541[illegible]36	14.63276
696.0111163	1044.017	112.7110842	9.262768	20.71989	10.13824332	4.9	127.7493275	8.172[illegible]85	18.28081
812.0925859	1218.139	96.60002922	12.61013	28.2076	18.78971483	4.9	120.289744	10.126[illegible]1	22.65243
928.0148217	1392.022	84.53331314	16.46714	36.83535	32.04185545	4.9	121.4751686	11.459[illegible]2	25.63334
1044.323828	1566.486	75.11862258	20.85349	46.64718	51.38528344	4.9	131.403906	11.9211[illegible]	26.66642
1160.018527	1740.028	67.62665051	25.72991	57.55524	78.22718615	4.9	150.7538367	11.54218	25.8187

Appendix B: Detail and Assembly Drawings

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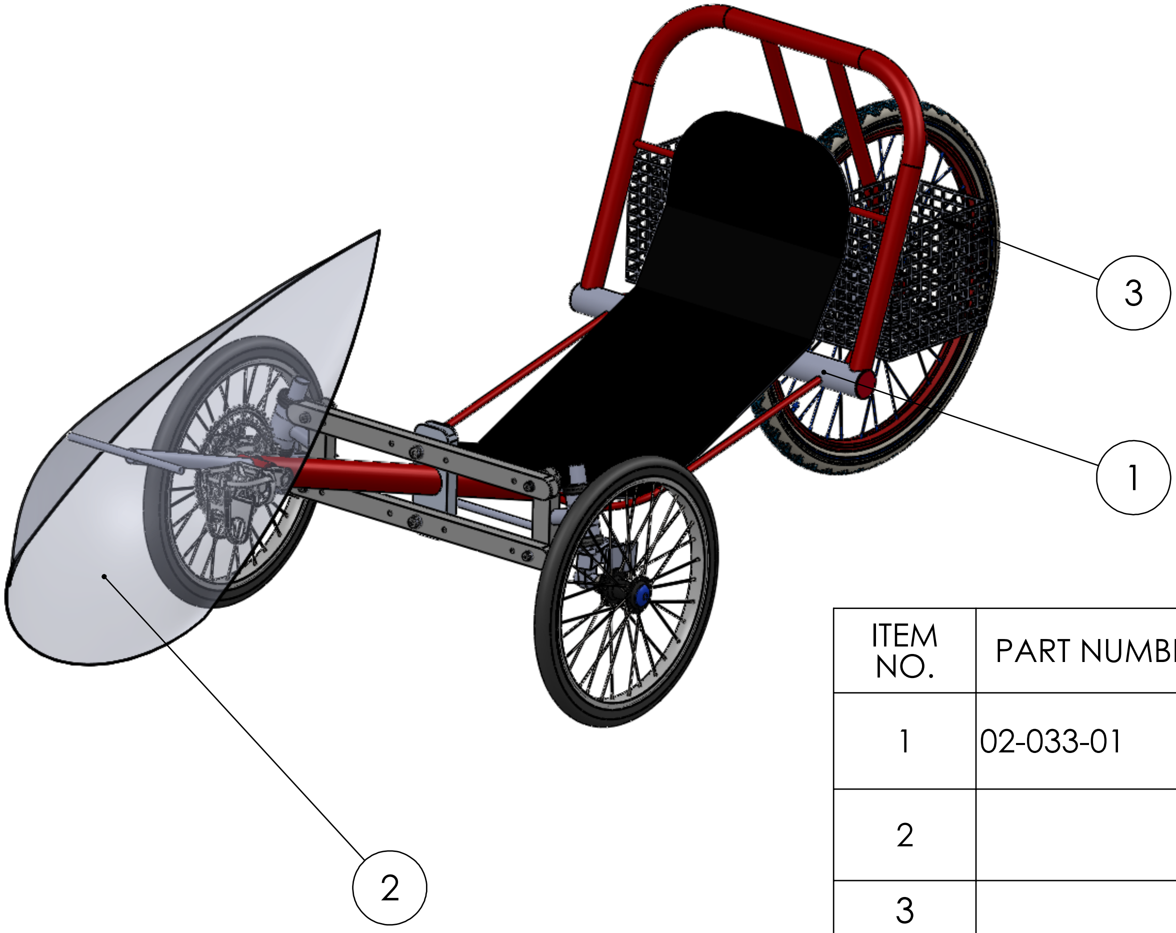

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-033-01	FINAL ASSEMBLY WITHOUT FAIRING	1
2		Z-ZIPER FAIRING ASSEMBLY	1
3		BASKET	2

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BEND ±0.5
TWO PLACE DECIMAL ±0.1
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
ALUMINUM-6061 T6

FINISH

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	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY:

TITLE:

FINAL ASSEMBLY

SIZE	DWG. NO.	REV
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SCALE: 1:13 WEIGHT: SHEET 1 OF 1

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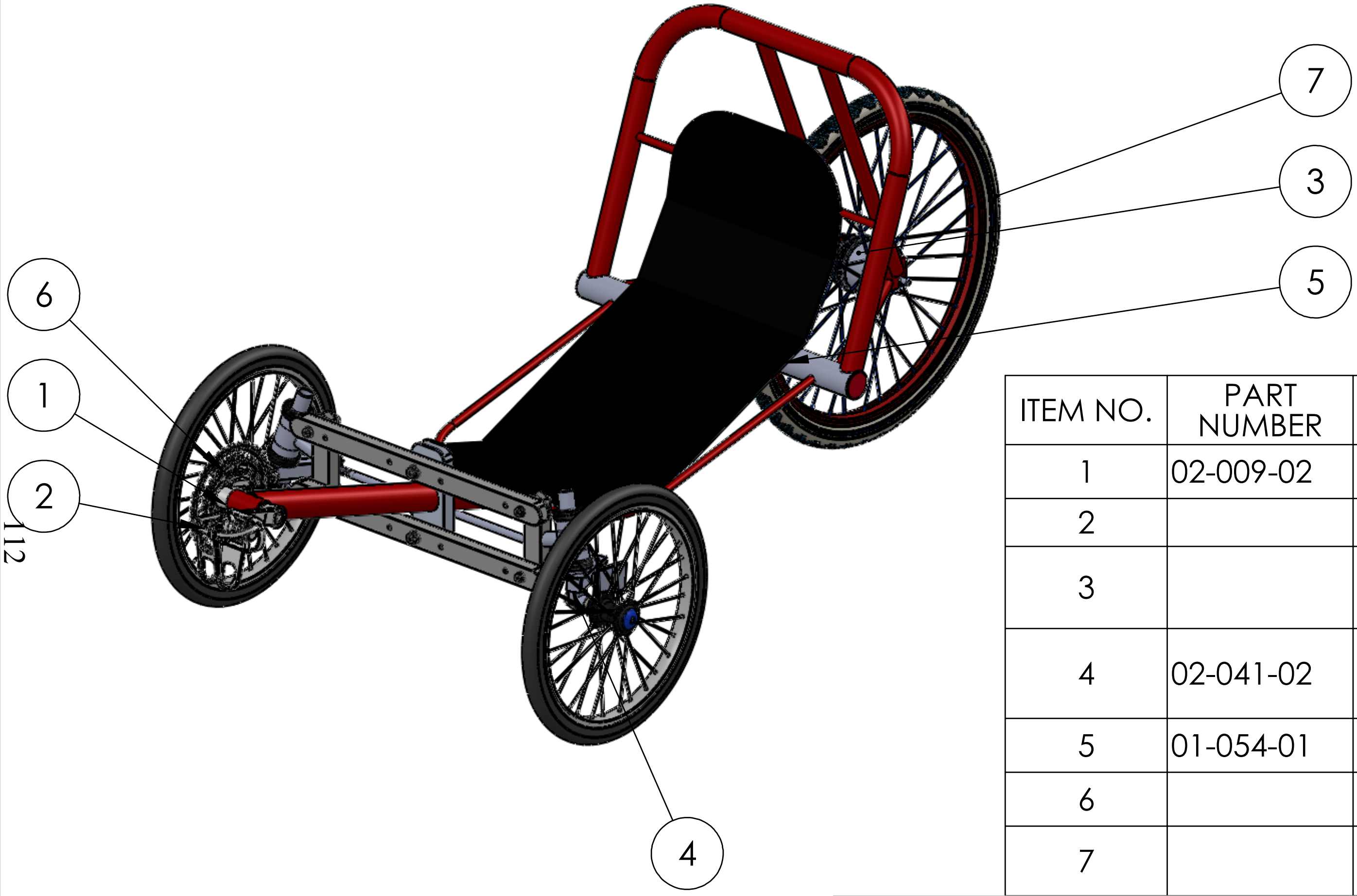

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	02-009-02	FRAME ASSEMBLY	1
2		PEDALS AND CRANKSET	1
3		SHIMANO ALFINE INTERNAL HUB	1
4	02-041-02	FULL STEERING ASSEMBLY	1
5	01-054-01	SEAT BASE	1
6		20 INCH BIKE WHEEL	2
7		26 INCH BIKE WHEEL	1

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BEND ±0.5
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THREE PLACE DECIMAL ±0.005

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ALUMINUM-6061 T6

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	NAME	DATE
DRAWN	P. CHESTER	1/30/14
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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY:

TITLE:

FINAL ASSEMBLY WITHOUT FAIRING

SIZE **A** DWG. NO. 02-033-01 REV

SCALE: 1:13 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
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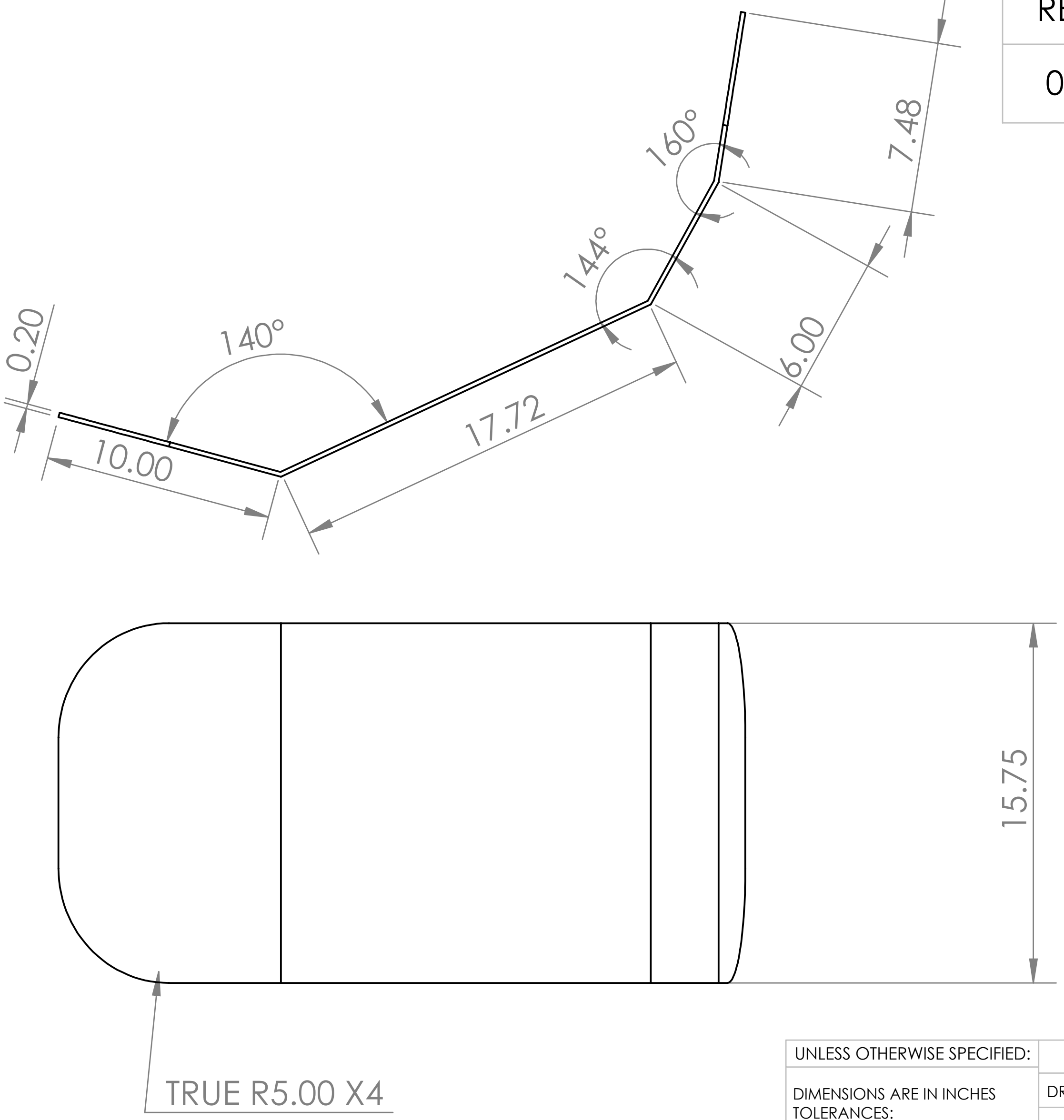
NOTE: MADE FROM CARBON FIBER



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CARBON FIBER

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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FINAL ASSEMBLY

TITLE:

SEAT BASE

SIZE A
DWG. NO. 01-054-01
REV

SCALE: 1:8
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

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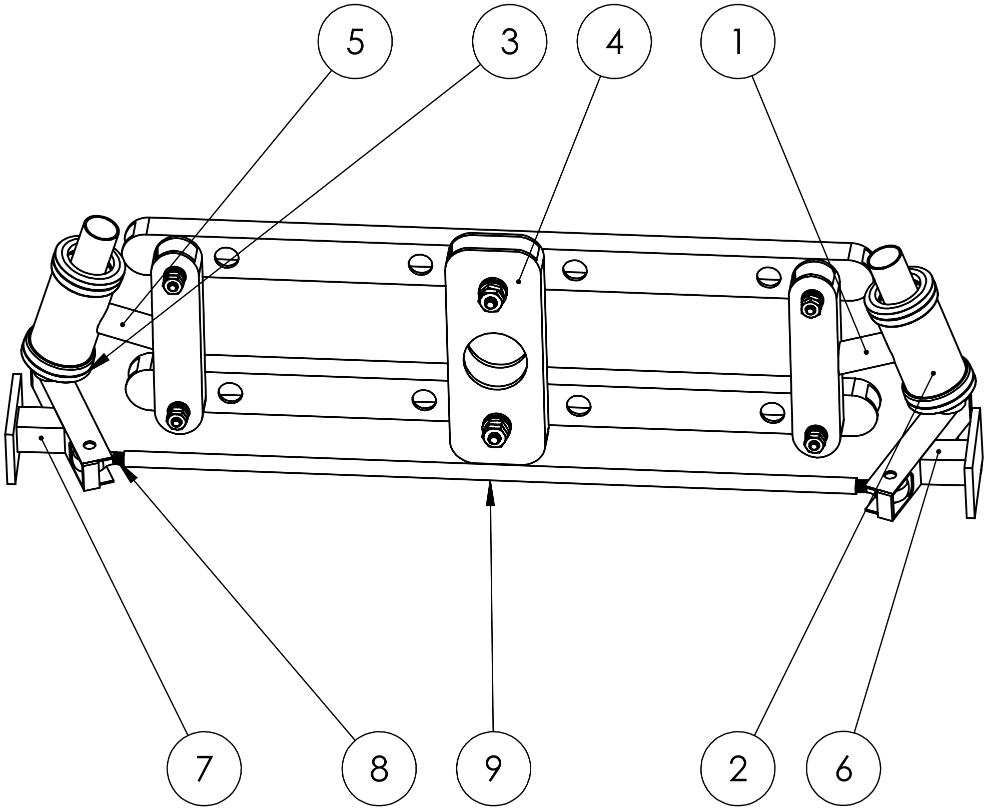
02	UPDATE	PC



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
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2	01-030-01	KINGPIN AXLE SHELL	2
3	01-031-01	FSA ORBIT HEADSET	4
4	02-040-02	TILT STEER ASSEMBLY	1
5	01-028-01	KINGPIN ATTACH, PORT	1
6	02-048-02	FRONT WHEEL ATTACH ASSEMBLY, STARBOARD	1
7	02-049-02	FRONT WHEEL ATTACH ASSEMBLY, PORT	1
8	6960T61	ROD END BEARINGS	2
9	01-052-02	ACKERMANN ROD	1

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BEND ±0.5
TWO PLACE DECIMAL ±0.1
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
ALUMINUM-6061 T6

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	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

TILT STEERING ASSEMBLY

SIZE A
DWG. NO. 02-041-02
REV

SCALE: 1:6 WEIGHT: SHEET 1 OF 1

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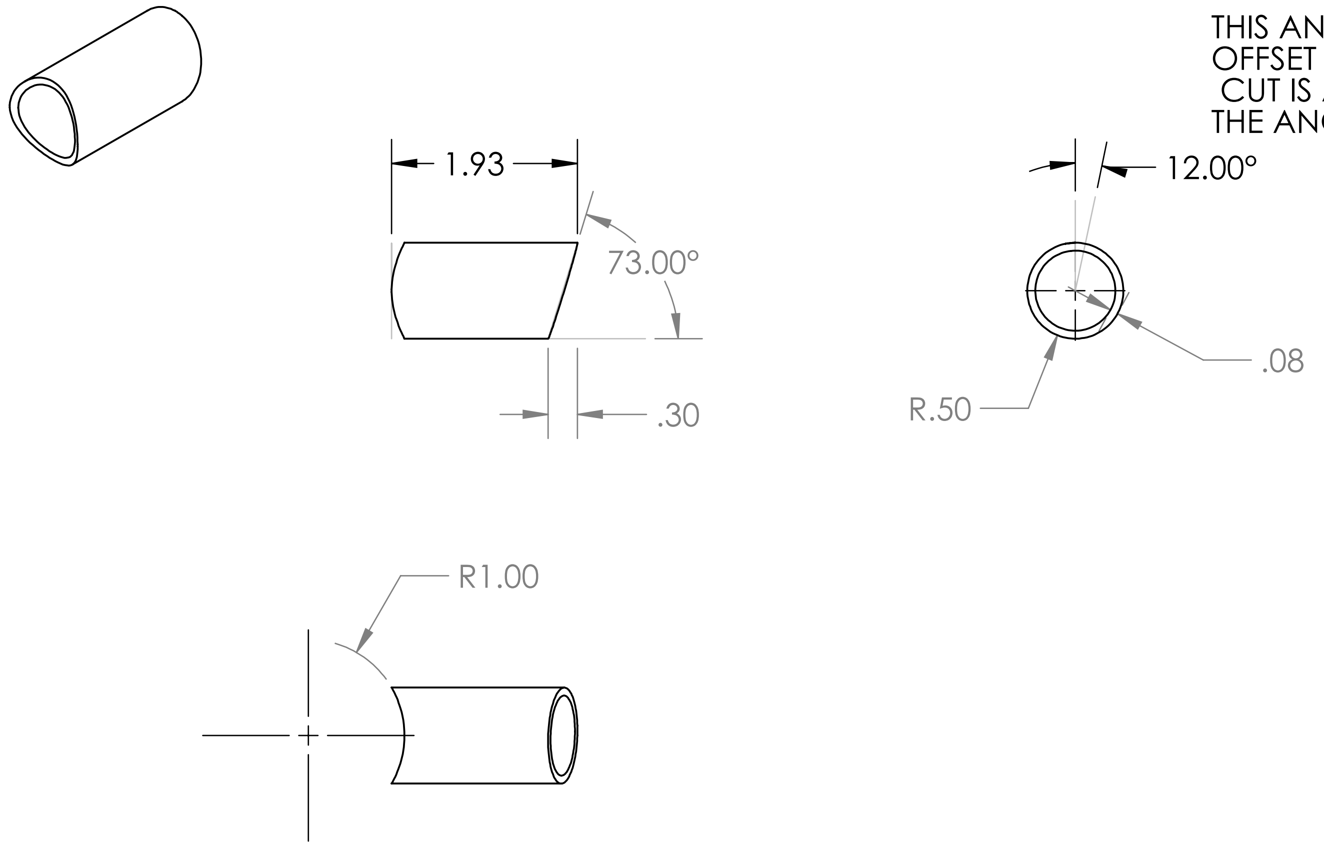

THIS ANGLE DESCRIBES THE
OFFSET THAT THE FISHMOUTH
CUT IS AT FROM
THE ANGLED CUT

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
ALUMINUM-6061 T6

FINISH

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	NAME	DATE
DRAWN	R.NAKAMURA	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PROPRIETARY AND CONFIDENTIAL

SUB-ASSEMBLY: STEERING

TITLE:
KingPin Attach,
Starboard Side

SIZE A
DWG. NO. 01-027-01
REV

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
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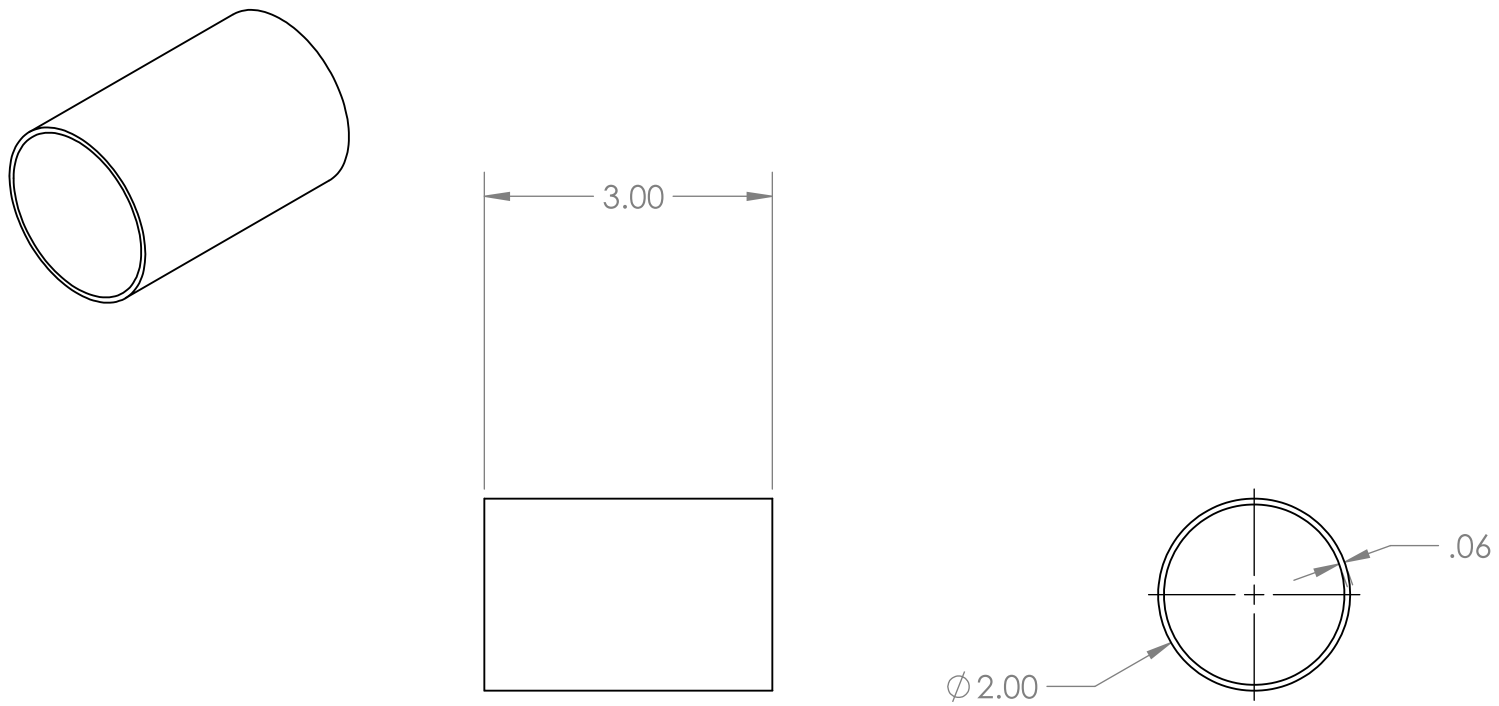

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: ANGLE ±0.5 BEND ±0.5 TWO PLACE DECIMAL ±0.1 THREE PLACE DECIMAL ±0.005	DRAWN	R.NAKAMURA	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
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SUB-ASSEMBLY: STEERING

TITLE:

Kingpin Axle Shell

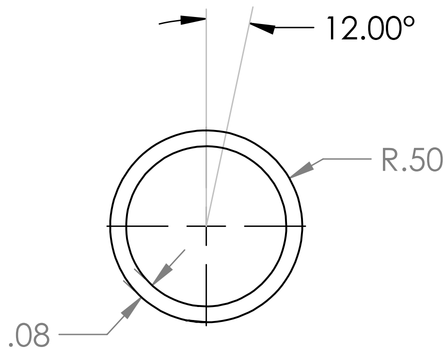
SIZE	DWG. NO.	REV
A	01-030-01	

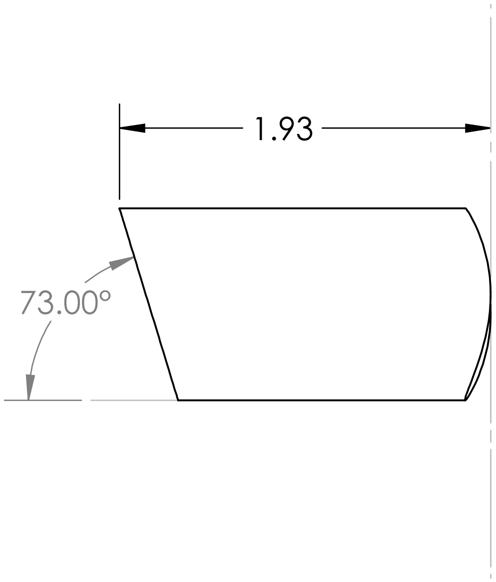
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

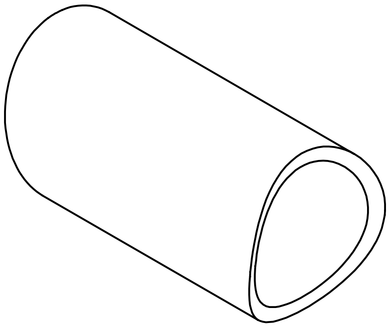
5 4 3 2 1

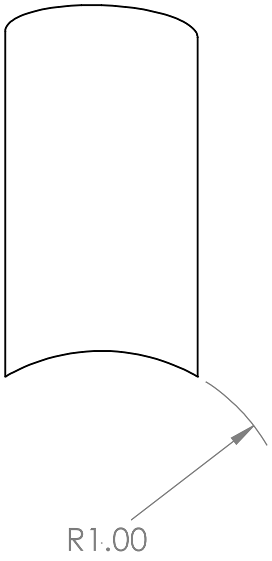
REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	RN

THIS ANGLE DESCRIBES THE
OFFSET THAT THE FISHMOUTH
CUT IS AT FROM
THE ANGLED CUT









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BEND ±0.5
TWO PLACE DECIMAL ±0.1
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R. NAKAMURA	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

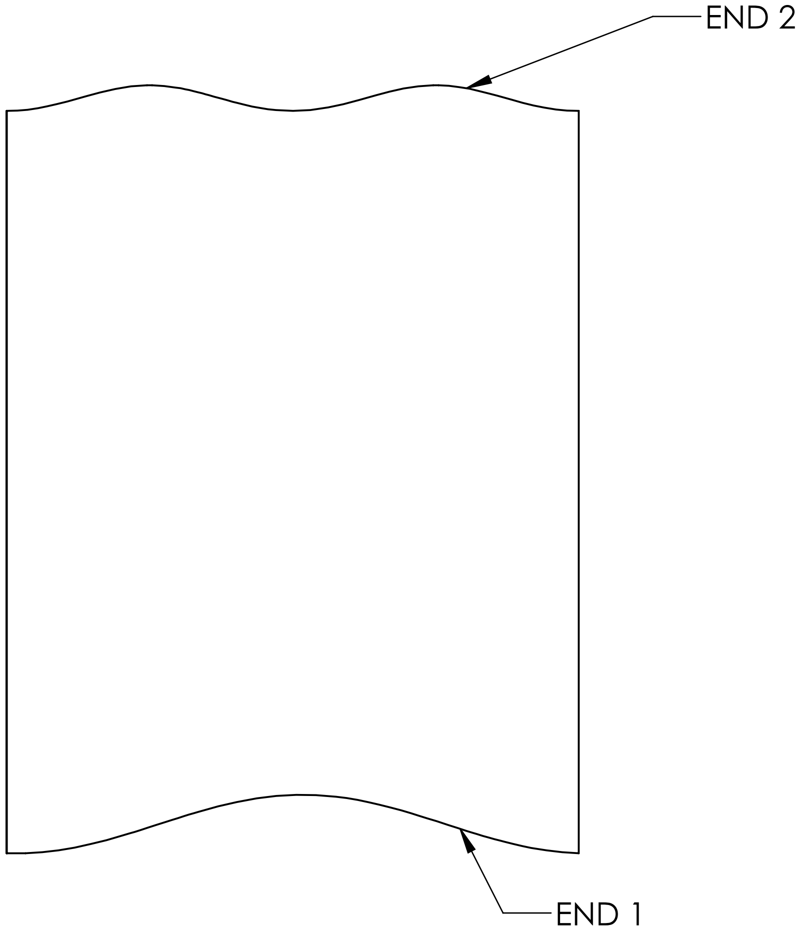
KingPin Attach,
Port Side

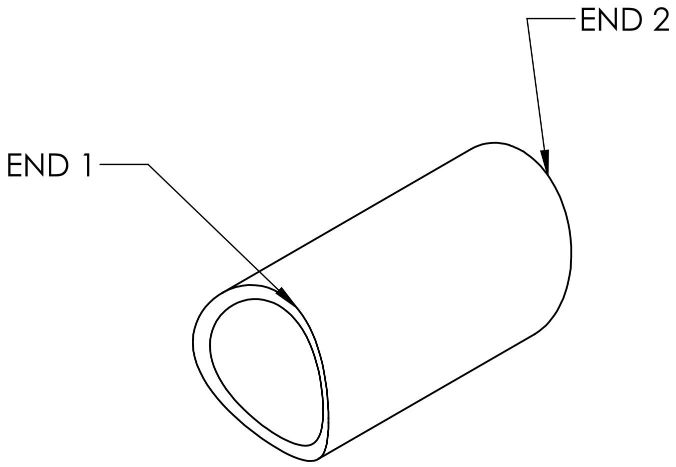
SIZE	DWG. NO.	REV
A	01-028-01	

SCALE: 1:2 WEIGHT: SHEET 1 OF 2

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC





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BEND ±0.5
TWO PLACE DECIMAL ±0.1
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

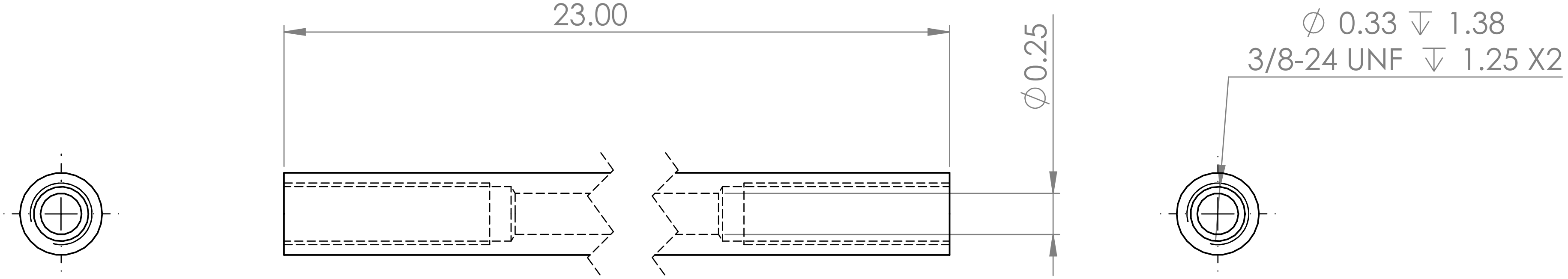
KingPin Attach,
Port Side

SIZE A
DWG. NO. 01-028-01
REV

SCALE: 1:1
WEIGHT:
SHEET 2 OF 2

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	TUBE INNER DIAMETER CHANGE	PC



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	P. CHESTER	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: STEERING

TITLE:

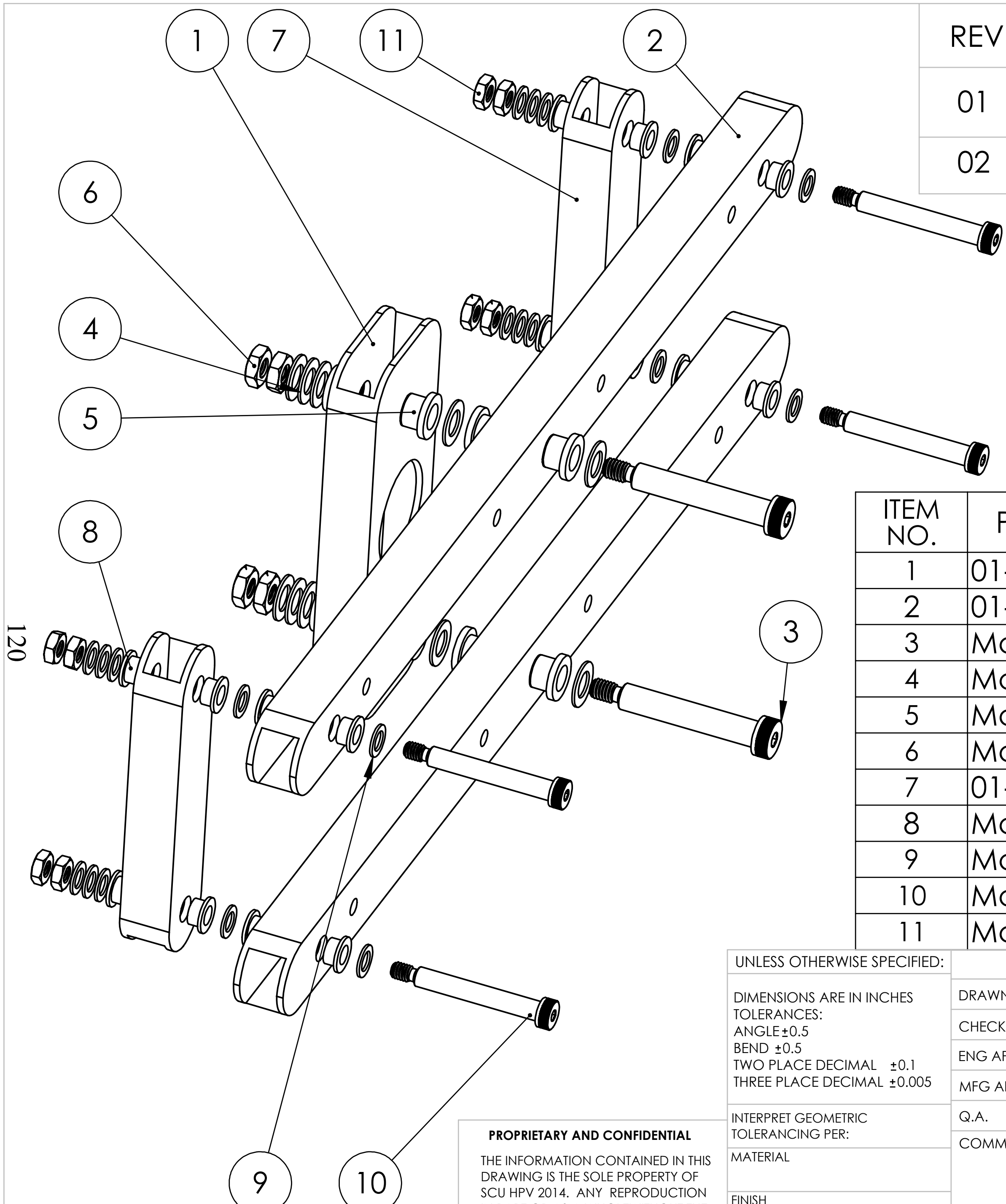
ACKERMANN
ROD

SIZE A
DWG. NO. 01-052-02
REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	UPDATED JOINTS	PC



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	01-016-01	TILT STEER CENTER BOX	1
2	01-022-02	TILT STEER LONG EDGE	2
3	McM 91259A723	1/2" SHOULDER SCREW	2
4	McM 93286A049	1/2" WASHER	10
5	McM 2938T11	1/2" SLEEVE BEARING	8
6	McM 90502A031	1/2" NUT	4
7	01-023-01	TILT STEER SHORT EDGE	2
8	McM 2938T6	3/8" SLEEVE BEARING	16
9	McM 93286A045	3/8" WASHERS	20
10	McM 91259A634	3/8" SHOULDER SCREW	4
11	McM 90502A030	3/8" NUT	8

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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

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

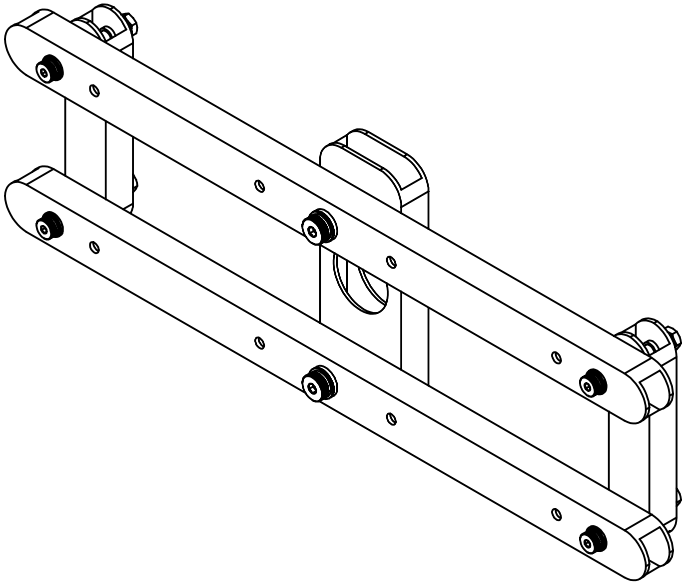
TILT STEER BOX ASSEMBLY

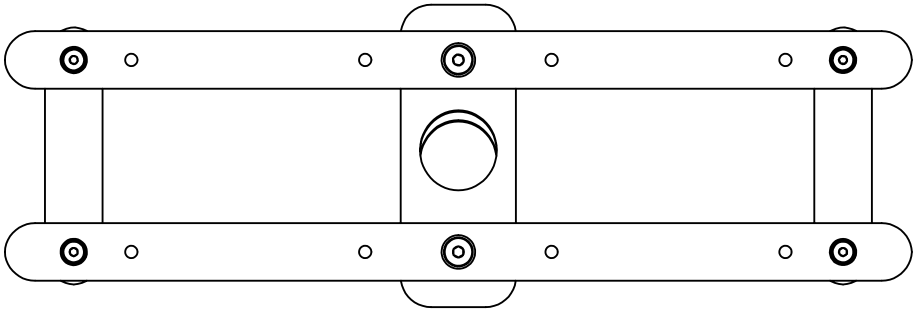
SIZE	DWG. NO.	REV
A	02-040-02	

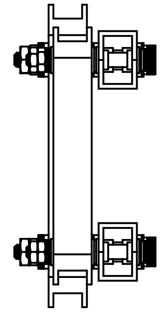
SCALE: 1:3 WEIGHT: SHEET 1 OF 2

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC







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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

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

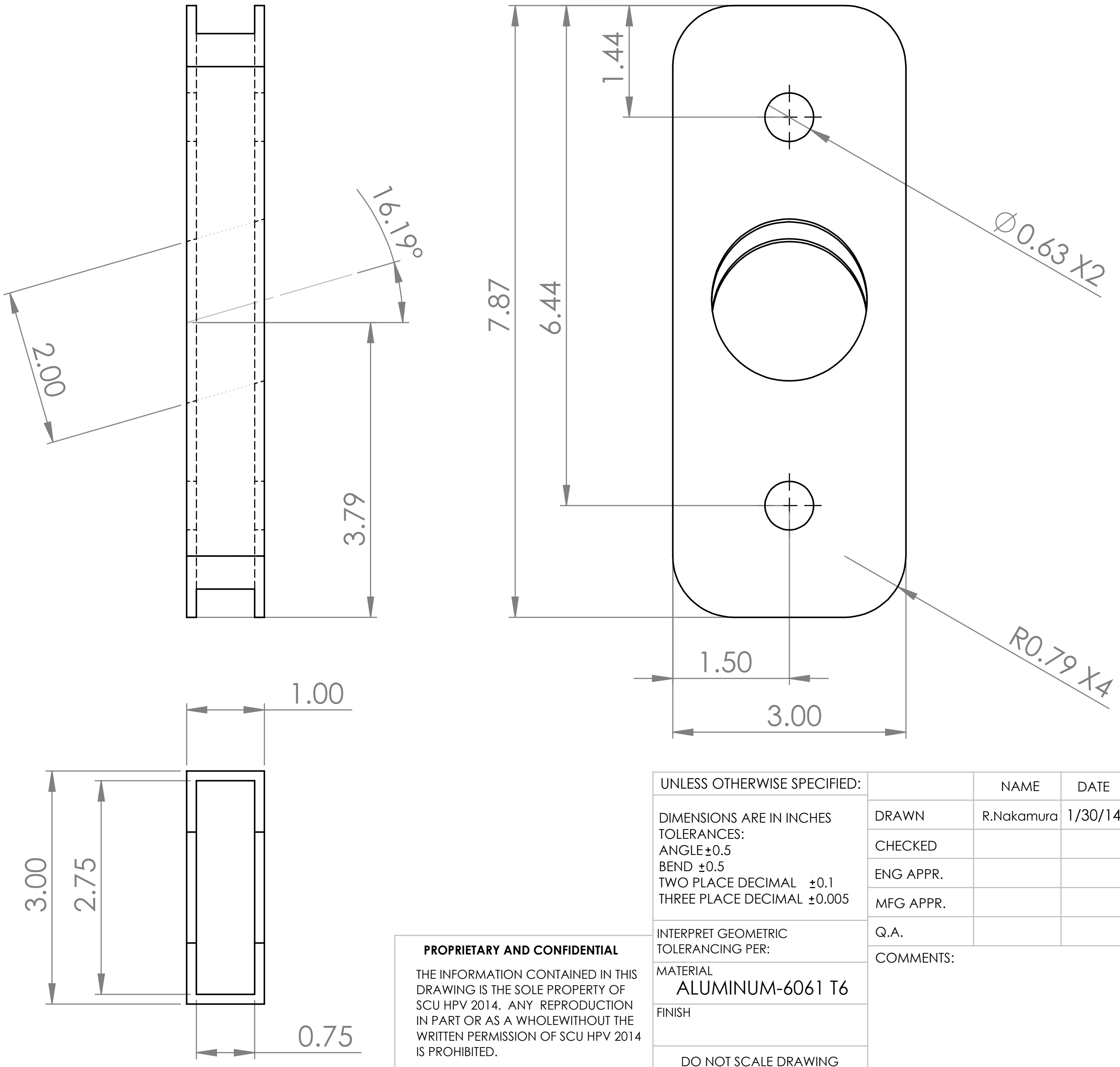
TITLE:
TILT STEER BOX ASSEMBLY

SIZE A
DWG. NO. 02-040-02
REV

SCALE: 1:5
WEIGHT:
SHEET 2 OF 2

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	RN



PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R.Nakamura	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

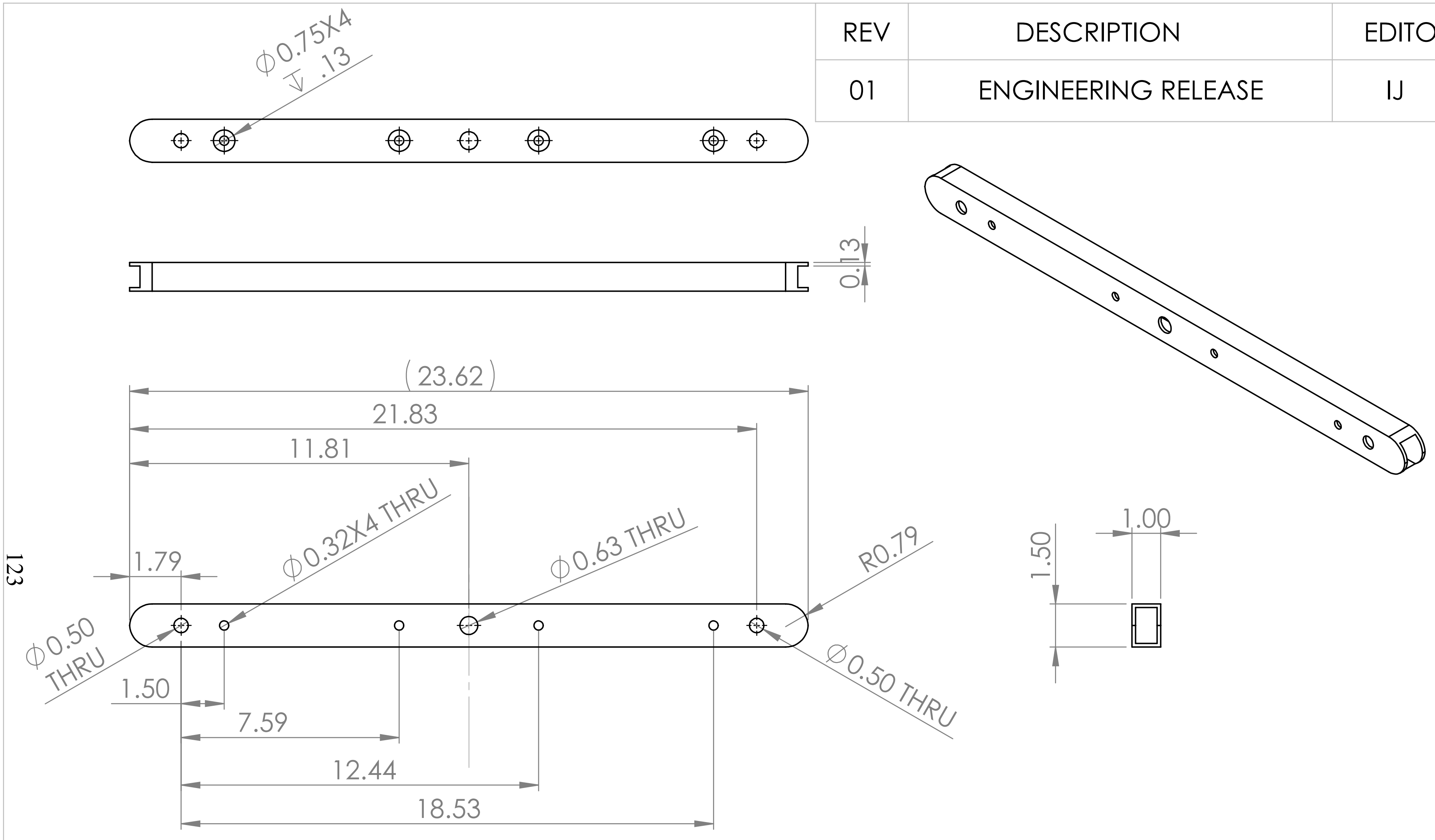
SUB-ASSEMBLY: STEERING

TITLE:
Tilt Steer Center Box

SIZE A
DWG. NO. 01-016-01
REV

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	IJ



123

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	IAN JONES	1/31/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: STEERING

TITLE:

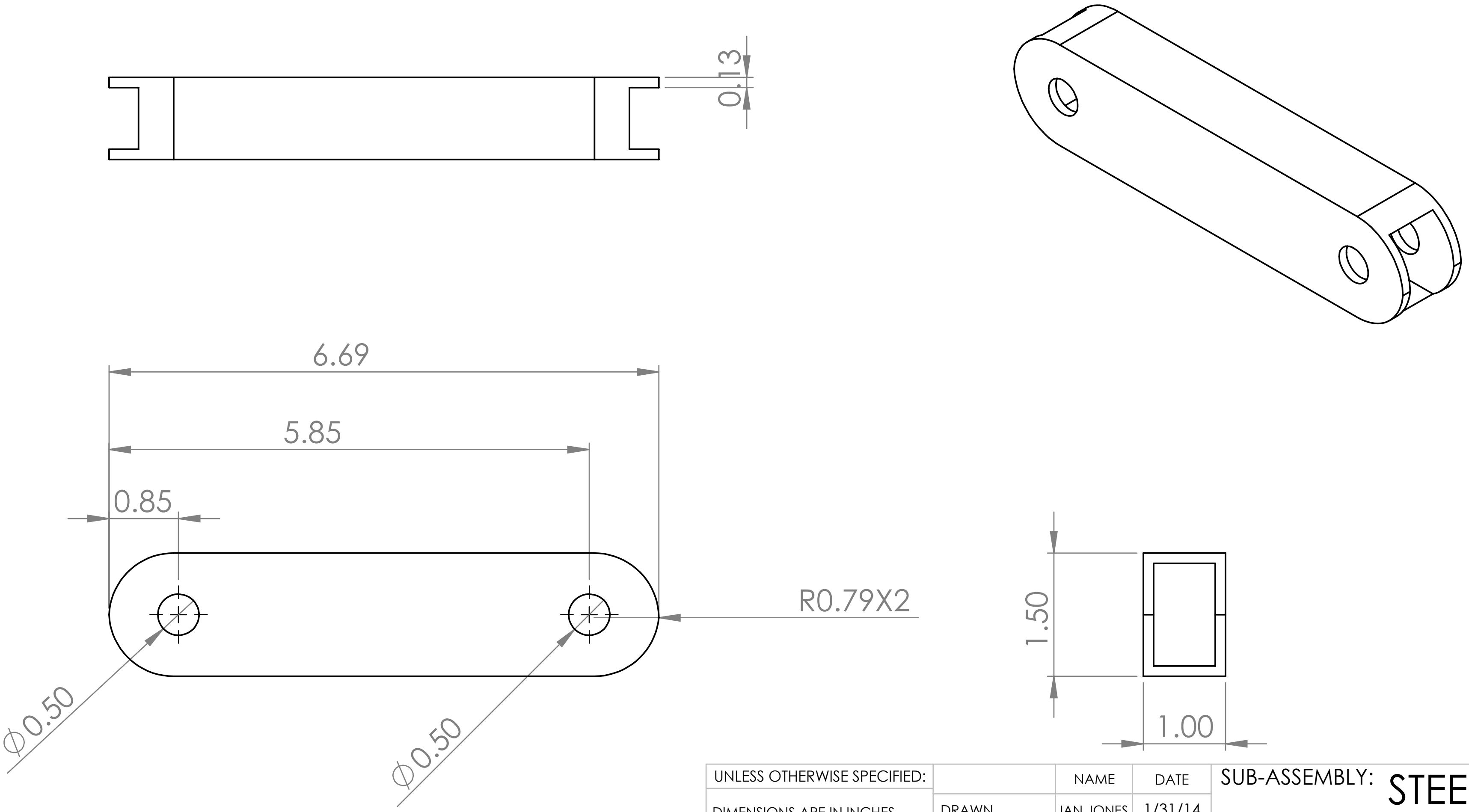
TILT STEER LONG EDGE

SIZE	DWG. NO.	REV
A	01-022-02	

SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	IJ



PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6063 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	IAN JONES	1/31/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

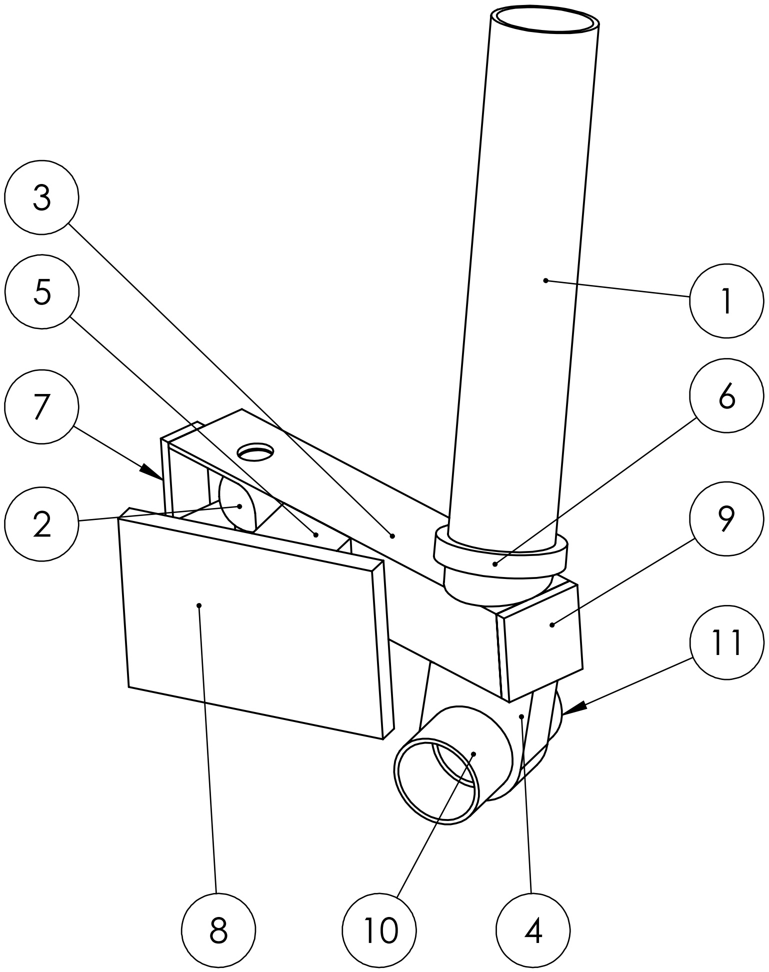
TILT STEER SHORT EDGE

SIZE
A
DWG. NO.
01-023-01
REV

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	REMOVAL OF COMPLEX ANGLES	PC



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	01-032-02	STEER TUBE	1
2	McM 6960T61	ROD END BEARING	1
3	01-046-04	CONTROL ARM	1
4	01-051-02	FRONT AXLE	1
5	01-065-01	BREAK PAD SUPPORT	1
6	01-066-02	STEERING RING SUPPORT	1
7	01-068-01	CAP STEERING ACKERMANN END	1
8	01-043-04	BRAKE TAB	1
9	01-067-02	STEERING END CAP	1
10	01-073-01	BRAKE AXLE BOLT SPACER	1
11	01-074-01	AXLE BOLT SPACER	1

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

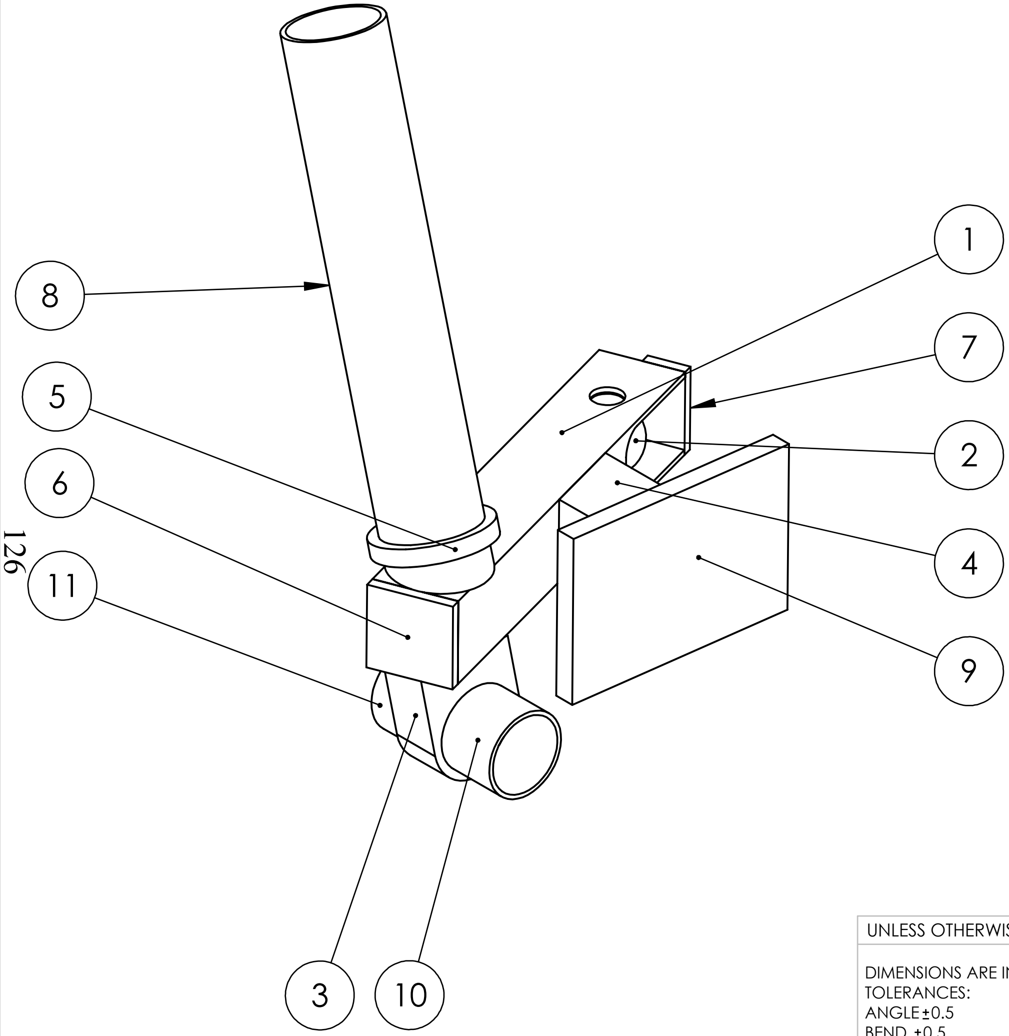
TITLE: FRONT WHEEL ATTACH ASSEMBLY, STARBOARD

SIZE	DWG. NO.	REV
A	02-048-02	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	REMOVAL OF COMPLEX ANGLES	PC



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	01-046-04	CONTROL ARM	1
2	McM 6960T61	ROD END BEARING	1
3	01-051-02	FRONT AXLE	1
4	01-065-01	BREAK PAD SUPPORT	1
5	01-066-01	STEERING RING SUPPORT	1
6	01-067-02	STEERING END CAP	1
7	01-068-01	CAP STEERING ACKERMANN END	1
8	01-032-02	STEER TUBE	1
9	01-043-04	BRAKE TAB	1
10	01-073-01	BRAKE AXLE BOLT SPACER	1
11	01-074-01	AXLE BOLT SPACER	1

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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE: FRONT WHEEL ATTACH ASSEMBLY, PORT

SIZE A

DWG. NO. 02-049-02

REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

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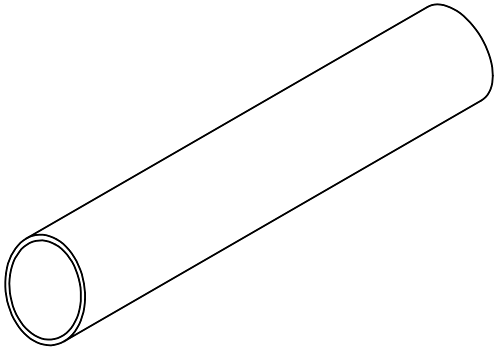
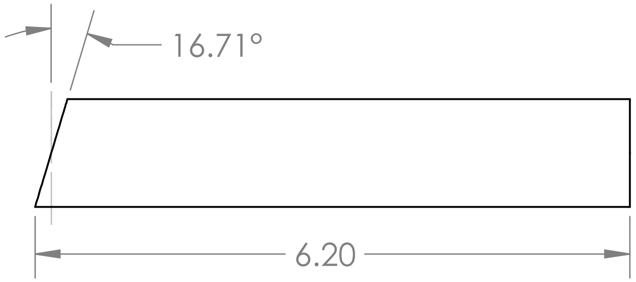
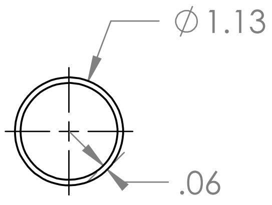
5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	SIMPLIFIED	PC







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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

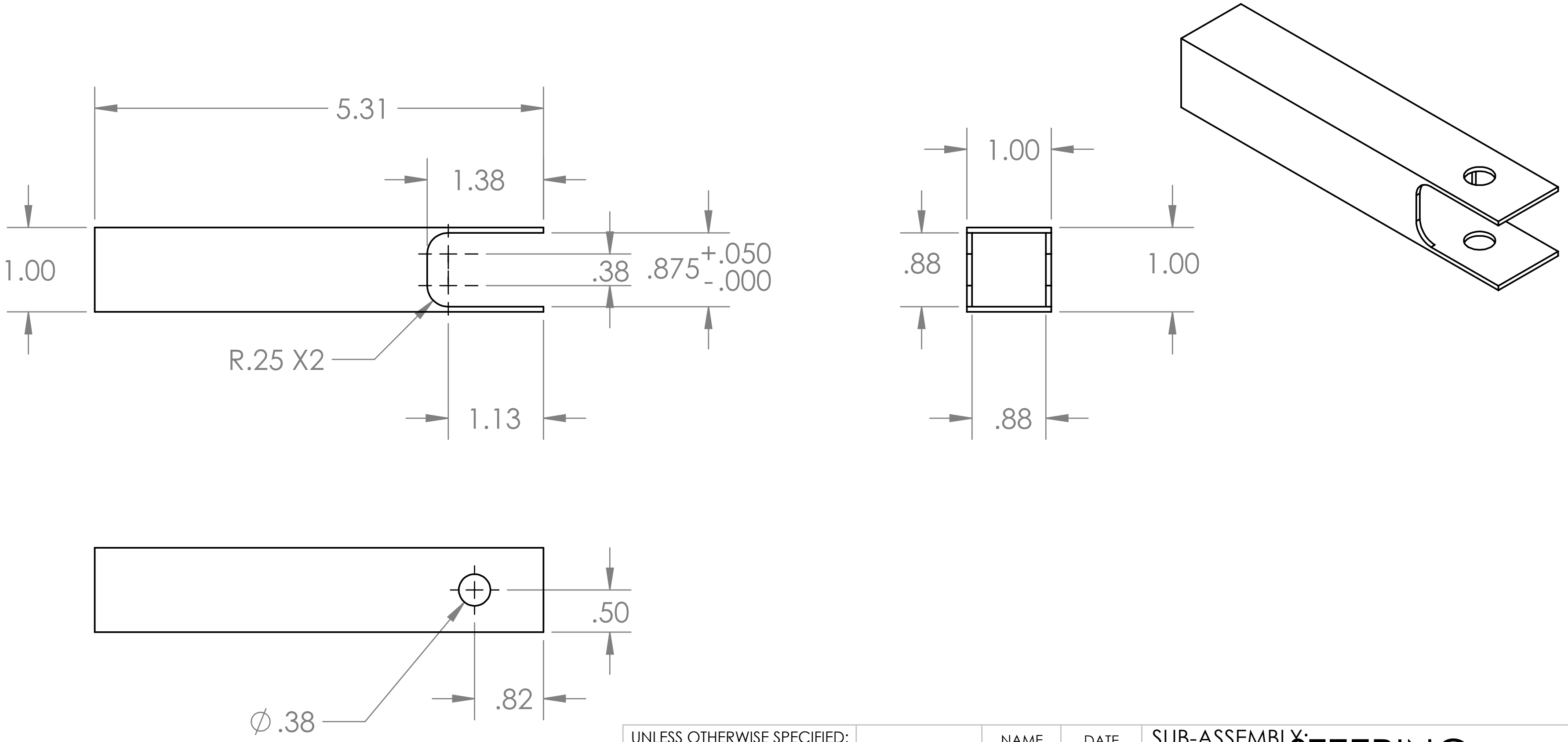
STEER TUBE

SIZE A
DWG. NO. 01-032-02
REV

SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PS
04	CHANGED TO SQUARE TUBING	PC



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	P. CHESTER	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

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SUB-ASSEMBLY: STEERING

TITLE:

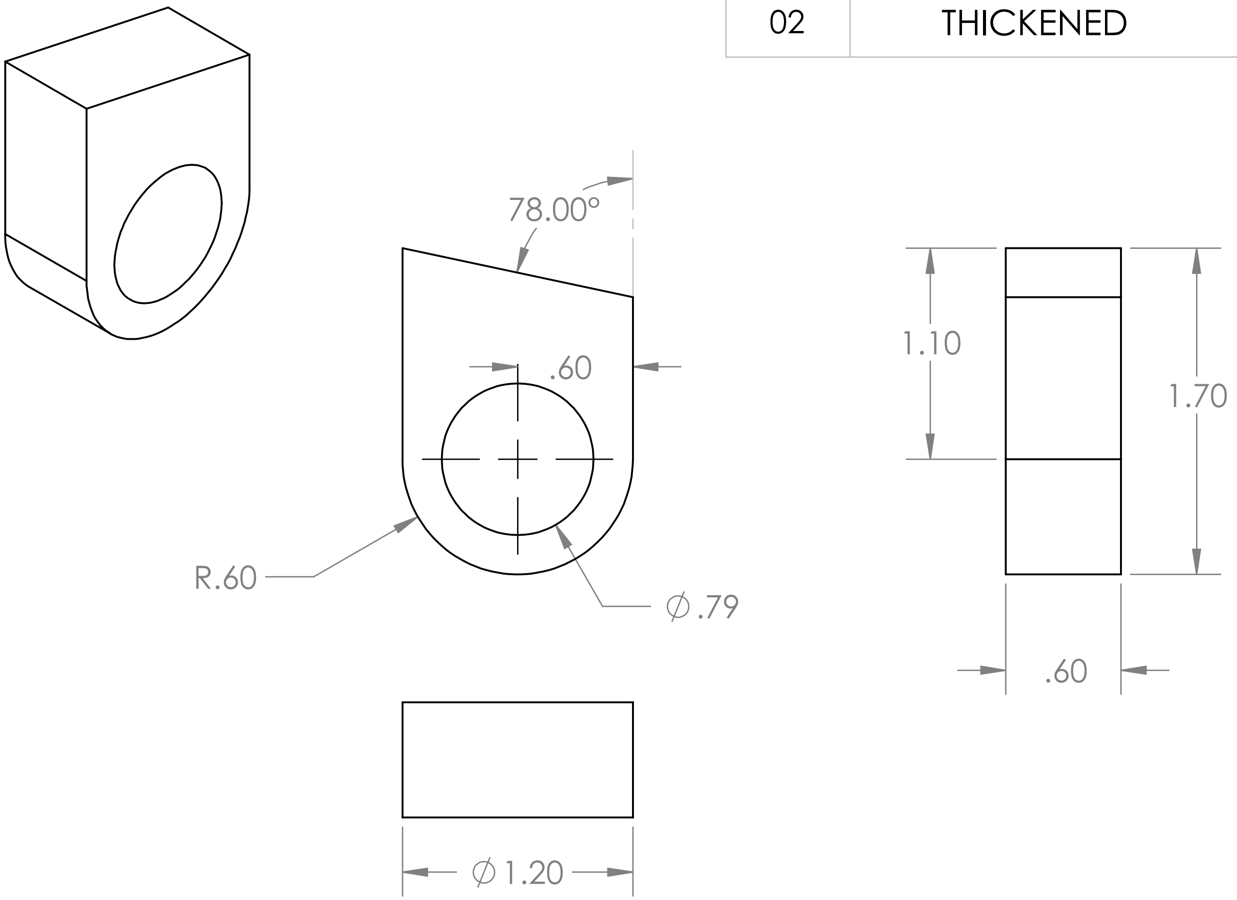
CONTROL ARM

SIZE	DWG. NO.	REV
A	01-046-04	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	THICKENED	PC



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	P. CHESTER	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: STEERING

TITLE:

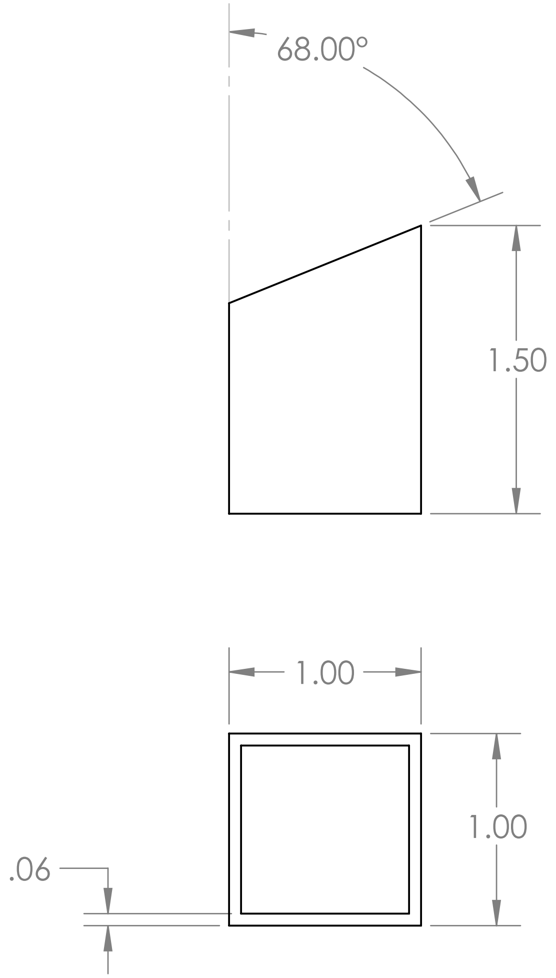
FRONT AXLE

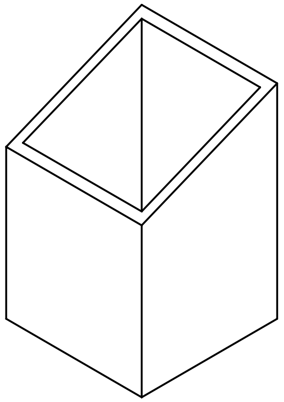
SIZE A
DWG. NO. 01-051-02
REV

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC





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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

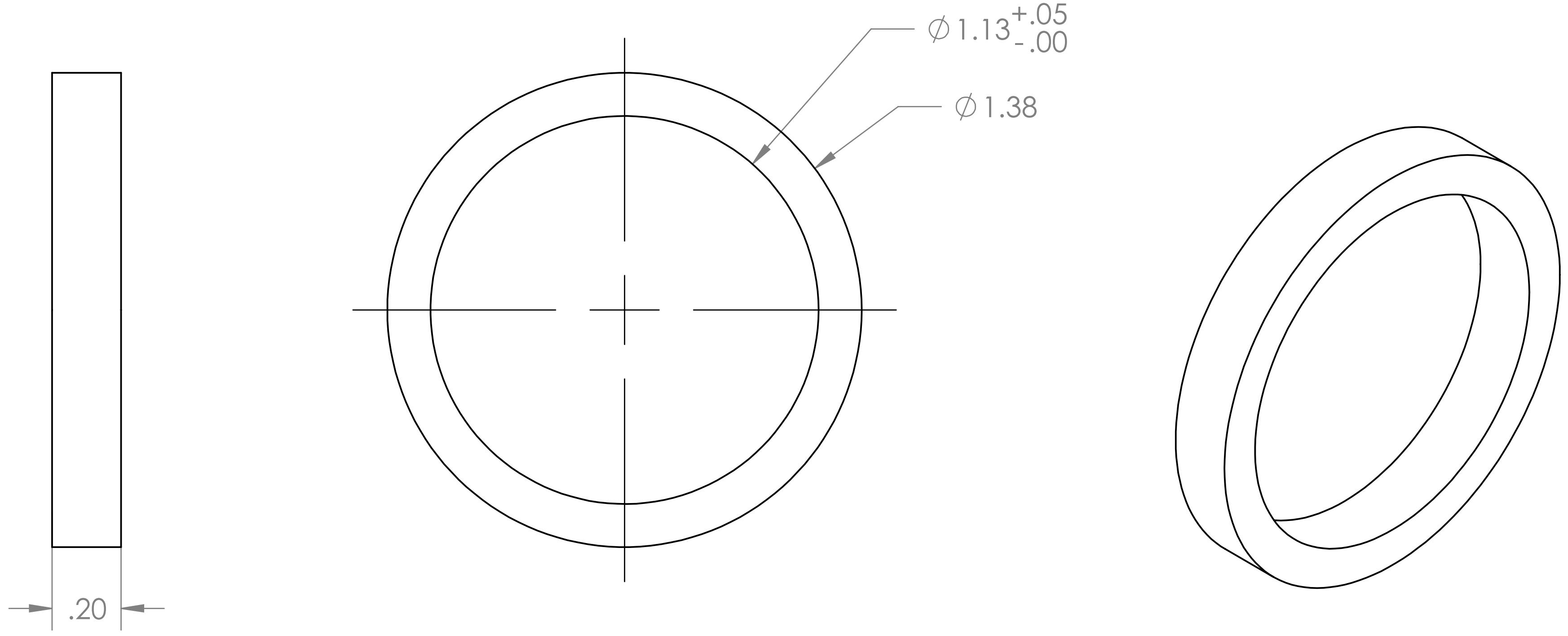
BREAK PAD
SUPPORT

SIZE **A** DWG. NO. 01-065-01 REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC



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	P. CHESTER	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: STEERING

TITLE:

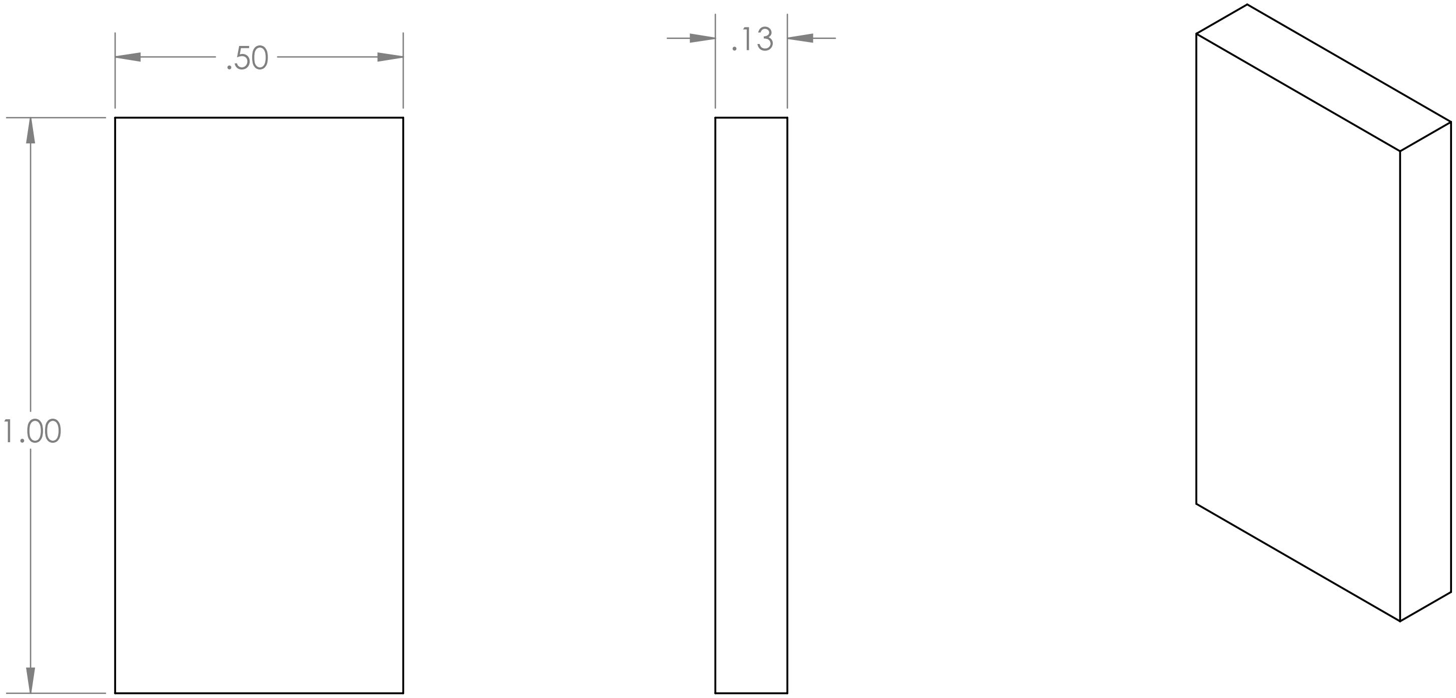
STEERING RING SUPPORT

SIZE	DWG. NO.	REV
A	01-066-01	

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC



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	P. CHESTER	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: STEERING

TITLE: CAP STEERING ACKERMANN END

SIZE A

DWG. NO. 01-068-01

REV

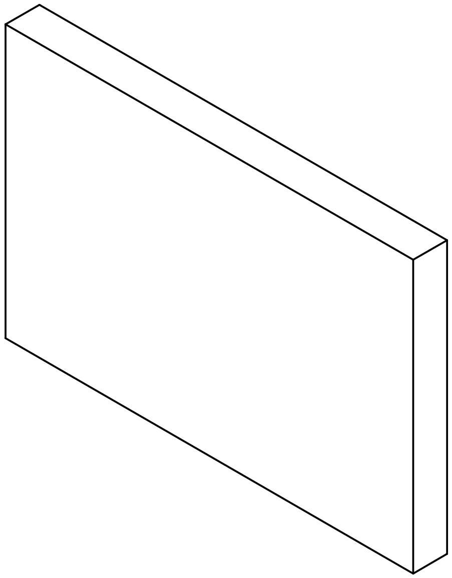
SCALE: 3:1

WEIGHT:

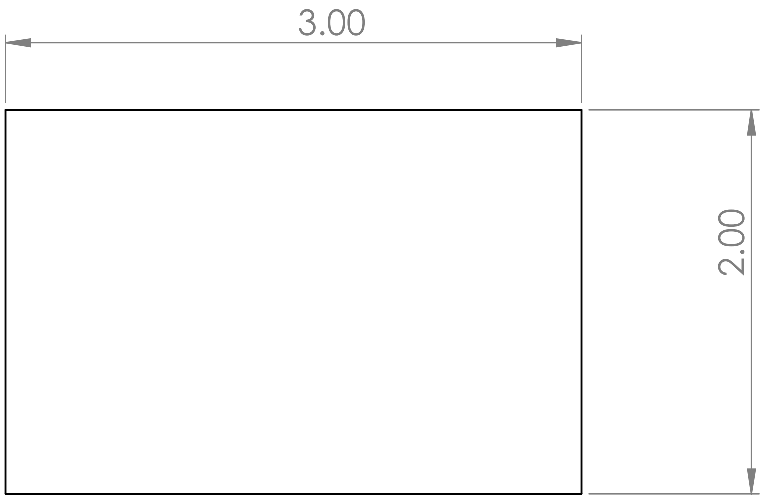
SHEET 1 OF 1

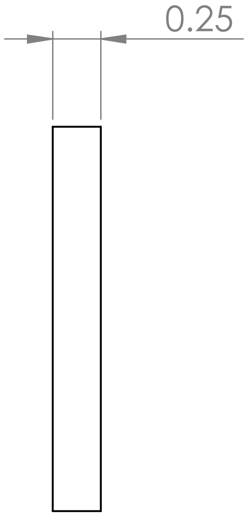
5 4 3 2 1

NOTE;
BEFORE MANUFACTORING
AND WELDING ENSURE
THAT THE BRAKES WILL FIT
ON THE TABS. THE FIT FOR
BOTH SIDES WILL BE
DIFFERENT, PAD MAY
REQURIRE SLIGHT
MODIFICATION.



REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	SIZE CHANGE	PC





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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

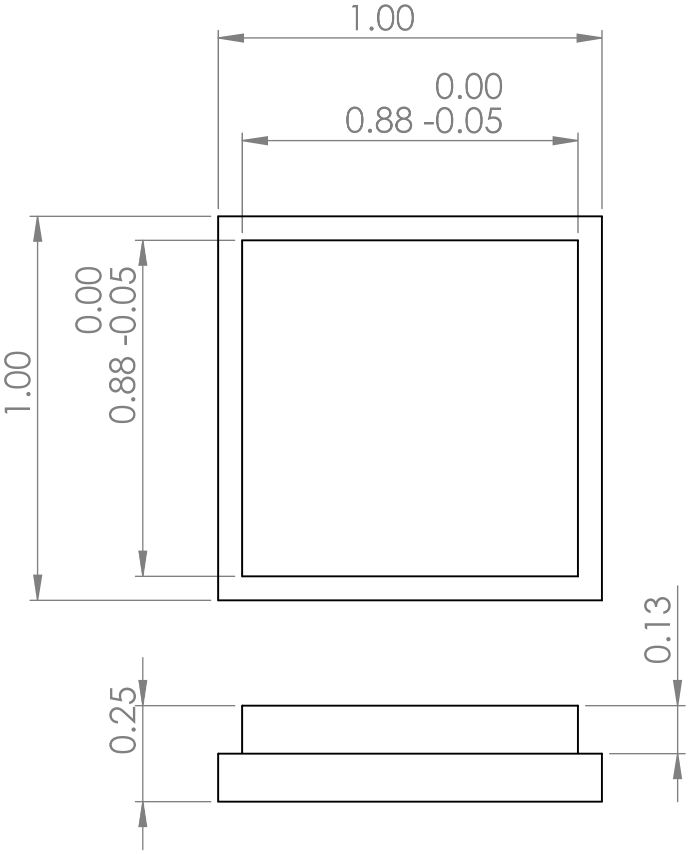
BRAKE TAB

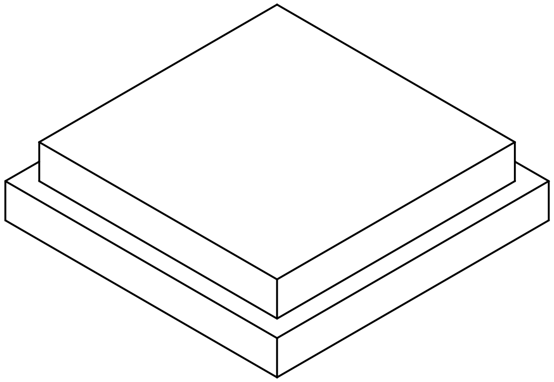
SIZE A
DWG. NO. 01-043-04
REV

SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	WEDGE ADDED	PC





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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

STEERING END CAP

SIZE A

DWG. NO. 01-067-02

REV

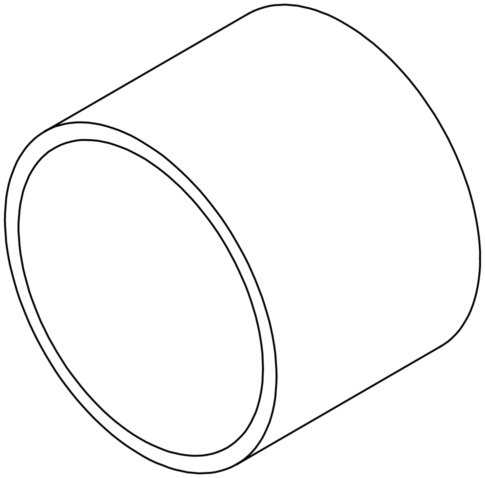
SCALE: 2:1

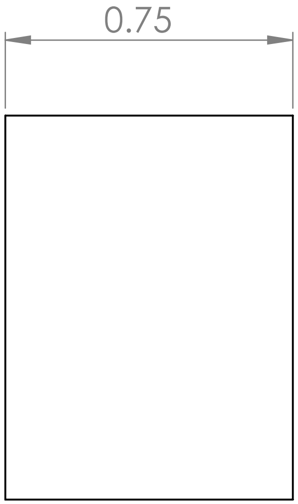
WEIGHT:

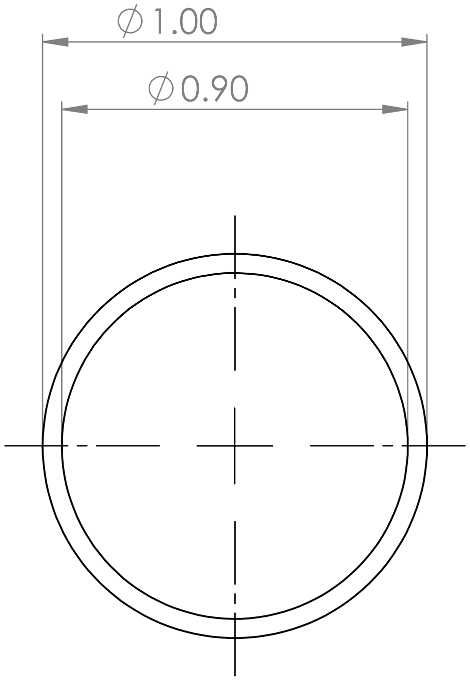
SHEET 1 OF 1

NOTE:
LENGTH MAY NEED
TO BE MODIFIED TO
ENSURE THE BRAKES
DON'T RUB.

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC







PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

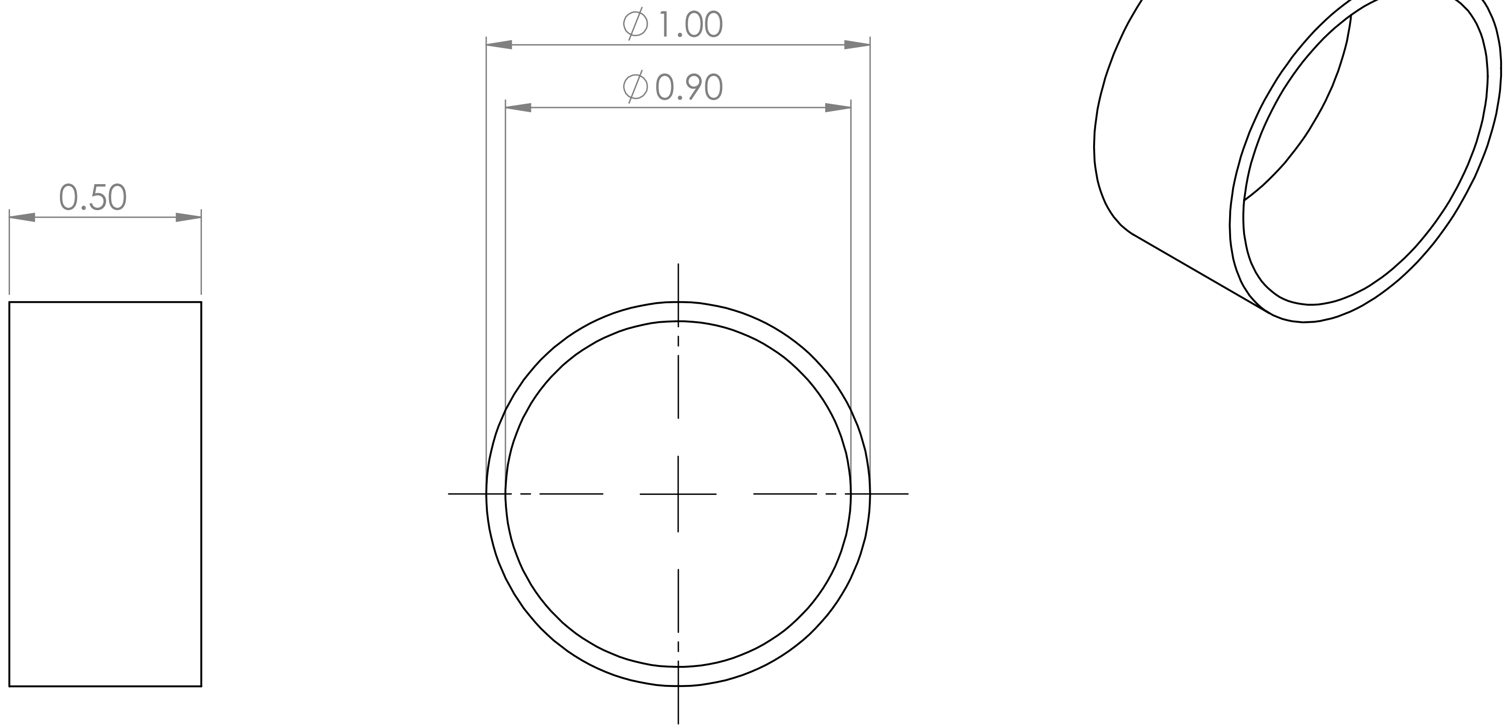
BRAKE AXLE BOLT SPACER

SIZE: **A**
DWG. NO. 01-073-01
REV

SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC



PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: STEERING

TITLE:

AXLE BOLT SPACER

SIZE **A**

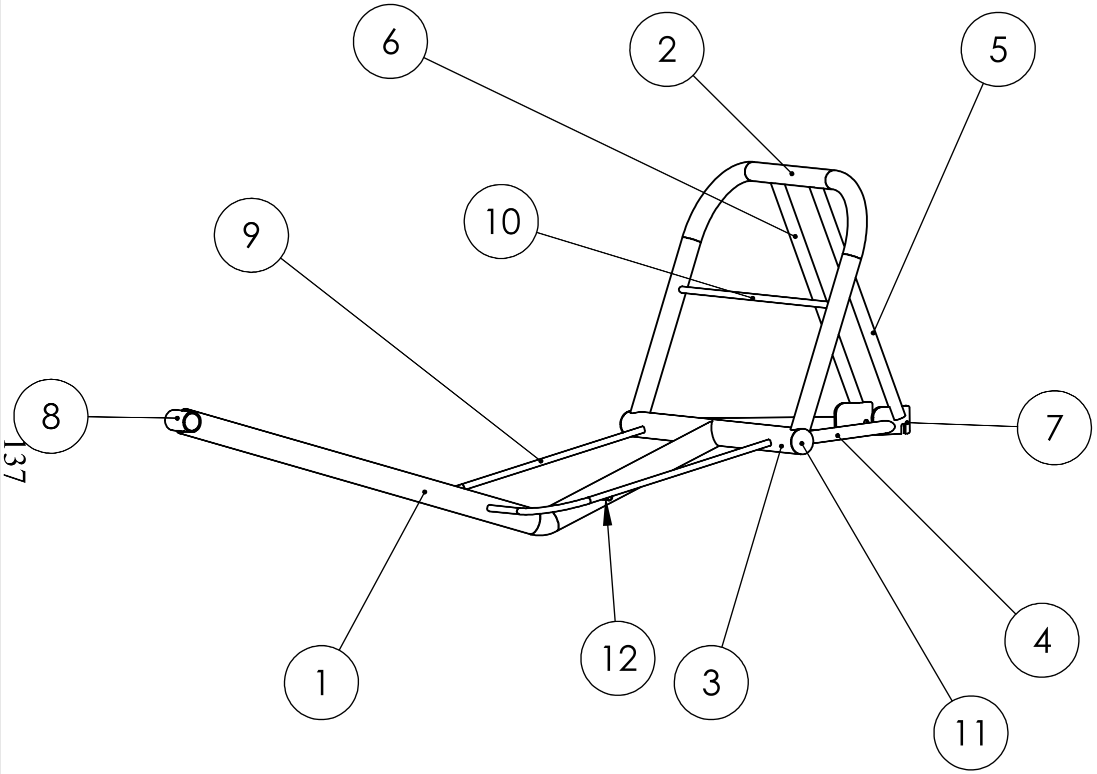
DWG. NO. 01-074-01

REV

SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	01-007-02	Frame Central Bar	1
2	01-008-02	Roll Cage Tube	1
3	01-006-02	Roll Cage Center Tube	1
4	01-011-01	Lower Chain Stay	2
5	01-014-02	Port Upper Chain Stay	1
6	01-013-02	Starboard Upper Chain Stay	1
7	01-015-01	Rear Drop-Outs	2
8	01-037-01	Bottom Bracket Shell	1
9	01-055-02	Lateral Supports	2
10	01-056-01	Roll Cage Seat Support	1
11	01-057-01	Roll Cage End Cap	2
12	01-059-01	Seat Belt Fixture	1

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

TITLE:

FRAME ASSEMBLY

SIZE A
DWG. NO. 02-009-02
REV

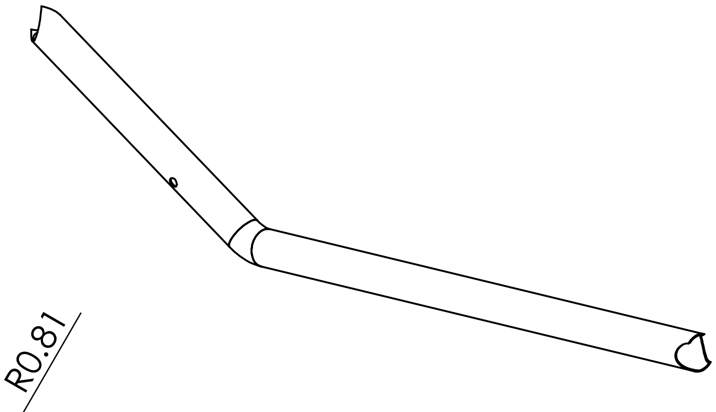
SCALE: 1:15 WEIGHT: SHEET 1 OF 2

5 4 3 2 1

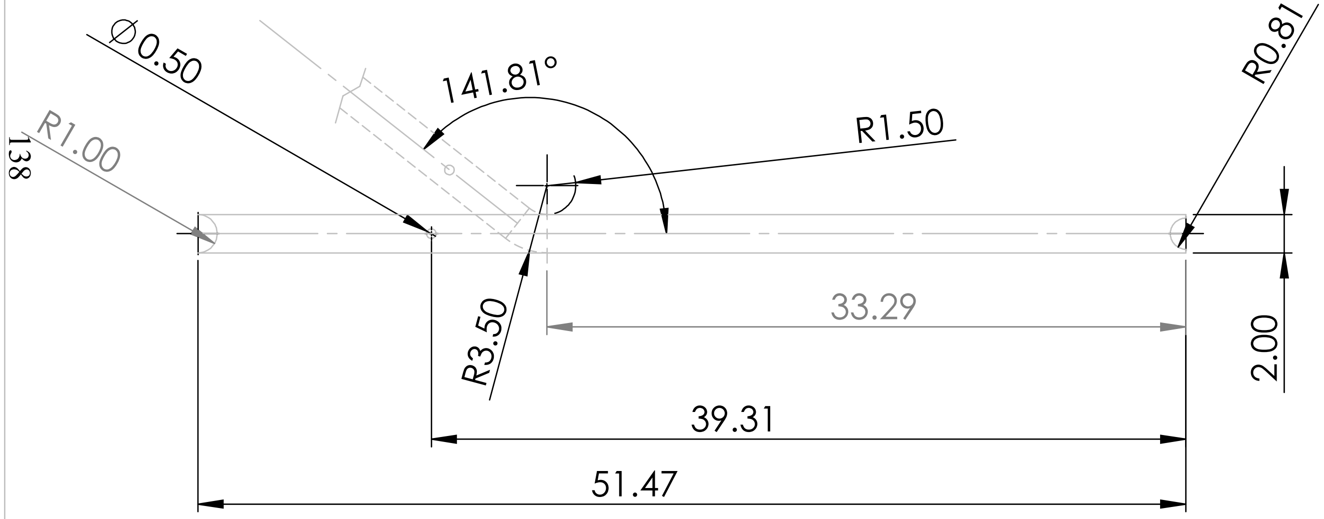
NOTE: USE ALUMINUM-6061 T6
TUBING WITH 2 INCH O.D.
AND 1.87 INCH I.D.

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	ADDED HOLE	PS

TUBING BENT



TUBING UNBENT



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	P. CHESTER	1/30/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: FRAME

TITLE:

FRAME CENTRAL BAR

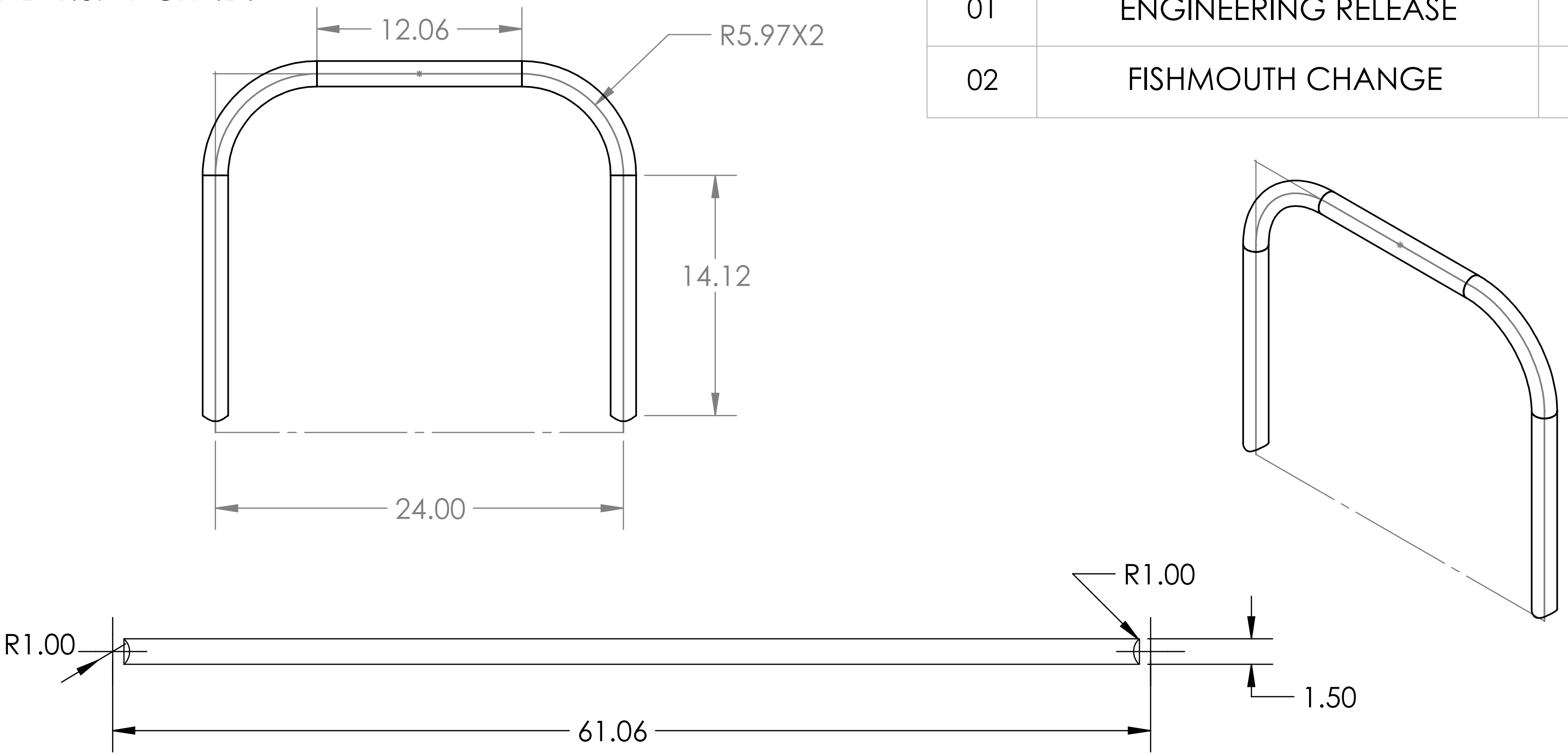
SIZE	DWG. NO.	REV
A	01-007-02	

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

NOTE: USE ALUMINUM-6061 T6
TUBING WITH 1.5 INCH O.D.
AND 1.37 INCH I.D.

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	FISHMOUTH CHANGE	PS



PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

TITLE:

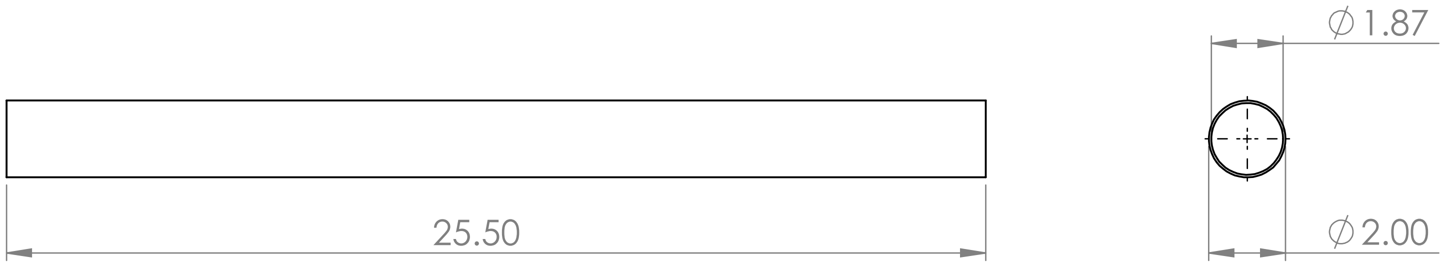
ROLL CAGE
TUBE

SIZE	DWG. NO.	REV
A	01-008-02	
SCALE: 1:10	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

NOTE:
USE ALUMINUM-6061 T6
TUBING WITH 2.0 INCH O.D.
AND 1.87 INCH I.D.

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	CHANGE WELD INTERFACE	PS



PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	2/12/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

TITLE:
ROLL CAGE
CENTER TUBE

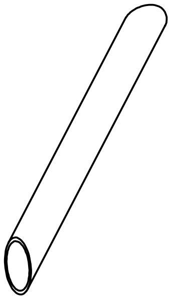
SIZE	DWG. NO.	REV
A	01-006-02	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

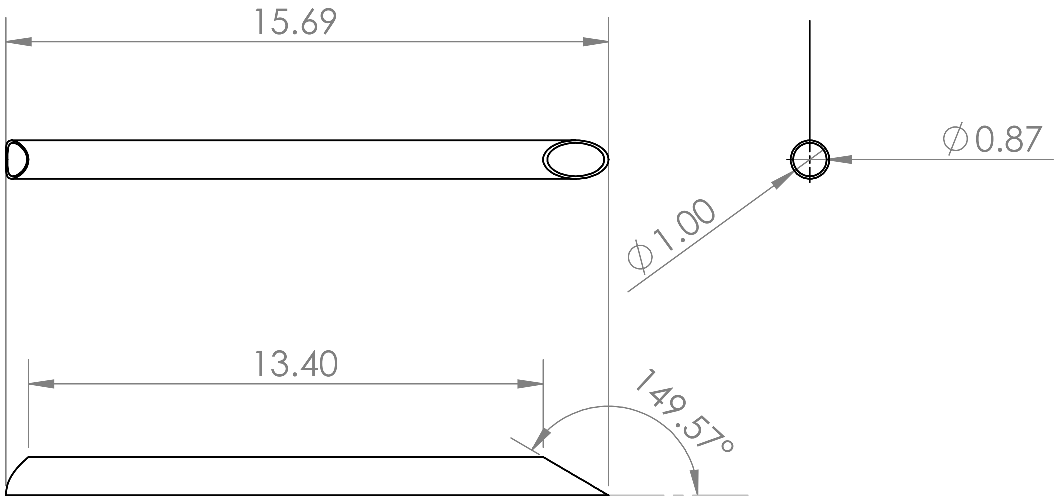
5 4 3 2 1

NOTE:
USE ALUMINUM-6061 T6
TUBING WITH 1 INCH O.D.
AND 0.87 INCH I.D.

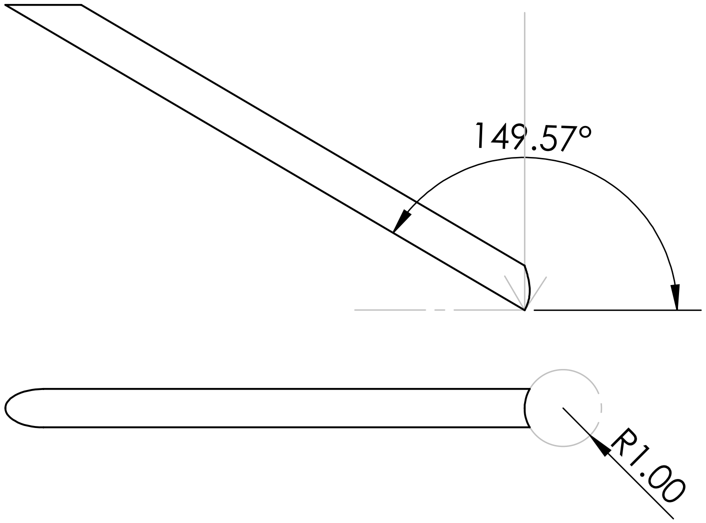
REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	RN



141



FISHMOUTH CUT DIAGRAMS



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 ALUMINUM-6061 T6
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R. NAKAMURA	2/3/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

PROPRIETARY AND CONFIDENTIAL

SUB-ASSEMBLY: FRAME

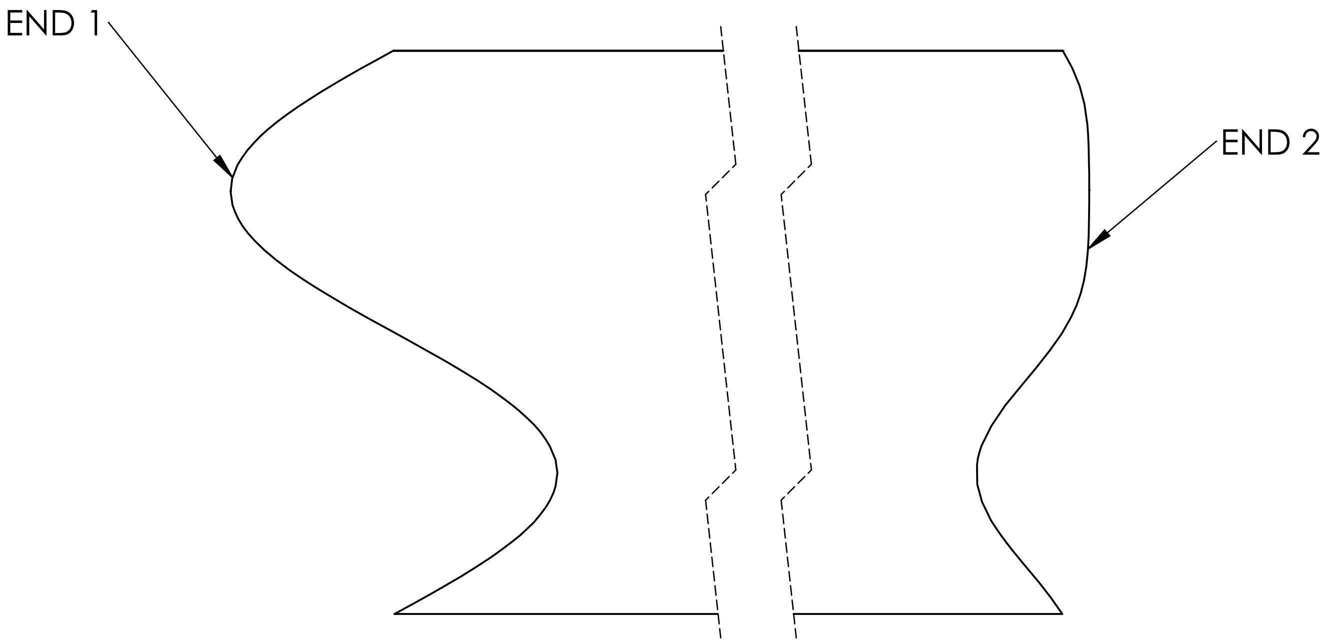
TITLE: Lower Chain Stay

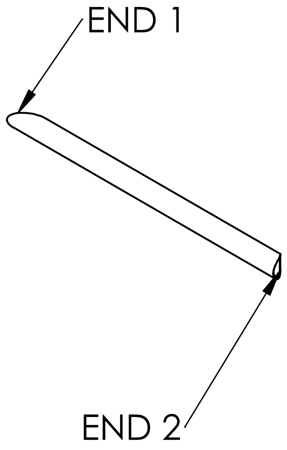
SIZE	DWG. NO.	REV
A	01-011-01	
SCALE: 1:5	WEIGHT:	SHEET 1 OF 2

5 4 3 2 1

FISHMOUTH TEMPLATE

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC





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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	R. NAKAMURA	2/3/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PROPRIETARY AND CONFIDENTIAL

SUB-ASSEMBLY: FRAME

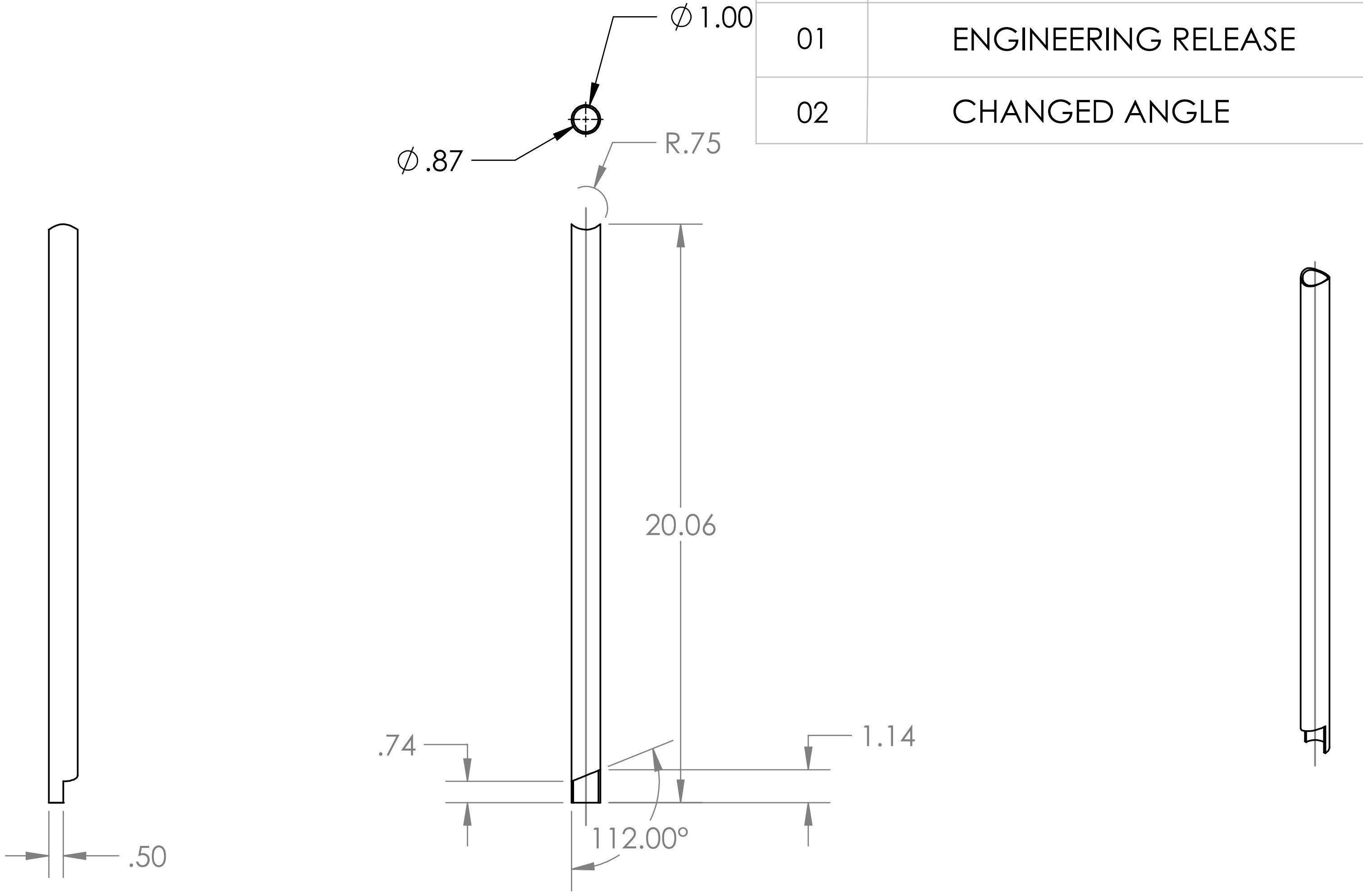
TITLE:
Lower Chain Stay

SIZE A
DWG. NO. 01-011-01
REV

SCALE: 1:1
WEIGHT:
SHEET 2 OF 2

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	CHANGED ANGLE	PC



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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

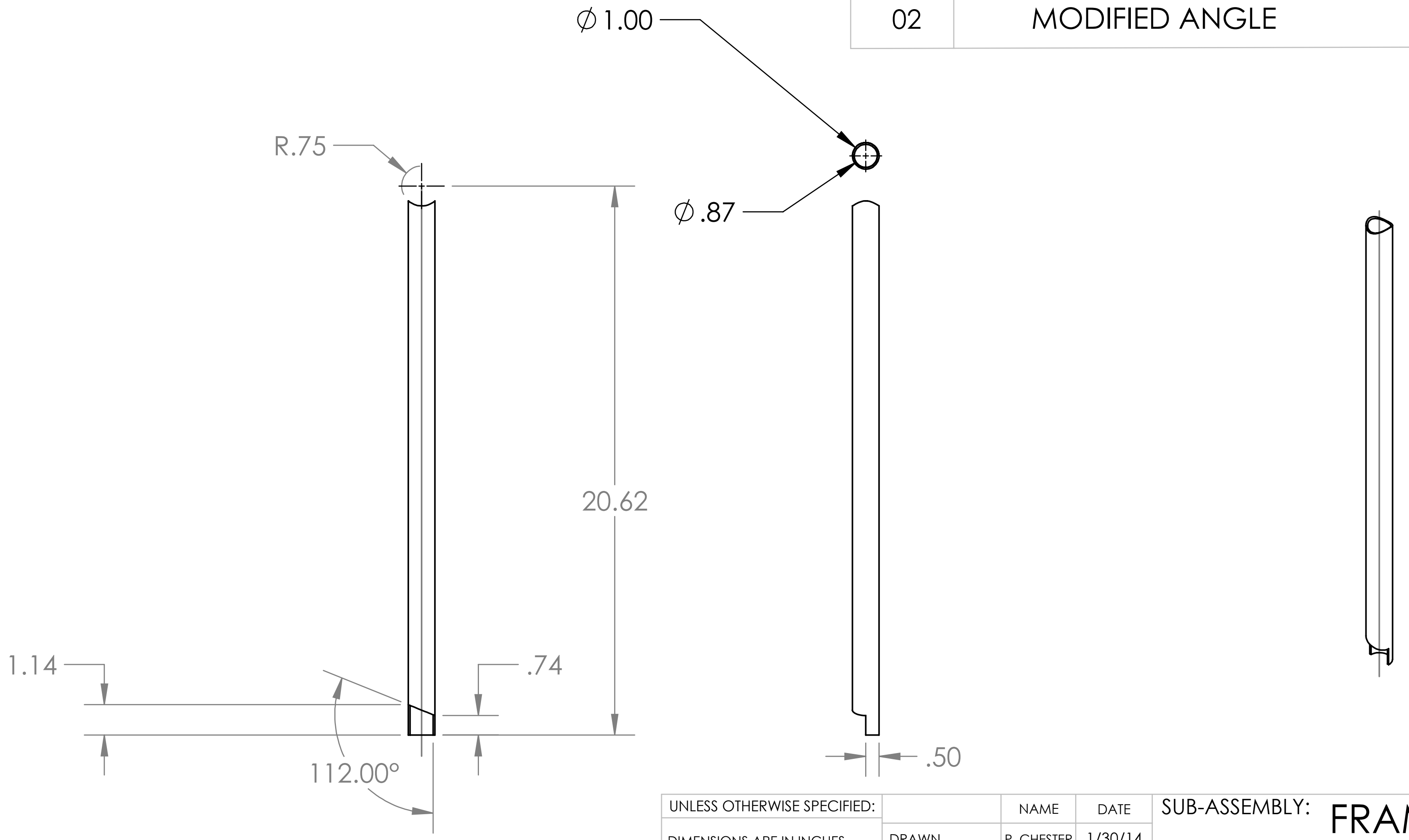
TITLE:
PORTSIDE UPPER
CHAIN STAY

SIZE A
DWG. NO. 01-014-02
REV

SCALE: 1:6
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	MODIFIED ANGLE	PC



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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: FRAME

TITLE:
STARBOARD SIDE
UPPER CHAIN STAY

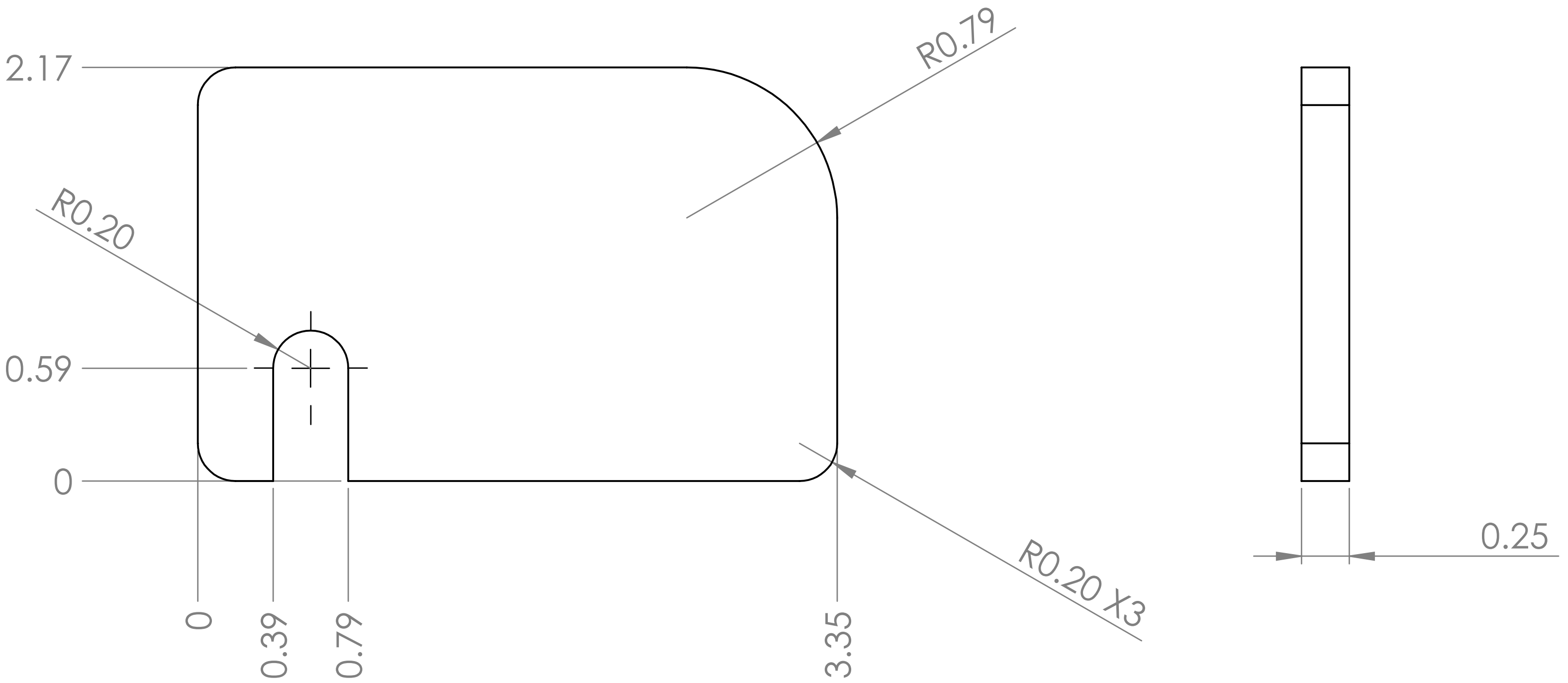
SIZE A DWG. NO. 01-013-02 REV

SCALE: 1:6 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

NOTE:
USE ALUMINUM-6061 T6
0.25 INCH PLATE

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC



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	ALUMINUM-6061 T6
FINISH	
DO NOT SCALE DRAWING	

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: FRAME

TITLE:

REAR DROPOUTS

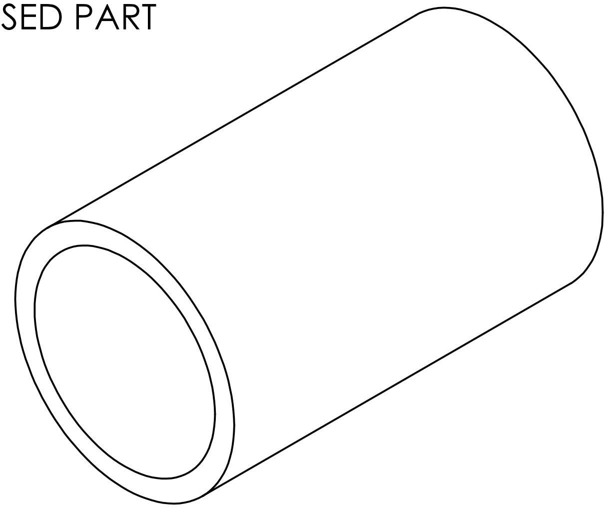
SIZE	DWG. NO.	REV
A	01-015-01	

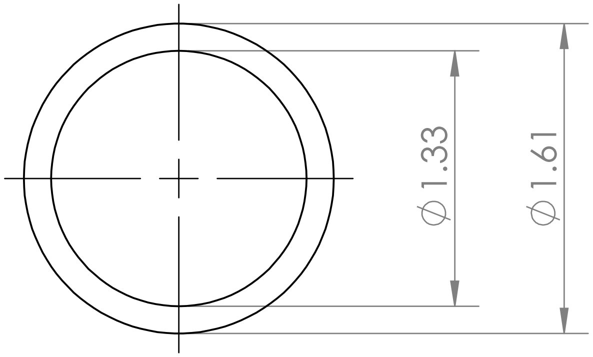
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

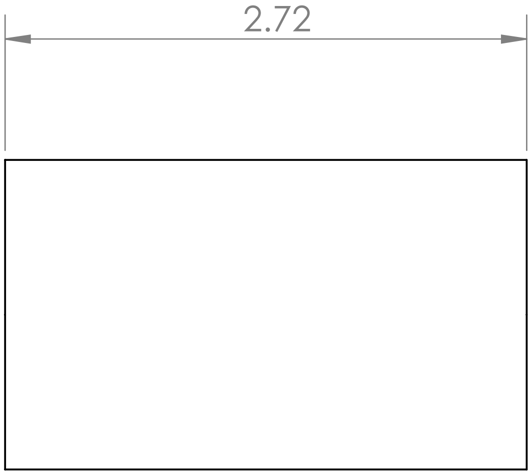
5 4 3 2 1

PURCHASED PART

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC







PROPRIETARY AND CONFIDENTIAL

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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

TITLE:
BOTTOM BRACKET SHELL

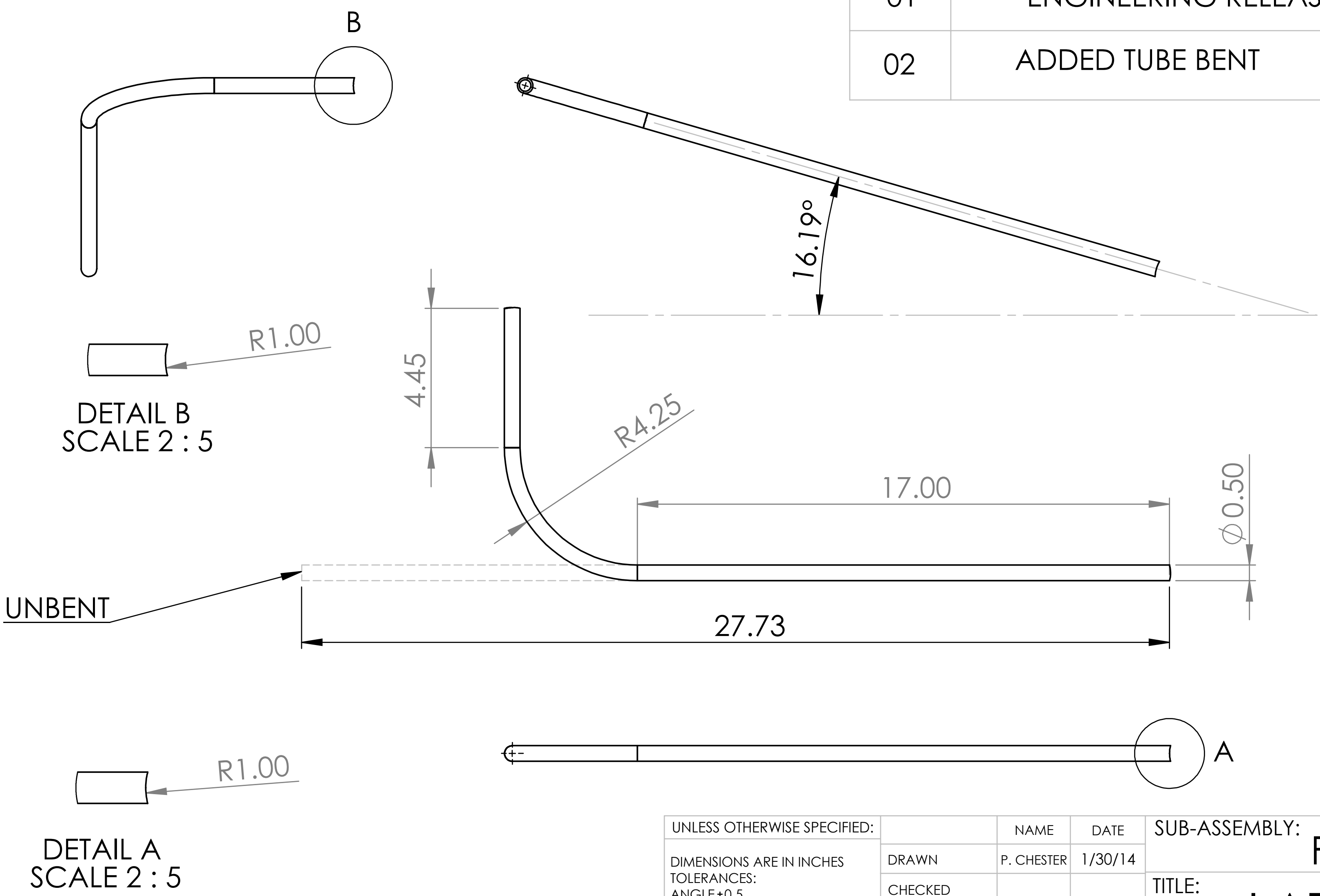
SIZE	DWG. NO.	REV
A	01-037-01	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

NOTE: 0.5 INCH O.D., 0.37 INCH I.D. TUBING

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	PC
02	ADDED TUBE BENT	PS



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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	P. CHESTER	1/30/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

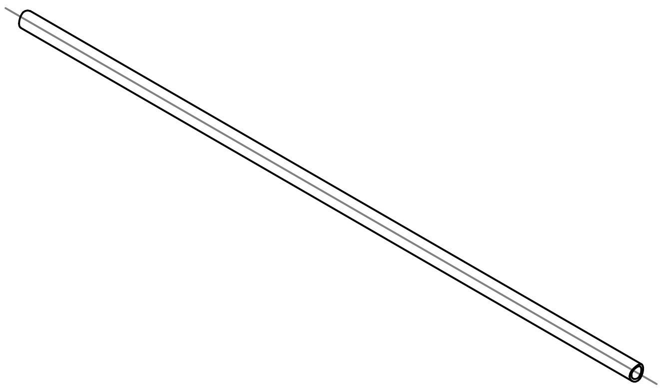
TITLE: LATERAL SUPPORTS

SIZE A
DWG. NO. 01-055-02
REV

SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	IJ



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	I. JONES	2/19/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

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SUB-ASSEMBLY: FRAME

TITLE:

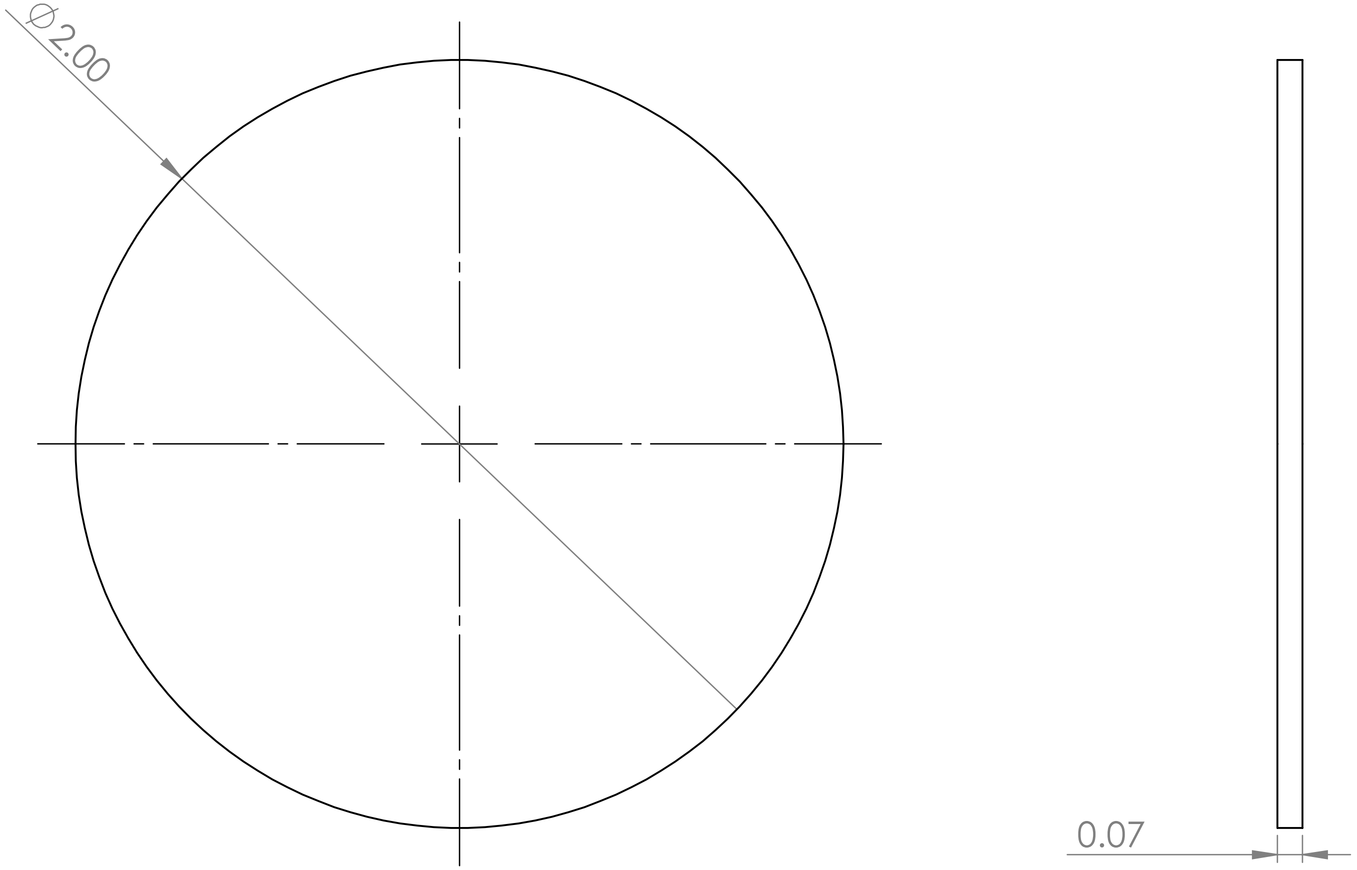
ROLL CAGE
SEAT SUPPORT

SIZE	DWG. NO.	REV
A	01-056-01	

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	IJ



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	I. JONES	2/19/14
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL ALUMINUM-6061 T6	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

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SUB-ASSEMBLY: FRAME

TITLE:

ROLL CAGE END CAP

SIZE A

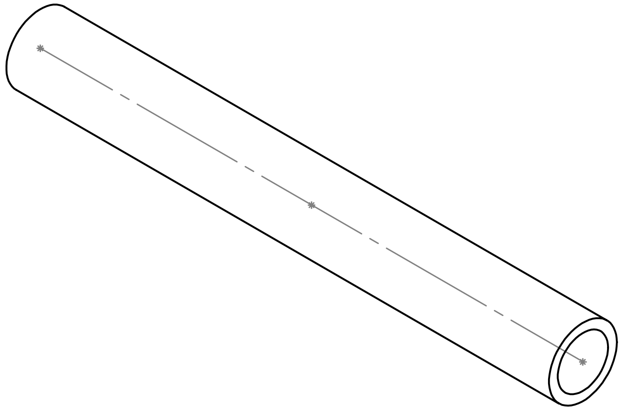
DWG. NO. 01-057-01

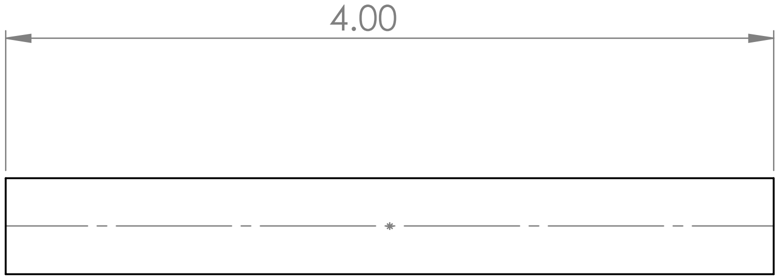
REV

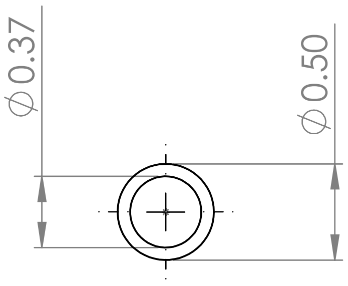
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

5 4 3 2 1

REV	DESCRIPTION	EDITOR
01	ENGINEERING RELEASE	IJ







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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
ALUMINUM-6061 T6

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	I. JONES	2/19/14
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SUB-ASSEMBLY: FRAME

TITLE:

SEAT BELT FIXTURE

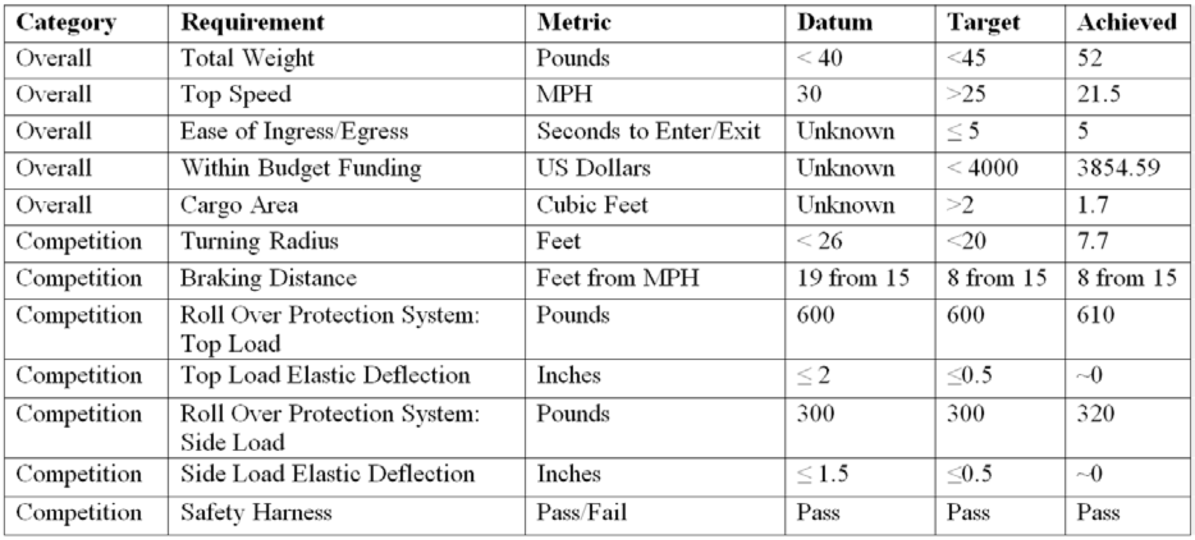
SIZE	DWG. NO.	REV
A	01-059-01	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Appendix C: Initial Design Aids and Background Material

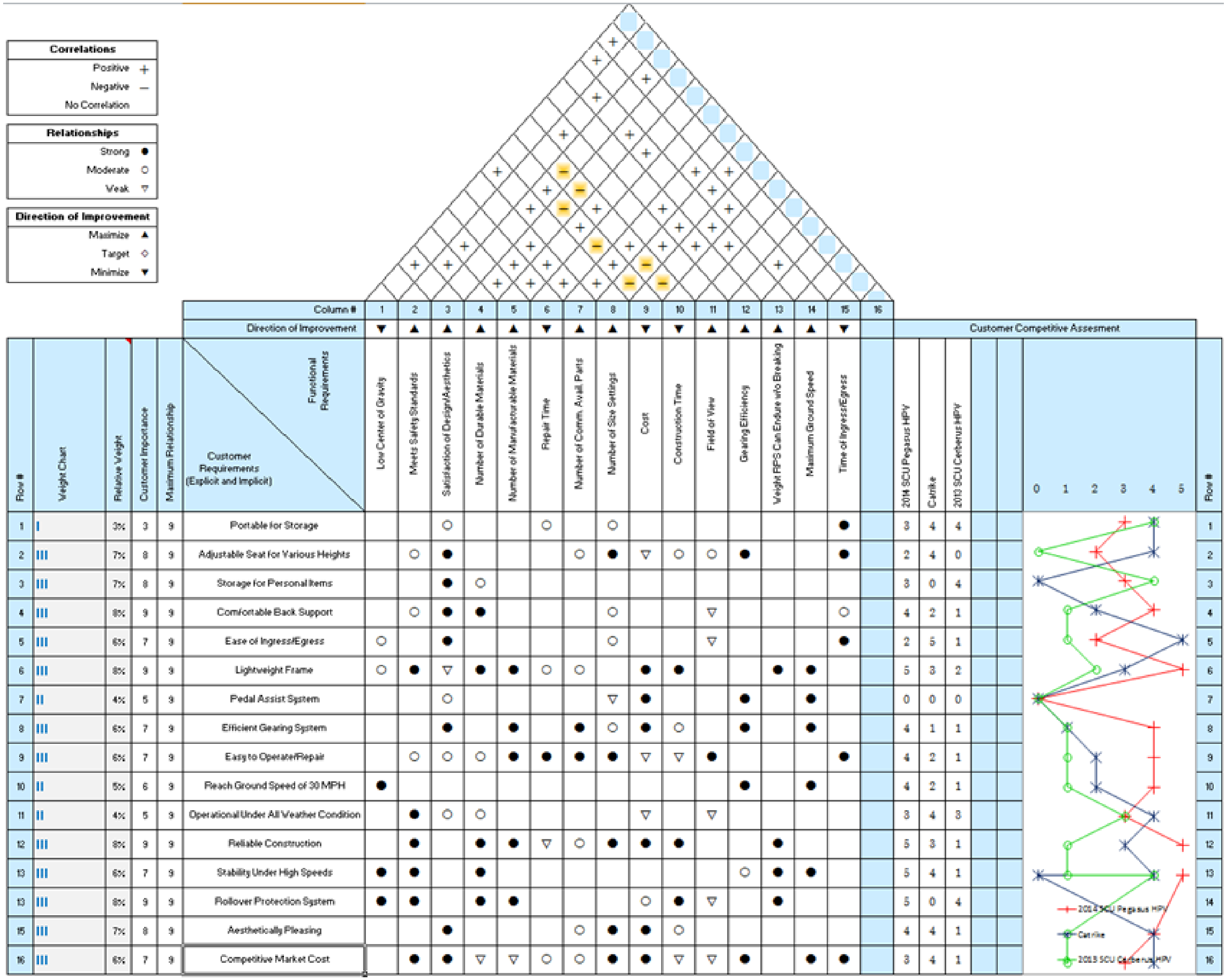
Product Design Specification (PDS)

Table C.1: Product Design Specifications for SCU 2014 Pegasus Human Powered Vehicle



Category	Requirement	Metric	Datum	Target	Achieved
Overall	Total Weight	Pounds	< 40	<45	52
Overall	Top Speed	MPH	30	>25	21.5
Overall	Ease of Ingress/Egress	Seconds to Enter/Exit	Unknown	≤ 5	5
Overall	Within Budget Funding	US Dollars	Unknown	< 4000	3854.59
Overall	Cargo Area	Cubic Feet	Unknown	>2	1.7
Competition	Turning Radius	Feet	< 26	<20	7.7
Competition	Braking Distance	Feet from MPH	19 from 15	8 from 15	8 from 15
Competition	Roll Over Protection System: Top Load	Pounds	600	600	610
Competition	Top Load Elastic Deflection	Inches	≤ 2	≤0.5	~0
Competition	Roll Over Protection System: Side Load	Pounds	300	300	320
Competition	Side Load Elastic Deflection	Inches	≤ 1.5	≤0.5	~0
Competition	Safety Harness	Pass/Fail	Pass	Pass	Pass

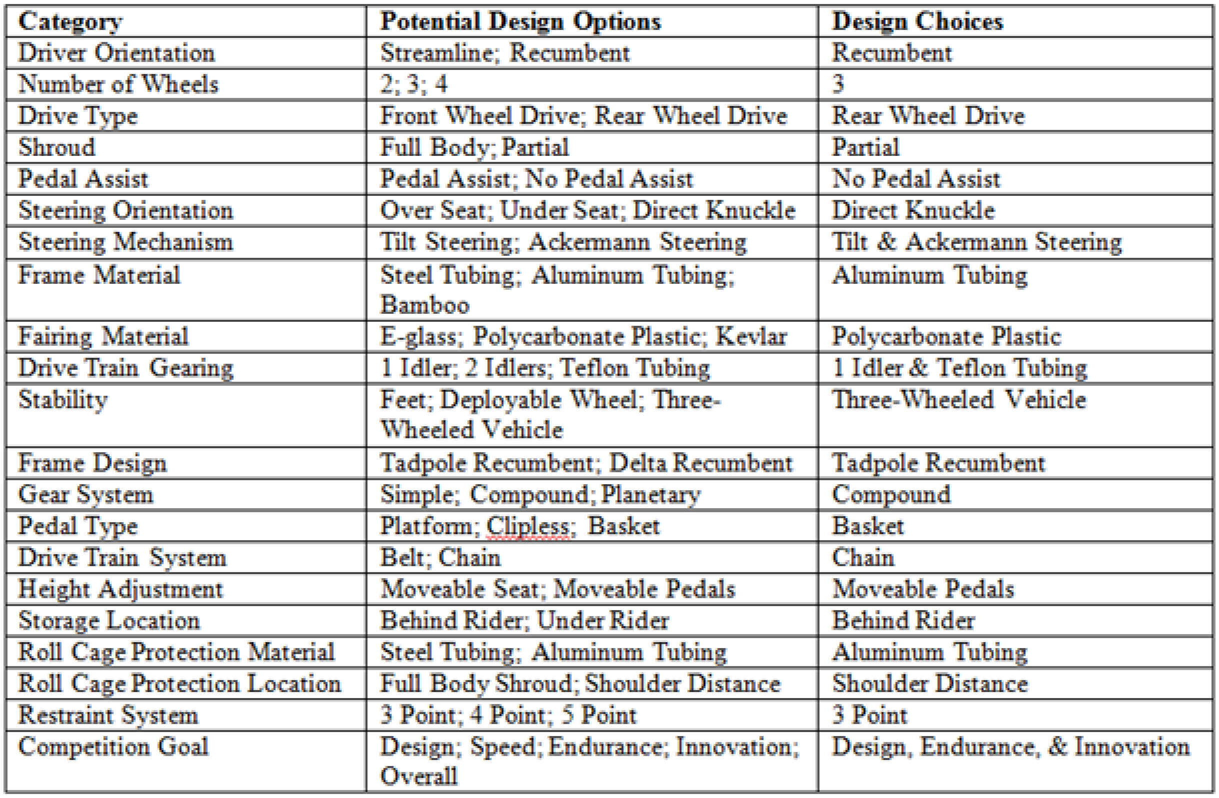
Table C.2: Quality Function Deployment (QFD)



Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	1 Low Center of Gravity	2 Meets Safety Standards	3 Satisfaction of Design/Aesthetics	4 Number of Durable Materials	5 Number of Manufacturable Materials	6 Repair Time	7 Number of Comm. Avail. Parts	8 Number of Size Settings	9 Cost	10 Construction Time	11 Field of View	12 Gearing Efficiency	13 Weight RPS Can Endure w/o Breaking	14 Maximum Ground Speed	15 Time of Ingress/Egress	16	2014 SCU Pegasus HPV	Catrike	2013 SCU Cerberus HPV	Row #
					Direction of Improvement	▼	▲	▲	▲	▲	▼	▲	▲	▼	▼	▲	▲	▲	▲	▼					
1	I	3%	3	9	Portable for Storage			○			○		○							●		3	4	4	1
2	III	7%	8	9	Adjustable Seat for Various Heights		○	●				○	●	▽	○	○	●			●		2	4	0	2
3	III	7%	8	9	Storage for Personal Items			●	○													3	0	4	3
4	III	8%	9	9	Comfortable Back Support		○	●	●				○			▽				○		4	2	1	4
5	III	6%	7	9	Ease of Ingress/Egress	○		●					○			▽				●		2	5	1	5
6	III	8%	9	9	Lightweight Frame	○	●	▽	●	●	○	○		●	●			●	●			5	3	2	6
7	II	4%	5	9	Pedal Assist System			○					▽	●			●		●			0	0	0	7
8	III	6%	7	9	Efficient Gearing System			●		●		●	○	●	○		●		●			4	1	1	8
9	III	6%	7	9	Easy to Operate/Repair		○	○	○	●	●	●	●	▽	▽	●				●		4	2	1	9
10	II	5%	6	9	Reach Ground Speed of 30 MPH	●											●		●			4	2	1	10
11	II	4%	5	9	Operational Under All Weather Condition		●	○	○					▽		▽						3	4	3	11
12	III	8%	9	9	Reliable Construction		●		●	●	▽	○	●	●	●			●				5	3	1	12
13	III	6%	7	9	Stability Under High Speeds	●	●		●								○	●	●			5	4	1	13
13	III	8%	9	9	Rollover Protection System	●	●		●	●				○	●	▽		●				5	0	4	14
15	III	7%	8	9	Aesthetically Pleasing			●				○	●	●	○							4	4	1	15
16	III	6%	7	9	Competitive Market Cost		●	●	▽	▽	○	○	●	●	▽	▽	●		●	●		3	4	1	16

Decision Matrix

Table C.3: Alternatives and Evaluation for SCU 2014 Pegasus Human Powered Vehicle.



Category	**Potential Design Options**	**Design Choices**
Driver Orientation	Streamline; Recumbent	Recumbent
Number of Wheels	2; 3; 4	3
Drive Type	Front Wheel Drive; Rear Wheel Drive	Rear Wheel Drive
Shroud	Full Body; Partial	Partial
Pedal Assist	Pedal Assist; No Pedal Assist	No Pedal Assist
Steering Orientation	Over Seat; Under Seat; Direct Knuckle	Direct Knuckle
Steering Mechanism	Tilt Steering; Ackermann Steering	Tilt & Ackermann Steering
Frame Material	Steel Tubing; Aluminum Tubing; Bamboo	Aluminum Tubing
Fairing Material	E-glass; Polycarbonate Plastic; Kevlar	Polycarbonate Plastic
Drive Train Gearing	1 Idler; 2 Idlers; Teflon Tubing	1 Idler & Teflon Tubing
Stability	Feet; Deployable Wheel; Three-Wheeled Vehicle	Three-Wheeled Vehicle
Frame Design	Tadpole Recumbent; Delta Recumbent	Tadpole Recumbent
Gear System	Simple; Compound; Planetary	Compound
Pedal Type	Platform; Clipless; Basket	Basket
Drive Train System	Belt; Chain	Chain
Height Adjustment	Moveable Seat; Moveable Pedals	Moveable Pedals
Storage Location	Behind Rider; Under Rider	Behind Rider
Roll Cage Protection Material	Steel Tubing; Aluminum Tubing	Aluminum Tubing
Roll Cage Protection Location	Full Body Shroud; Shoulder Distance	Shoulder Distance
Restraint System	3 Point; 4 Point; 5 Point	3 Point
Competition Goal	Design; Speed; Endurance; Innovation; Overall	Design, Endurance, & Innovation

Benchmarks

Table C.4: The table below shows the benchmarks that the SCU HPV 2014 team initially set for their goals.

Characteristic/Parameter	**Design Criticality**	**Parameter Units**	**Design Target**	**Benchmark 1 Range (Cerberus)**	**Benchmark 2 Range (ELF)**	**Benchmark 3 Range (Trek 1.1)**	**Benchmark 4 Range (Catrike 700)**
size		height by width by length	4' by 5' by 6'	35" by 25" by 60"	105" by 48" by 5'	~ 24" by 12"by 3ft	46" by 82" by 26.75"
weight	5	lbs	30	66	150	22	33
top speed unassisted	2	mph	30	22	23	25	
top electric speed		mph	20	n/a	20	n/a	n/a
acceleration		ft/s^2	5	4.2		excellent	
cost		US Dollar	$3,880.00	$2,280.00	$4,995.00	$769.99	$2950
aesthetic	1		sporty, modern, natural	3rd world appeal	chic, modern	simple, streamlined	aerodynamic seating
agility	4		good cornering due to tilt frame	prone to tipping		excellent	
comfort	3		adjustable seat length, lumbar support	not enough leg room	lumbar support, adjustable seat length, four incline	small hard seat, bent over posture	comfortable recumbant design

					settings		
storage space			4 cubic feet	two small storage bins	2 large storage bins, additional can be bought	add-ons over front or rear wheels possible	none
turn radius		feet	10'	5'8"	15.5	15	10’
electric range		miles	15	n/a	20	n/a	n/a

Build Plan

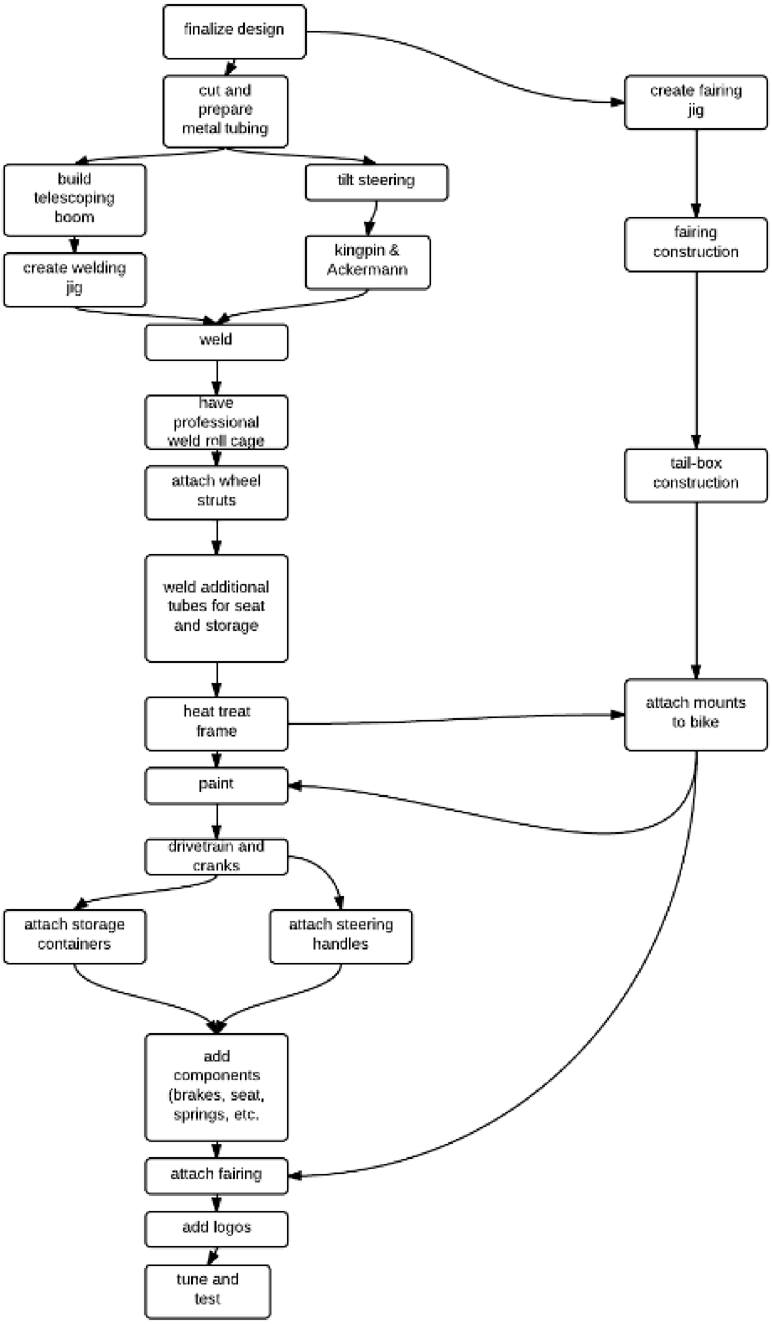


Figure C.1: The build plan for the vehicle. The order of steps for the construction of the tricycle is detailed.

Initial Frame Construction

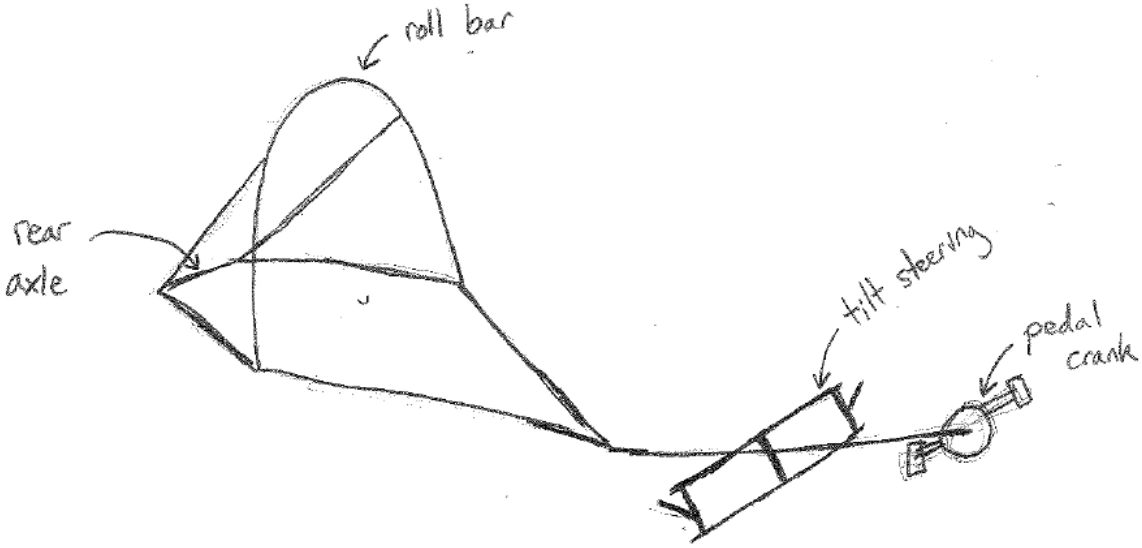


Figure C.2: A sketch of the main vehicle frame detailing the construction of the roll bar. From the roll bar two pieces extend to the central boom that runs up through the steering and pedal cranks.

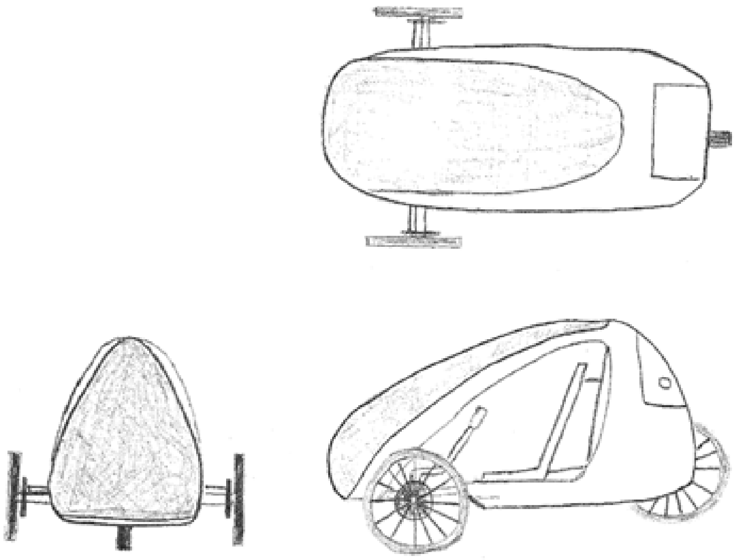


Figure C.3: This is the sketch of our concept idea used in the PDR.

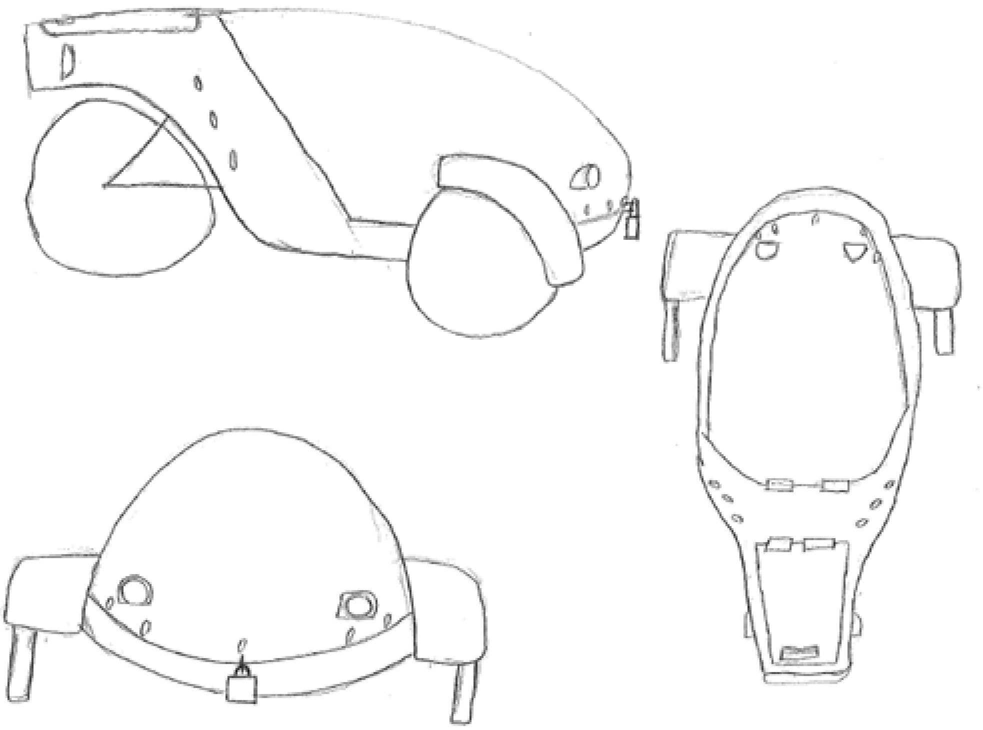


Figure C.4: This is the sketch of our design after looking at customer feedback on what they would like in a Human Powered Vehicle

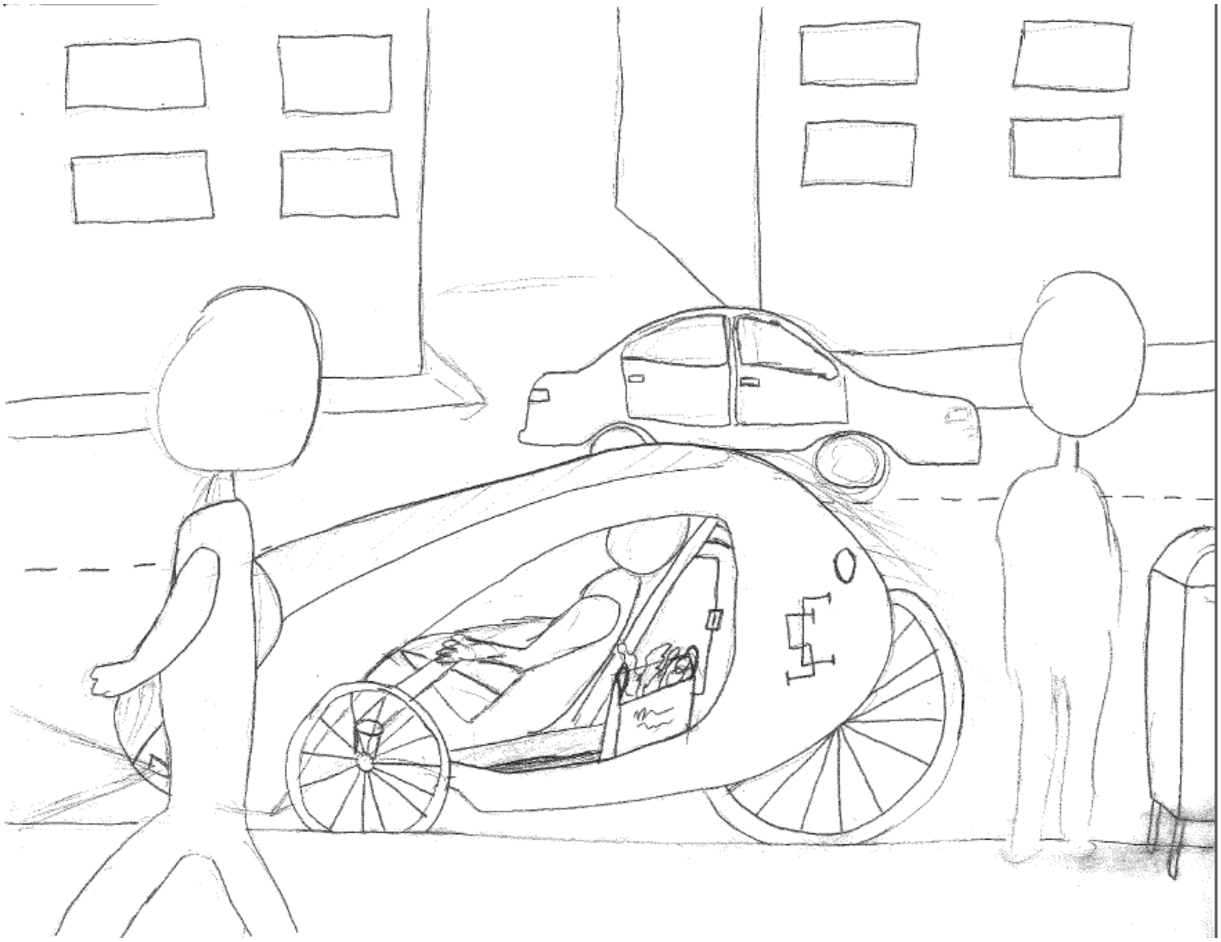
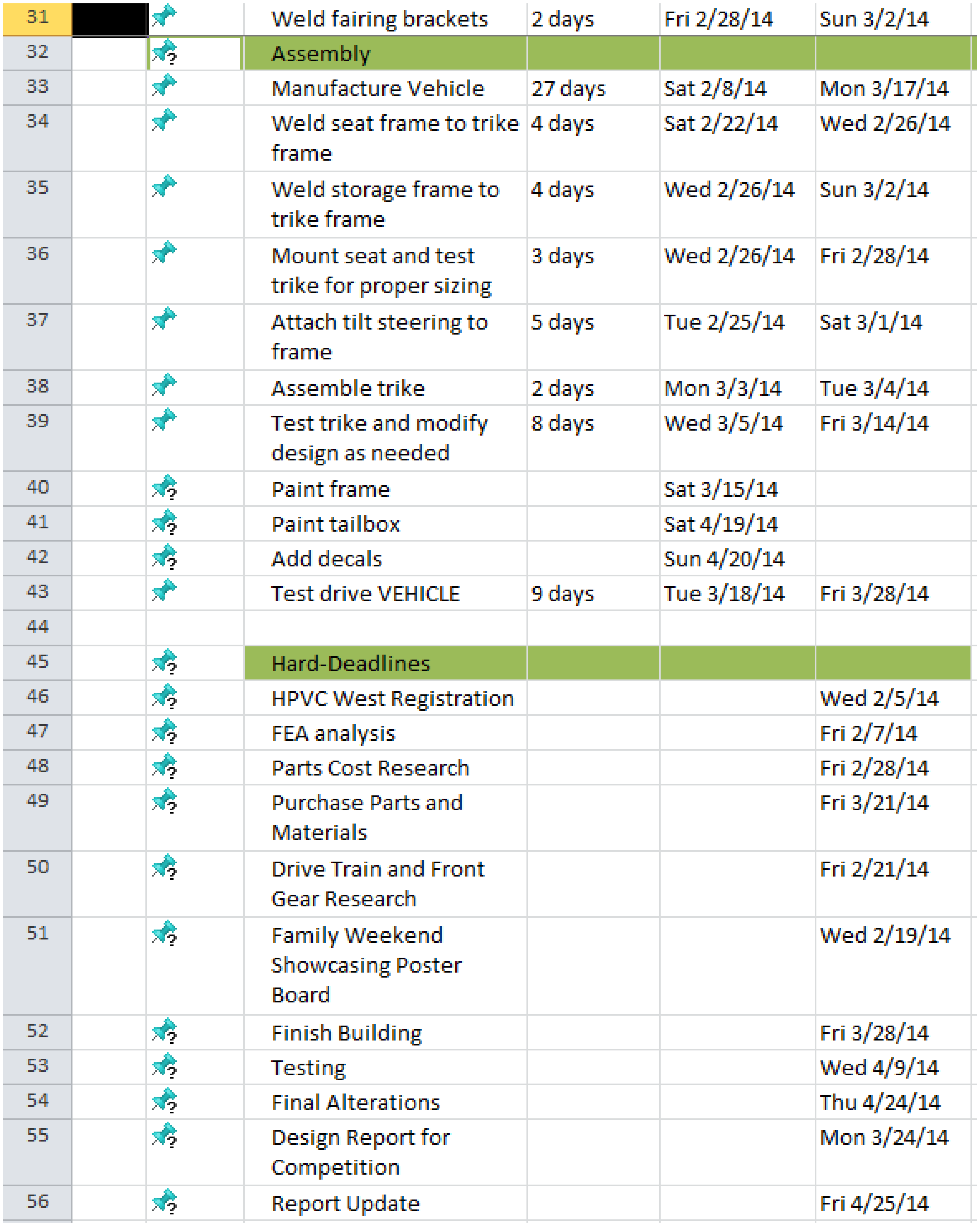


Figure C.5: An initial system level sketch of the vehicle which shows it interacting with its environment

Appendix D: Project Management Data

Gantt Chart

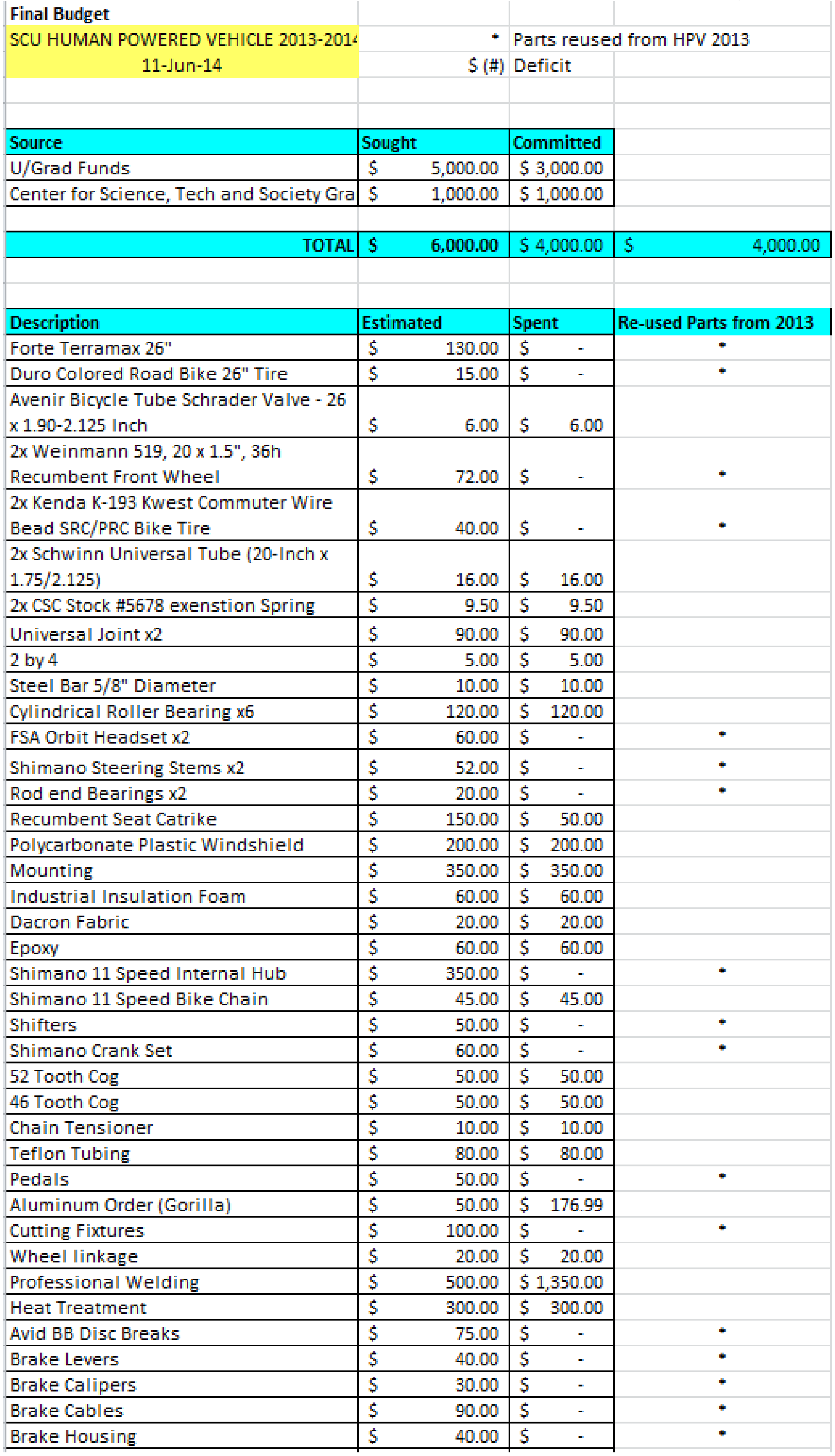
Table D.1: The table below displays the Gantt chart used for our senior design team.



31		📌	Weld fairing brackets	2 days	Fri 2/28/14	Sun 3/2/14
32		📌?	Assembly			
33		📌	Manufacture Vehicle	27 days	Sat 2/8/14	Mon 3/17/14
34		📌	Weld seat frame to trike frame	4 days	Sat 2/22/14	Wed 2/26/14
35		📌	Weld storage frame to trike frame	4 days	Wed 2/26/14	Sun 3/2/14
36		📌	Mount seat and test trike for proper sizing	3 days	Wed 2/26/14	Fri 2/28/14
37		📌	Attach tilt steering to frame	5 days	Tue 2/25/14	Sat 3/1/14
38		📌	Assemble trike	2 days	Mon 3/3/14	Tue 3/4/14
39		📌	Test trike and modify design as needed	8 days	Wed 3/5/14	Fri 3/14/14
40		📌?	Paint frame		Sat 3/15/14	
41		📌?	Paint tailbox		Sat 4/19/14	
42		📌?	Add decals		Sun 4/20/14	
43		📌	Test drive VEHICLE	9 days	Tue 3/18/14	Fri 3/28/14
44						
45		📌?	Hard-Deadlines			
46		📌?	HPVC West Registration			Wed 2/5/14
47		📌?	FEA analysis			Fri 2/7/14
48		📌?	Parts Cost Research			Fri 2/28/14
49		📌?	Purchase Parts and Materials			Fri 3/21/14
50		📌?	Drive Train and Front Gear Research			Fri 2/21/14
51		📌?	Family Weekend Showcasing Poster Board			Wed 2/19/14
52		📌?	Finish Building			Fri 3/28/14
53		📌?	Testing			Wed 4/9/14
54		📌?	Final Alterations			Thu 4/24/14
55		📌?	Design Report for Competition			Mon 3/24/14
56		📌?	Report Update			Fri 4/25/14

Prototype Cost Summary

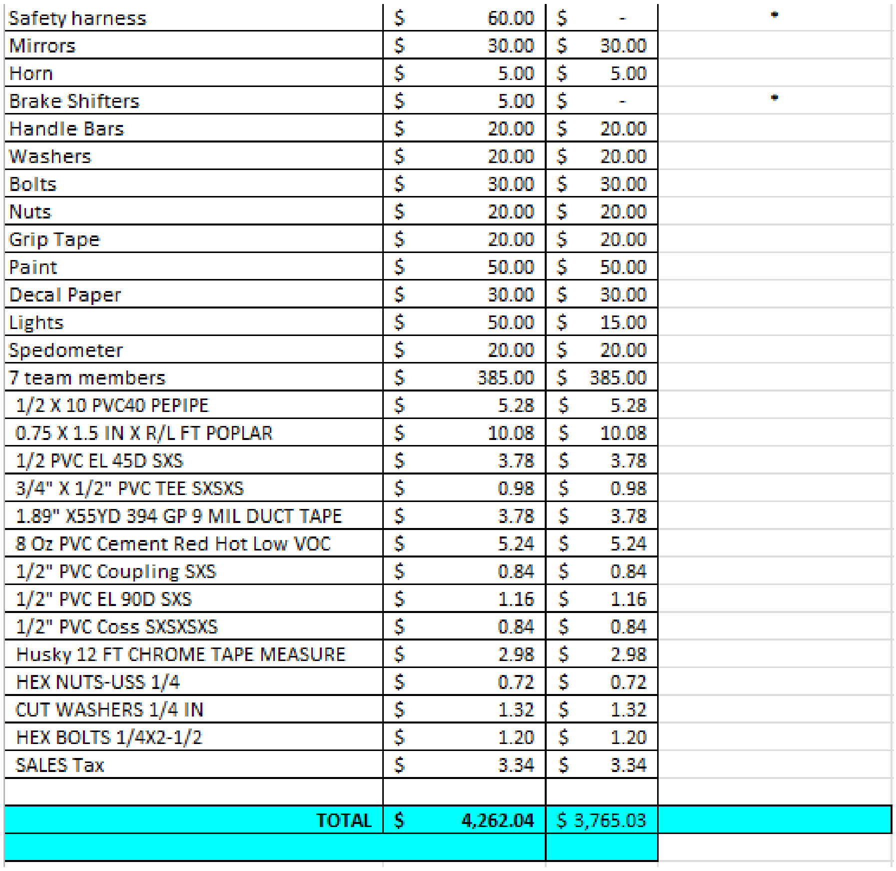
Table D.2: SCU HPV 2014 expenses estimated, pending, as well as recycled parts from SCU HPV 2013, our outside contractor expense, and our total prototype cost.



Final Budget			
SCU HUMAN POWERED VEHICLE 2013-201	•	Parts reused from HPV 2013	
11-Jun-14	$ (#)	Deficit	

Source	**Sought**	**Committed**	
U/Grad Funds	$ 5,000.00	$ 3,000.00	
Center for Science, Tech and Society Gra	$ 1,000.00	$ 1,000.00	
TOTAL	**$ 6,000.00**	$ 4,000.00	$ 4,000.00

Description	**Estimated**	**Spent**	**Re-used Parts from 2013**
Forte Terramax 26"	$ 130.00	$ -	•
Duro Colored Road Bike 26" Tire	$ 15.00	$ -	•
Avenir Bicycle Tube Schrader Valve - 26 x 1.90-2.125 Inch	$ 6.00	$ 6.00	
2x Weinmann 519, 20 x 1.5", 36h Recumbent Front Wheel	$ 72.00	$ -	•
2x Kenda K-193 Kwest Commuter Wire Bead SRC/PRC Bike Tire	$ 40.00	$ -	•
2x Schwinn Universal Tube (20-Inch x 1.75/2.125)	$ 16.00	$ 16.00	
2x CSC Stock #5678 exenstion Spring	$ 9.50	$ 9.50	
Universal Joint x2	$ 90.00	$ 90.00	
2 by 4	$ 5.00	$ 5.00	
Steel Bar 5/8" Diameter	$ 10.00	$ 10.00	
Cylindrical Roller Bearing x6	$ 120.00	$ 120.00	
FSA Orbit Headset x2	$ 60.00	$ -	•
Shimano Steering Stems x2	$ 52.00	$ -	•
Rod end Bearings x2	$ 20.00	$ -	•
Recumbent Seat Catrike	$ 150.00	$ 50.00	
Polycarbonate Plastic Windshield	$ 200.00	$ 200.00	
Mounting	$ 350.00	$ 350.00	
Industrial Insulation Foam	$ 60.00	$ 60.00	
Dacron Fabric	$ 20.00	$ 20.00	
Epoxy	$ 60.00	$ 60.00	
Shimano 11 Speed Internal Hub	$ 350.00	$ -	•
Shimano 11 Speed Bike Chain	$ 45.00	$ 45.00	
Shifters	$ 50.00	$ -	•
Shimano Crank Set	$ 60.00	$ -	•
52 Tooth Cog	$ 50.00	$ 50.00	
46 Tooth Cog	$ 50.00	$ 50.00	
Chain Tensioner	$ 10.00	$ 10.00	
Teflon Tubing	$ 80.00	$ 80.00	
Pedals	$ 50.00	$ -	•
Aluminum Order (Gorilla)	$ 50.00	$ 176.99	
Cutting Fixtures	$ 100.00	$ -	•
Wheel linkage	$ 20.00	$ 20.00	
Professional Welding	$ 500.00	$ 1,350.00	
Heat Treatment	$ 300.00	$ 300.00	
Avid BB Disc Breaks	$ 75.00	$ -	•
Brake Levers	$ 40.00	$ -	•
Brake Calipers	$ 30.00	$ -	•
Brake Cables	$ 90.00	$ -	•
Brake Housing	$ 40.00	$ -	•



Safety harness	$ 60.00	$ -	•
Mirrors	$ 30.00	$ 30.00	
Horn	$ 5.00	$ 5.00	
Brake Shifters	$ 5.00	$ -	•
Handle Bars	$ 20.00	$ 20.00	
Washers	$ 20.00	$ 20.00	
Bolts	$ 30.00	$ 30.00	
Nuts	$ 20.00	$ 20.00	
Grip Tape	$ 20.00	$ 20.00	
Paint	$ 50.00	$ 50.00	
Decal Paper	$ 30.00	$ 30.00	
Lights	$ 50.00	$ 15.00	
Spedometer	$ 20.00	$ 20.00	
7 team members	$ 385.00	$ 385.00	
1/2 X 10 PVC40 PEPIPE	$ 5.28	$ 5.28	
0.75 X 1.5 IN X R/L FT POPLAR	$ 10.08	$ 10.08	
1/2 PVC EL 45D SXS	$ 3.78	$ 3.78	
3/4" X 1/2" PVC TEE SXSXS	$ 0.98	$ 0.98	
1.89" X55YD 394 GP 9 MIL DUCT TAPE	$ 3.78	$ 3.78	
8 Oz PVC Cement Red Hot Low VOC	$ 5.24	$ 5.24	
1/2" PVC Coupling SXS	$ 0.84	$ 0.84	
1/2" PVC EL 90D SXS	$ 1.16	$ 1.16	
1/2" PVC Coss SXSXSXS	$ 0.84	$ 0.84	
Husky 12 FT CHROME TAPE MEASURE	$ 2.98	$ 2.98	
HEX NUTS-USS 1/4	$ 0.72	$ 0.72	
CUT WASHERS 1/4 IN	$ 1.32	$ 1.32	
HEX BOLTS 1/4X2-1/2	$ 1.20	$ 1.20	
SALES Tax	$ 3.34	$ 3.34	
TOTAL	**$ 4,262.04**	$ 3,765.03	

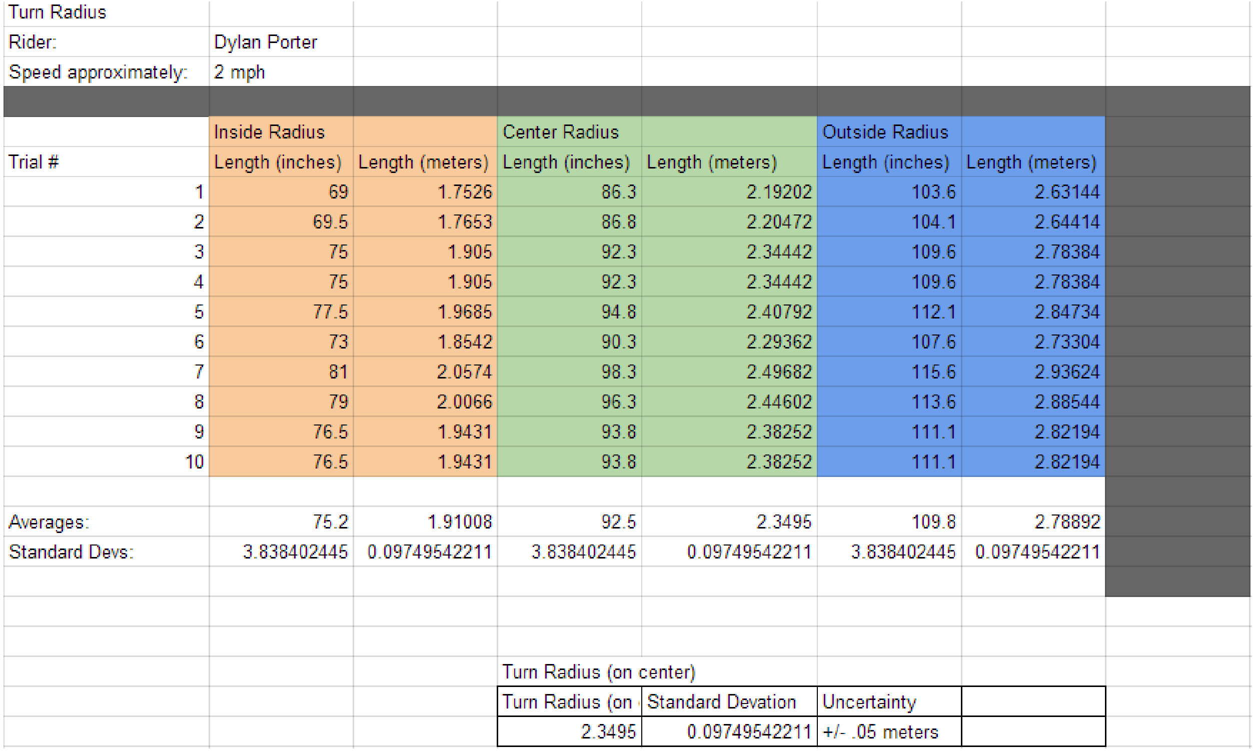
Table D.3: SCU HPV 2014 funding received.

Grant	Amount of Funding
SCU Engineering Undergraduate Funds	$3,000
Center for Science, Technology and Society Grant	$1,000
Mechanical Engineering additional funding	$800
Total Spent/Recieved	$3,765/$4800

Appendix E: Experimental Data

Turning Radius

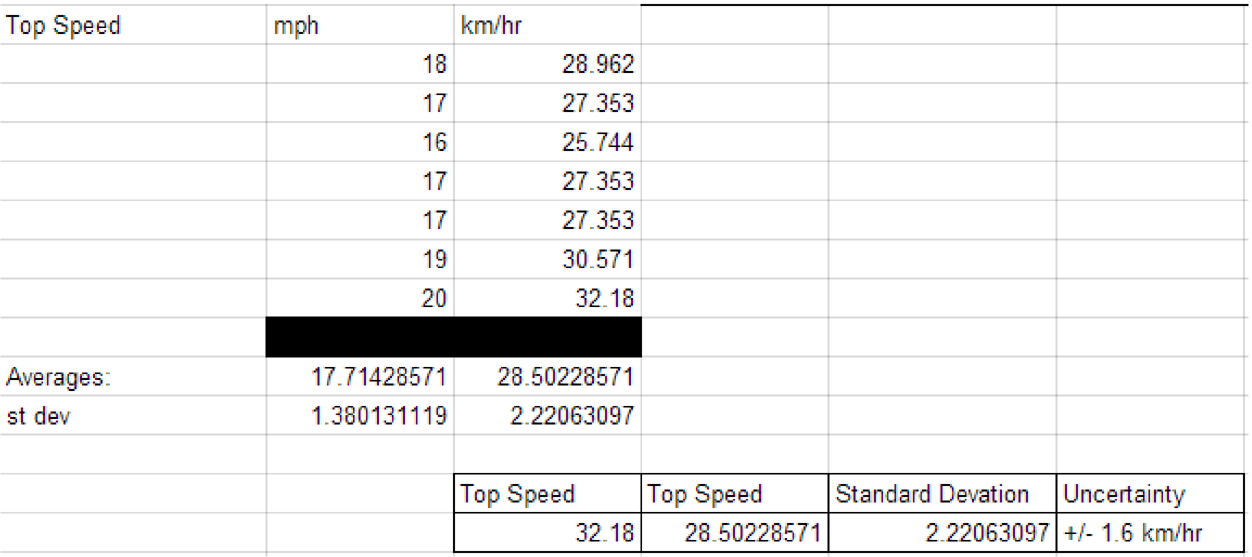
Table E.1: A table of the successive trials for the turning radius and the resulting average and standard deviation.



Turn Radius						
Rider:	Dylan Porter					
Speed approximately:	2 mph					
	Inside Radius		Center Radius		Outside Radius	
Trial #	Length (inches)	Length (meters)	Length (inches)	Length (meters)	Length (inches)	Length (meters)
1	69	1.7526	86.3	2.19202	103.6	2.63144
2	69.5	1.7653	86.8	2.20472	104.1	2.64414
3	75	1.905	92.3	2.34442	109.6	2.78384
4	75	1.905	92.3	2.34442	109.6	2.78384
5	77.5	1.9685	94.8	2.40792	112.1	2.84734
6	73	1.8542	90.3	2.29362	107.6	2.73304
7	81	2.0574	98.3	2.49682	115.6	2.93624
8	79	2.0066	96.3	2.44602	113.6	2.88544
9	76.5	1.9431	93.8	2.38252	111.1	2.82194
10	76.5	1.9431	93.8	2.38252	111.1	2.82194
Averages:	75.2	1.91008	92.5	2.3495	109.8	2.78892
Standard Devs:	3.838402445	0.09749542211	3.838402445	0.09749542211	3.838402445	0.09749542211
			Turn Radius (on center)			
			Turn Radius (on	Standard Devation	Uncertainty	
			2.3495	0.09749542211	+/- .05 meters	

Top Speed

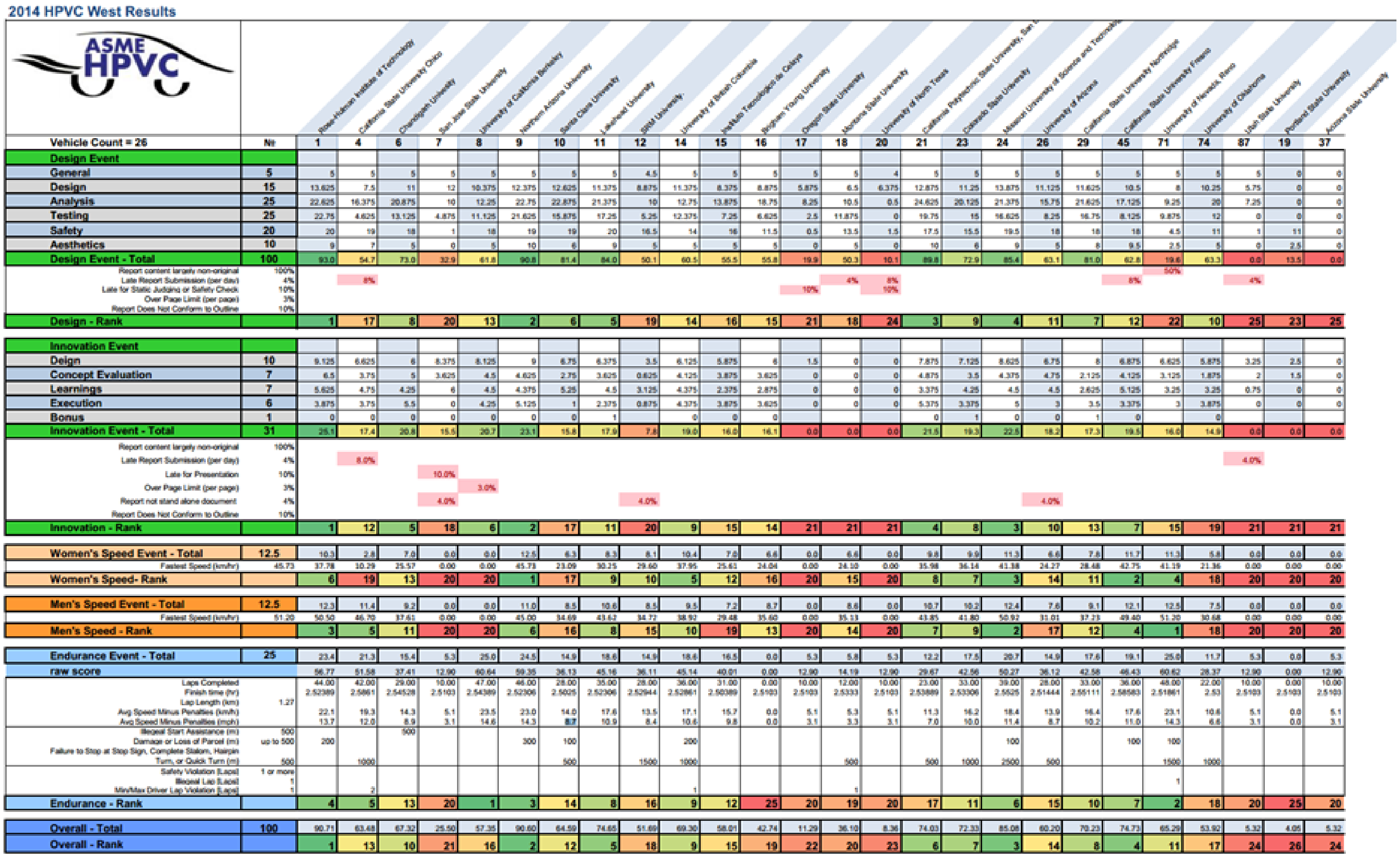
Table E.2: A table of the successive trials for the top speed of the vehicle in the parking garage. Note that these trials are separate from the top speed reported from the competition.



Top Speed	mph	km/hr			
	18	28.962			
	17	27.353			
	16	25.744			
	17	27.353			
	17	27.353			
	19	30.571			
	20	32.18			
Averages:	17.71428571	28.50228571			
st dev	1.380131119	2.22063097			
		Top Speed	Top Speed	Standard Devation	Uncertainty
		32.18	28.50228571	2.22063097	+/- 1.6 km/hr

Appendix F: ASME Competition Results

Table F.1: The results of the ASME HPVC 2014 West Competition



2014 HPVC West Results

		Rose-Hulman Institute of Technology	California State University Chico	Chandigarh University	San Jose State University	University of California Berkeley	Northern Arizona University	Santa Clara University	Lakehead University	SRM University	University of British Columbia	Instituto Tecnológico de Celaya	Brigham Young University	Oregon State University	Montana State University	University of North Texas	California Polytechnic State University, San	Colorado State University	Missouri University of Science and Technol	University of Arizona	California State University Northridge	California State University Fresno	University of Nevada, Reno	University of Oklahoma	Utah State University	Portland State University	Arizona State University
Vehicle Count = 26	Nr	1	4	6	7	8	9	10	11	12	14	15	16	17	18	20	21	23	24	26	29	45	71	74	87	19	37
Design Event																											
General	5	5	5	5	5	5	5	5	5	4.5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	0	0
Design	15	13.625	7.5	11	12	10.375	12.375	12.625	11.375	8.875	11.375	8.375	8.875	5.875	6.5	6.375	12.875	11.25	13.875	11.125	11.625	10.5	8	10.25	5.75	0	0
Analysis	25	22.625	16.375	20.875	10	12.25	22.75	22.875	21.375	10	12.75	13.875	18.75	8.25	10.5	0.5	24.625	20.125	21.375	15.75	21.625	17.125	9.25	20	7.25	0	0
Testing	25	22.75	4.625	13.125	4.875	11.125	21.625	15.875	17.25	5.25	12.375	7.25	6.625	2.5	11.875	0	19.75	15	16.625	8.25	16.75	8.125	9.875	12	0	0	0
Safety	20	20	19	18	1	18	19	19	20	16.5	14	16	11.5	0.5	13.5	1.5	17.5	15.5	19.5	18	18	18	4.5	11	1	11	0
Aesthetics	10	9	7	5	0	5	10	6	9	5	5	5	5	0	5	0	10	6	9	5	8	9.5	2.5	5	0	2.5	0
Design Event - Total	100	93.0	54.7	73.0	32.9	61.8	90.8	81.4	84.0	50.1	60.5	55.5	55.8	19.9	50.3	10.1	89.8	72.9	85.4	63.1	81.0	62.8	19.6	63.3	0.0	13.5	0.0
Report content largely non-original	100%																						50%				
Late Report Submission (per day)	4%		8%												4%	8%						8%			4%		
Late for Static Judging or Safety Check	10%													10%		10%											
Over Page Limit (per page)	3%																										
Report Does Not Conform to Outline	10%																										
Design - Rank		1	17	8	20	13	2	6	5	19	14	16	15	21	18	24	3	9	4	11	7	12	22	10	25	23	25
Innovation Event																											
Deign	10	9.125	6.625	6	8.375	8.125	9	6.75	6.375	3.5	6.125	5.875	6	1.5	0	0	7.875	7.125	8.625	6.75	8	6.875	6.625	5.875	3.25	2.5	0
Concept Evaluation	7	6.5	3.75	5	3.625	4.5	4.625	2.75	3.625	0.625	4.125	3.875	3.625	0	0	0	4.875	3.5	4.375	4.75	2.125	4.125	3.125	1.875	2	1.5	0
Learnings	7	5.625	4.75	4.25	6	4.5	4.375	5.25	4.5	3.125	4.375	2.375	2.875	0	0	0	3.375	4.25	4.5	4.5	2.625	5.125	3.25	3.25	0.75	0	0
Execution	6	3.875	3.75	5.5	0	4.25	5.125	1	2.375	0.875	4.375	3.875	3.625	0	0	0	5.375	3.375	5	3	3.5	3.375	3	3.875	0	0	0
Bonus	1	0	0	0	0	0	0	0	1		0	0	0				0	1	0	0	1	0		0			
Innovation Event - Total	31	25.1	17.4	20.8	15.5	20.7	23.1	15.8	17.9	7.8	19.0	16.0	16.1	0.0	0.0	0.0	21.5	19.3	22.5	18.2	17.3	19.5	16.0	14.9	0.0	0.0	0.0
Report content largely non-original	100%																										
Late Report Submission (per day)	4%		8.0%																						4.0%		
Late for Presentation	10%				10.0%																						
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Report not stand alone document	4%				4.0%					4.0%										4.0%							
Report Does Not Conform to Outline	10%																										
Innovation - Rank		1	12	5	18	6	2	17	11	20	9	15	14	21	21	21	4	8	3	10	13	7	15	19	21	21	21
Women's Speed Event - Total	12.5	10.3	2.8	7.0	0.0	0.0	12.5	6.3	8.3	8.1	10.4	7.0	6.6	0.0	6.6	0.0	9.8	9.9	11.3	6.6	7.8	11.7	11.3	5.8	0.0	0.0	0.0
Fastest Speed (km/hr)	45.73	37.78	10.29	25.57	0.00	0.00	45.73	23.09	30.25	29.60	37.95	25.61	24.04	0.00	24.10	0.00	35.98	36.14	41.38	24.27	28.48	42.75	41.19	21.36	0.00	0.00	0.00
Women's Speed- Rank		6	19	13	20	20	1	17	9	10	5	12	16	20	15	20	8	7	3	14	11	2	4	18	20	20	20
Men's Speed Event - Total	12.5	12.3	11.4	9.2	0.0	0.0	11.0	8.5	10.6	8.5	9.5	7.2	8.7	0.0	8.6	0.0	10.7	10.2	12.4	7.6	9.1	12.1	12.5	7.5	0.0	0.0	0.0
Fastest Speed (km/hr)	51.20	50.50	46.70	37.61	0.00	0.00	45.00	34.69	43.62	34.72	38.92	29.48	35.60	0.00	35.13	0.00	43.85	41.80	50.92	31.01	37.23	49.40	51.20	30.68	0.00	0.00	0.00
Men's Speed - Rank		3	5	11	20	20	6	16	8	15	10	19	13	20	14	20	7	9	2	17	12	4	1	18	20	20	20
Endurance Event - Total	25	23.4	21.3	15.4	5.3	25.0	24.5	14.9	18.6	14.9	18.6	16.5	0.0	5.3	5.8	5.3	12.2	17.5	20.7	14.9	17.6	19.1	25.0	11.7	5.3	0.0	5.3
raw score		56.77	51.58	37.41	12.90	60.64	59.35	36.13	45.16	36.11	45.14	40.01	0.00	12.90	14.19	12.90	29.67	42.56	50.27	36.12	42.58	46.43	60.62	28.37	12.90	0.00	12.90
Laps Completed		44.00	42.00	29.00	10.00	47.00	46.00	28.00	35.00	28.00	36.00	31.00	0.00	10.00	12.00	10.00	23.00	33.00	39.00	28.00	33.00	36.00	48.00	22.00	10.00	0.00	10.00
Finish time (hr)		2.52389	2.5861	2.54528	2.5103	2.54389	2.52306	2.5025	2.52306	2.52944	2.52861	2.50389	2.5103	2.5103	2.5333	2.5103	2.53889	2.53306	2.5525	2.51444	2.55111	2.58583	2.51861	2.53	2.5103	2.5103	2.5103
Lap Length (km)	1.27																										
Avg Speed Minus Penalties (km/h)		22.1	19.3	14.3	5.1	23.5	23.0	14.0	17.6	13.5	17.1	15.7	0.0	5.1	5.3	5.1	11.3	16.2	18.4	13.9	16.4	17.6	23.1	10.6	5.1	0.0	5.1
Avg Speed Minus Penalties (mph)		13.7	12.0	8.9	3.1	14.6	14.3	8.7	10.9	8.4	10.6	9.8	0.0	3.1	3.3	3.1	7.0	10.0	11.4	8.7	10.2	11.0	14.3	6.6	3.1	0.0	3.1
Illegal Start Assistance (m)	500			900																							
Damage or Loss of Parcel (m)	up to 500	200					300	100			200								100			100	100				
Failure to Stop at Stop Sign, Complete Slalom, Hairpin Turn, or Quick Turn (m)	500		1000					500		1500	1000				500		500	1000	2500	500			1500	1000			
Safety Violation [Laps]	1 or more																										
Illegal Lap [Laps]	1																						1				
Min/Max Driver Lap Violation [Laps]	1		2								1				1												
Endurance - Rank		4	5	13	20	1	3	14	8	16	9	12	25	20	19	20	17	11	6	15	10	7	2	18	20	25	20
Overall - Total	100	90.71	63.48	67.32	25.50	57.35	90.60	64.59	74.65	51.69	69.30	58.01	42.74	11.29	36.10	8.36	74.03	72.33	85.08	60.20	70.23	74.73	65.29	53.92	5.32	4.05	5.32
Overall - Rank		1	13	10	21	16	2	12	5	18	9	15	19	22	20	23	6	7	3	14	8	4	11	17	24	26	24

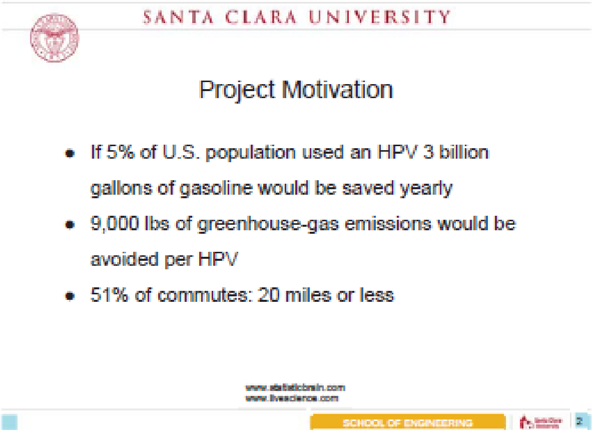
Appendix G: Senior Design Conference Presentation Slides and Summary

Human Powered Vehicle 2014

Peter Chester
Luis Flores
Ian Jones
Ryan Nakamura
Dylan Porter
Peter Stephens

Presentation Overview

- Motivation and Background Research
- Project Goals
- Design and Innovation
- Vehicle Testing
- ASME Competition Results
- Design Modifications
- The Future of SCU HPV



Project Motivation

- If 5% of U.S. population used an HPV 3 billion gallons of gasoline would be saved yearly
- 9,000 lbs of greenhouse-gas emissions would be avoided per HPV
- 51% of commutes: 20 miles or less

www.statisticbrain.com
www.livescience.com

Automobile vs Bicycle

- 15 - 30 % efficiency
  - Majority loss through heat
- Rider is 5% total weight

- 80 - 98 % efficiency
  - Majority loss in chain friction
- Rider is 78-86% total weight

www.fueleconomy.gov

Wilson, David; *Bicycling Science* (3rd)

Bicycle vs Tricycle

- High speed stability
- Lighter design
- Higher visibility in traffic
- Low cost

- Low speed stability
- Head, neck and back support
- Lower drag coefficient
- Storage

www.ebicycles.com

Addressing the Customer

- General Survey
  - Pedal Assist
  - Device Charging
  - Comfort
  - Safety/Security
  - Storage
- Target Customers Interviewed
  - Bike Commuter
  - Trike Manufacturer

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Project Goals

Design and Manufacture a Human Powered Vehicle:

- Safe
- Sustainable
- Efficient
- Practical
- Aesthetic
- ASME Competition

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Pegasus CAD Modeling

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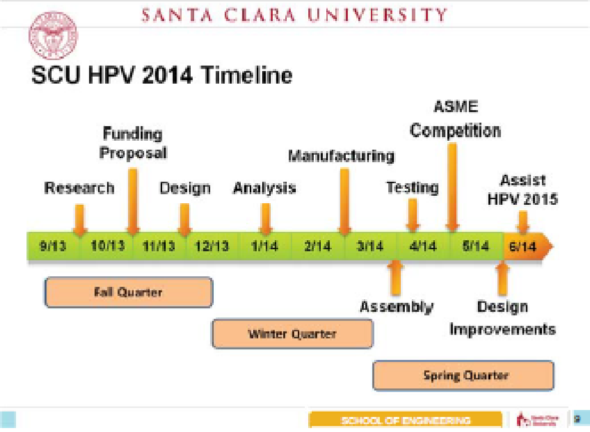
ASME Competition

Events:

- Design
- Innovation
- Speed
- Endurance

+Safety Requirement



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SCU HPV 2014 Timeline

Research

Funding Proposal

Design

Analysis

Manufacturing

Testing

ASME Competition

Assist HPV 2015

9/13 10/13 11/13 12/13 1/14 2/14 3/14 4/14 5/14 6/14

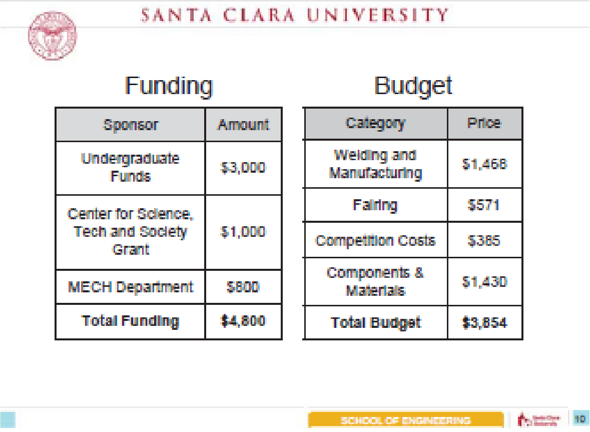
Assembly

Design Improvements

Fall Quarter

Winter Quarter

Spring Quarter



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Funding

Sponsor	Amount
Undergraduate Funds	$3,000
Center for Science, Tech and Society Grant	$1,000
MECH Department	$800
Total Funding	**$4,800**

Budget

Category	Price
Welding and Manufacturing	$1,468
Fairing	$571
Competition Costs	$385
Components & Materials	$1,430
Total Budget	**$3,854**

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Ergonomics

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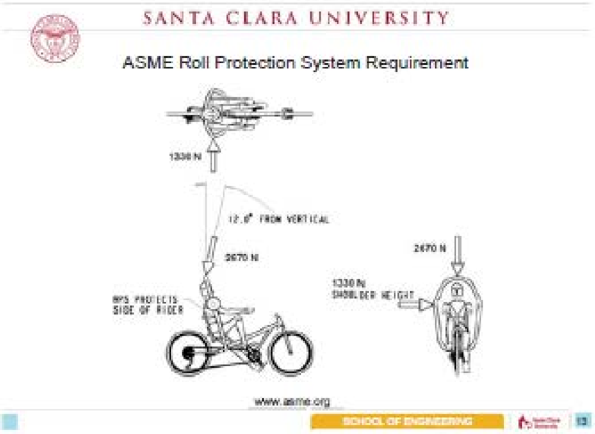
Frame Design

- Critical Criteria
  - Center of Gravity
  - Tipping Point
  - Braking Weight Transfer
  - Ergonomics
  - Rollover Protection
- Frame Material
  - 6061 T6 Aluminum



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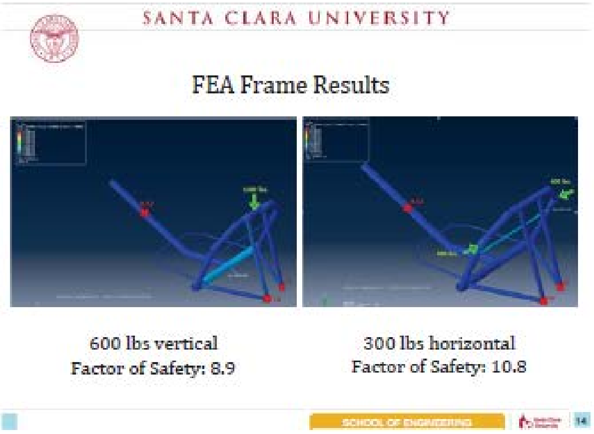
ASME Roll Protection System Requirement

www.asme.org



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FEA Frame Results

600 lbs vertical
Factor of Safety: 8.9

300 lbs horizontal
Factor of Safety: 10.8

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RPS Top Load Testing

Top Load: 610 lbs

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RPS Side Load Testing

Side Load: 320 lbs

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Steering Design

- Center of Gravity
  - 13" off the ground
  - 17" from front axles
- Direct Knuckle Linkage
- Steering Angles

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Steering Innovation

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Tilt Steering Design

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Aerodynamic Design

Drag Coefficient
- Pegasus: 0.51
- Bicycle: 1.1
- Recumbent w/out fairing: 0.77

Human Powered Vehicle Performance - FloCycling

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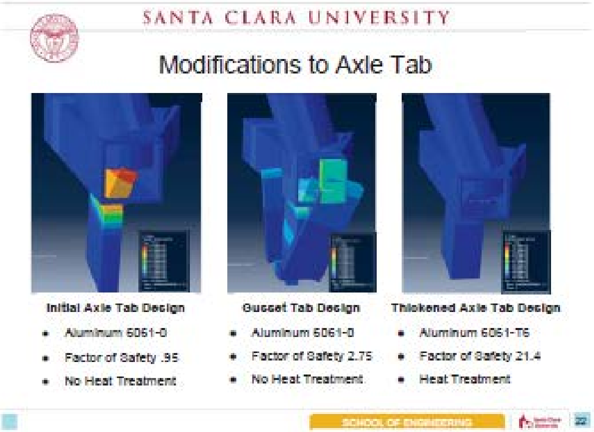
Axle Tab Failure

SCHOOL OF ENGINEERING 21



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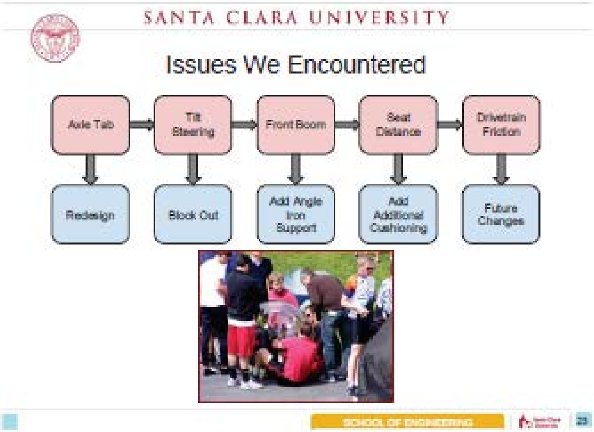
Modifications to Axle Tab

Initial Axle Tab Design
- Aluminum 6061-0
- Factor of Safety .95
- No Heat Treatment

Gusset Tab Design
- Aluminum 6061-0
- Factor of Safety 2.75
- No Heat Treatment

Thickened Axle Tab Design
- Aluminum 6061-T6
- Factor of Safety 21.4
- Heat Treatment

SCHOOL OF ENGINEERING 22



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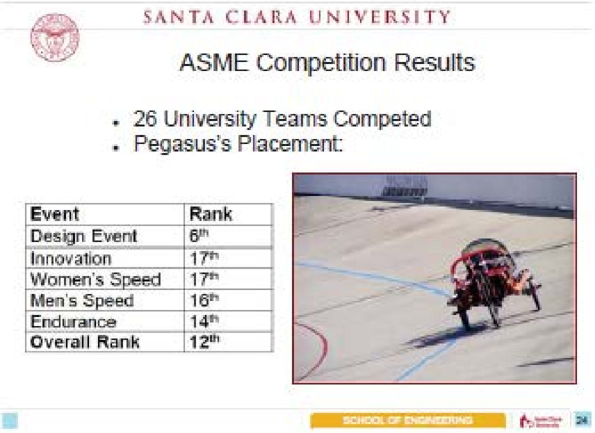
Issues We Encountered

Axle Tab
Redesign
Tilt Steering
Block Out
Front Boom
Add Angle Iron Support
Seat Distance
Add Additional Cushioning
Drivetrain Friction
Future Changes

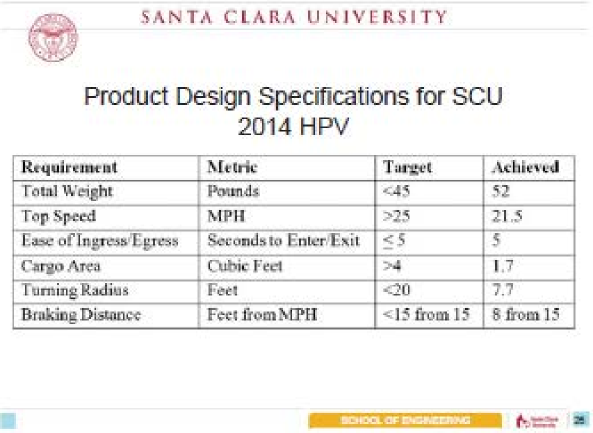
SCHOOL OF ENGINEERING 23



ASME Competition Results

- 26 University Teams Competed
- Pegasus's Placement:

Event	Rank
Design Event	6th
Innovation	17th
Women's Speed	17th
Men's Speed	16th
Endurance	14th
Overall Rank	12th



Product Design Specifications for SCU 2014 HPV

Requirement	Metric	Target	Achieved
Total Weight	Pounds	<45	52
Top Speed	MPH	>25	21.5
Ease of Ingress/Egress	Seconds to Enter/Exit	≤ 5	5
Cargo Area	Cubic Feet	>4	1.7
Turning Radius	Feet	<20	7.7
Braking Distance	Feet from MPH	<15 from 15	8 from 15

Santa Clara University HPV Legacy

- Assist SCU HPV 2015
  - Design Report
  - Competition Specifics
  - Finite Element Analysis (Abaqus)
  - Funding Requests
  - Industry Contacts

Sponsors & Donations from:

BYINGTON STEEL TREATING, INC.

The Off Ramp
Bicycles
Accessories
Services

La Dolce Velo

Hyland Family Bicycles

Chavez Welding & Machining

Acknowledgements

- Santa Clara University, School of Engineering
  - Dr. Drazen Fabris
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  - Don MacCubbin
  - Calvin Sellers
  - Dr. Tim Hight
  - Dr. Robert Marks
  - Dr. Donald Riccomini
  - Rachel Donahoe
- SCU Center For Science, Technology, & Society
  - Roelandts Family

Thank You and Go Broncos!

Contact Info

Peter Chester
- pchester@scu.edu
- 916.248.3347

Dylan Porter
- dporter@scu.edu
- 509.720.4740

Ryan Nakamura
- rnakamura@scu.edu
- 808.754.5229

Luis Flores
- l1flores@scu.edu
- 831.840.5207

Ian Jones
- ijones@scu.edu
- 503.884.9328

Peter Stephens
- pstephens@scu.edu
- 408.893.1719

Appendix Slides

Product Design Specifications for SCU 2014 HPV

Category	Requirement	Metric	Datum	Target	Achieved
Overall	Total Weight	Pounds	<40	<45	52
Overall	Top Speed	MPH	30	>25	21.5
Overall	Ease of Ingress/Egress	Seconds to Enter/Exit	Unknown	≤5	5
Overall	Within Budget Funding	US Dollars	Unknown	<4000	3854.59
Overall	Cargo Area	Cubic Feet	Unknown	>2	1.7
Competition	Turning Radius	Feet	<20	<20	7.7
Competition	Braking Distance	Feet from MPH	19 from 15	8 from 15	8 from 15
Competition	Roll Over Protection System: Top Load	Pounds	600	600	610
Competition	Top Load Elastic Deflection	Inches	≤2	≤0.5	~0
Competition	Roll Over Protection System: Side Load	Pounds	300	300	320
Competition	Side Load Elastic Deflection	Inches	≤1.5	≤0.5	~0
Competition	Safety Harness	Pass/Fail	Pass	Pass	Pass

What was Learned from Design Analysis

- Discovered critical points and optimized design
  - Increased/Decreased Tubing
  - Added rear support beam
  - Thinner lateral bars could be used in tilt
- The frame should meet the ASME safety requirements from analysis

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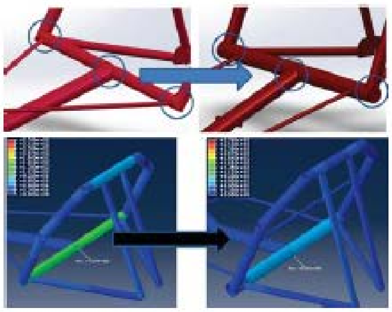


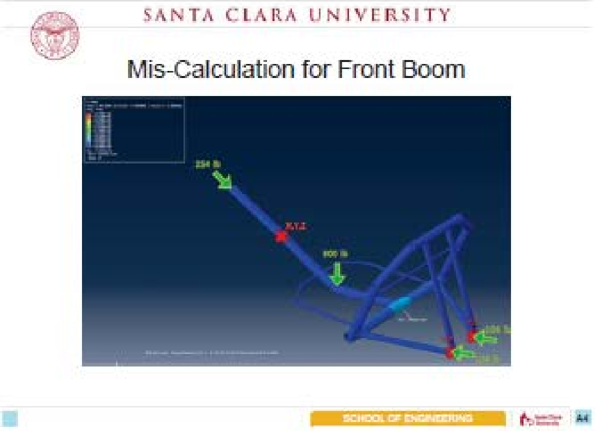
Tilt Steering Design Modification

Initial Tilt Steering Design

- Composed of 6061-T6
- Steel Roller-Bearing Fasteners
- Factor of Safety 2.6
- Initial design considered to be too heavy
- Highest stress in Roller Bearings

Final Tilt Steering Design

- Lateral Bars composed of 6063
- Steel Roller-Bearing Fasteners
- Half the thickness of original design
- Factor of Safety of 1.5
- Highest stress in Roller Bearings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Mis-Calculation for Front Boom

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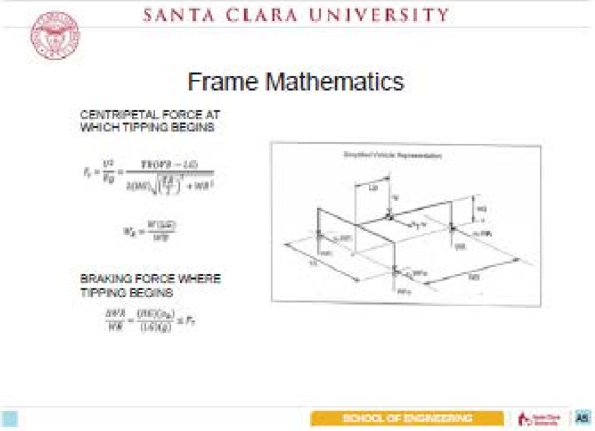
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Frame Mathematics

CENTRIPETAL FORCE AT WHICH TIPPING BEGINS

$$F_y = \frac{V^2}{Rg} = \frac{TR(WB - LG)}{2(HG)\sqrt{\left(\frac{TR}{2}\right)^2 + WB^2}}$$

$$W_R = \frac{W(LG)}{WB}$$

BRAKING FORCE WHERE TIPPING BEGINS

$$\frac{\Delta WR}{WR} = \frac{(HG)(a_x)}{(LG)(g)} \leq F_y$$

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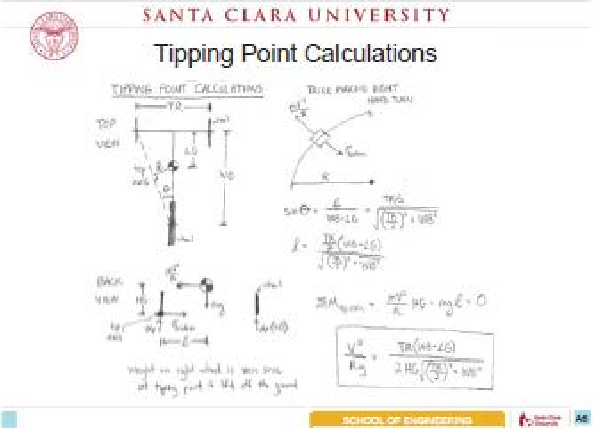
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Tipping Point Calculations

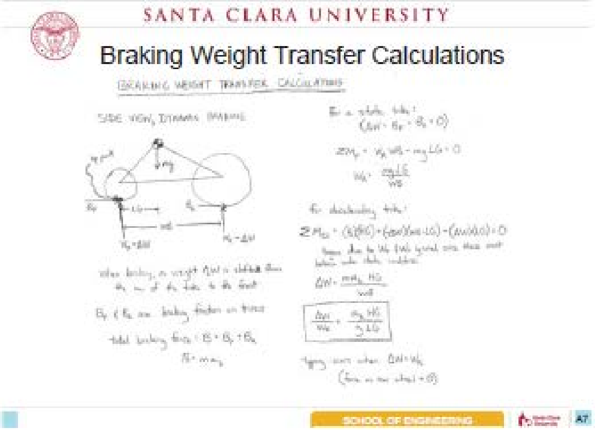
TIPPING POINT CALCULATIONS

TRIKE MAKING RIGHT HARD TURN

$$\sum M_{tip\,axis} = \frac{mV^2}{R} HG - mg\ell = 0$$

$$\boxed{\frac{V^2}{Rg} = \frac{TR(WB-LG)}{2HG\sqrt{\left(\frac{TR}{2}\right)^2 + WB^2}}}$$

SCHOOL OF ENGINEERING A6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Braking Weight Transfer Calculations

BRAKING WEIGHT TRANSFER CALCULATIONS

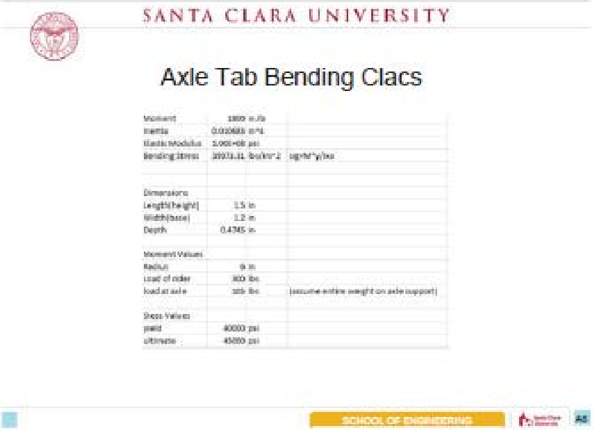
SIDE VIEW, DYNAMIC BRAKING

$$W_R = \frac{mg\,LG}{WB}$$

$$\Delta W = \frac{ma_x\,HG}{WB}$$

$$\boxed{\frac{\Delta W}{W_R} = \frac{a_x\,HG}{g\,LG}}$$

SCHOOL OF ENGINEERING A7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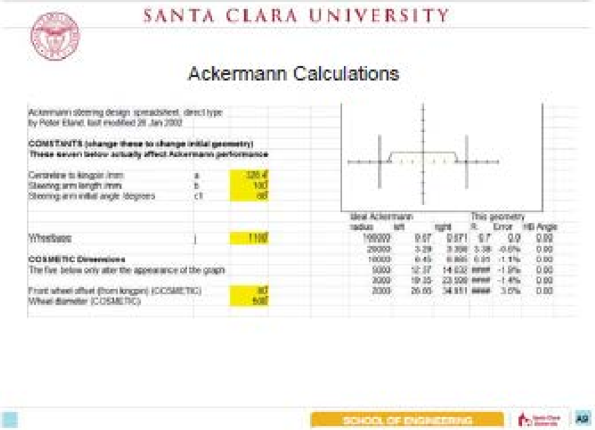
Axle Tab Bending Clacs

Moment	1800 in-lb	
Inertia	0.010686 in^4	
Elastic Modulus	3.00E+08 psi	
Bending Stress	39371.11 lbs/in^2	sigma=M*y/Ixx
Dimensions		
Length(height)	1.5 in	
Width(base)	1.2 in	
Depth	0.4745 in	
Moment Values		
Radius	6 in	
Load of rider	300 lbs	
load at axle	305 lbs	(assume entire weight on axle support)
Stress Values		
yield	40000 psi	
ultimate	45000 psi	

SCHOOL OF ENGINEERING A8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Ackermann Calculations

Ackermann steering design spreadsheet, direct type
by Peter Eland, last modified 28 Jan 2002

CONSTANTS (change these to change initial geometry)
These seven below actually affect Ackermann performance

Centreline to kingpin /mm	a	326.4
Steering arm length /mm	b	100
Steering arm initial angle /degrees	c1	68
Wheelbase	l	1100

COSMETIC Dimensions
The five below only alter the appearance of the graph

Front wheel offset (from kingpin) (COSMETIC)	80
Wheel diameter (COSMETIC)	508

Ideal Ackermann			This geometry		
radius	left	right	R	Error	HB Angle
100000	0.67	0.671	6.7	0.0	0.00
20000	3.29	3.300	3.38	-0.0%	0.00
10000	6.45	6.866	6.93	-1.1%	0.00
5000	12.37	14.032	####	-1.9%	0.00
3000	19.35	23.506	####	-1.4%	0.00
2000	26.66	34.911	####	3.0%	0.00

SCHOOL OF ENGINEERING A9

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Preliminary Gearing Calculation Results

new mph
3.310955561
4.175403415
5.133721852
6.182081312
7.315262606
9.005969143
12.52173168
16.26322519
19.74132147
22.40916765
24.01572384

new mph
3.310956
6.367924
7.814347
9.38856
11.65803
14.63276
18.28081
22.65243
25.63334
26.66642
25.6167

- 34 tooth gear
- 52 tooth gear

$$F_{Drag} = \frac{1}{2}\rho V^2 C_D A$$

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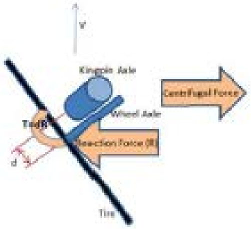
Stable Steering Setup



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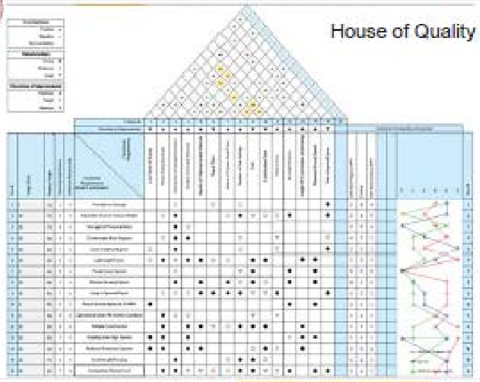
House of Quality



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Frame Material Tradeoffs

AISI 4130 Steel

- Strong (670 MPa)
- Easy to work with
- Heavy (7.85 g/cc)
- Failure very unlikely to happen

Aluminum 6061-T6

- Weaker (310 MPa)
- Not as easy to work with
- Lighter (2.7 g/cc)
- Desirable failure characteristics

Carbon Fiber

- Similar strength properties to steel
- High skill level required
- Lightest Option (1.4 g/cc)
- Failure is critical

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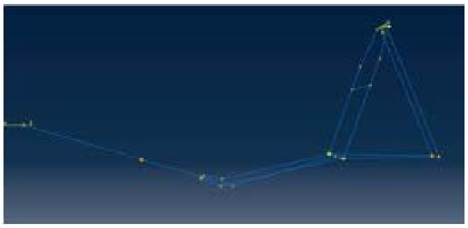
"Connect-the-Dot" Method



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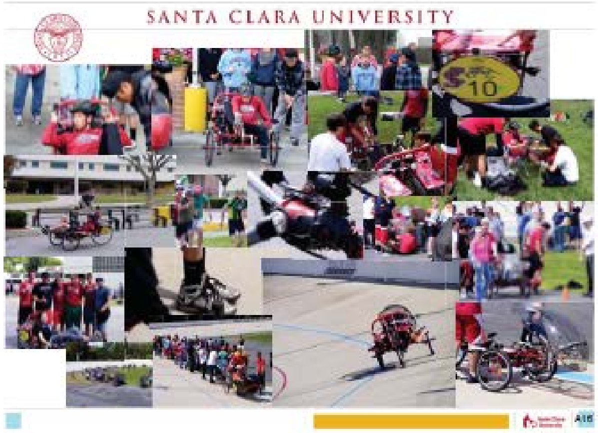
Steering Assembly



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A16

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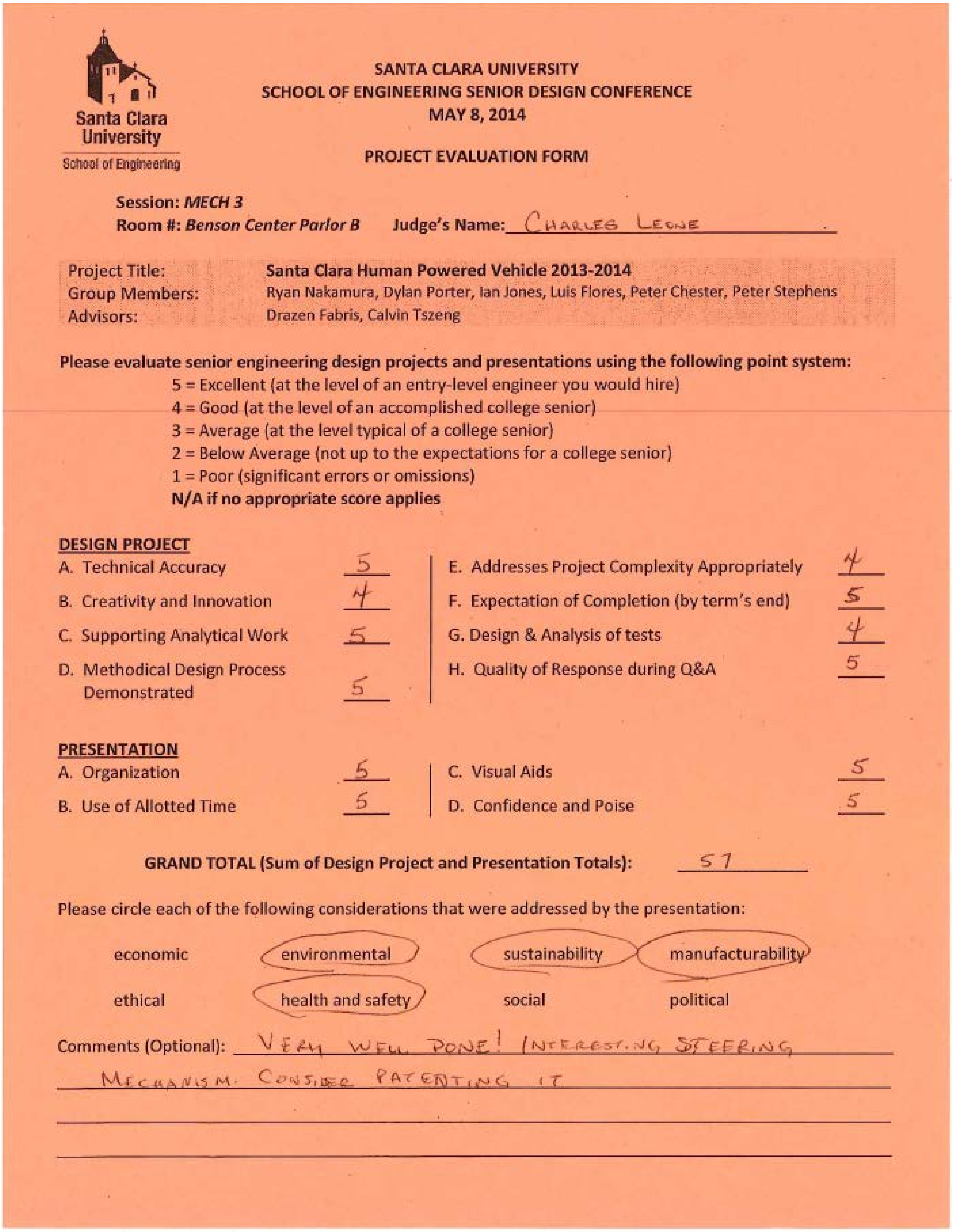
SCHOOL OF ENGINEERING

A17

Judges' Summaries



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MAY 8, 2014

Santa Clara University
School of Engineering

PROJECT EVALUATION FORM

Session: *MECH 3*
Room #: *Benson Center Parlor B* **Judge's Name:** CHARLES LEONE

Project Title:	**Santa Clara Human Powered Vehicle 2013-2014**
Group Members:	Ryan Nakamura, Dylan Porter, Ian Jones, Luis Flores, Peter Chester, Peter Stephens
Advisors:	Drazen Fabris, Calvin Tszeng

Please evaluate senior engineering design projects and presentations using the following point system:

5 = Excellent (at the level of an entry-level engineer you would hire)
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	5	E. Addresses Project Complexity Appropriately	4
B. Creativity and Innovation	4	F. Expectation of Completion (by term's end)	5
C. Supporting Analytical Work	5	G. Design & Analysis of tests	4
D. Methodical Design Process Demonstrated	5	H. Quality of Response during Q&A	5

PRESENTATION

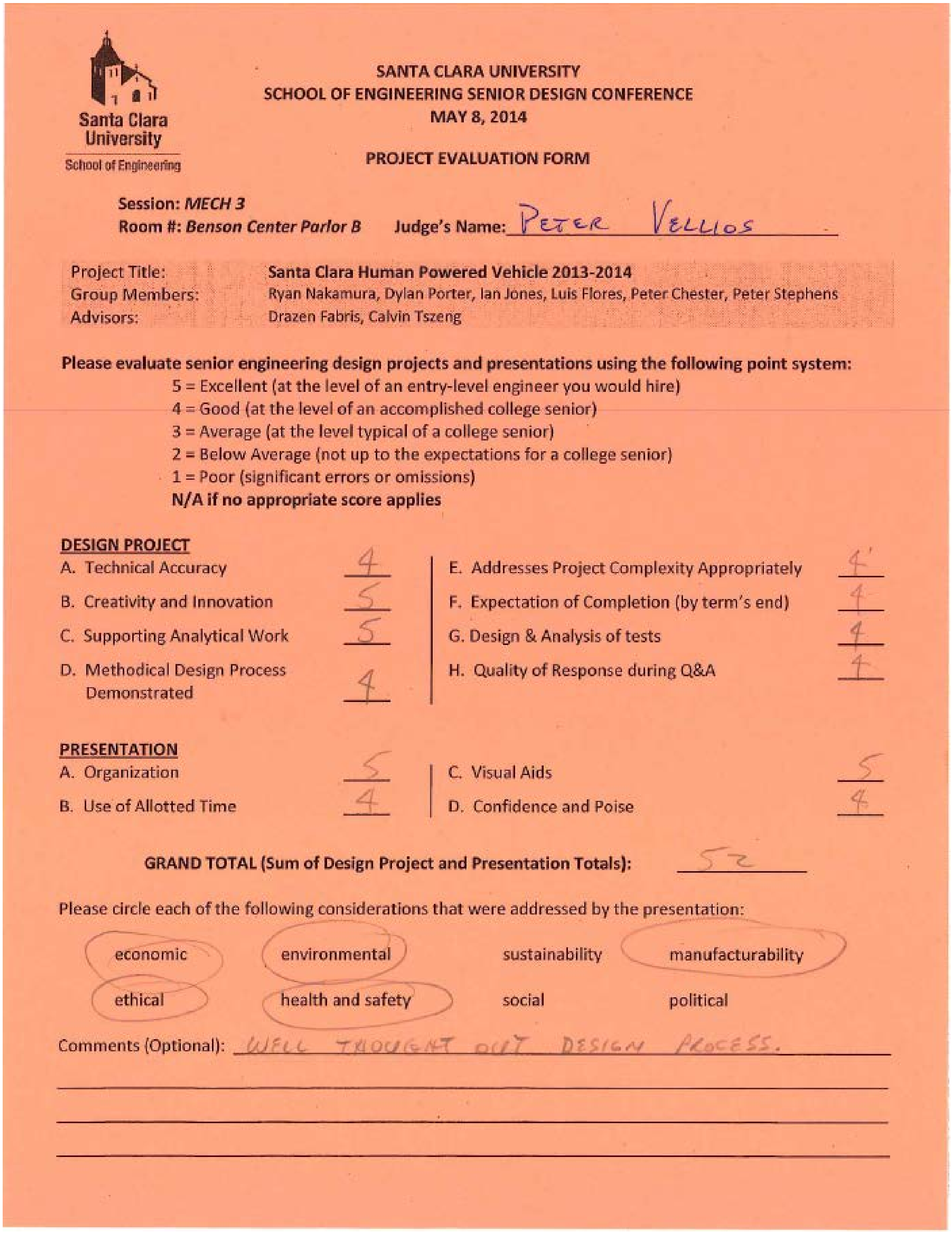
A. Organization	5	C. Visual Aids	5
B. Use of Allotted Time	5	D. Confidence and Poise	5

GRAND TOTAL (Sum of Design Project and Presentation Totals): 57

Please circle each of the following considerations that were addressed by the presentation:

economic [✓ environmental] [✓ sustainability] [✓ manufacturability]
ethical [✓ health and safety] social political

Comments (Optional): VERY WELL DONE! INTERESTING STEERING MECHANISM. CONSIDER PATENTING IT.



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MAY 8, 2014

PROJECT EVALUATION FORM

Session: ***MECH 3***
Room #: ***Benson Center Parlor B*** **Judge's Name:** PETER VELLIOS

Project Title: **Santa Clara Human Powered Vehicle 2013-2014**
Group Members: Ryan Nakamura, Dylan Porter, Ian Jones, Luis Flores, Peter Chester, Peter Stephens
Advisors: Drazen Fabris, Calvin Tszeng

Please evaluate senior engineering design projects and presentations using the following point system:

5 = Excellent (at the level of an entry-level engineer you would hire)
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy 4
B. Creativity and Innovation 5
C. Supporting Analytical Work 5
D. Methodical Design Process Demonstrated 4
E. Addresses Project Complexity Appropriately 4
F. Expectation of Completion (by term's end) 4
G. Design & Analysis of tests 4
H. Quality of Response during Q&A 4

PRESENTATION

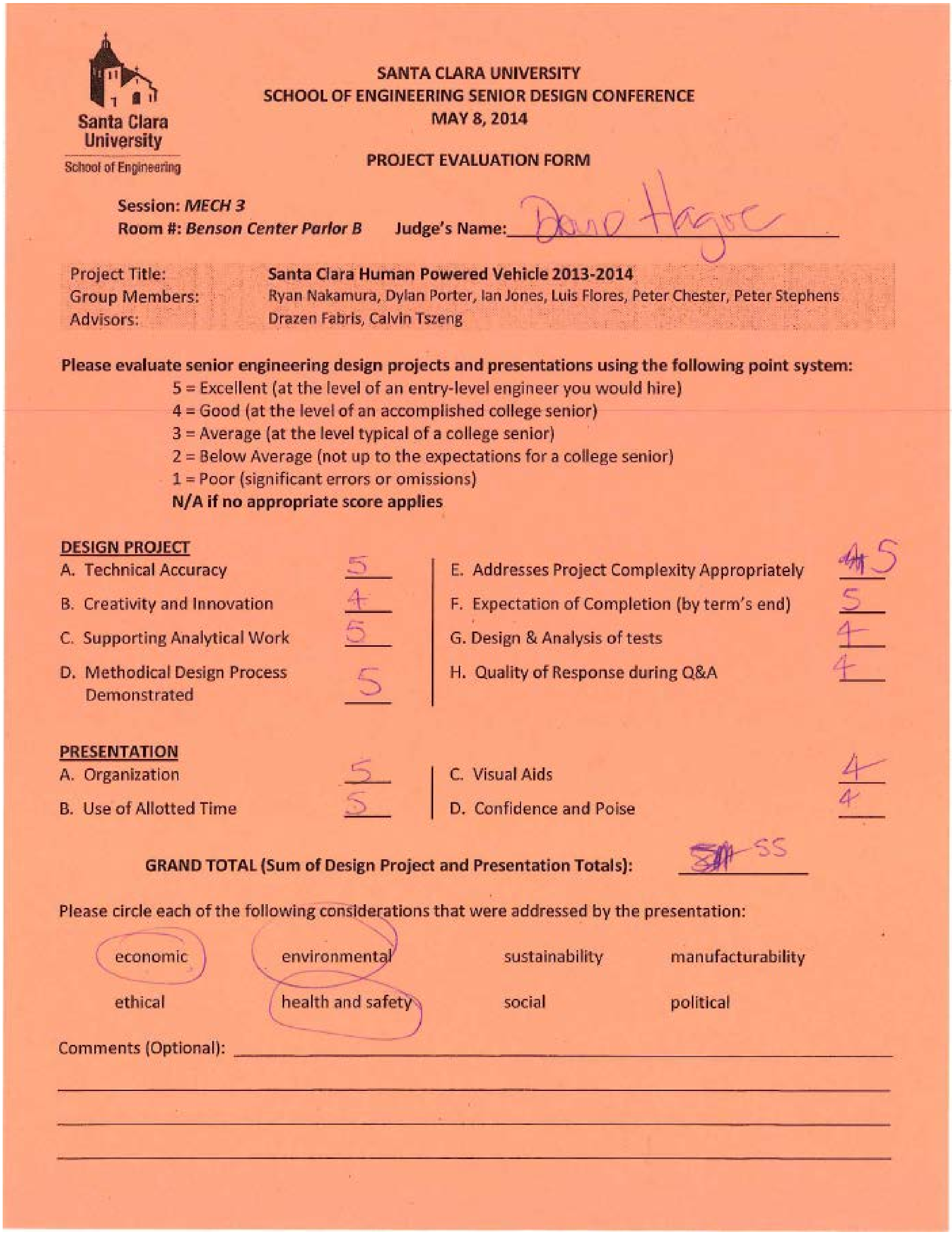
A. Organization 5
B. Use of Allotted Time 4
C. Visual Aids 5
D. Confidence and Poise 4

GRAND TOTAL (Sum of Design Project and Presentation Totals): 52

Please circle each of the following considerations that were addressed by the presentation:

[✓ economic] [✓ environmental] sustainability [✓ manufacturability]
[✓ ethical] [✓ health and safety] social political

Comments (Optional): WELL THOUGHT OUT DESIGN PROCESS.



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MAY 8, 2014

PROJECT EVALUATION FORM

Session: ***MECH 3***
Room #: ***Benson Center Parlor B*** **Judge's Name:** Dave Hagre

Project Title:	**Santa Clara Human Powered Vehicle 2013-2014**
Group Members:	Ryan Nakamura, Dylan Porter, Ian Jones, Luis Flores, Peter Chester, Peter Stephens
Advisors:	Drazen Fabris, Calvin Tszeng

Please evaluate senior engineering design projects and presentations using the following point system:

5 = Excellent (at the level of an entry-level engineer you would hire)
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	5	E. Addresses Project Complexity Appropriately	~~4~~ 5
B. Creativity and Innovation	4	F. Expectation of Completion (by term's end)	5
C. Supporting Analytical Work	5	G. Design & Analysis of tests	4
D. Methodical Design Process Demonstrated	5	H. Quality of Response during Q&A	4

PRESENTATION

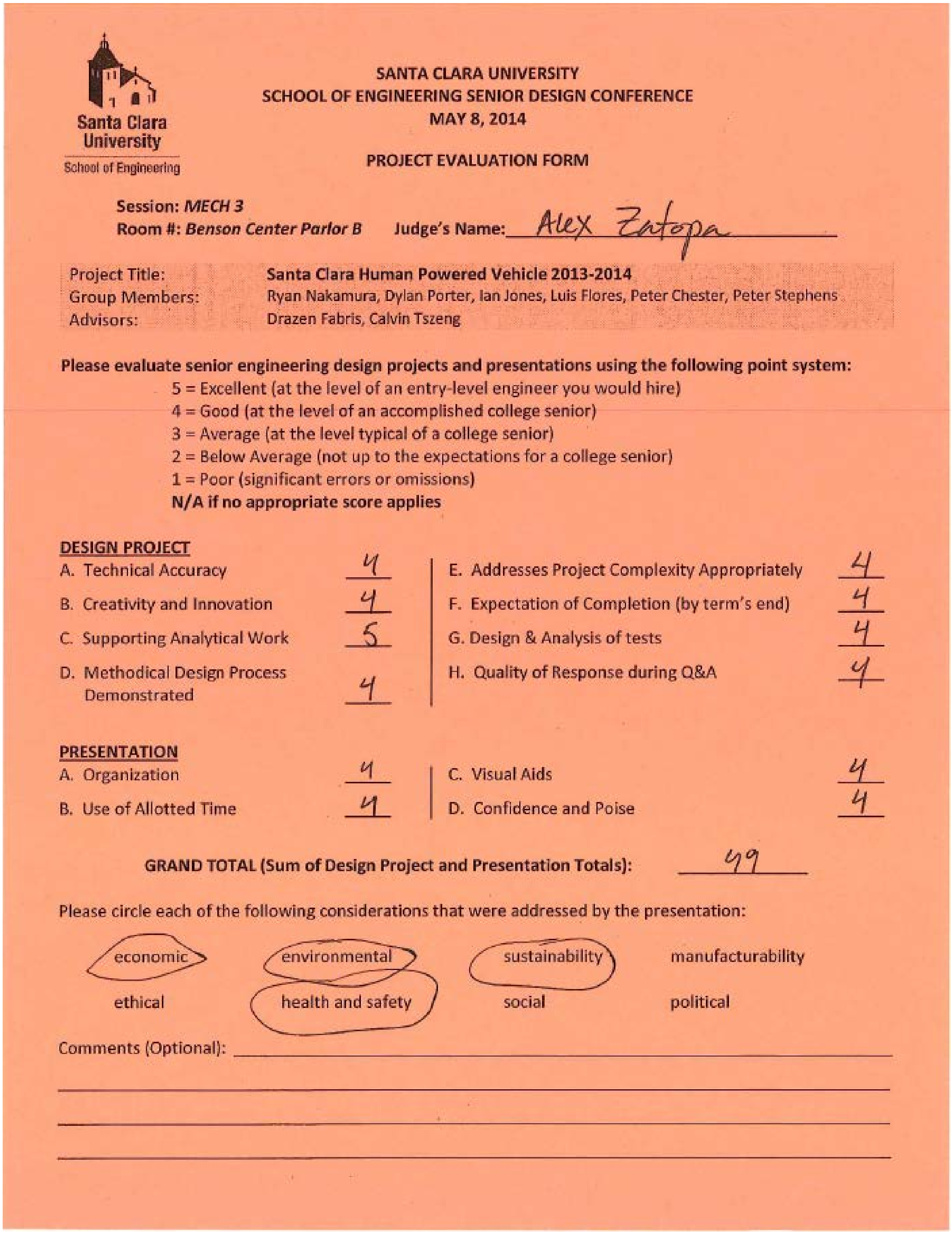
A. Organization	5	C. Visual Aids	4
B. Use of Allotted Time	5	D. Confidence and Poise	4

GRAND TOTAL (Sum of Design Project and Presentation Totals): ~~54~~ 55

Please circle each of the following considerations that were addressed by the presentation:

[✓ economic] [✓ environmental] sustainability manufacturability
ethical [✓ health and safety] social political

Comments (Optional):



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MAY 8, 2014

PROJECT EVALUATION FORM

Session: ***MECH 3***
Room #: ***Benson Center Parlor B*** **Judge's Name:** Alex Zatopa

Project Title: **Santa Clara Human Powered Vehicle 2013-2014**
Group Members: Ryan Nakamura, Dylan Porter, Ian Jones, Luis Flores, Peter Chester, Peter Stephens
Advisors: Drazen Fabris, Calvin Tszeng

Please evaluate senior engineering design projects and presentations using the following point system:

5 = Excellent (at the level of an entry-level engineer you would hire)
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	4	E. Addresses Project Complexity Appropriately	4
B. Creativity and Innovation	4	F. Expectation of Completion (by term's end)	4
C. Supporting Analytical Work	5	G. Design & Analysis of tests	4
D. Methodical Design Process Demonstrated	4	H. Quality of Response during Q&A	4

PRESENTATION

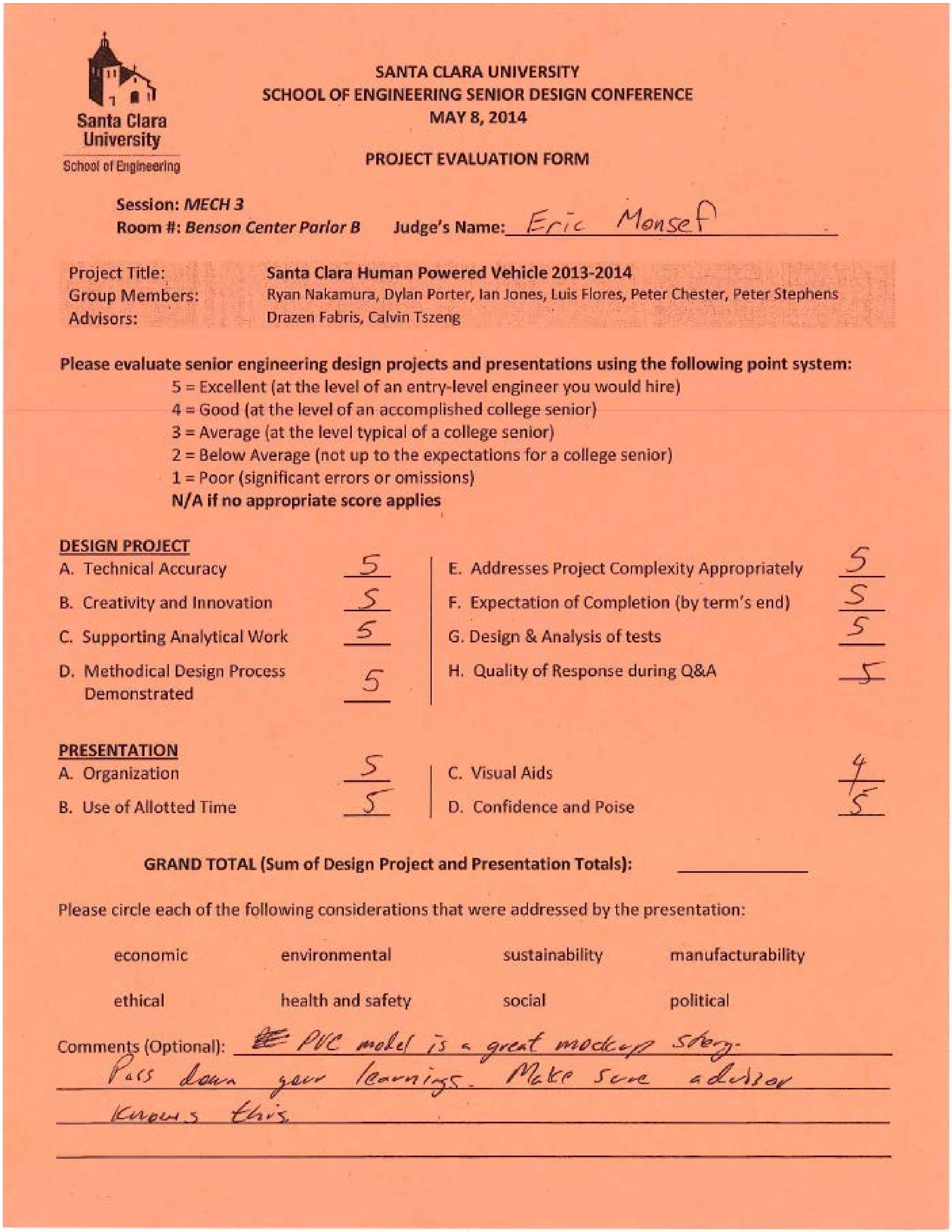
A. Organization	4	C. Visual Aids	4
B. Use of Allotted Time	4	D. Confidence and Poise	4

GRAND TOTAL (Sum of Design Project and Presentation Totals): 49

Please circle each of the following considerations that were addressed by the presentation:

[✓ economic] [✓ environmental] [✓ sustainability] manufacturability
ethical [✓ health and safety] social political

Comments (Optional):



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SANTA CLARA UNIVERSITY
SCHOOL OF ENGINEERING SENIOR DESIGN CONFERENCE
MAY 8, 2014

PROJECT EVALUATION FORM

Session: *MECH 3*
Room #: *Benson Center Parlor B* **Judge's Name:** Eric Monsef

Project Title: **Santa Clara Human Powered Vehicle 2013-2014**
Group Members: Ryan Nakamura, Dylan Porter, Ian Jones, Luis Flores, Peter Chester, Peter Stephens
Advisors: Drazen Fabris, Calvin Tszeng

Please evaluate senior engineering design projects and presentations using the following point system:

5 = Excellent (at the level of an entry-level engineer you would hire)
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	5	E. Addresses Project Complexity Appropriately	5
B. Creativity and Innovation	5	F. Expectation of Completion (by term's end)	5
C. Supporting Analytical Work	5	G. Design & Analysis of tests	5
D. Methodical Design Process Demonstrated	5	H. Quality of Response during Q&A	5

PRESENTATION

A. Organization	5	C. Visual Aids	4
B. Use of Allotted Time	5	D. Confidence and Poise	5

GRAND TOTAL (Sum of Design Project and Presentation Totals): ____________

Please circle each of the following considerations that were addressed by the presentation:

economic
environmental
sustainability
manufacturability
ethical
health and safety
social
political

Comments (Optional): PVC model is a great mockup step. Pass down your learnings. Make sure advisor knows this.

Appendix H: Relevant Patents

Patent US 6402174 B1 by Alan Maurer

While searching the internet to find designs that incorporated Tilt and Ackermann steering, we discovered the U.S. patent submitted by Alan Maurer in 2002 that was mentioned in the previous section. The system that was designed by Maurer was a steering system for three wheel recumbent tricycles that incorporated tilt steering and a steering system similar to Ackermann steering. The system that Maurer designed emphasizes similar results compared to our steering system; however, the system that he designed is more complicated than the design of the Pegasus vehicle.

Maurer's Tilt steering system has individual leaning tie rods connecting the wheels to the frame, as depicted in Figure 3. This design slightly reduces the weight of the vehicle but requires more time and accuracy in manufacturing and assembly. Overall, the design that Maurer patented is lighter than that of Pegasus but it is more complex. The increased number of parts of Maurer's design would make the manufacturing and assembly cost more money and require more precision than that of the Pegasus.

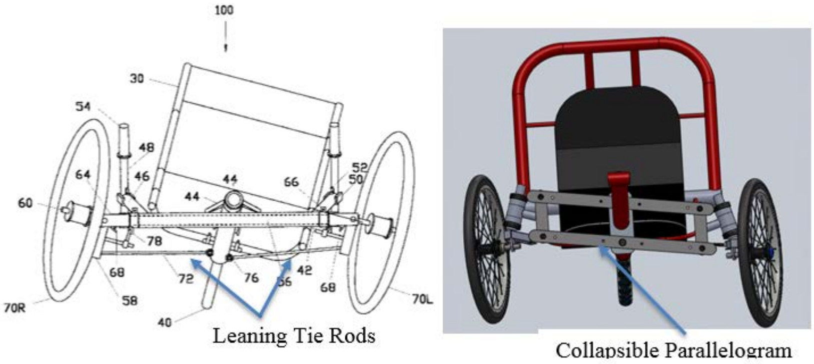


Figure H.1: *The figure above displays the Leaning Tie Rods from Maurer's Tilt system on the left (Maurer) and the single beam Tilt steering used on the Pegasus on the right.*

Appendix I: Customer Research

Personal Interview Questionnaire:

1) What do you currently like about your bike?

2) What don’t you like about your bike?

3) What bothers you the most when commuting?

4) Do you use a speed suit when riding a bike?

5) What features do you like most about your bike?

6) If you could design your “dream bike”, what features would it have and how would it look?

7) Do you ride your bike on sidewalks or on the road?

8) What makes you feel safe on the road?

9) How far do you commute on average on a daily basis?

10) Do you drive to work. If not, why don't you drive to work?

11) What do you like and dislike about Cars?

12) What is the distance (miles) at which you decide to drive your car instead of riding your bike?

13) What are the things that annoy/bother you about drivers around you?

14) Do you know any other people/organizations with biking experience that we can meet/interview?

15) What are the advantages/disadvantages of a carbon fiber and/or steel frame?

Survey Monkey Questionnaire Posted on Facebook:

1. What is your age?

0 to 18
18 to 24
25 to 34
35 to 44
45 to 54
55 to 64

65 to 74
75 or older

2. Are you currently enrolled as a student?

Yes, full time in graduate school
Yes, part time in graduate school
Yes, full time at a four year undergraduate college/university
Yes, part time at a four year undergraduate college/university
Yes, full time at a two year undergraduate college/university
Yes, part time at a two year undergraduate college/university
Yes, at a high school or equivalent
No, I am not currently enrolled as a student

3. Do you live on campus?

Yes
No

4. What do you use to commute?

Longboard/Skateboard
Walk
Bike
Drive
Train

Bus

5. How far do you commute on average (One Way)?

0 - 5 miles
5 - 10 miles
10 - 15 miles
15 - 20 miles
20 - 25 miles
25+ miles

6. What is the longest distance you are willing to commute by bicycle?

0 - 5 miles
5 - 10 miles
10 - 15 miles
15 - 20 miles
20 - 25 miles
25+ miles

7. If you could design your dream bicycle (human powered vehicle), what features would you want (i.e. GPS system, pedal assist, cargo space, etc)?

8. What do you dislike about your bicycle (or bicycles in general if you do not have one)?

Listings of Raw Customer Feedback

Personal Interview Questionnaire Answers from Dainuri Rott:

1) What do you currently like about your bike?

It is simple, easy gear shifts, and I am not worried about it getting stolen.

2) What don’t you like about your bike?

Mountain bike design switch for commute bigger seat as opposed to now.

3) What bothers you the most when commuting?

I feel safer in a car. If there were more bike lanes I would feel safer. This is an important political issue.

4) Do you use a speed suit when riding a bike?

No.

5) What features do you like most about your bike?

It is easy to use, simple, and effective.

6) If you could design your “dream bike”, what features would it have and how would it look?

Stability / storage / hybrid for longer ranges/ choice about amount of exercise integrating smartphones and trikes sending medical information/how many calories burning etc.

7) Do you ride your bike on sidewalks or on the road?

Both - when the bike lane isn’t good I use the sidewalk.

8) What makes you feel safe on the road?

Good lights and flags for good visibility.

9) How far do you commute on average on a daily basis?

I commute three blocks. I used to commute nine miles and would drive my car instead of my bike because it allowed me to commute faster.

10) Do you drive to work. If not, why don't you drive to work?

I live three blocks away from home so I ride my bike instead

11) What do you like and dislike about Cars?

Cars are a pain to park

Cars use a lot of gas(expensive)

Wars are fought to keep gas lines open for America

I bought a hybrid as soon as it came out

12) What is the distance (miles) at which you decide to drive your car instead of riding your bike?

Now this distance is half a mile because I can commute faster on a car.

13) What are the things that annoy/bother you about drivers around you?

There are a lot of people that text and use their phones while driving. This is very dangerous for other drivers on the road.

Personal Interview Questionnaire Answers from Dr. Robert Marks:

1) What do you currently like about your bike?

-Long distance (within reason)

    -Could do 100 miles in a day

-Doesn’t like Gps Voice

-Drive = bike ability → bikes are easier

2) What don’t you like about your bike?

-Maintaining the bike is a hassle (continuously keeping it clean)

-Flat tires

3) What bothers you the most when commuting?

-left turns

4) Do you use a speed suit when riding a bike?

-comfortable

-chafing is non-existent

5) What features do you like most about your bike?

-triple crank

-features inherent to a road bike

-steel frames are more comfortable

-carbon fiber is nice but too expensive

6) If you could design your “dream bike”, what features would it have and how would it look?

-Our HPV

-weight

-recumbent appealed to him

-research showed it was faster -->age was a factor

-wide array of gearing

-high on the performance

7) Do you ride your bike on sidewalks or on the road?

-prefers biking over driving

-good exercise

-bike lanes not on curb a wide

8) What makes you feel safe on the road?

-not riding with inexperienced cyclists

-research has said cycling is safer than driving

9) How far do you commute on average on a daily basis?

-25 miles on average

10) What do you like about Cars?

-good against the weather

-security

- freeway accessibility

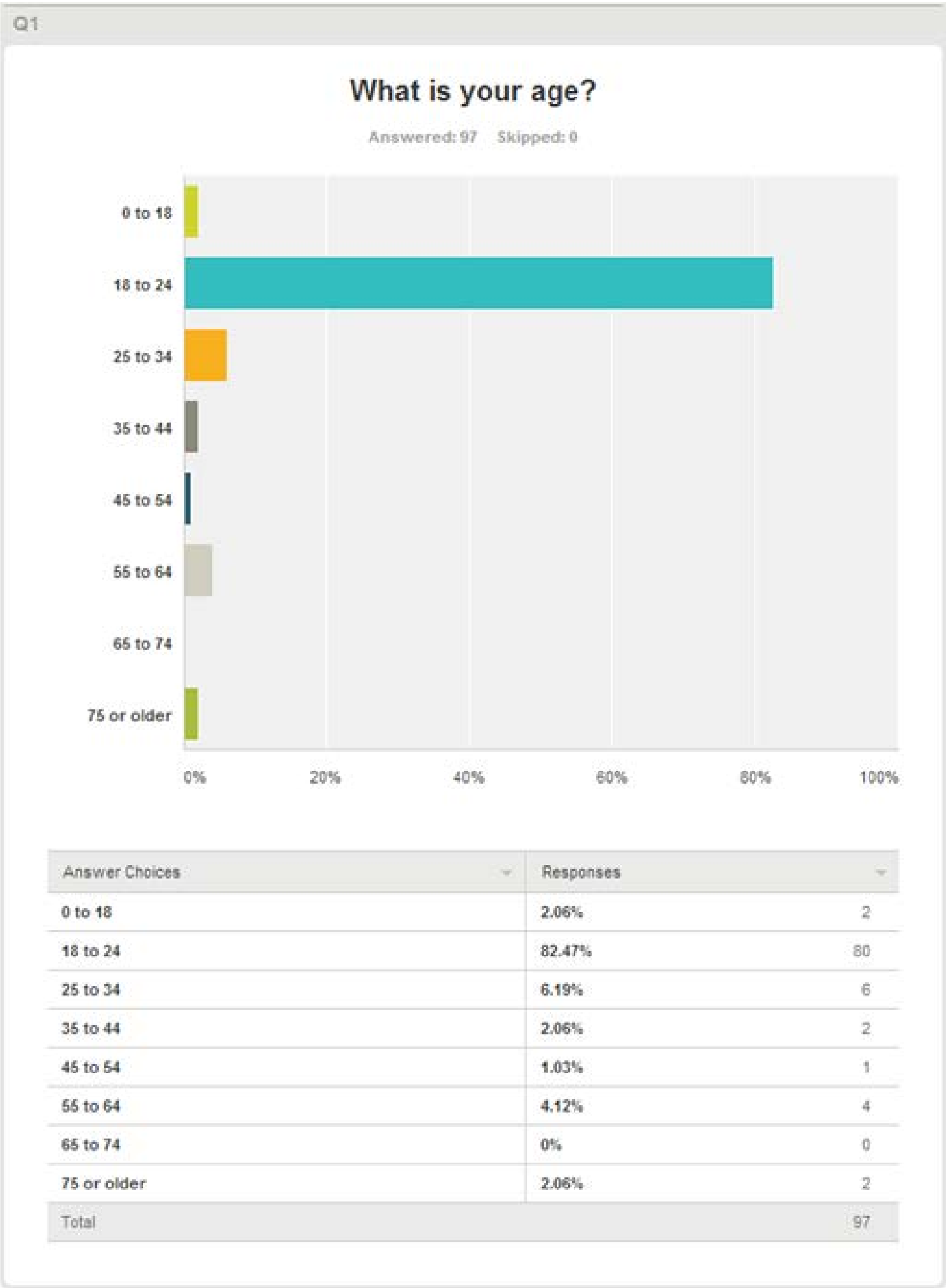
11) What is the distance (miles) at which you decide to drive your car instead of riding your bike?

-40 mile commutes (3 days out of the week)

12) Do you know any other people/organizations with biking experience that we can meet/interview?

-recreational bike club

Organized Feedback, Tabulated and/or in Diagrams

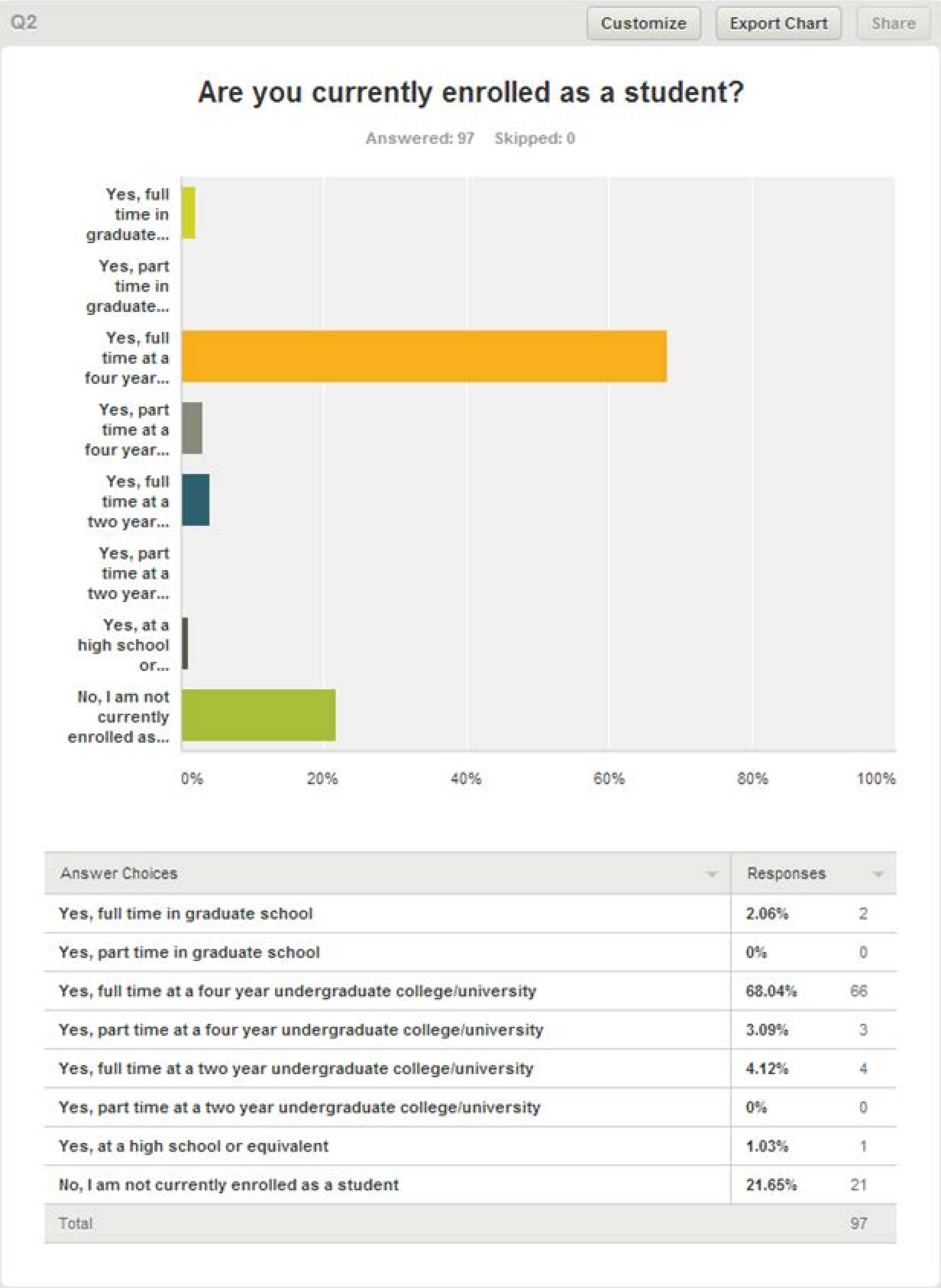


Q1

What is your age?

Answered: 97 Skipped: 0

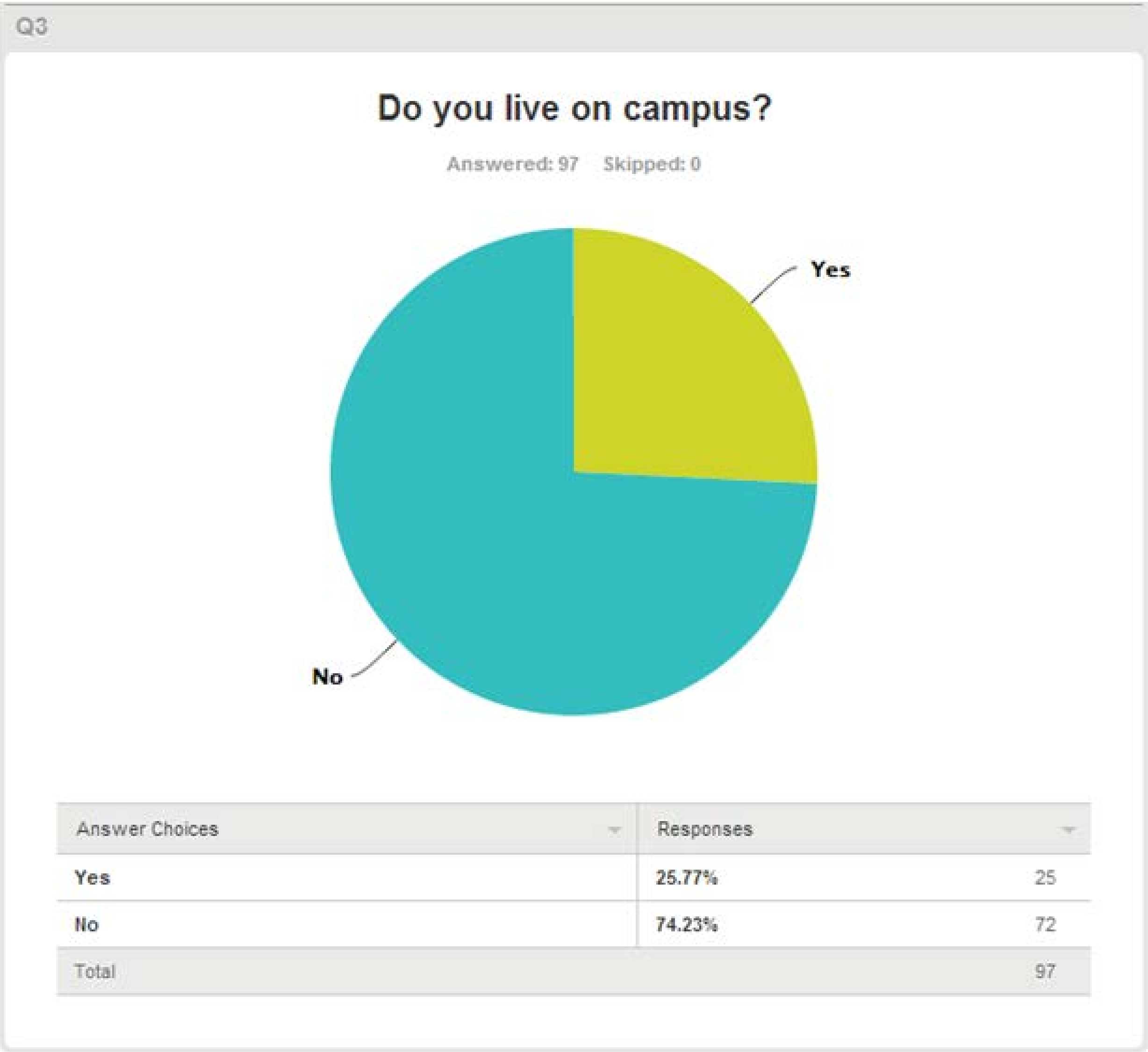
Answer Choices	Responses	
0 to 18	2.06%	2
18 to 24	82.47%	80
25 to 34	6.19%	6
35 to 44	2.06%	2
45 to 54	1.03%	1
55 to 64	4.12%	4
65 to 74	0%	0
75 or older	2.06%	2
Total		97



Are you currently enrolled as a student?

Answered: 97 Skipped: 0

Answer Choices	Responses	
Yes, full time in graduate school	2.06%	2
Yes, part time in graduate school	0%	0
Yes, full time at a four year undergraduate college/university	68.04%	66
Yes, part time at a four year undergraduate college/university	3.09%	3
Yes, full time at a two year undergraduate college/university	4.12%	4
Yes, part time at a two year undergraduate college/university	0%	0
Yes, at a high school or equivalent	1.03%	1
No, I am not currently enrolled as a student	21.65%	21
Total		97

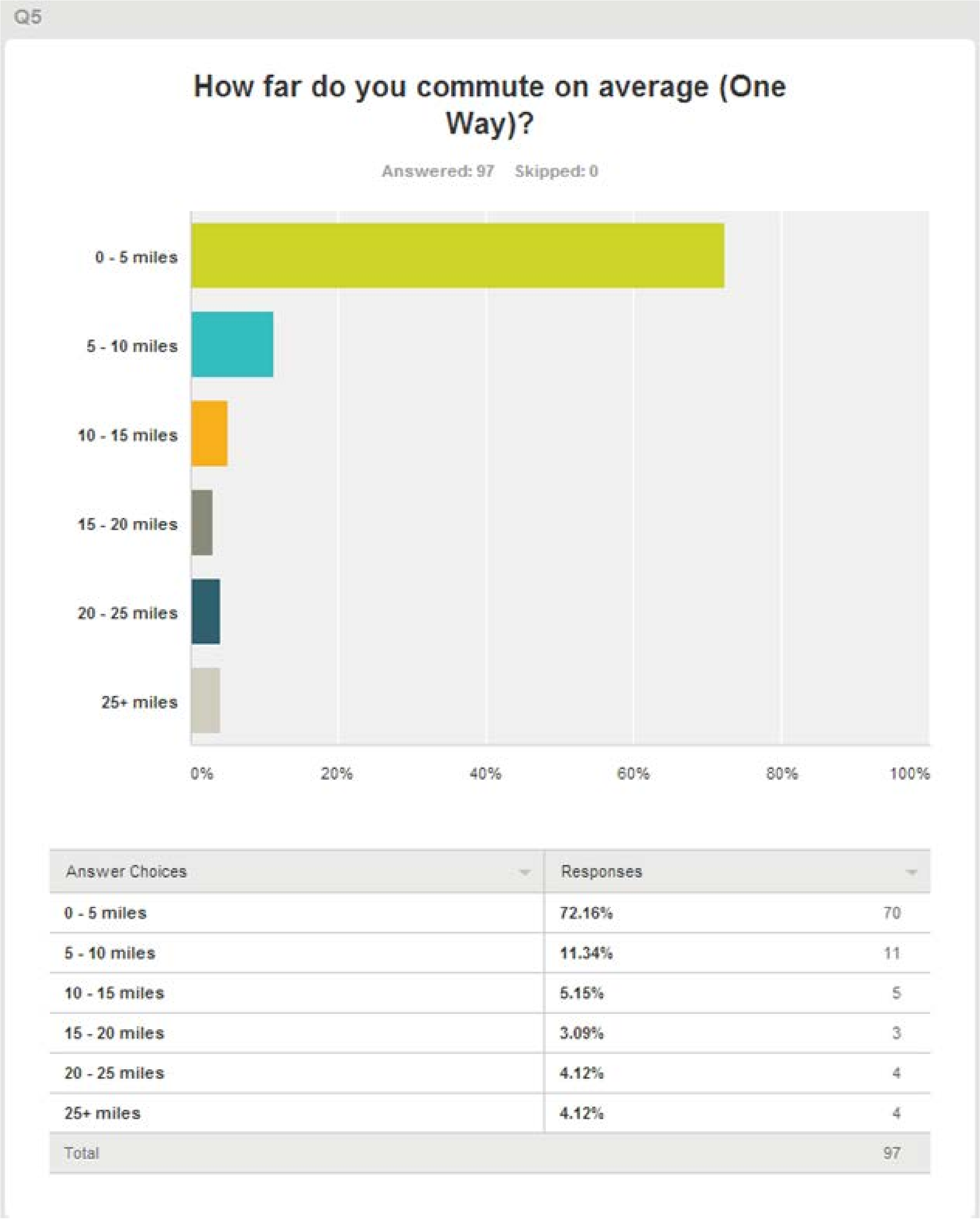


Q3

Do you live on campus?

Answered: 97 Skipped: 0

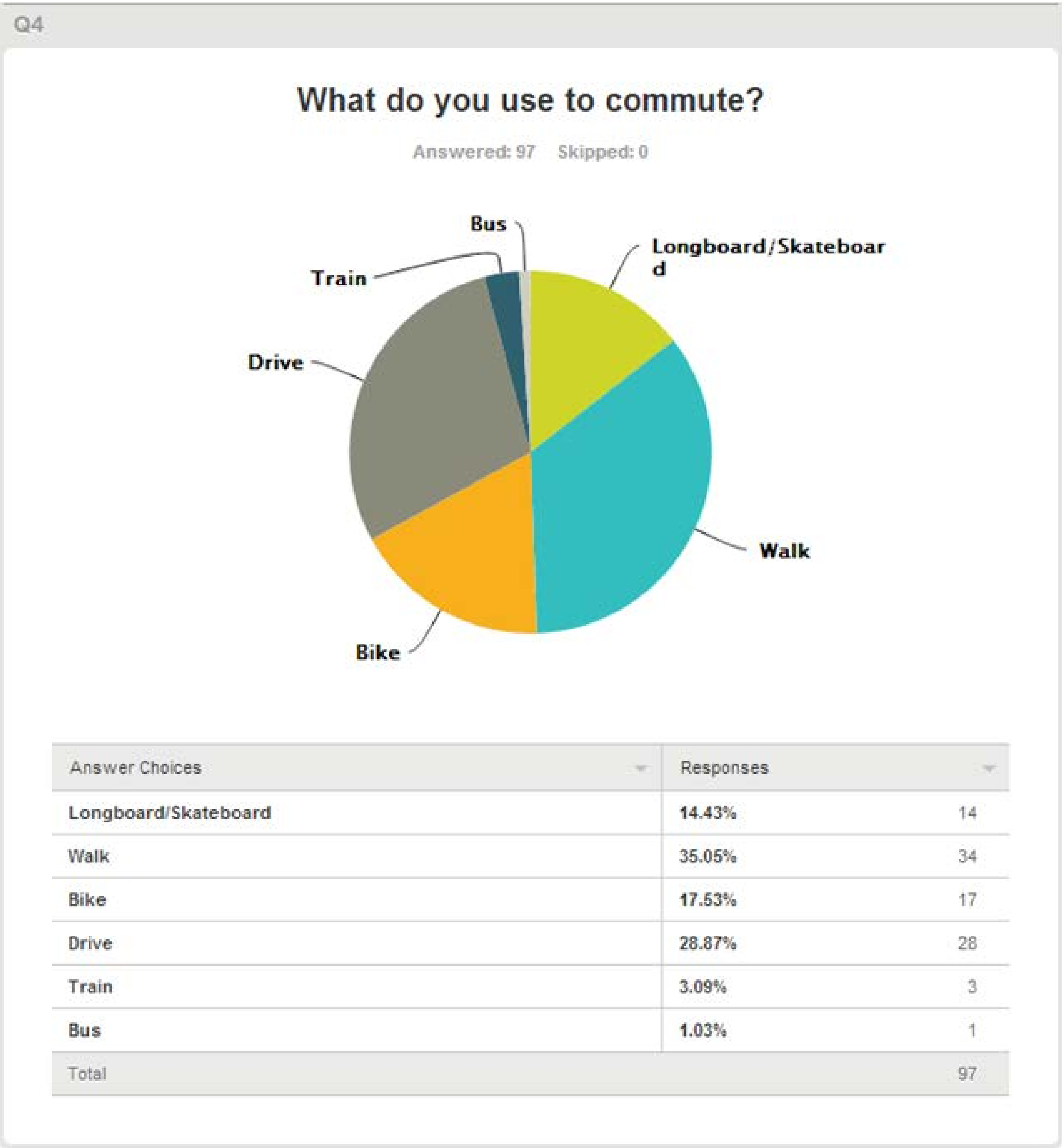
Answer Choices	Responses	
Yes	**25.77%**	25
No	**74.23%**	72
Total		97



How far do you commute on average (One Way)?

Answered: 97 Skipped: 0

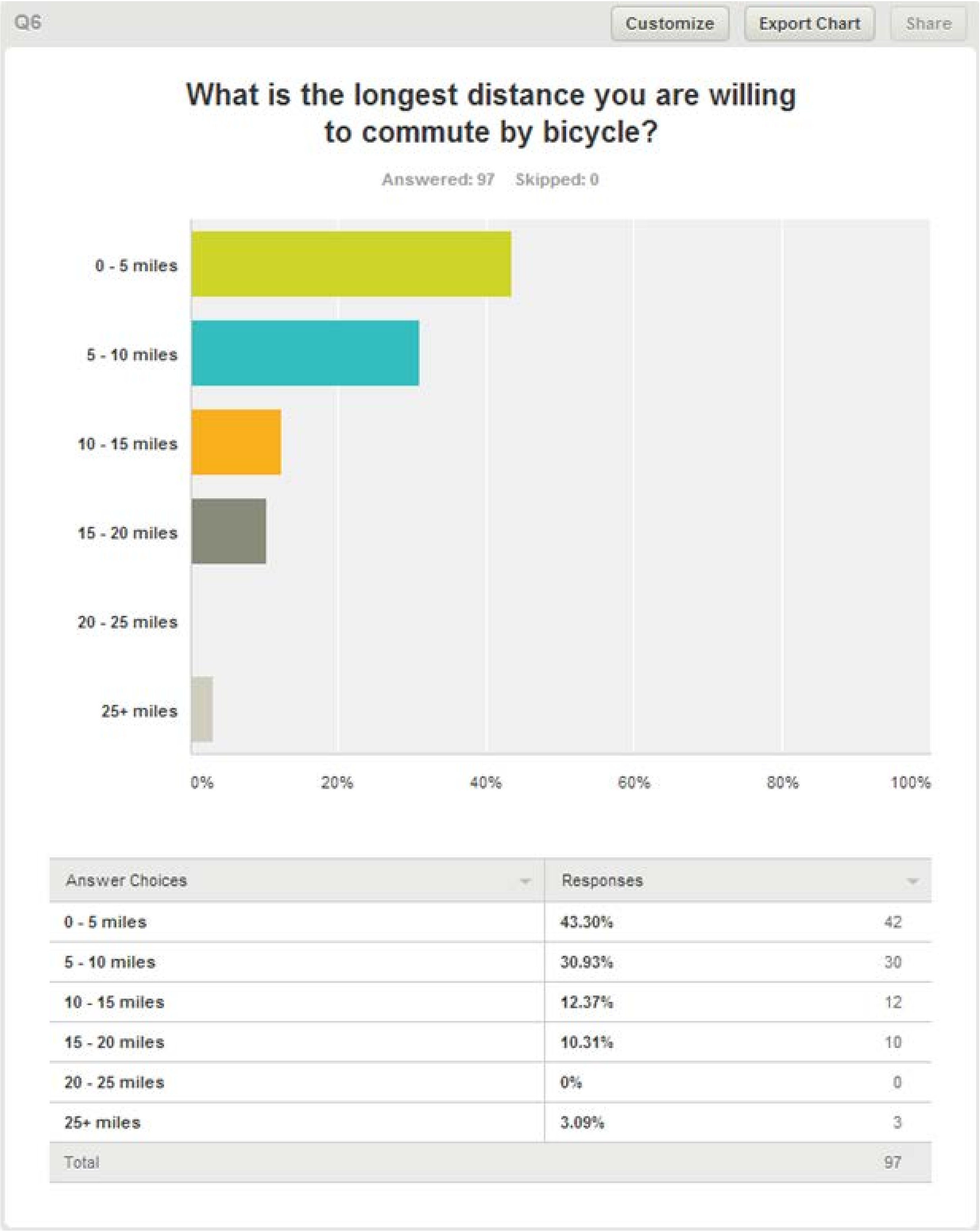
Answer Choices	Responses	
0 - 5 miles	72.16%	70
5 - 10 miles	11.34%	11
10 - 15 miles	5.15%	5
15 - 20 miles	3.09%	3
20 - 25 miles	4.12%	4
25+ miles	4.12%	4
Total		97



What do you use to commute?

Answered: 97 Skipped: 0

Answer Choices	Responses	
Longboard/Skateboard	14.43%	14
Walk	35.05%	34
Bike	17.53%	17
Drive	28.87%	28
Train	3.09%	3
Bus	1.03%	1
Total		97



What is the longest distance you are willing to commute by bicycle?

Answered: 97 Skipped: 0

Answer Choices	Responses	
0 - 5 miles	43.30%	42
5 - 10 miles	30.93%	30
10 - 15 miles	12.37%	12
15 - 20 miles	10.31%	10
20 - 25 miles	0%	0
25+ miles	3.09%	3
Total		97