A Solar Powered Automated Public Transportation System

San Jose State University
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Advisor: Burford J. Furman
Author: 2015-2016 Spartan Superway Team

Authors
Mark Acoba
Cassandra Acosta
Kenneth Aganon
Rebecca Alvarez
Enkhjin Baasandorj
Ali Akber Bootwala
Tyler Broder
Jeffrey Chau
David Chen
Aaron Cheng
Jon David De Ocampo
Christopher Fong
Dale Franklin
Scott Garfield
Garrett Gemmel
Nasratullah Haidari
Chin Man Bryan Ho
Matt Holst
Michael Hurst
Ian Johnsen
Chin Ming Lui
David Luo
Steven Luong
Dianna Man
Christopher McCormick
Matthew Menezes
Thang Ngo
Thomas Nguyen
Lucas Petersen
Uday Ranjeet
David Paul Sales
Ivan Servin
Karmjot Singh
Augustine Soucy
Kenny Strickland
Ivan Tapia-Pantoja
Brian To
Steven Trevillyan
Alejandro Valenzuela
Vicente Viqueira Plasencia
Allan Wai
Henry Xie
Jaymie Grey Zapata

Abstract

The Spartan Superway Team is comprised mostly of senior level Undergraduate Students from the Charles W. Davidson College of Engineering at San Jose State University. The main core of Mechanical Engineering Students is joined by a small group of Electrical Engineering Seniors, as well as a few Masters Students of the University from various engineering departments. Working together with the International Institute of Sustainable Transportation (INIST) and a select group of Industry Mentors and Faculty Advisors the student group has a wealth of practical experience and knowledge to draw from.

This current academic year's Spartan Superway Team has inherited the project as a legacy from previous students of San Jose State University; this is the fourth year of development as a Senior Design Project for the University. The first three years of the project teams developed a One-Twelfth Scale Model supported by working software and a control system for a single car, as well as a Full Scale length of track faithfully demonstrates an intersection of track, as well as shows the manner in which the system can steer and switch while in motion on the track.

The Spartan Superway Team is much larger than it has been in previous years; almost fifty students have taken up the mantle left by their predecessors. To accompany the expanded roster, the team also has greater expectations and goals for this academic year. An expansion of the One-Twelfth Scale Model is planned that will increase the size of the system by four times and add more robust software to control multiple cars on the track simultaneously. This One-Twelfth Scale Model expansion is a challenge in its own right, but a newly built Intermediate Scale Model will be the focus of this year's Spartan Superway Team. The Intermediate Scale design will be faithful to the Full Scale system designed by previous years but will complete a loop to demonstrate continuous operation and will add slopes to the track and active suspension to the system to further prove the robustness of this design. As with any project of this size and scope the safety of those who interact in any manner with this system is a large concern, the current team is also researching the implementation of measures to make this system safer and add fail-safes to the design.

The Intermediate scale was somewhat of a success. The biggest issue that haunted the project was trying to get propulsion, steering, and braking working and synchronized. At Maker Faire we were not able to get the system operational but we still were able to acquire three editor's choice awards for our efforts in the project. The One-twelfth scale was also a somewhat success also. There were a few issues involving carts and the track where at points on the track the cart would fall off. There was a also a minor issue with programming of the carts to have them navigate the track where the carts did not seem to cooperate.

Overall, with the minor issues that we encountered, the project was still a success. We were able to accomplish the majority of our goals and were able to reap the rewards of our hard work at Maker Faire. With the foundation laid down by us, the next year group should be able to make many refinements and upgrades.

Acknowledgements

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The Intermediate Guideway team focused on to be able to assemble a complete intermediate scale track for the Spartan Superway. The problem is without the guideway there would be no means of travel for the bogie and cabin. Not only does it provide a pathway, it provides a solid structure for steering to engage its mechanism on. Also the slope has a gradual slope which allows the suspension to actuator at its specifications. The guideway would have two pathways. One would be 70' long and a second path would have a 17-degree slope. The importance of this is to show that the Spartan Superway project is not limited to one elevation. It shows that we can descend to lower elevation to pick up patrons and take them to their destinations.

The objective of the guide is to design a closed loop track for the bogie to traverse on. Design the track to be able to carry the load of the bogie/cabin and solar and electrical equipment. Also to accommodate other sub-teams designs.

The design requirements are as follows: design so it has ease of assembly, support structures at every 17.5', design it so it has 17 degree slope, provide a gradual slope for suspensions actuators, and the bogie must return to its initial position after it has traveled from the start.

The design began as a SolidWorks model during the Fall Semester. The Spring semester is when fabrication initialized. Welding techniques had to be learned in order to be able to properly assemble the track. The process begins with using the SolidWorks model to calculate the amount of track needed to purchase. Once that was figured out, the metal was purchase, cut to length and deburred. The posts were the first to be tack welded, then the support ribs, finally the track. After everything seemed like it was aligned final welds were applied.

The analysis that was performed was stress analysis and physical point load testing. The stress analysis showed that the max deflection would be almost 4 mm at the point the load is applied or the load of the bogie. Physical test included hanging weight at the critical points of the rail for testing. The test showed the rail could hold load more than 300 lbs. The total cost of the guideway was calculated to be $1907.07.

The guideway was a success and was able to stand on Maker Faire. However, despite the success, there are a number of blemish and imperfects all over the track. There are posts that aren't flat with the ground. There are railings that deflects and needs to straighten out, that could be fixed with proper placement of the post. There are surfaces that need to be ground down. For future work, work can be done to apply location tracking sensors, making the track more aesthetic or making a mockup of a station.

Bogie

The Spartan Superway is a project that aims to create a network of podcars suspended far enough above streets so that other vehicles can travel below without interference, yet there are no fail-safes implemented in the project yet. The possibility of the bogie falling from the guideway is a risk for its users and passersby. Fail-safe mechanisms had to be fully mechanical and able to prevent the bogie from falling off the guideway in case the steering mechanism, stabilizing or main support wheels fail. As an intermediate scale model was developed to fully test the functionality of the fail-safe and other subteams designs, great care had to be taken to ensure that none of the different designs conflicted to each other.

In this section, objectives of the intermediate scale bogie team will be explained, followed by the description and requirements of the bogie and fail-safe designs. The research done by the team will be presented as background information to help understand the nature of the design specifications. Moreover, the designs will be explained along with detailed CAD drawings, finite element analysis of the models and built model pictures. The implications of scaling down a full size model and grouping together the different designs of the subteams will be addressed as well as a bill of material. Lastly, the accomplishments of the intermediate scale bogie team will be presented along with what design elements performed as expected while addressing possible recommendations for future work.

Propulsion

Propulsion is an essential component to move the bogie along the guideway. For the 2014-2015 year, the solution was to press a hub motor into the ceiling of the guideway for traction and to allow the motor to move up and down to adapt to small changes in the elevation of the ceiling while still maintaining the same normal force for traction. The hub motor is able to do this because a hub motor is designed to have the wheel spin while the axle remains stationary instead of the motor being stationary and the axle turning. This year, the design requirements also included an intermediate scale bogie and a 17° slope in the guideway. This necessitated a new hub motor that could handle the additional power required to get the bogie up the slope, as well as a new mount for the motor to fit it on the smaller bogie and still press it into the ceiling with sufficient force.

Steering and Braking

The goals of the project are refining the steering mechanism and adding a braking system. The steering mechanism is redesigned without deviating too much from the original design by altering some critical components. A braking system was proposed to be installed next to guiding wheels to allow the braking force to be directly applied to the wheels to safely stop the bogie. It was also kept in mind to make the designs as simple as possible to reduce fabrication complexities and costs.

The design process started out with brainstorming ideas and visualizing the existing bogie to get an idea what should be changed in the design. These ideas were then sketched out on paper to clarify the changes made. The top and bottom steering links were connected by one long rigid shaft to synchronize the movement with one stepper motor. A braking system consisting of electric scooter disc brakes was chosen to be implemented due to low cost and reliability.

Finite Element Analysis was performed on the critical parts of the steering mechanism and braking system to ensure the parts are able to handle the stresses produced and yield a minimum safety factor of 2. The L-bracket has the lowest safety factor of 2.5164, while the highest Von mises stress was 9.935E7 N/ m^2 with 250 lb-f applied. For fabrication, the team chose A36 steel as the material for most parts due to its low cost and easy machinability. The parts would be fabricated using a miter saw, welding machine, and waterjet cutter.

Active Suspenstion

The Spartan Superway personal rapid transit system has been in development for the past 3 to 4 years and has yet to have a suspension system designed. This year the “Active Suspension Development Team” was created to fill this gap. The team was tasked with creating a passive and active system that would be able to suit the needs of the intended final product. Some design requirements were to isolate the vibration to the cabin, keep the cabin level during traverse of 17 degree slopes, and provide self levelling while at the station. The suspension system was an integral part that had been missing from the Spartan Superway system.

The following sections are from the team of academic year of 2015-2016 that designed the suspension system. Most importantly, the Finite Element Analysis FEA on the parts were finished to prove that the system will be able to handle more than the max expected load with room to spare. The final section will discuss what the team has accomplished thus far and what needs to be accomplished for next year.

Cabin

The cabin team is responsible for designing and improving cabin designs that were created from past Superway teams. The cabin is very important as it accommodates the passengers when the system is running. The cabin must be able to hold 4 passengers, have acceptable safety features, and have a streamlined shape as to reduce drag. The cabin team will be making overall adjustments to past designs, as well as taking inspiration from other cabins already in use. A cabin design has been successfully chosen and fabricated. The chosen full scale design is 12 feet long, 7 feet high, and 6 feet wide. Flow simulations have been run on the design and it returns a low drag coefficient of 0.19 with a measly 6 N of drag force. The cabin design was then fabricated in two different forms. One quarter scale model that shows the interior in detail, and one half scale model that houses necessary components and is mounted on the intermediate scale track. These models were successfully created and used for their specified purposes. The quarter scale model was a fan favorite at Maker Faire, and the half scale fit snugly on the intermediate track when fully mounted. Overall, the cabin team's project this year has been one hundred percent completed on time and to the design specifications.

Wayside Power

The wayside power team is focused on creating a power pickup system to run bogie cars with power supplied through solar energy. Over the past years the Spartan Superway models have been battery powered which requires charging of the batteries which defeats the purpose of a sustainable mode of transportation. To make the Spartan Superway a sustainable transportation system, the wayside team will create a new power pick up system, which will enable bogies to collect solar power from a power rail to charge its battery. This will eliminate the hassle of recharging batteries and would benefit the environment by reducing the use of electricity and the associated carbon emission.

The wayside pickup system used for this project is based on a four-rail system, where two rails are the support or guiding rails while the other two rails are the supply and return rails. The conductive material chosen for the rails was 4 AWG bare copper that was flatten into 6 AWG copper wires using a cold roller. The flatten copper wires was then placed in curved and straight schedule 40 PVC pipes using silicone caulk. The conductive material is protected in the pipes to prevent people from shocks. The shoe collector was made out of 8 AWG insulated copper wire that was hooked into a spring system to maintain contact during fluctuations when the bogie moves. Recommendations for future teams with regards to the collector shoe are to design for ease of redesign to move multi directions.

Power Systems

The Sustainable Mobility System for Silicon Valley (SMSSV), also known as the Spartan Superway, is an interdisciplinary student-run project with the goal of developing a solar powered, rapid-transit system to be implemented in urban areas. The goal of the project is to design a system that will be able to provide a renewable energy-based transportation system to the public while minimizing the system's overall environmental footprint. As part of the SMSSV project, our team of electrical engineers has created a solar interface system that will supply power to the Spartan Superway and utilize solar energy to offset the environmental impact of the transportation system.

Torsion

The primary goal for the torsion test subteam is to optimize the design of the guideway for maximum strength at a minimized cost. The loading on the guideway from the vehicle causes a net torque on the guideway. This is due to the design of the vehicle's guideway switching system. For this reason the guideway must be analyzed under torsional loading. Two methods will be used to analyze the most current track design: theoretical analysis and physical experimentation. The current guideway design will first be analyzed using FEA in ANSYS. The design will then be scaled down and fabricated to be tested in a torsion testing machine. The torsion test results should confirm the FEA results, allowing for the optimization of the cross section through ANSYS. Two simple cross sections, in addition to the guideway, will be modelled in ANSYS and torsion tested. The following section outlines the theory of the tests, the basic procedure used in the experiment, and the test's results. Future plans for the torsion test subteam will also be discussed.

<u>Small Scale</u>

Guideway

To improve on the previous team's work, we had to analyze the old track. We liked that the track was made out of aluminum which would make the track withstand the rain and would not rust. However, there were a lot of things we didn't like about the old track. The main thing that we didn't like was that the track was made of several pieces that were screwed together. This was not ideal since these screws always got loose which would make the track get misaligned and make the vehicle get stuck or make it fall off. We also didn't like the supports that the track was on because they were very flimsy and also crooked in the concrete. We also wanted to make the track twice as big so it can fit more vehicles. One of the biggest problems with the track was that it was difficult to reassemble if we took it somewhere to showcase it.

In order to fabricate our version of the ideal track, we first had to address the issue of the abundance of little pieces the track was made of. To address this issue, we decided to weld the track together with the help of the ME 41 Professor Mr. Muntz. We recycled some of the pieces of the old track to make the straight rails and welded them together to omit some of the screws. We also welded the connectors to the bottom rail. To address the issue of the supports, we redesigned them so they would be made with 1 in. square tubing rather than flimsy aluminum rod. We also made them slip into the concrete bases which made it easier to assemble the track on to go. We also made the track twice as big which could easily accommodate multiple vehicles rather than just one.

While fabricating the track, we learned a lot and thought of suggestions to help the next team. The next team should extend the length of the curve to so it adds some uniformity throughout the track. We ran into this issue and we had to screw in tiny pieces to add rigidity. The outer and inner curves caused the top wheel of the switching arm on the vehicle to lose connection of the top rail causing it to fall down. Some minor adjustments are also required with the top rail curves to prevent it from "pinching" the vehicle.

Controls and Bogie

The current servo to steering arm link on the small-scale bogie suffers from slipping issues, which causes the steering mechanism to not become fully engaged with the rail. The steering mechanism is currently connected to the servo by a piano wire, which often loses contact with the servo joints. This would lead to the vehicle falling from the track and damaging the major components. Furthermore, the current overall vehicle assembly is missing the cabin that would allow the audience to better visualize what the full-scale model would look like.

A new servo to steering link was designed to counteract the slipping issue. The original piano wire would be replaced with a hobby grade ball linkages that are found in RC vehicles. The ball linkages are more rigid compared to piano wires, which would establish a stronger hold on the servo joints. In addition, a cabin model will be 3D printed using ABS plastic with the 3D printer that is already in-house. Modifications to the cabin model have been designed to allow for easy access to all of the components such as splitting the model into two half shells and combining the two over the assembly by hinges.

The current control system utilizes magnets and hall effect sensors to track the motion of the vehicles as they travel along the rails. Although this method works, there are limitations in the overall position tracking, as the magnets only serve to act as checkpoints that the encoder uses to measure how many more rotations that the wheels can travel before hitting a station. They do not provide any more information on current whereabouts on the track. Furthermore, there was no collision detection system implemented within the current control system, which would lead to potential accidents occurring with multiple vehicles running on the track at the same time.

A new type of sensor technique will be implemented in order to counteract the tracking issue. Barcodes will be printed along major points of the track and an optical encoder on the vehicle will run through and scan the lines. This would yield multiple bits of information for the main system to collect and analyze rather than the single bit of information gained by the use of magnets. In addition, in terms of the collision detection problem, an ultrasonic sensor was installed and a test program was written. The sensors worked as expected in terms of detecting an object in front of the vehicle. The corresponding test code also was able to slow the vehicle to a complete stop once obstacle was detected.

Solar

Intermediate Scale Solar

The Intermediate Solar Team used their time to develop an Excel based calculator for use in the design and production of a Solar Cell Power Supply system for the Spartan Superway. This calculator takes into account the parameters of the other sub-systems of the Superway and design specifications to output meaningful values to be used in the development of variable sized Power Supply Systems. In addition to the development of the calculator, the team also designed Full Scale and Intermediate Scale Solar Mounting Solutions to be used in the Power Supply System. The Intermediate Scale Mounting Solution was implemented on the Intermediate Scale Spartan Superway at the Bay Area Maker Faire 2016. This mounting system takes into account the orientation of the track and utilizes two different arrangements to accomplish optimal energy generation.

The purpose of this design process was to improve the sustainability of the Superway system. A green energy source is critical to the project and continual improvement and research will keep the system viable into the future stages of development. The redesign of the system to use a static mounting system for large scale energy farming has many benefits over the previous design of a dynamic tracking system; the previous design was also changed to accommodate the new sub-systems being implemented on the Superway. The new mounting system and Solar Cell array design takes into account as many design challenges of the Superway as possible.

Research into already existing systems for energy generation and solar cell mounting was undertaken as a preliminary design task; from this gathered information the team was able to design the system to accommodate existing technology and ease the process. Working from information derived by previous students and groups of the project was also beneficial instead of trying to start from a scratch-point. Analysis of the project needs and parameters was done to optimize the design and build an effective system.

The Intermediate Solar Team succeeded in developing a working calculator to ease adaptation of the system and a static mounting system that takes advantages of the Superway design while minimizing the flaws in its configuration. The Intermediate Solar Team delivered a working, grid-tied solar array to be used in conjunction with the Intermediate Scale Spartan Superway at Bay Area Maker Faire 2016.

Small Scale Solar

The main focus of the 1/12th scale solar team was to provide usable and sustainable solar energy for the scaled track. Previous semesters have not implemented in any way the use of solar panels within the track design. Initially, the track design was a simple two-loop track with bogies powered by detachable Ni-MH batteries. Through many revisions in design among the 1/12th scale solar team, a more efficient design was implemented to power the scaled track. The purpose behind creating a small-scale model of the solar track was to visually display a more realistic representation to potential future investors. The 1/12th scale solar team along with Spartan Superway aims to entice future investors to help San Jose further advance in green technology. However, without the sustainable solar aspect of the project, the scaled model can not accurately portray the idea of the Superway. The goal of our team this year was to efficiently create and implement solar energy into the 1/12 scaled track.

Introduction

Traffic congestion is a problem in dense urban areas during rush hour. As of now, there is no alternative type of transportation that has been implemented in the urban areas that can help avoid the traffic congestion. Many problems are caused by our impacted roadways, such as wasted time, accidents, and pollution. This report discusses a potential solution to these problems in addition to addressing increasing the quality of public transportation and the high cost of vehicle ownership, the Spartan Superway Project.

The Spartan Superway Team from San Jose State University is developing a Sustainable Mobility System for Silicon Valley (SMSSV) following the Personal Rapid Transit (PRT) archetype that has been becoming increasingly more popular across the world. Small, automated pod-cars will carry up to four passengers efficiently and without stops from their origin to their destination in a citywide network of track that is suspended above the city streets. The Spartan Superway Team's desire is to reduce congestion on highways and arterial roads within cities in Silicon Valley and improve the public transportation experience for commuters in the area; to meet the criteria of a sustainable system the Spartan Superway Team is also designing a solar cell array that can be installed atop the length of the track so that the system can generate its own energy without drawing from a non-renewable source.

The fundamental problem that The Spartan Superway Team aims to solve is local, urban transport within the Silicon Valley. Silicon Valley is situated in the San Francisco South Bay Area of California and is one of the most populated places in the world. Unfortunately the area is plagued by suboptimal public transportation and in need of a dramatic shift in local travel technology. Not only is the public transportation system outdated, the population of highway commuters is already large and only growing larger. This traffic congestion is a problem that ridesharing and smart-cars cannot address; the Spartan Superway aims to alleviate this issue by removing cars from the road and riding above existing infrastructure in urban areas.

Tackling a second issue, The Spartan Superway Team aims to implement a fully solarized power system onto the SMSSV. Fossil Fuels and non-renewable energy sources are prevalent and pervasive as today's power source; however, they are also harmful to the environment and the general population of the planet. Installing a system of solar cells on the lengths of track used to carry passengers will not only supply energy to the SMSSV system but has the potential to over-producing energy and decrease dependence on non-renewable sources for the city that installs the system.

Chapter 1: Intermediate Scale

Intermediate Scale Guideway

Background and Context

It is very simple to understand why the guideway is important. It is the means for which the cabin and bogie can travel from one point to another. The first design for the guideway demonstrated straight path, the next design demonstrated straight path and a switching turning path. This year the guideway will demonstrate a straight, switch and a sloped pathway. This is importance next step allows people so see that we can come down to stations and pick up them then move above ground level to take them away from traffic from harm and to reach their destinations faster.

This guideway was to provide two pathways, one that simulated travel to a destination and a second to simulate arrival to a station. These two pathways would be only accessible through a fork split. The path to destination side was a long 70-foot path of straight rail suspended 10 feet into the air. The path to station included a turn out followed by a drop of a 17-degree slope. Then finally to a straight pathway that was the station whose max height was at seven feet in the air. Afterward, it would go upward to meet back at the end of the path to a destination.

Objectives

The goal for the guideway is to show that the bogie/cabin is capable of traveling turns and different elevations. Last year's team successfully demonstrated that the bogie can travel along a straight line as well as a curved section. This year the goal is to show the bogie decline and incline a sloped path at a 17-degree angle, this will simulate arrival and departure to a ground level station to pick up patrons. Another goal is to have a complete closed loop to allow the bogie complete laps around the track. This is different from last year, as that design would move forward and after it has reached the final position, it would have to reverse direction to come back to its original position. A switching in the guideway will also be demonstrating as the sloped tracked is located at the entering fork to the right, from the respected starting position. The guideway design is a direct design from the full-scale with the exception the rib supported was extended to give the upper steering arm clearance to safely move across without hitting the support. Another direct change was the angle of the bottom of the post; they were changed from 30-60-90 supports to 45-45-90 supports. This was done to provide more stability to the slenderer 2x2 support posts. The objectives for this year's design are as follows:

- Design a complete loop guideway
- Provide the bogie the required pathway to travel across
- Design the guideway to be able to carry the load of the cabin, bogie, suspension and the electronic interfaces for the EE team
- Design the supports to be able to carry the load of the 5 solar panels across the straight path
- Provide adequate room for wayside to mount their designs

Design Requirements and Specifications

The guideways design requirements are as follows:

- Design sections to be able to come apart into smaller 8’9” sections for ease of transportation, assembly, and disassembly
- Support Structures: 1 per every 17’6” of track, end of turning section and end of lowest point of track
- Desired elevation change with a slope of 17 degrees to demonstrate declination to station followed by inclination back to track
- An allowance of four degrees per second to allow suspensions actuators to level cabin
- Complete closed loop guideway to allow the cabin to complete path and return to initial position.

The guideway was assembled in 8'9" sections. This was done to allow for ease of transportation in smaller trucks. However, the longest piece was the sloped sections at 16 feet. This was made one piece to allow a smooth gradual descend and ascend travel. For Maker Faire, the team was able to provide an 18-foot flatbed trailer, because of this we were able to keep two sections together and transported the slopes with ease. The slope section was the most difficult to fabricate, more detail about this will be addressed later, for now, Master Metal Products were able to provide the bends that were specified in the design. The four degrees per second was a specification that was provided by the Suspension Team. Their actuators moved at that speed and if the curved sections were too sharp the actuators would not level in time and cause the cabin to dip forward. The guideway was a closed looped section, as stated above, the bogie/cabin begin on one end, travel across and returns to the initial position. These design and requirements were successfully fulfilled in time for Maker Faire.

<u>State-of-the-art/Literature Review for the Subteam’s Sphere of Work</u>

For the guideway, there weren’t many options we had to take research from since the Spartan Super Way would be the first suspended Personal Rapid Transit. All we had were two designs to go by Bengt Gustafsson’s and Jake Parkhurst’s. Also research was done on existing suspended rollercoasters to see how the supports were built. That search was a little less fruitless since their rails were mainly circularly tubes. We ended up reviewing Bengt Gustafsson’s design and extending the support ribs to allow clearance for the steering arms.

<u>Description of Design</u>

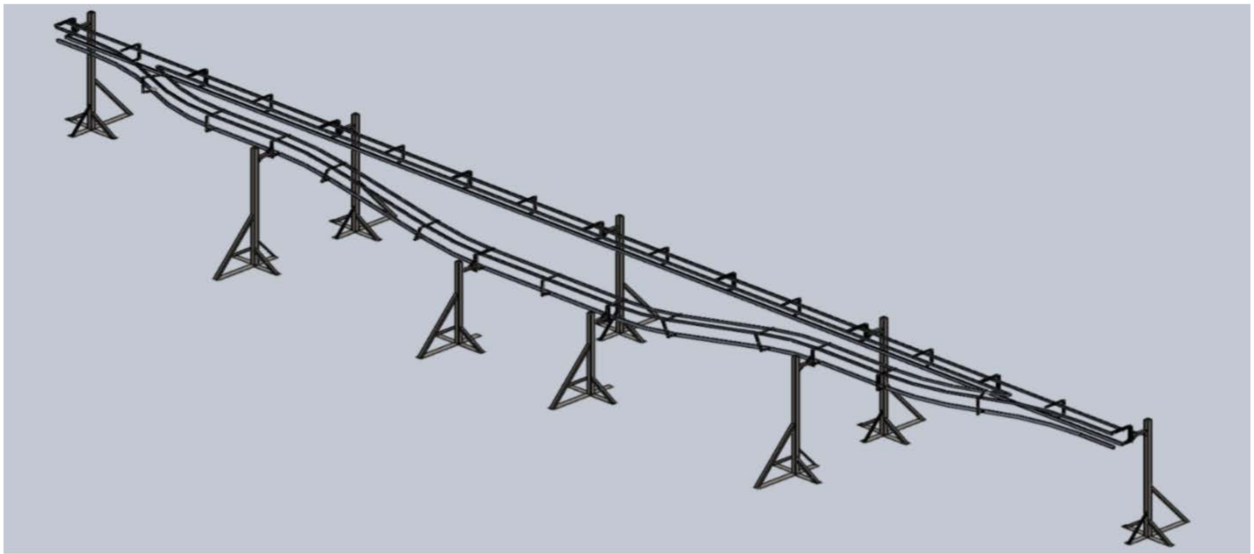


Figure 1- 1:SolidWorks Model of Guideway

At the start of the Spring semester, it became known to me that the design needed to be changed to accommodate the size of the Maker Faire lot. To accomplish this, the length had to be shortened; the length was taken from the ends of the track as well as the length of the station. The length of the station is enough for the bogie to rest on a straight rail.

The guideways rails and support ribs were made from A513 Steel and the support posts were made from A36 steel. The track was designed to demonstrate a 17-degree slope and a rise. Because of this low angle, the length of the track needed to be long in order to provide this station pathway. The length of the track is 70'. The straight portion of the track was assembled using cut to length 8'9" pieces of straight ¼"-thick rectangular tube of cross-section 1"x3" and 1"x2", lower and the upper rail, respectively.

Figure 1- 2: Straight sections of track on the right and uncut rib support steel

The slopes and the turns were made of the same cross-section steel. They were bent as a donation from Master Metal Products in San Jose.

Figure 1- 3: Curved sections of the track cut to length

For the rib supports, they were cut to length using ¼" thick 1"x1" square tubes.

Figure 1- 4: Support ribs for track and 2"x2" connecting post

For each end of the track, there is a section that has double supported lower rails these sections needed specials supports, the follow figure shows the front view of these supports.

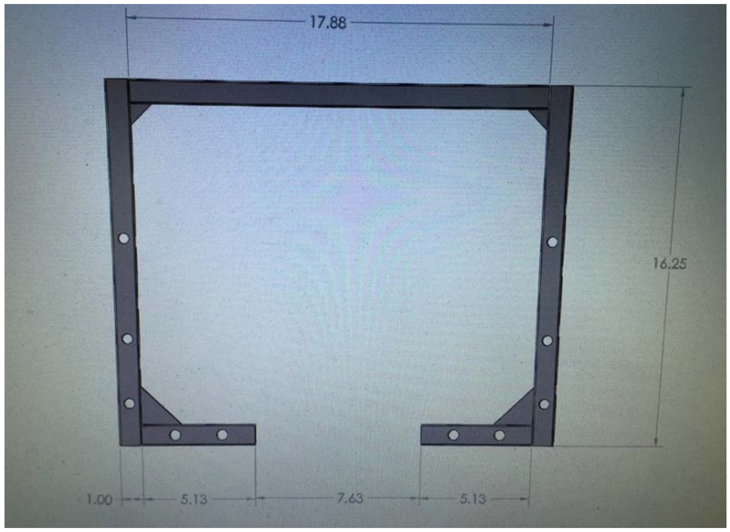


Figure 1- 5: Double rib support and its dimensions in inches

The posts were made of ¼" thick 3"x3" post. They were cut to 10' long pieces. They were then tack welded on with ¼" thick 3-inch flat bar. Then1/2" holes were drilled through both flat bar and post to provide accurate holes. Afterward, a flat bar was tack welded to the bottom of the post and then 45-degree angle supports were welded between them. Finally, the connecting post to ribs pieces was tack welded 108 inches from the bottom of the long posts and 72 inches from the bottom of the shorter posts.

Figure 1- 6: Posts with support attachments tack welded on

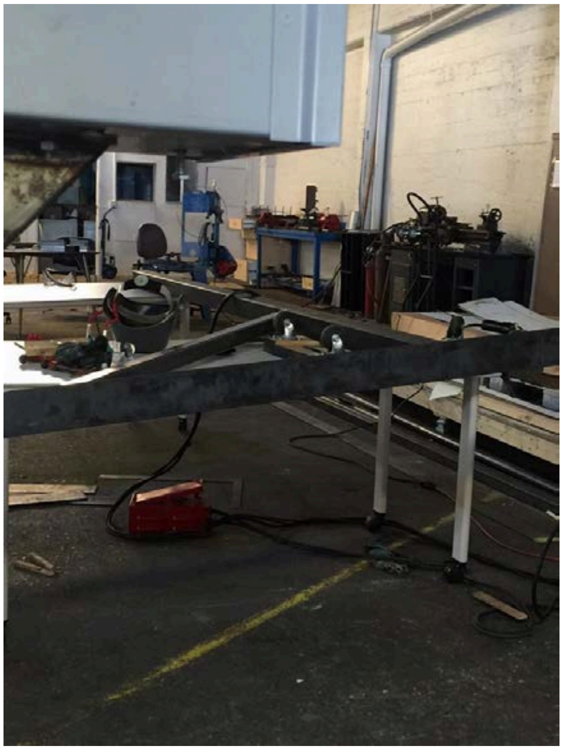


Figure 1- 7: Tack welding the supporting flat bars to the bottom of post

Figure 1- 8: Flat iron supports and 45-degree supports

Figure 1- 9: Different view of post

Figure 1- 10: Tack welding of post-to-rail support (top side of post)

The posts were the first thing that was done during the fabrication. Afterward, the straight path was assembled by first tack welding the straight rail with the rib supports. However, it is important to note that for every section of rail there are two single rib supports and at the ends of the sections there is either a double joining section or a post support section. The following figure shows the post section.

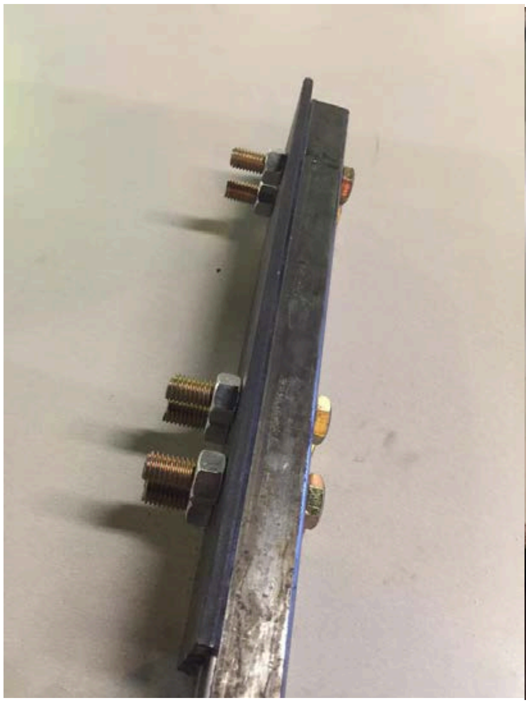


Figure 1- 11: Two views of the rib-to-post sections

To make each rib-to-post section as similar as possible a jig was made and was used to combine the flat bar and two square tubes together.

Figure 1- 12: View of jig that was made to align rib-to-support sections

After the rib supports were ready they were aligned with the rail, and tack welded on. This was repeated for the rest of the straight and for the curved sections. The welding table that was available at the Design Center was almost perfect for one section of track, but as it got longer it was difficult to line things up. That is when I started using multiple tables and then the floor. I should note that I have never welded before and did not take the necessary precautions when welding parts. It shows in early parts of the track and my ability improves throughout.

Figure 1- 13: Getting the ribs and rails ready for tack welding

Figure 1- 14: Using a square to align ribs to rail followed by clamping and tack welding

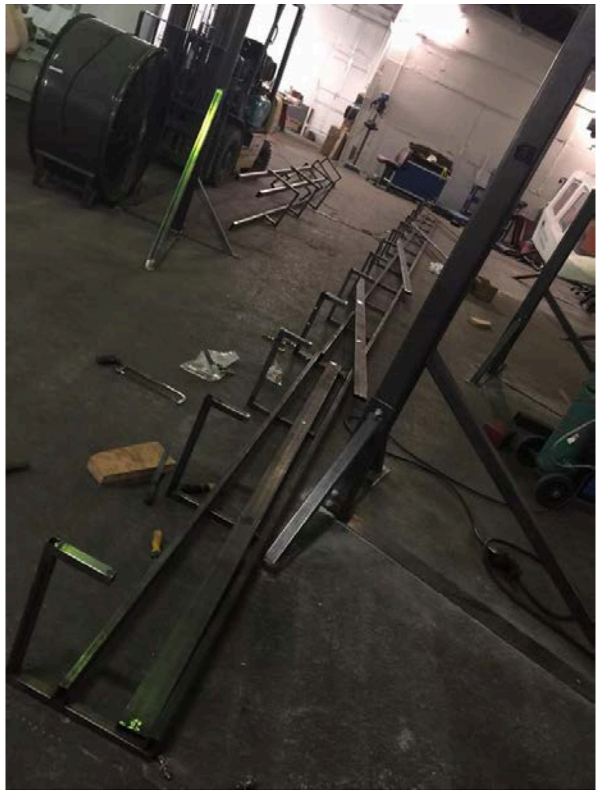


Figure 1- 15: Sections of rail lining together

A joining support can be seen in the following figure. The pair of ribs on the lower left section of the picture is joining ribs. Notice the holes are parallel with the rail.

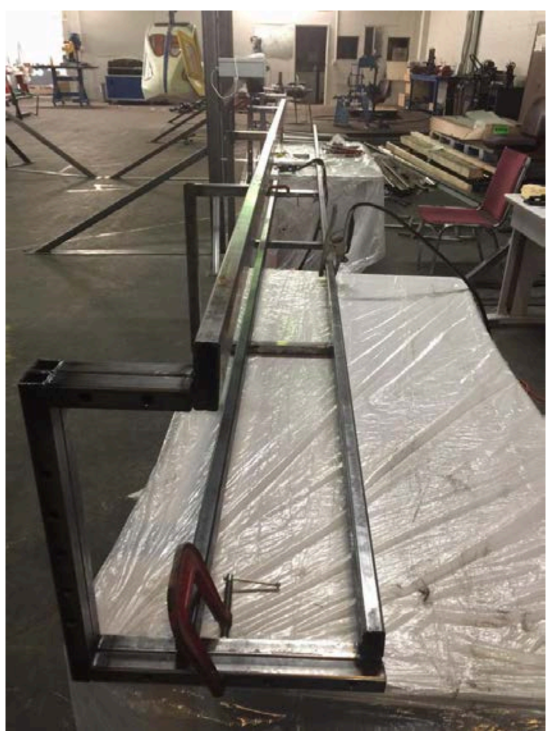


Figure 1- 16: Top and Bottom rails after tack weld.

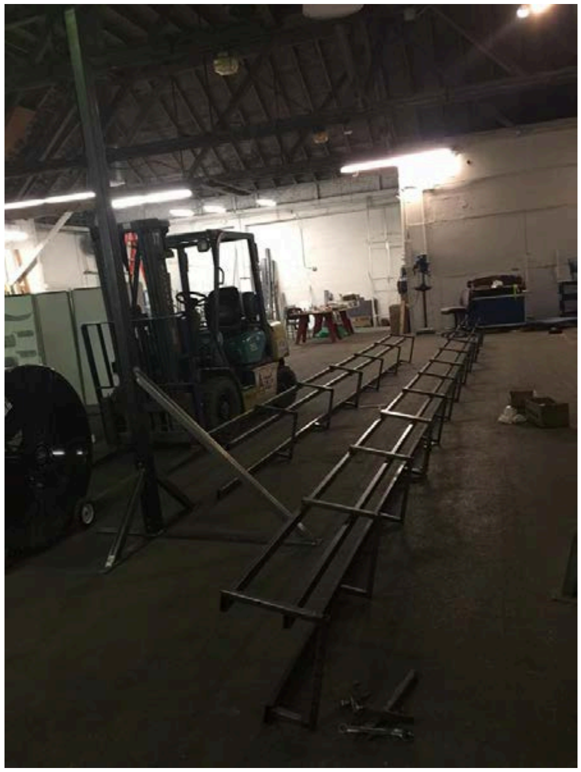


Figure 1- 17: Completed sections of rail

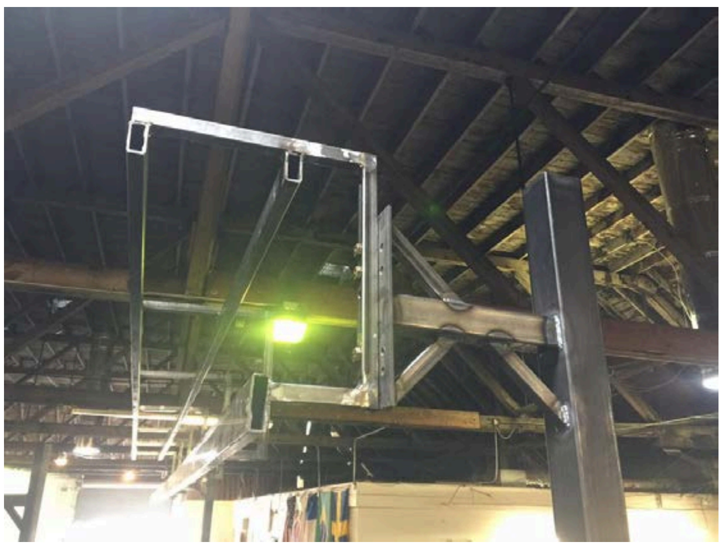


Figure 1- 18: View of a section of the railway on a post.

The curve section was tricky. It was crucial to constantly level and square things up. As long as things were checked, the parts will align.

Figure 1- 19: Beginning of curve section

I used wooden blocks that were cut to length to determine the spacing between each rule. The lengths were the tolerated distances the bogie needed to travel across.

Figure 1- 20: Almost complete switching section

Figure 1- 21: Slope section on posts.

The propulsion boards were added last. This is important to give the motor something to push against and travel by.

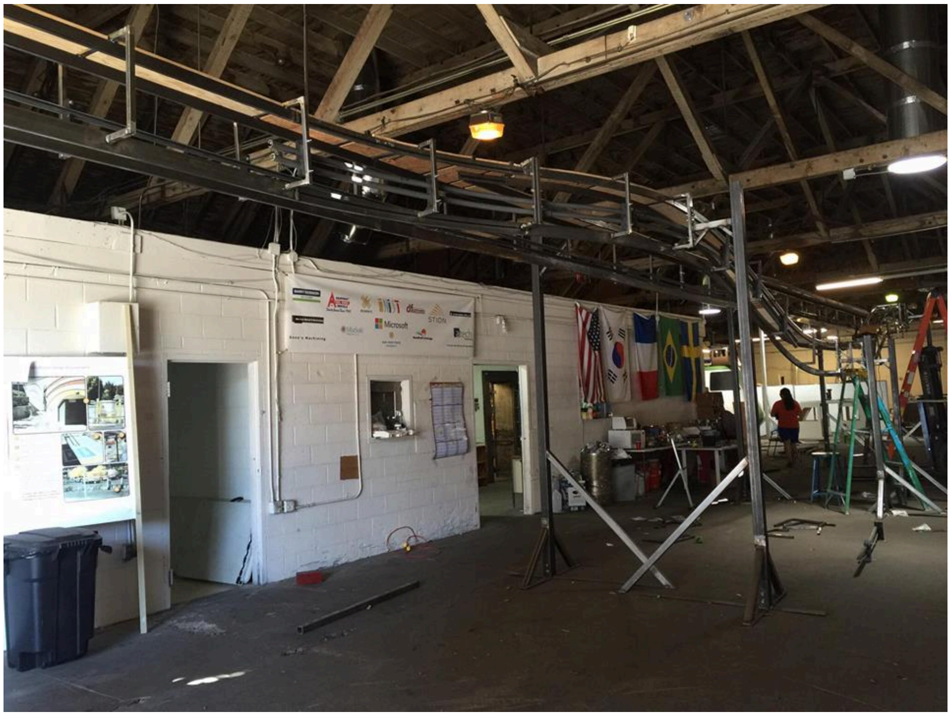


Figure 1- 22: Completed track with propulsion boards

Figure 1- 23: Complete track at Maker Faire

Analysis/Validation/Testing

The analysis was performed on the sloped part of the guideway. From the Solidworks FEA simulation, it was found that maximum deflection occurred at the top rail where the white steering wheels apply a normal force to keep the bogie suspended. The maximum deflection is 0.39 mm.

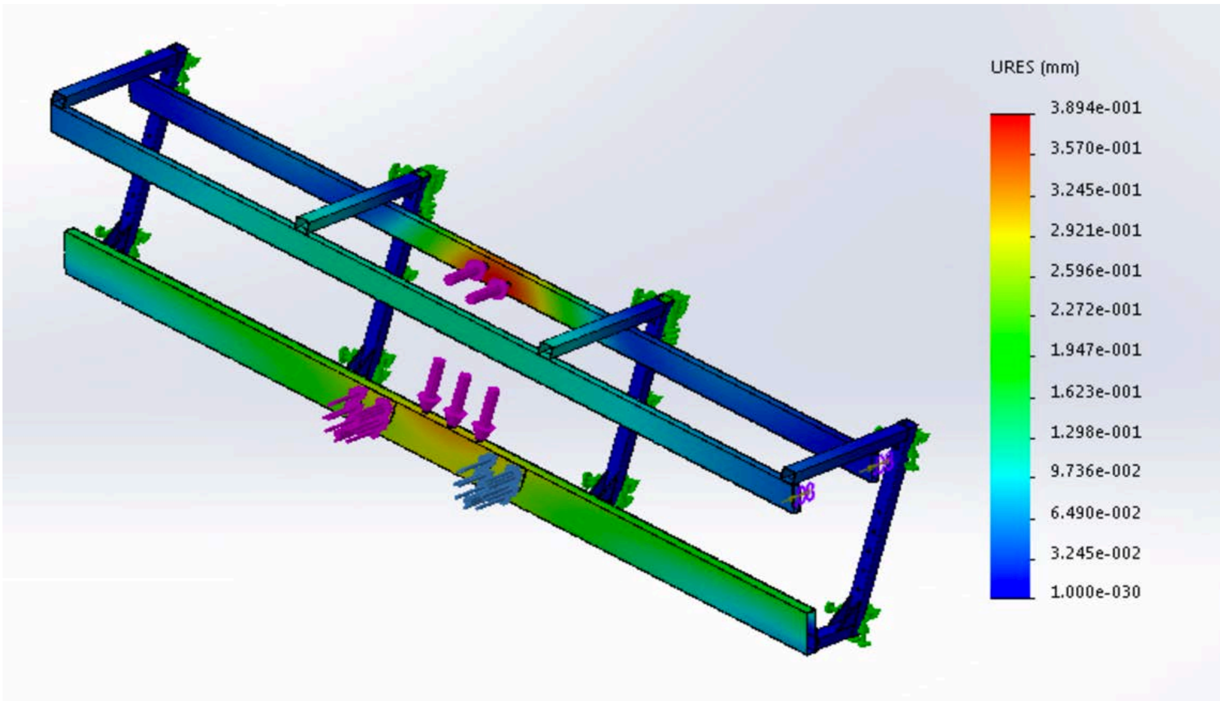


Figure 1- 24: Testing on Beam Section

Testing was performed in house. After each section was assembled we would hang point loads at the critical sections of the rails. The rails proved to be able to support over 300lbs of force. The results were validated when we hung the bogie and cabin on the rail. It proved to be able to hold itself up. However the way the shorter posts were assembled allowed them to tilt forward. Since the bogie passes through 2.5 inches from the ground, I had to make the supports shorter. This resulted in a less stabile post. Changes are planned to fix this problem, more will be addressed later in the report.

To prove that the rule was indeed straight and sloped at a 17-degree angle we took measurements and it showed to indeed be at those angles. Other proving results are TBD since the bogie and suspension were not able to be demonstrated at Maker Faire due to complications in software.

Money Spent on Project

A lot of the expenses that can come up were metal steel for the railing. The fasteners were the next big cost and finally the supplies needed to weld the metal together.

Table 1- 1: Intermediate Guideway Costs

Vendor	Item Description	Quantity	Price per Unit	Total Cost
Sims	A36 1/4 thick plate 48"x24"	1	58.32	58.32
Sims	20', 1/8 thick 3"x3" sq tube	9	77.4	696.6
Sims	20', 1/8 thick 2"x2" sq tube	2	46.26	92.52
Sims	20', 1/8 thick 1"x1" sq tube	8	26.46	211.68
Sims	Useable Ferrous Tubing	60lb	n/a	46.8
Sims	20', A513 16 ga Rect. 3"x1"	4	35.16	140.64
Sims	20', A513 16 ga Rect. 2"x1"	7	20.16	141.12
Sims	10' 1/4 x 3 HR flat A36	2	27.48	54.96
Home Depot	1/4"x4"-1/2" Bolts	27	0.36	9.72
Home Depot	3/8" Washers	100	0.0314	3.14
Home Depot	3/8" Hex Nuts	25	0.3828	9.57
Home Depot	8" Clamp	1	14.34	14.34
Praxair	Argon	4	42.18	168.72
Praxair	Tig Rod	1	8.98	8.98
Praxair	3 pack Tungsten 3/32"x7"	1	18.65	18.65
Fastenal	1/2 SAE F/Washer	50	0.12	6
Fastenal	1/2-13 x 2 Bolt Grade 8	40	1.05	42
Fastenal	1/2-13 x 2.5 Bolt Grade 8	20	1.18	23.6
Fastenal	1/2-13 x 3 Bolt Grade 8	50	1.4	70
Fastenal	1/2-13 x 4.5 Bolt Grade 8	20	2.55	51
Fastenal	1/2"-13 Nuts	75	0.42	31.5
Fastenal	1/2" drill bit	1	7.21	7.21
Master Metals	Curved Rail **Donated**	1	0	0
			TOTAL	1907.07

Results and Discussion

The outcome of the project was partially incomplete. It was successfully built so it could accommodate other teams and demonstrate that the slope drops different elevation. Why is this important? It goes without saying that if the track didn't fulfill other teams requirements their designs would not work. The importance of the slope shows that we are not limited to one elevation. It shows that stations can be built at ground level to pick people up and take them above traffic for a safer way of travel. It is incomplete as a physical solid track. Even though the track is fully assembled, it has blemishes all over the place. It can be cleaned up to be more aligned and ground down to make it smoother. An idea is to make the rails where the posts meet more aligned. To even out clamps could be used and weld brackets to keep them fixed. I did this with one post and it helped make the rails more flushed.

Figure 1- 25: A photo of a post support with a bracket welded at end to properly align the rails

Another thing that needs to be fixed is the posts. It was quite difficult to make sure everything was leveled with respect to each other piece. Since I was new to welding, I overlooked some small details. I have learned from this, yet I made it difficult for future students to make repairs on the track. I would suggest adding one more post between the short post and the next tall post on both sides of the slope to give the track more stability as it travels across the slope.

Conclusions and Suggestions for Future Work

The design specifications were all met. The 17-degree slope, the gradual curve for suspension, the ease of assembly, and the closed loop track. If I could do things different I would get started on it right away, have more people on my team early on, look for the sloped track first because that was a nightmare trying to find someone to get it done. Over this last year, I learned how manufacturing works from a customer-company point of view. I learned what can be made and what cannot be made. I learned how to MIG and TIG weld on the fly, after investing hours into research and getting help from other Superway members. I took part a TechShop pilot program to learn safety and proper uses of MIG welding. The major accomplishes of my team was people came together, for around the first ¾ of the year I was alone. At the end, I had help from many people and I will give acknowledgment too.

I suggest for future work; we must stop building track for we are running out of room at the Design Center. I suggest making improvements on the existing track. Things like adding a few more supports, making everything leveled and flushed with the ground and making the connections of the rail more even. An even more beyond the scope of repairing track is to add sensors to the guideway. Some ideas may be tracking sensors to return feedback on where the location of the bogie with respect to the track. Also maybe some more aesthetic looking posts, add lighting or a mockup of a station.

<u>Intermediate Bogie</u>

<u>Background and Context for the Work of the Sub-Team</u>

The intermediate scale bogie team is responsible for interconnecting all the different intermediate scale team designs. This also meant accounting for a 17° slope guideway. Additionally, the team designed fail-safe mechanisms. In the past years, there have not been any fail-safe mechanisms, which left the bogie unprotected from several failure systems. The focus this year was to address failure situations related to the wheels by creating mechanical designs, which would not rely on any power.

<u>Description of the Sub-team and Objectives</u>

The intermediate scale bogie team will involve working on a bogie that is half-scaled. The primary focus of the intermediate scale team is to design and manufacture a bogie that will be able to properly house other sub-team's designs and fail-safe mechanisms that would prevent the bogie from derailing. The first semester of the project was utilized to design the fail-safe mechanisms and bogie while the second semester is spent manufacturing and testing the designs.

The objectives of the intermediate scale team were to:

- Re-design bogie to be able to traverse up and down a guideway sloped at ±17° (30% grade).
- Design/Fabricate fail-safe mechanisms to prevent the bogie from falling off the guideway in case the steering mechanism, stabilizing or main support wheels fail.
- Re-design the bogie and h-bar to integrate all supporting teams (propulsion, steering, braking, guideway, suspension, wayside power, and cabin).

<u>Design Requirements and Specifications for the Sub-team's Work Products</u>

The design will fulfill the requirements and specifications listed below:

- Bogie must have multiple fail-safe mechanisms for the following situations:
    - Falling straight down
    - Falling to the left or right
- Fail-safe mechanisms must be mechanical and operate without the usage of sensors and/or power
- Each fail-safe mechanism must be able to hold 300lbs(weight of whole bogie and cabin)
- Bogie must be able to traverse up and down a guideway sloped at ±17° (30% grade)
- Bogie must have at least a safety factor of 2

State-of-the-Art/Literature Review for the Sub-team's Sphere of Work

When it comes to suspended personal rapid transit systems, there aren't any that are currently on the market. Because of this, the team focused on analyzing fail-safe mechanisms that are implemented by roller coaster systems as they undergo significant testing to be considered safe. The two mechanisms that seemed the most applicable to the design was the safety chain and the under friction wheel.

When roller coasters traverse an incline, there is a fail-safe mechanism called a safety chain dog that keeps the roller coaster from rolling back in case there is a failure. The safety chain dog consists of a ratchet and pawl system Figure 1-26 (Pescovitz).

Figure 1- 26: Safety Chain Dog used for Roller Coaster (Theme Park Review, 2010)

Generally the pawl is located on the car, while the ratchet is on the incline portion of the track. As the roller coaster traverse the incline, the pawl drags over each tooth of the ratchet. The pawl can only move over the ratchet in one direction; there can be no movement in the other direction because the pawl is 'locked' by the ratchet. Since the new guideway design has an incline, the team considered this fail-safe mechanism as it could be useful. Eventually the design concept wasn't implement because it was determined that the braking system would be sufficient enough in keeping the bogie from moving backwards.

The other fail-safe mechanism that is applicable is the implementation of an under friction wheel, later referred to as an upstop wheel (Pescovitz). The under friction wheel acts as one of the wheels that fully 'lock' the car to the tracks Figure 1-27.

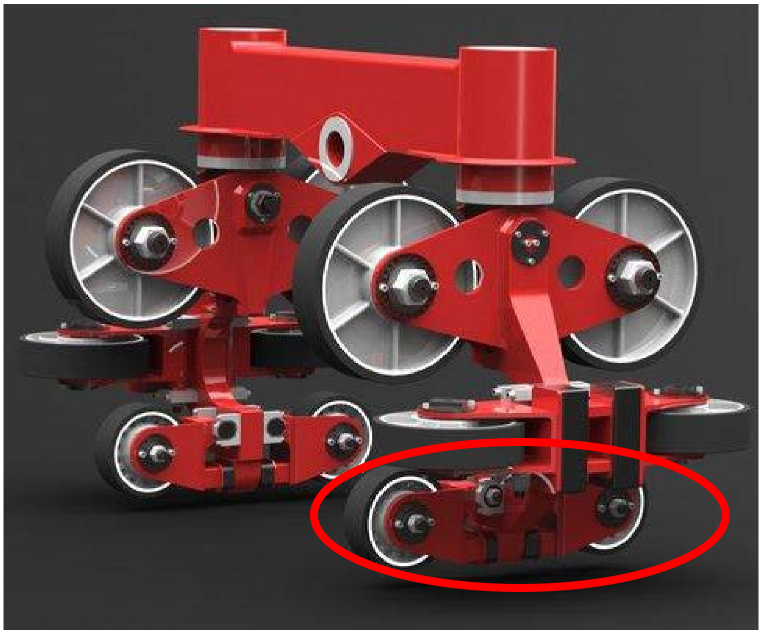


Figure 1- 27: Upstop wheel from a rollercoaster (Theme Park Studio, 2013).

Since roller coasters maneuver in all different directions, it is able to stay on the track because there track is surrounded by different wheels that will not allow the car to fall off. In terms of this project, the upstop wheel also acts as a stabilizing factor when the bogie traverses the incline and decline.

Description of Your Design

During the Fall 2015 semester, there were several fail-safe design concepts explored by the team. The previous teams had not created fail-safe mechanisms for the Spartan Superway. The primary concern involving the bogie is that if the steering mechanism or any of the wheels fail, it can derail. When designing the Spartan Superway, the safety and mindset of the passengers are taken into consideration. The team researched roller coasters and other transportation systems to develop ideas applicable to the Spartan Superway. While the team explored various ideas like redundancy and the safety chain dog(a common roller coaster fail-safe), the team decided to prioritize redundancy and derailment prevention. The final bogie design with the fail-safe mechanisms assembled is shown in Figure 1-28.

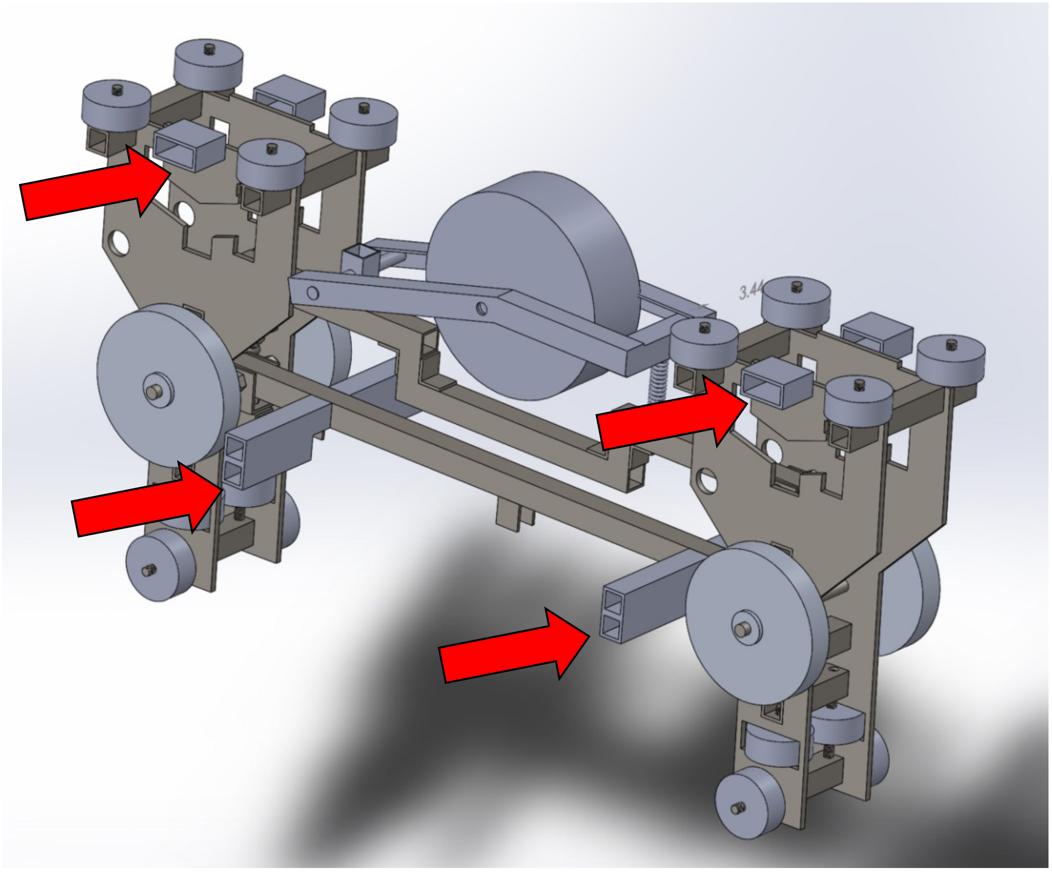


Figure 1- 28: CAD drawing of an assembled bogie showing the fail-safe mechanism (steering is omitted from this drawing).

Initially, the team focused on integrating ideas from a roller coaster into the Spartan Superway since roller coasters are able to travel at high speeds with the passengers suspended. The two ideas that came from that are the safety chain dog and the upstop wheel. As the semester progressed, the safety chain dog was dropped from the design. Additionally, the upstop wheel, which was originally placed on the steering mechanism, was placed on a static portion of the bogie, as shown in Figure 1-29.

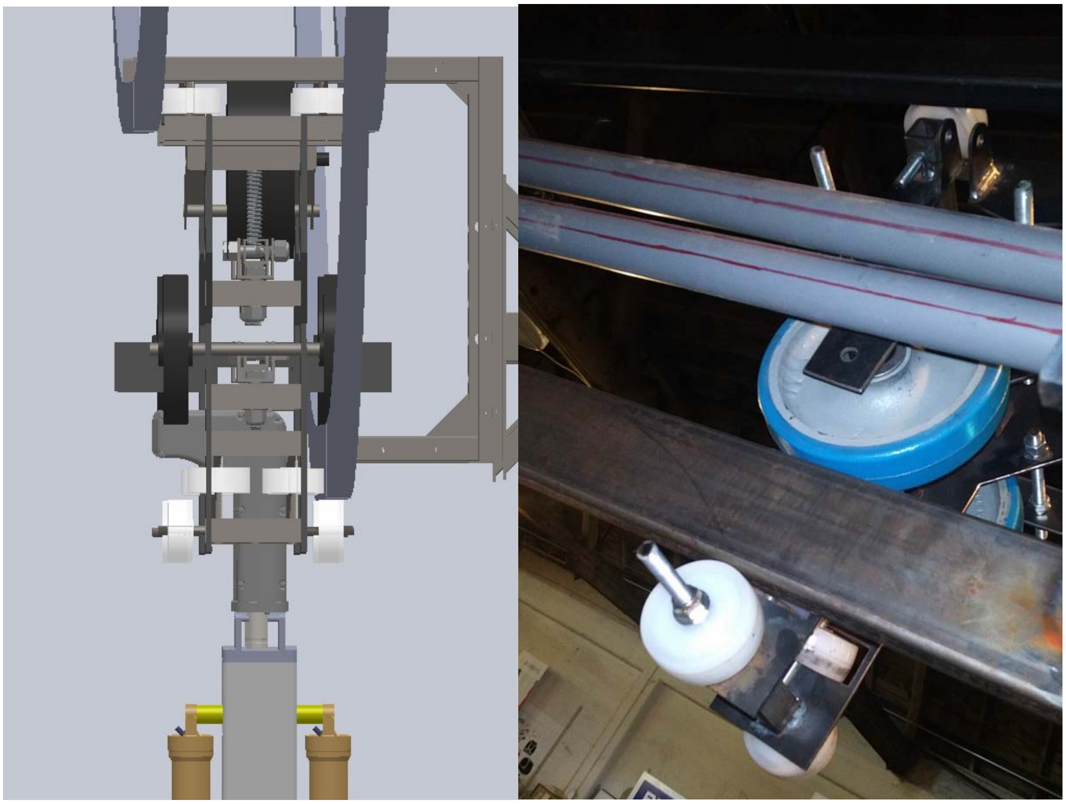


Figure 1- 29: CAD drawing of an assembled bogie showing upstop(left). Actual picture of fabricated and assembled upstop wheel(right).

By placing the upstop wheel on a static portion of the bogie, it stabilizes the bogie during inclines/declines and acts as one of the three wheels that lock the bogie to the guideway, keeping it from derailing it.

The upper and lower catches were also designed to help prevent the bogie from falling off the guideway. When the bogie is about to derail by tilting to either left or right, the top catches attached would collide with the top rail of the guideway, preventing the bogie from derailing, as shown in Figure 1-30. These designs differed from those proposed in the Fall in order to work with the design changes the other teams made when fabricating their parts.

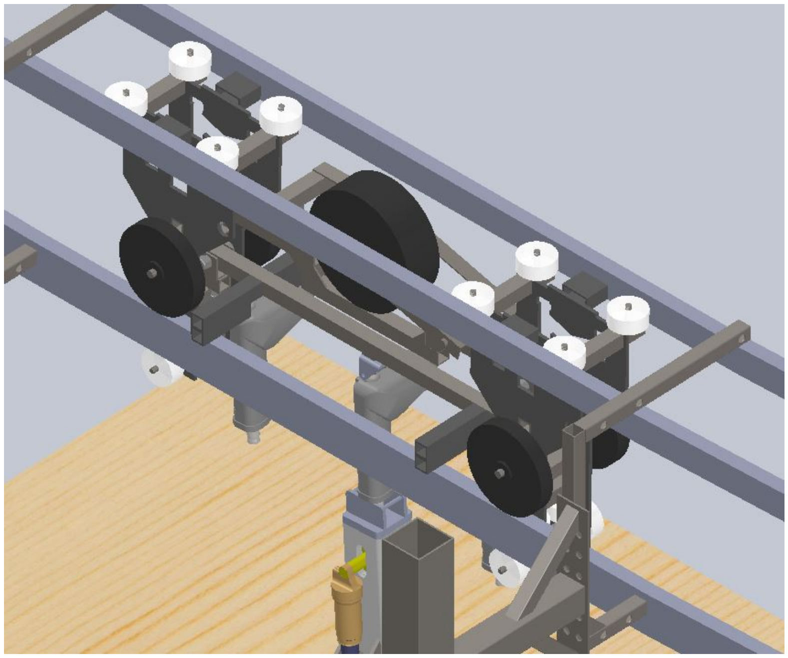


Figure 1- 30: Upper catches with small clearance to the track will avoid tilting of bogie in case of wheel failure

When the bogie is about to derail by falling down vertically, the bottom catches will collide with the bottom rail of the guideway, stopping it from falling downward. The catches will have no issue with the guideway while in motion, even during track switching, due to the design of the catches. The team designed the catches to be able to clear the guideway. The distance between the guideway and the catches was modified as the guideway is finalized to ensure there is adequate clearance in the case of any variations in the track due to manufacturing. The distance could not be too far or the catches' to ensure that it can withstand the impact load. Reducing the distance between the catches and the track will also avoid any possible damage to the catches and railway while also minimizing any violent movement in the cabin.

As the new guideway will include a slope of 17 degrees, there will be moments that the two half bogies will be located at different heights at a specific moment. This new feature of the Spartan Superway also required modifications on the joints between the bogie and their connecting bars (H-bar) two allow 2-degrees of freedom movement. In order to achieve this, u-joints were designed to allow enough vertical and horizontal travel between the bogies. By creating a u-joints, the bogie can now move like a four-bar mechanism, ensuring that the half bogies are parallel to each other at any given moment (Figure 1-31).

U-Joints allows the bogie to traverse the incline, decline and turns. The center tubing where the u-joint rests is extended outward to move the h-bar out from the center of the half bogie

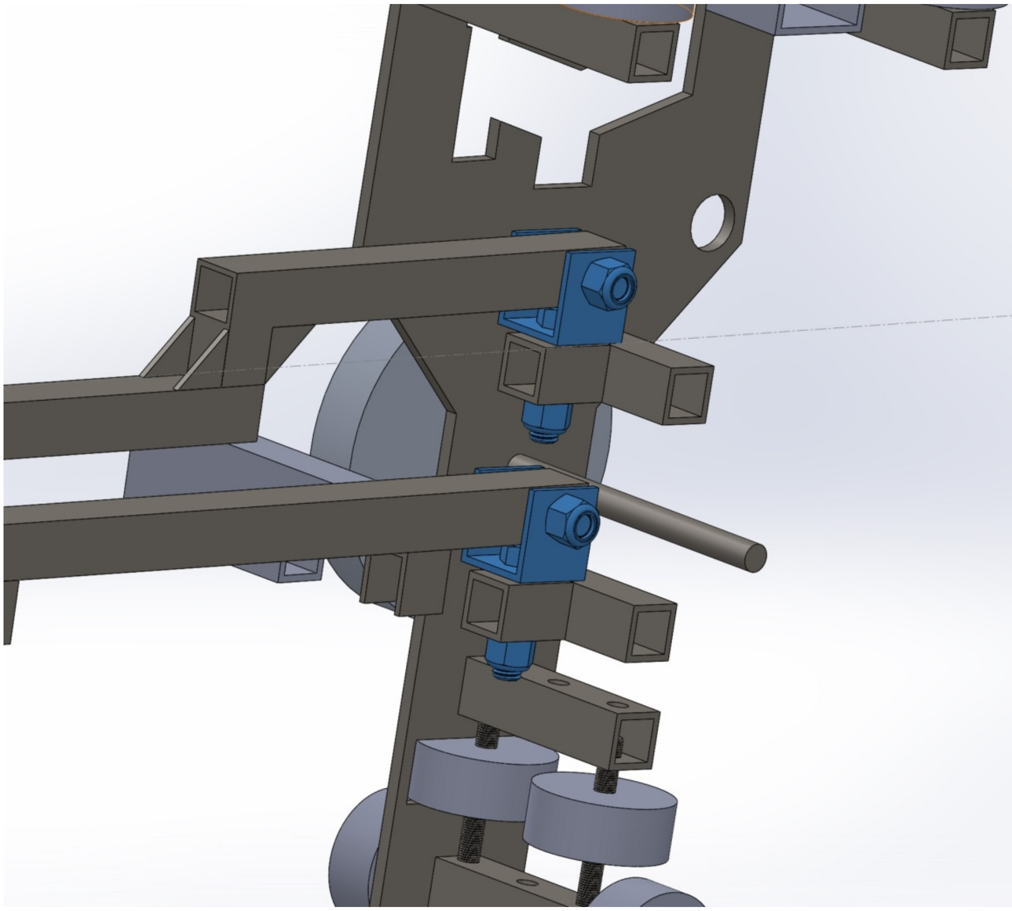


Figure 1- 31: U-Joints allows the bogie to traverse the incline, decline and turns. The center tubing where the u-joint rests is extended outward to move the h-bar out from the center of the half bogie.

Because an intermediate scale and 17° slope in the railway was desired, a bigger hub motor would be needed to move the bogie along the guideway. To accommodate the larger hub motor, the hub motor could no longer sit within a half bogie, as there is no space for it. Therefore, the hub more position was moved between the half bogies, which resulted in a redesign of the H-bar as shown in Figure 1-32. This redesign considers the top portion of the original H-bar. Originally the top portion of the H-bar was a single bar straight across the bogie. The redesign lowers the center section of the bar so that the hub motor could fit above. The H-bar was constructed using 1”x1” 11 GA A36 steel square tubing. Along with the center section, a 90° angle bar was cut and welded in for additional support. The total length of the H-bar was lengthened to 30” to accommodate the space needed to mount the actuators for suspension. Additionally, the steel tubing on the bogie that attaches to the h-bar was re-designed to push the h-bar further from the center of the half bogies(Figure 1-31). This allowed for the h-bar to not collide with the side plates as it maneuvers along the turns.

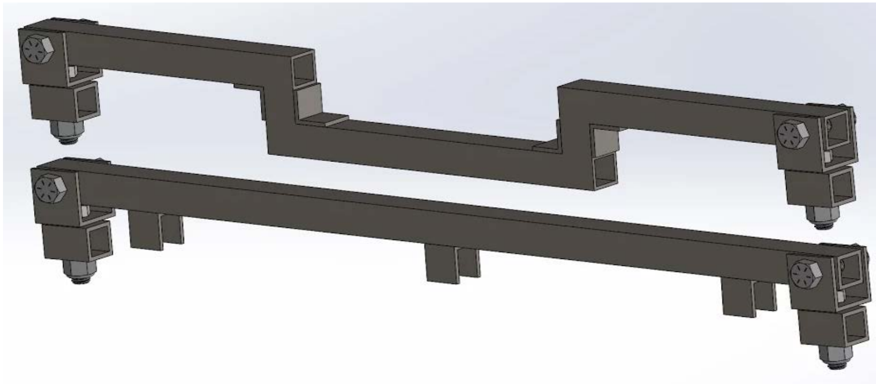


Figure 1- 32: H-Bar Redesign

Because Professor Furman wanted to keep the original design of the bogie, only small changes were made to accommodate the other teams. The bogies were fabricated using ⅛” thick A36 steel. The main side plates of the bogie along with other small miscellaneous mounting tabs were cut out using CNC waterjet cutting, shown in Figure 1-33. Due to fabrication changes made by steering team, the top cut out section had to be modified using a cutting blade on a dremel to allow for the steering mechanism to fit through. To provide structural stability to the frame of the bogie, 1”x1” 11GA A36 steel square tubing was used. The bogie’s frame is created using six 1”x1” steel square tubing, two on the top and four down the center of the bogie side plates which are welded on. The six square tubes provide support for the bogie as well as mounting holes for the eight wheels needed. The main load bearing wheels are mounted using a hole cut out on the side plates of bogie and then a ½” steel rod is inserted through the bogie and two wheels are mounted at each side with retaining lock collars. All parts of the structure were MIG welded together.

Figure 1- 33: Bogie’s main side plates cut using CNC Waterjet Cutter

Analysis/Validation/Testing

Once the final design was approved by the team and Professor Furman, the different fail-safe mechanisms were tested in SolidWorks. For this, finite element analysis(FEA) was performed on every part simulating fully loaded condition of 300lb using A36 steel as the material. The load was chosen to be 300lbs as that is the current estimated maximum weight of the bogie, cabin and suspension systems together.

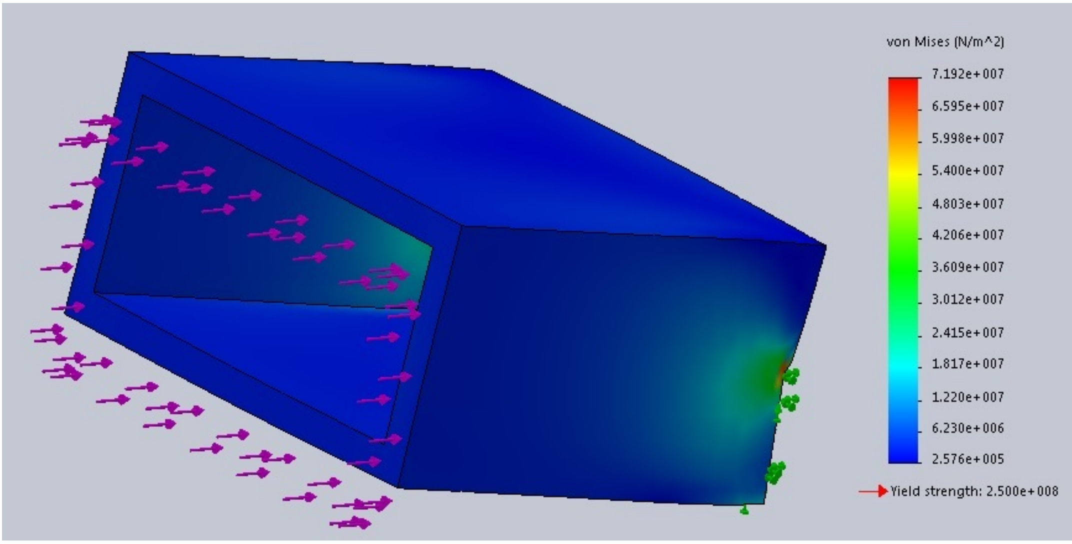


Figure 1- 34: FEA of the Upper Catch under a 300lb load.

The FEA simulations performed in SolidWorks to the upper catches suggested that the material and dimensions chosen would produce a safety factor of 3.5(Figure 1-34). Using the same tool, the lower catches were tested under the same load, generating a safety factor of 3.6 as shown in Figure 1-35.

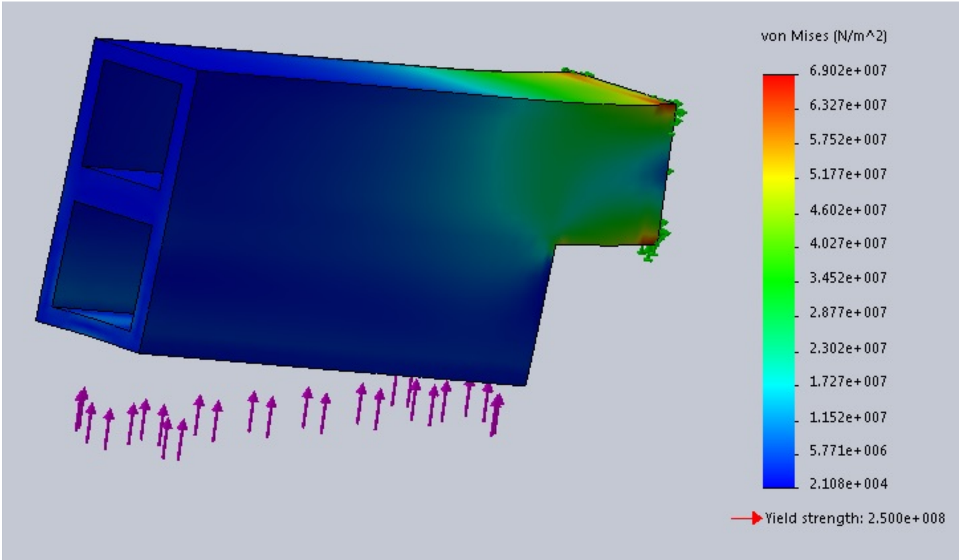


Figure 1- 35: Lower Catch made of ⅛ thick A36 Steel square tube under 300lb load.

Lastly, the new u-joint design along with the redesigned H-bar, shown in Figure 1-36, was tested to guarantee that they will hold the stresses exerted by the weight of the cabin, suspension and motor. Through the finite element analysis, it shows that the new design produced a safety factor of 2.4

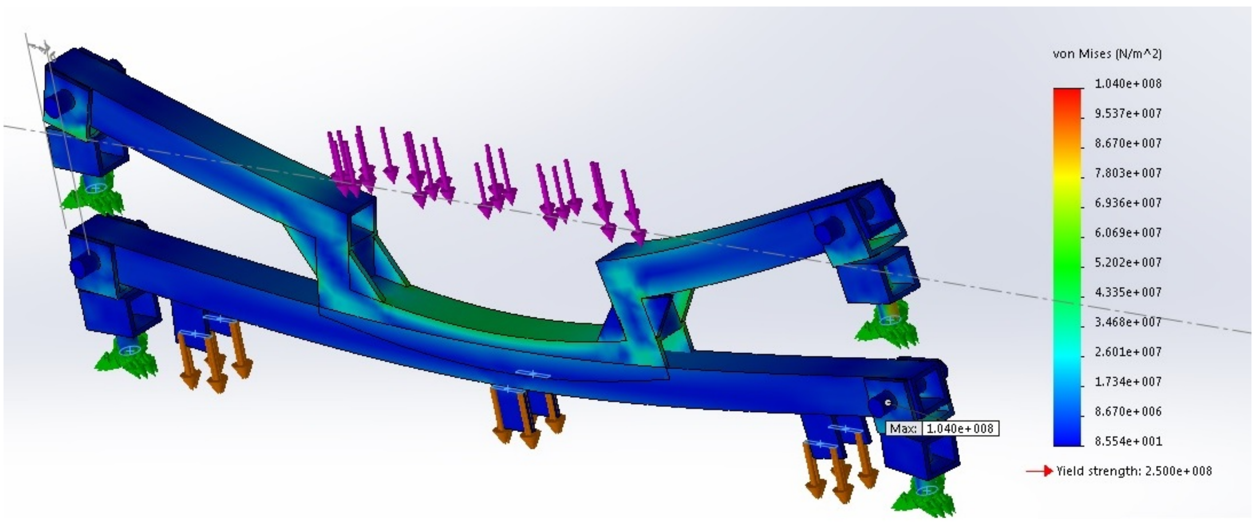


Figure 1- 36: U-Joint under a combined force of 300lb.

During this semester the different parts previously shown were fabricated and assembled at the Spartan Superway Design Center. The upper catches were tested by first rolling the bogie throughout the whole guideway to verify that it would not touch the side of the rails during normal operation. Then, the upper catch was tested by simulating a failure on the upper inner wheels from one half of the bogie. These wheels were removed, letting the bogie rest on the upper catch. The upper catch performed as expected, keeping the bogie from tilting and falling off the guideway as shown in Figure 1-37.

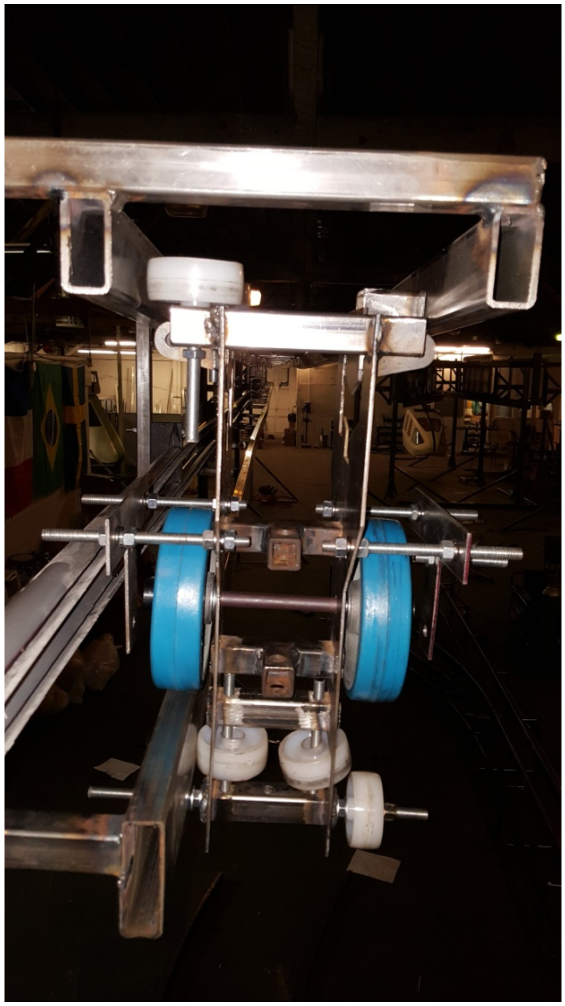


Figure 1- 37: Bogie resting on upper catches during failsafe mechanisms testings.

U-joints were also tested by connecting both half bogies and connecting bars together and simulating the movements that they would experience while traveling through the slopes and turns of the guideway. The u-joints rotated over the vertical and horizontal axis trouble free while keeping more clearance than needed between the connecting bars and other components. Also, full loading tests were performed, as shown in Figure 1-38, by assembling cabin, steering, suspension, wayside and the bogie together and placing them on the guideway. The u-joints along with the bogie were able to support full load conditions without failing.

Figure 1- 38: Bogie fully assembled on the guideway

A problem discovered during testing after assembly was the independency of each half bogie. The bogie can lean forward, as shown in Figure 1-39. When the half bogie leans forward, the wheels located at the top of the bogie make contact with the wooden panels and prevent the bogie from moving. This issue is resolvable by attaching two wheels on the front end and back end of each half bogie. This will prevent the bogie from leaning in either direction while enabling it to roll along the wooden panels located on top of the guideway.

Figure 1- 39: Half bogie tilted with top wheels making contact with the wooden panels which prevents movement.

Money Spent on your Project

Table 1- 2: BOM for Bogie Side Plate Fabrication

Vendor	Description	Rate	Total Cost
Techshop San Jose	CNC Waterjet Cutter	$3/min	$191.18

Table 1- 3: BOM for Load Wheels and Supporting wheels

Vendor	Description	Quantity	Price per item	Total Cost
Grainger	(2-1/2" x 1", 3/8")Caster Wheel	16	4.86	$77.46
McMaster	Load Polyurethane-Tread Wheel, 6" X 1-1/2", 1/2" Axle	4	40.98	$163.92
McMaster	Oil-Resistant Neoprene Rubber Wheel, Cushion Tread, 2" X 7/8", 3/8"	4	7.14	$28.56
			Tax	$23.24
			Shipping	$26.05
			Total	$319.23

Table 1- 4: BOM for metals for bogie/fail-safe mechanisms

Vendor	Description	Total Cost
Sims Metal	11 GA A36 Metal Sheet (4' X 2'	$13.23
Sims Metal	1'x1' 11 GA A36 Steel Tube (10')	$27.00
	Tax	$3.52
	Total	$43.75

Table 1- 5: BOM for Fasteners

Vendor	Description	Quantity	Price per item	Total Cost
The Home Depot	3/8-24 Stainless Steel Nylon Lock Nuts 8-Pack	4	$8.8	$35.2
McMaster	Grade 8 Steel Fully Threaded Rod 3/8"-24 Thread, 3" Long	3	$4.25	$12.75
McMaster	Type 18-8 Stainless Steel Flat Washer 3/8" Screw Size, 0.406" ID, 0.875" OD 100-Pack	1 pack	$5.45	$5.45
McMaster	Grade 8 Steel Nylon-Insert Locknut, Zinc Yellow-Chromate Plated, 1/2"-13 Thread Size, Packs of 10	1 pack	$4.31	$4.31

McMaster	Black-Oxide Coated Steel Shaft, 1/2" OD, 36" Length	1	$21.09	$21.09
McMaster	One-Piece Clamp-on Shaft Collar, for 1/2" Diameter, Black-Oxide Steel	4	$2.17	$8.68
			Shipping + Tax	$10.58
			Total	$98.06

Table 1- 6: Final Costs

BOM Category	Total Amount
Bogie Side Plate Fabrication	$191.18
Load Wheels and Supporting Wheels	$319.23
Metal for Bogie & Fail-Safes	$43.75
Fasteners	$98.06
Total Spent	$652.22

<u>Results and Discussion</u>

The intermediate scale bogie team has some major accomplishments for this semester: the upper catch, lower catch, upstop wheel, and a bogie that is compatible with all the interconnecting teams' designs. All of these designs help satisfy the objectives, design requirements and specifications. Based on the testing done by the team, the fail-safe mechanisms prevented the bogie from derailing, sustained the weight of the whole bogie and the cabin, and the bogie was able to traverse up and down a guideway sloped at ±17°. The upstop assembly stabilized the bogie, as it locks down the bogie from the bottom plate of the guideway. It also made traversing from the slope smoother and safer, as the upstop wheels act as an additional support. Both the upper and lower catches have a safe clearance from the guideway during a failure-free operation. In a failure scenario in which the upper inner wheel fails and the bogie starts to tilt sideways, the upper catch will come in contact with the guideway, so that the tilting is a mere ⅛ of an inch, that is the clearance that the upper catch has from the guideway. While the upper catch takes care of an unintended horizontal movement, the lower catch takes care of the vertical movement by contacting the bottom rail, if there is an unintended vertical movement due to the failure of the load wheel, thus preventing the bogie from falling.

The bogie houses all the mechanical components of the system, making it the most important section of the project. The team has made sure the bogie is protected from all possible directions. Each half bogie consists of load wheel on top of the lower rail on the guideway, followed by 6 inner wheel that will be rolling on the inner sides of the rails of the guideway, 2 upstop wheels that will roll on underneath the guideway, and a steering mechanism that would roll on the outers sides of the upper rail of the guideway, thus locking the bogie onto the guideway from all possible direction. If either of these wheels fail, the upper catch and/or the lower catch will prevent the bogie from derailing and falling. At this point, it is safe to assert the fact that the bogie is equipped with the proper fail-safe mechanisms to nullify the possible consequences of a mechanical failure.

Conclusions and Suggestions for Future Work

As stated earlier in the report, the original bogie was created without any mechanical fail-safe mechanisms. Although the steering mechanism was meant to aid in holding the bogie to the guideway, it was later mentioned that it did not reliably do so. Moreover, if the power or a sensor failed in the steering mechanism, there would be nothing to help hold it. Thus, this year's aim was to create purely mechanical fail-safe mechanisms, reducing the reliance on sensors or power.

The fail-safe mechanisms designed by the team fulfill the current objectives. They address the selected situations of failure (falling down vertically, tilting left or right) along with stabilizing the bogie during incline/decline, which in turn helps lock the bogie to the guideway when the steering mechanism is activated. Based on the stress analysis performed on the catches, the mechanisms should perform successfully.

The benefits implementing these fail-safe mechanisms on the intermediate bogie will be twofold. For one, it will allow failure testing to be done, making certain components intentionally fail to ensure that the designed fail-safe mechanisms will catch the bogie, keeping it on the track and protecting the potential people inside or below safe. The other benefit is that the model will be able to show that the bogie is safe, making the Spartan Superway as a whole more appealing for potential investors.

The main focus for next year would be to focus on a fail-safe mechanism for when the bogie is switching tracks. To date, the team was unable to design a mechanical fail-safe mechanism that would keep the bogie from falling during switching. Future teams may also build upon this work by using failure testing to find additional fail-safe mechanisms or improvements that may be necessary to the ones designed this semester.

Intermediate Propulsion

Background and context for the work of the sub-team

Within the intermediate scale, there are several teams that are working together. However, one of the most important teams in this project is the propulsion team. Without a propulsion system, the bogie would not be able to move along the guideway. Additionally, the implementation of a propulsion system acts as another way for teams to prove their designs work on an actual moving prototype.

Description of the Sub-team and Objectives

The purpose of the propulsion system is to move the bogie and cabin according to the preset design requirements. This year's propulsion team had to design a system that could not only move the bogie forward, but also handle a 17-degree slope. Which required determining new power and torque requirements; in order to create a theoretical and used the 2014-2015 design as a guide.

The objectives of the intermediate scale propulsion team were to:

- Determine requirements/specifications for theoretical model
- Select a motor and controller
- Design a mount for the motor within the bogie
- Develop a code that integrates the steering and/or braking code

<u>Design Requirements and Specifications for the Sub-team's Work Products</u>

The design will fulfill the requirements and specifications listed below:

- Motor must be able to move the bogie up the slope with the following requirements:
    - Able to exert 465 N of force at its radius
    - Output power of at least 415W or 0.55HP
- Motor and mount must fit within the intermediate scale bogie
- Mount must exert 465N of force upwards on the motor to press it into the ceiling of the track for sufficient traction

<u>State-of-the-Art/Literature Review for the Sub-team's Sphere of Work</u>

Hub motors have been a concept since 1884 with Wellington Adams first patented it in 1884. Since then, there have been many different applications for the hub motor. Aside from the most common use of the hub motor to automate bicycles, hub motors have applied to industrial vehicles. Concept cars have developed with in-wheel motors. Companies such as General Motors, Mitsubishi, Peugeot and many others have been implementing hub motor technology in their vehicles (Figure 1-40).

Figure 1- 40: Photo of a pre-production model of a Hiriko Fold vehicle, which uses hub motors

Currently there are a few types of hub motors. Direct drive hub motors are slick and discreet. They are used on bicycles, scooters, solar cars, and many light electric vehicles. These hub motors provide no need for drive chains or transmission. Instead, everything is contained inside the direct drive motor. The direct drive is the simplest type of hub motor. There is no moving parts, but the wheel itself. They are designed as radial-flux brushless DC motors and can spin freely on its center axle. The magnet sits on the axle while the copper coils are along the circumference of the motor. This allows for a balanced free spinning motor as shown in Figure 1-41.

Figure 1- 41: Direct Drive Hub Motor. (http://www.ebikes.ca/media/wysiwyg/ddmotoropen.jpg)

Their disadvantage is that they usually have a large power output. Their power is proportional to the speed between the magnets and the coil winding. In other words, to have a larger and adequate power and torque, the motor needs to be large, which results in a heavier motor.

Another type of hub motor is the geared hub motor as shown in Figure 1-42.

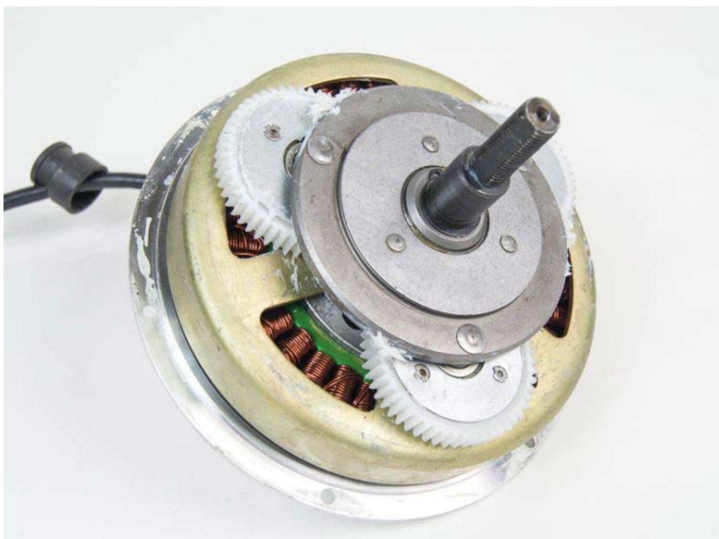


Figure 1- 42: Geared Hub Motor. (http://www.ebikes.ca/learn/hub-motors.html)

The geared hub motor has gearing inside to reduce the high speed. The gear hub usually has a smaller radius, but wider than a direct drive hub. Inside the motor is a planetary gear set linked to the rotor. They weigh about 50% less than the than direct drive motors. They have superior torque outputs. For instance, the German-made Heinzmann can produce about 80 Newton-meters, compared to 35 Newton-meter for typical direct drive motors. Other companies that develop gear hub motors include Sanyo, eZee, and Ethinkar. Some disadvantages to these hub motors include being generally more expensive. They also have many moving small parts, which means they are susceptible to wear and generate loud noise. Figure 1-43 lists the pros and cons side by side.

	Direct-Drive	Geared
Pros	More Durable	Less Drag
	Faster	Smaller
	Quieter	Lighter
		More torque
Cons	Drag when pedal	More noise
	Less range	Lower top speed
	Larger	
	Heavier	

Figure 1- 43: Pros and Cons of Direct-Drive and geared hub motors.(http://electricbikereport.com/electric-bike-direct-drive-geared-hub-motors/)

The team chose to use a Crystalyte hub motor. The torque that is provided by one of these motors varies in direct proportion to the total current flowing around each pole. Figure 1-44 shows the inside of a Crystalyte hub motor.

Figure 1- 44: Crystalyte Hub Motor.(http://i49.tinypic.com/2e31vs1.jpg)

The RoadRunner Crystalyte Motor Model 408 was selected because it is more cost efficient while providing the necessary torque and power needed to satisfy the design specifications. The 8 in 408 represents the number of turns of copper around each pole. The 400 series motors can provide the same amount of torque. Between the 408 with a 404, the 408 takes ½ the amperage to provide the same amount of torque. The electrical engineering team will be providing 20 Amps, which will provide 160 amps around the pole. At that amperage, the maximum torque of 51.2 can be provided. Since a torque of 44.4 is needed to traverse the incline, this motor is sufficient. There is a drawback: the 408 has 4 times the resistance the net electrical loss. Also, the 408 would need twice the voltage to be powered to spin the same speed as the lower 408. This just means the battery needs to be bigger than normally used for small hub motors of the series. Another benefit of this type of motor is that they are heavy performance motors. They are also extremely reliable when used under normal conditions. They are protected from dirt and water, which makes it a great exterior motor.

Description of Your Design

In order to determine which motor to use for the propulsion, the team first had to determine the motor requirements. Table 1-7 outlines the values calculated to determine the motor's required specifications.

Table 1- 7: Input Values used to Determine Motor Specifications

Input Values			Calculated Values	
Drag + Rolling Resistance (N) (From Solar's power calculation)	75		Opposing gravity force (N)	390.3
Speed going up slope (m/s)	0.89	(~2 mph)	All opposing forces (N)	465.3
Scaled weight (N)	1335	(~300lbs)	Power Required (W) (up slope, constant speed)	414.1
Slope grade (º)	17		-> (HP)	0.55

With the motor requirements determined, then the spacing within the bogie was considered. With the bogie in intermediate scale, it was determined that the chosen motor and tire could not exceed a 9 inch diameter. In accordance with last year's design, the team searched for a hub motor to fit the requirements. The motor chosen was the Crystalyte SAW408 (Figure 1-45).

Figure 1- 45:Crystalyte SAW408 Hub Motor

This motor could operate at 800W and exert a torque of 44.40N-m, which would exert enough force at the hub motor's radius of 3.5in to move the bogie. The motor came with a Crystalyte 4825F controller could be used to interface the propulsion system with logic. Most importantly, it was the only motor with the ability to satisfy both the necessary motor requirements and the sizing constraints within the bogie.

The design from 2014-2015 integrated the hub motor mount between the two sides plates of the half bogies. The hub motor was pressed against the ceiling of the track with a linear actuator. However, because of the size of the motor chosen, it was not possible to mount the motor between the side plates of the half bogies. With the larger hub motor now located in between the two half bogies, a new motor mount was needed. The first design for the motor mount consisted of using ⅜" thick A36 steel plate that would be cut using CNC waterjet cutting. However, through much consideration, the cost of using CNC waterjet cutting was no longer feasible as the budget was quickly depleting. Another reason why the ⅜" plate was not used was because of the possibility of torsion. In order to prevent the twisting, the mount would need to have additional plates welded in. Instead, the mount was made using a 90° bent angled bar. The angled bars were able to provide stability against torsion as well as press the hub motor against the ceiling of the track as seen in Figure 1-46. The angled bars were cut to length with a 15° angle, and then welded together. At the end of the mount, a 1"x 1" 11GA A36 steel square tubing was welded to provide a flat surface for the spring to push up against. The coefficient of friction for rubber against wood varies from 1 to 4. Considering the worst case scenario of a coefficient friction of 1 for rubber against wood, the spring would need to exert a load of 470 N, equivalent to roughly 100lb-f. A spring with a rate of 186lb/in was used.

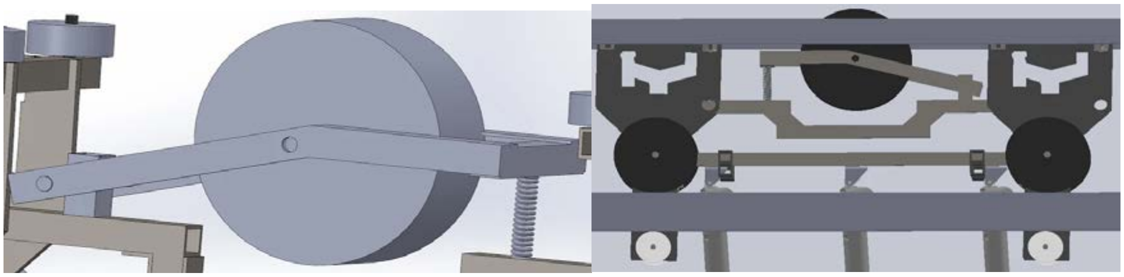


Figure 1- 46 : Motor mount and spring assembly within bogie

<u>Analysis/Validation/Testing</u>

For testing, we confirmed that the motor could be controlled with an Arduino and that the mount would press the motor into the ceiling with at least 100 lb-f to gain enough traction to move the bogie. The propulsion code was initially tested on the 2014-2015 test stand mount. This allowed for speed testing and Hall Effect sensor testing. With an initial test code written, the team was able to use it to write the code to be used on the track. However, it was decided to integrate the steering code into the propulsion code. This led to the decision to use Hall Effect sensors as a counter. By integrating the two codes, the usage of a Mega Arduino and larger bread board was necessary to enough pins available to plug in. During testing, four 12 volts batteries were connected to give the necessary 48 volts required for the motor. Although this worked for testing, when mounted onto the bogie and in the cabin, the power inverter and power supply that was provided by the electrical engineering team did not work. This led to more troubleshooting to ensure that the wiring between the steering and propulsion team was done correctly. For final testing, the team relied on the usage of the connected batteries to limit the amount of variables within the set up.

<u>Money spent on your project</u>

Table 1- 8: BOM for Propulsion

Vendor	Description	Quantity	Price per item	Total Cost
ElectroRide	Crystalyte SAW400-series motor	1	$302.20	$302.20
ElectroRide	Crystalyte 4825 Controller	1	$161.80	$161.80
McMaster	Steel Compression Spring, Zinc-Plated Music Wire	1	$11.10	$11.10
Orchard Supply Hardware Store	Tire Materials	2	$17.48	$34.96
			Discount	-$14
			Shipping	$20
			Total	**$516.06**

Results and Discussion

Due to time constraints and ease, the propulsion team chose to adapt to the steering code and rely on using their Hall Effect sensor as a counter. Depending on the counter, the code would read whether it was time to slow down or speed up for a determined amount of time. Although this code worked, it depended on a fair amount of troubleshooting to refine the variables within the code. Initially, a disc brake was mounted onto the motor. This caused some issues with the centering of the motor, but since the braking system did not become a working prototype, it was taken off. When the disc brake was tested with the motor, it also caused the motor to spin within the mount when it tried to slow down the motor.

Conclusions and Suggestions for Future Work

Propulsion is one of the most important factors within the Spartan Superway. A propulsion team was not organized until a month into Spring semester, when the intermediate scale bogie team stepped in to fill the role. The late start, in addition to the motor requirements and design constraints led to major issues with completing the project on time. Additionally, the team greatly needed someone skilled in coding and willing to work on the project.

Two areas of possible improvement are the controls aspect and the method of pressing the hub motor into the ceiling of the guideway. In keeping with the previous design, a spring was used to apply a vertical force, pushing the motor into the roof of the guideway. This became an issue when loading the bogie onto the guideway because it was difficult to compress the spring enough to allow the bogie to slide into the guideway. A linear actuator, like the 2014-2015 design, may be a better choice, but it was not feasible for the team to determine one that fit within the time and budget constraints. Also, the mount did not allow for the motor to be properly attached to the mount with a nut, which may be why the brake caused the motor rod to spin in place when braking. The controls could use improvements as well, as the controller for the motor has a great many special features that could be taken advantage of such as an encoder to detect the turns of the motor, electronic braking, and cruise control. Additionally, the code could be re-written to use the Hall Effect sensor more effectively than solely as a counter.

Intermediate Steering and Braking

Objectives

The 2014-2015 bogie team made a great achievement in successfully designing the switching mechanism for the top and bottom rail and a system to actuate the switching mechanism automatically. However, not enough thought was put into the reliability and efficiency of the bogie as well as how the bogie behaves on the guideway.

Upon observing the full scale bogie at the beginning of the semester, a few shortcomings were identified. The main aspect that stood out the most was the slow and sluggish operation of the steering mechanism. Such mechanism would not qualify to operate in real world conditions as this would hamper the flow of traffic due to the podcar having to slow down to allow sufficient time for the switching mechanism to operate. Another aspect was the temporary loss of contact of between the steering wheels and guideway when the bogie makes a turn after hitting the Y intersection. Furthermore, the bogie is prone to a lot of vibration, thus providing a rough ride experience for the passengers.

The main goal of this year is to modify and further improve the steering mechanism while maintaining the structure and function of the last year's bogie. One improvement that needs to be made is to develop a mechanism to synchronize the motion of both the upper and lower switching links to prevent mechanical failure when either one of the actuators fail to operate. Our team has decided to use stepper motors to replace linear actuator in order to provide better torque output, response, and accuracy. Furthermore, an extra pair of steering wheels are added on the top steering link to align them directly with the ceiling wheels to add extra stability to the steering mechanism,

The 2014-2015 bogie team also had proposed a braking system in their CAD model which is located on top of the bogie between the ceiling wheels. However, it ultimately was scrapped when building the full size model because of technical issues. So for this year in addition to the steering mechanism, a new braking system will be implemented next to the guiding wheels which allows the brakes to directly apply braking force to the wheels.

Design Requirements and Specifications

While designing the prototype of the steering and braking mechanism, several requirements must be taken account to ensure the design is compatible with the designs of the fail-safe team.

Steering

- The new bogie is developed in half scale rather than in full scale. This decision was made in the beginning of the semester by the team lead to reduce cost of fabrication and prove the viability of our concept. While designing the bogie on SolidWorks, each part was measured and dimensioned accurately. The bogie was first designed in full scale using SolidWorks and was then scaled down to half scale after the assembly was finished. Prior to scaling down the model, we worked closely with the fail-safe team to ensure their designs were compatible with ours.
- In contrast to last year's design using two actuators where one each operates the top and bottom steering link, the team decided to use one stepper motor to control both the upper and bottom steering links simultaneously. The rotational motion of the stepper motor is converted into linear action of both the upper and lower control arms, which are synchronized using tie rods and a L-shaped bracket . This decision was made because lowering the number of motors decreases the chance of mechanical failure and providing a better reliability.
- The switching time of last year's steering mechanism was 7 seconds. To keep the available track length for the steering mechanism to switch as low as possible, the operation time of the steering mechanism needs to be cut roughly in half to around 3 seconds. Also in the previous design, both actuators are not operated at the same time. By using a stepper motor, this can drastically reduce the switching period when both the upper and lower control arms are activated together.
- The upper control arms need to rotate 70 degree and the lower control arms need to rotate 35 degree from one dead end position to another.

- Two pair of wheels on upper steering link to increase stability and balance Switching must occur smoothly with little vibration to ensure smooth rides for passengers
- During cornering the centripetal acceleration causes the bogie to swing out in the radial direction. The steering mechanism needs to counter this force to prevent from the bogie from "flying out"

Braking

- Assuming the pod-car was moving at 7.333 ft./ sec (5 mph), braking distance was 9 ft. in 2 seconds, total weight was 600 lb, coefficient of friction was 0.7 for dry track, the average braking power was estimated to be 1.971 Kw for half scale model for straight track section. In addition, braking bracket has the lowest safety factor of 38.1128 with 1000 lb force applied on it. There are lots of changes to the ways of controlling the brake.
- First it was intended to use ultrasonic sensor to incorporate in the distance braking but the response time of the ultrasonic sensor is very slow. The wii nunchuck control can be use to apply to control the braking system by setting wireless receiver on the arduino pin. The nunchuck can be calibrate and increase higher RPM of the motor which provides much better torque. In addition, for prototype, it is better to have a remote controller to test out the brake and figure out the right RPM needed to apply on the brake at crucial parts of the guide way to prevent crashing at either ends of the guide-way and the bottom of the slope. The control of the brake system need to be responsive for instant stop and slow down

State-Of-Art/Literature

Steering

Originally, research was done to determine what would be the best method to actuate the steering mechanism. It was decided to move forward with a stepper motor for it's high static torque and precise rotation . The geometry of the linkage system was carefully studied in order to . The steering mechanism needs to provide precise action of the control arms while the design should be as simple as possible to improve reliability and efficiency.

Braking

From the beginning the braking team decided on implementing disc brakes onto the bogie system since they were were good in heat transfer, easy to maintain, have strong braking power and no fading in wet condition. In addition, mechanical disc brake was easy to setup and modify parts. Braking pad and rotor can be easy replace, requiring less maintenance and clean up.

Design Concepts

During the design process of the steering mechanism, most of the major components such as the upper and lower control arms were retained to reduce the amount of changes that needed to be made on the main structure of the bogie.

The only changes made is that the upper and lower steering mechanism are now connected and synchronized by linkage system and the 2 actuators are replaced with a stepper motor. Also some changes are also made on the upper steering wheels since our team decided to install an extra pair of green guiding wheels on the bracket made with square tubing for better stability of the bogie during cornering. The lower steering arm is almost identical except a triangular support is installed for the linkage. The motion of both the upper and lower control arms is controlled by a L-shaped bracket, which is connected to the output shaft of the stepper motor using a coupling. The upper and lower steering arms have different geometrical radius and hence the upper control arms have higher angular velocity than the lower one. Therefore, the arm connected to the the lower control arm on the L-shaped bracket has to be much shorter than the one connected to the upper control arm in order to have the both the upper and lower arm at the same horizontal level when they are at top dead position. The gear reduction ratio of the upper and lower control arms is 3.34 and 0.45 respectively with respect to the L-shaped bracket. The new parts made are based on the previous teams' design and the bogie's structure hasn't been altered or redesigned significantly. The 2 side plates, which is the main structure of the bogie, needs to have a larger opening to accommodate the redesigned Y-shaped control arms.

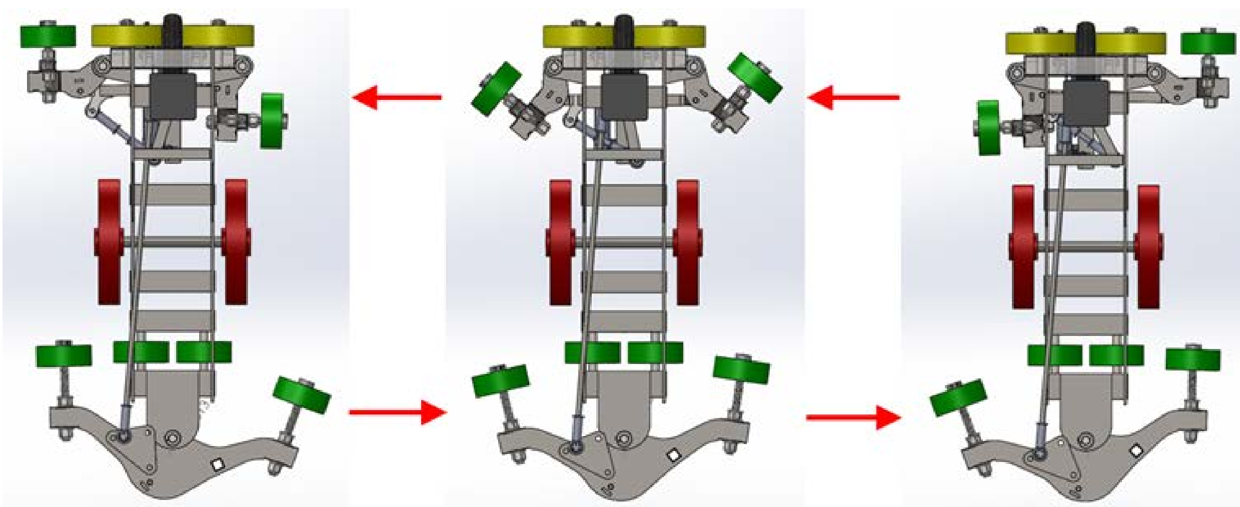


Figure 1- 47:Steering mechanism in action

A stepper motor was chosen as the actuation due to high accuracy and torque. Furthermore, it was chosen because of the low angle of rotation of the control arms and low speed application. A stepper motor with gear reduction of 36:1 was chosen to increase the torque output and rotor inertia to ensure the moment of inertia of the steering arms would be overcome. The control arms must be aligned very accurately with the guideway to make absolute contact. The angle of rotation can be controlled by the Arduino IDE program by setting the number of steps the stepper motor needs to take.

After performing force analysis and calculations on the steering mechanism, it was determined a minimum torque of 5 Nm was needed for the control arms to actuate at decent speed. It was proposed to have the control arms switch direction in 3 seconds. This feat was accomplished by setting the motor speed at 3 rpm.

Because the stepper motor used for actuation did not have an encoder, the position of the control arm needed to be initialized. A switch was placed on the left side of the bogie to stop the control arms from rotating when it was pressed. This way, the control arm is in its initial position and will rotate the desired angle of rotation.

A hall effect sensor was utilized to determine which side the steering mechanism would be engaged. Every time the hall effect sensor passes the magnet, the control arms would rotate in the desired direction. The magnets are placed on the guideway and the hall effect sensor was programmed in a way so it knows what direction it needs to switch. Our starting point would be at the beginning of the track right before the intersection. The left section of the guideway is straight, while the right section makes an S-curve and makes a 17-degree incline downhill and uphill before it enters the intersection again. The control arms won't switch at the beginning and the bogie enters the right section of the guideway. After that, the hall effect sensor will sense the magnet near the end of the guideway which tells the bogie to come to a stop and reverse direction. When the bogie comes to a stop, the control arms will rotate clockwise to have the left wheels engage against the guideway. The bogie would then travel straight back on the left section of the guideway all the way to the beginning. The hall effect sensor would then be triggered again near the beginning of the track, where the bogie would slow down and come to a stop and set the direction to forward. The control arms would then rotate counterclockwise to have the right wheels engage against the guideway. The whole scenario would then be repeated.

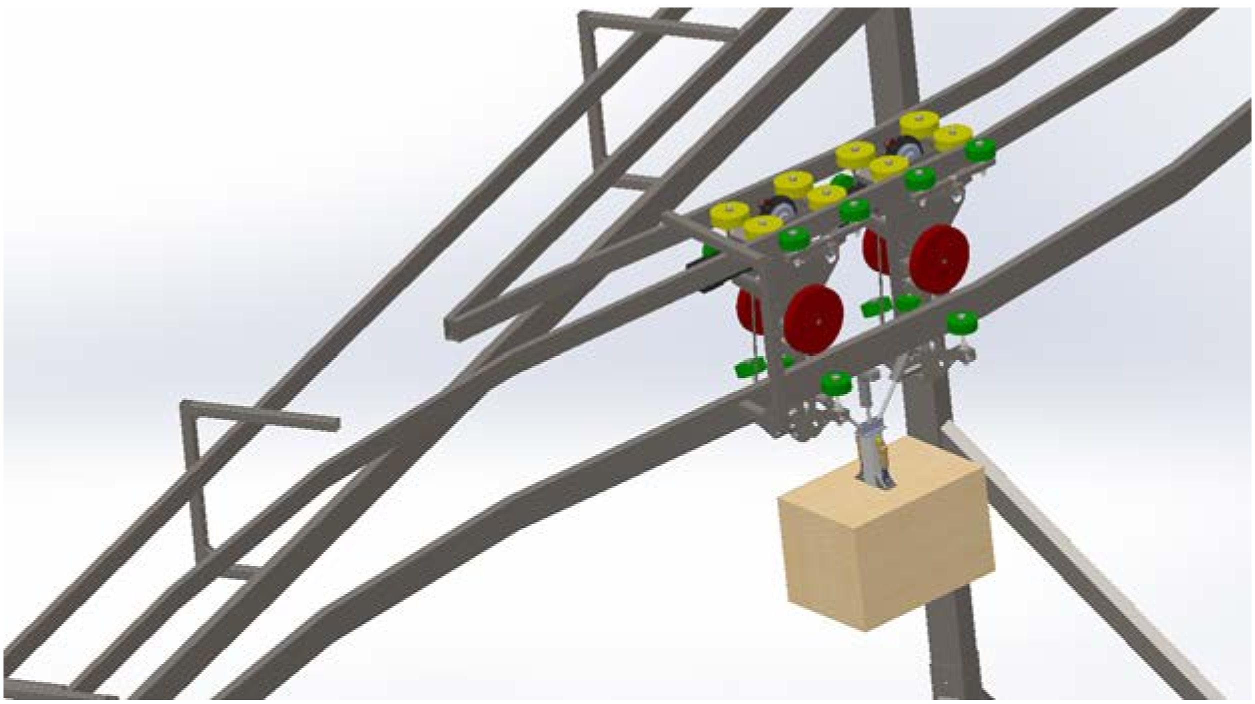


Figure 1- 48: Position of control arms when travelling on cornered and inclined section of the guideway

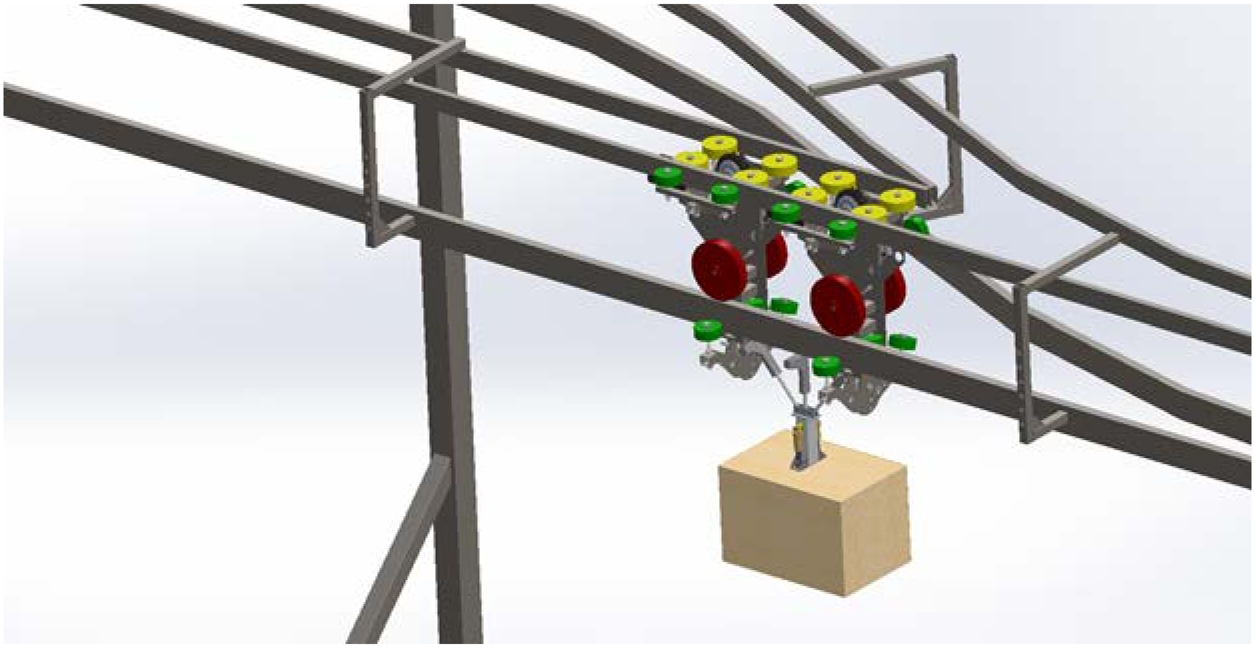


Figure 1- 49: Position of control arms when traveling on straight section of the guideway

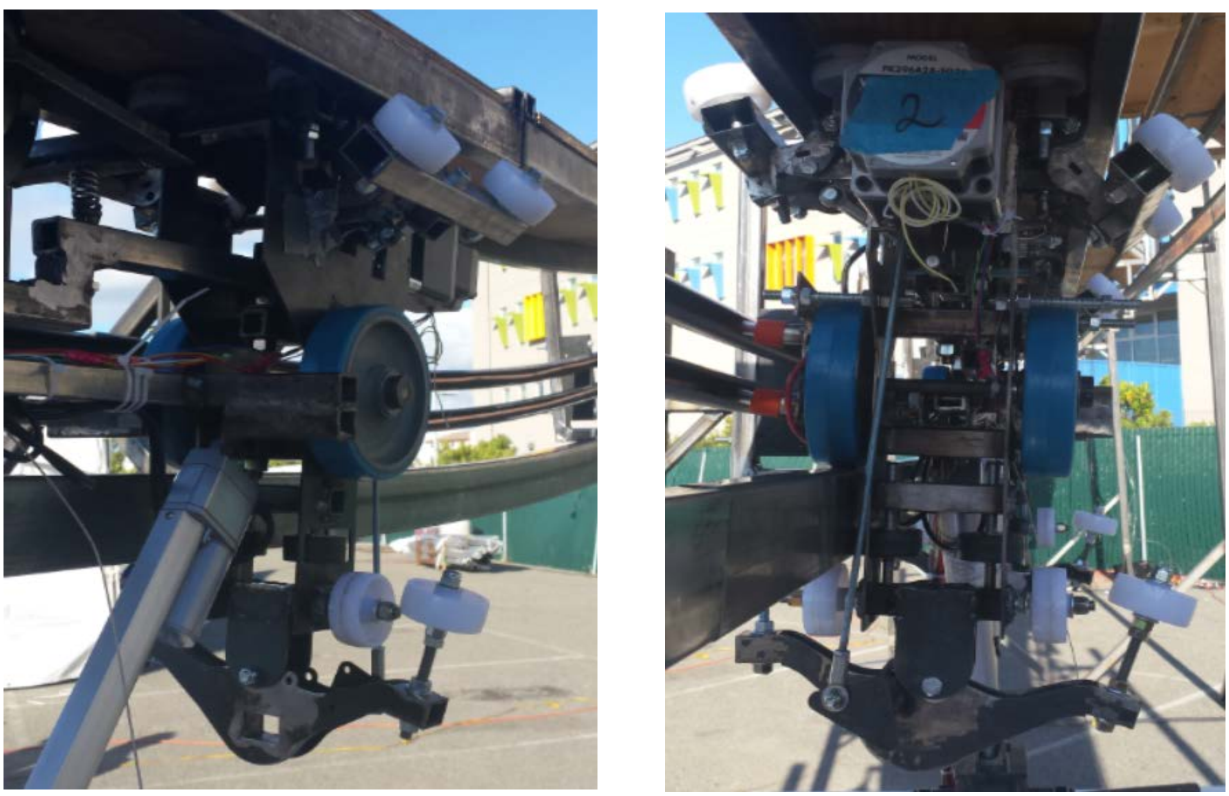


Figure 1- 50: Left: Isometric view of the bogie, Right: Front view of the bogie

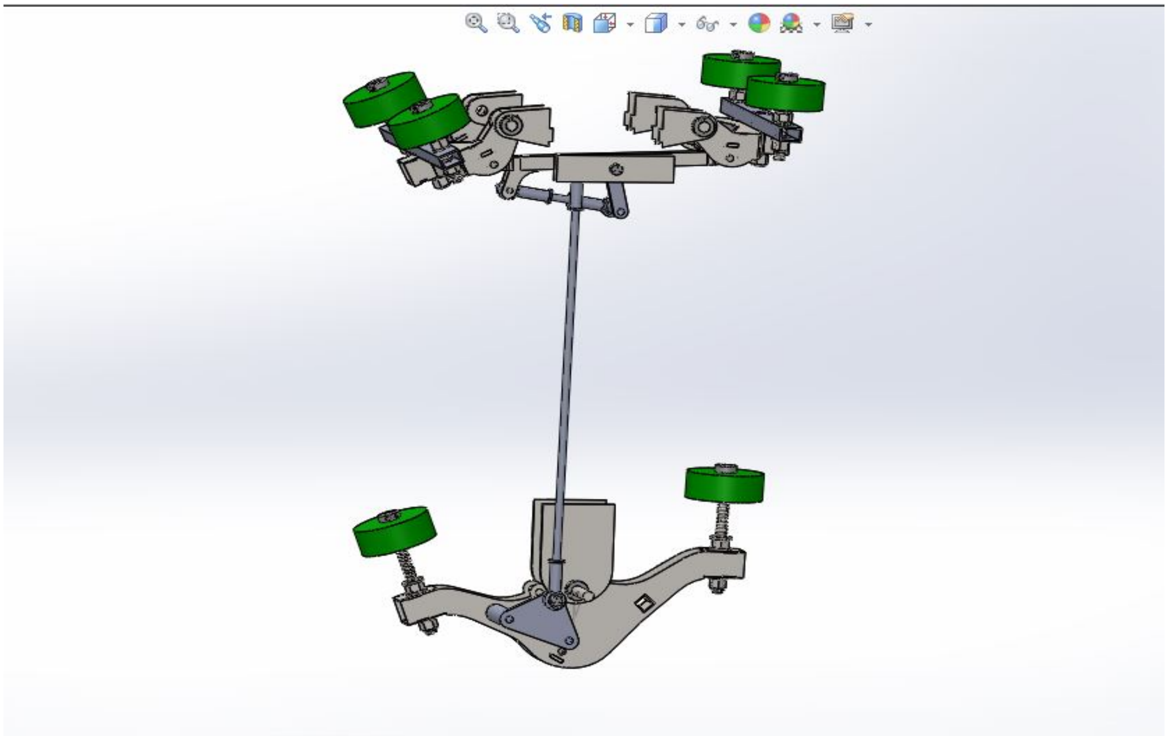


Figure 1- 51:LCAD model of modified steering mechanism

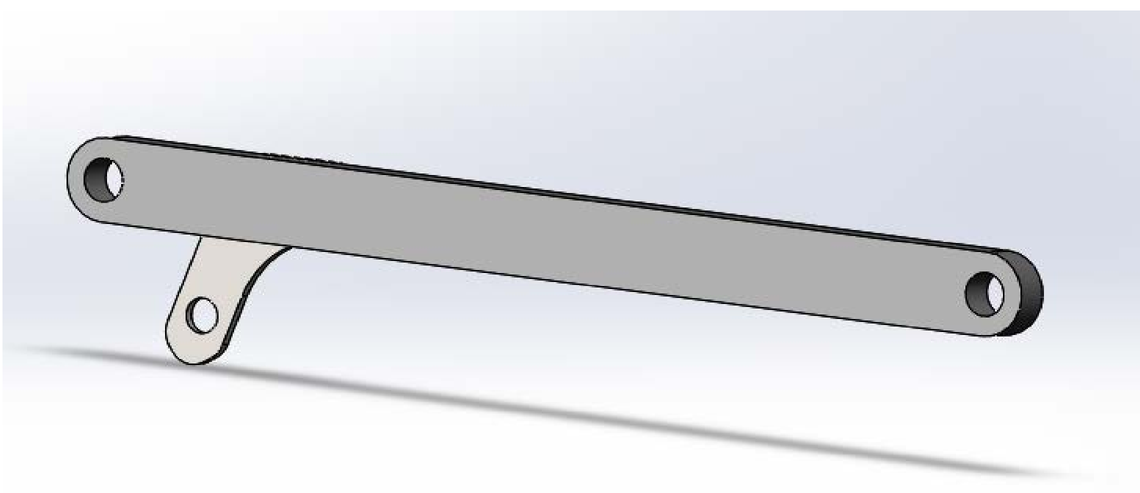


Figure 1- 52: Linkage for connecting left and right upper control arms

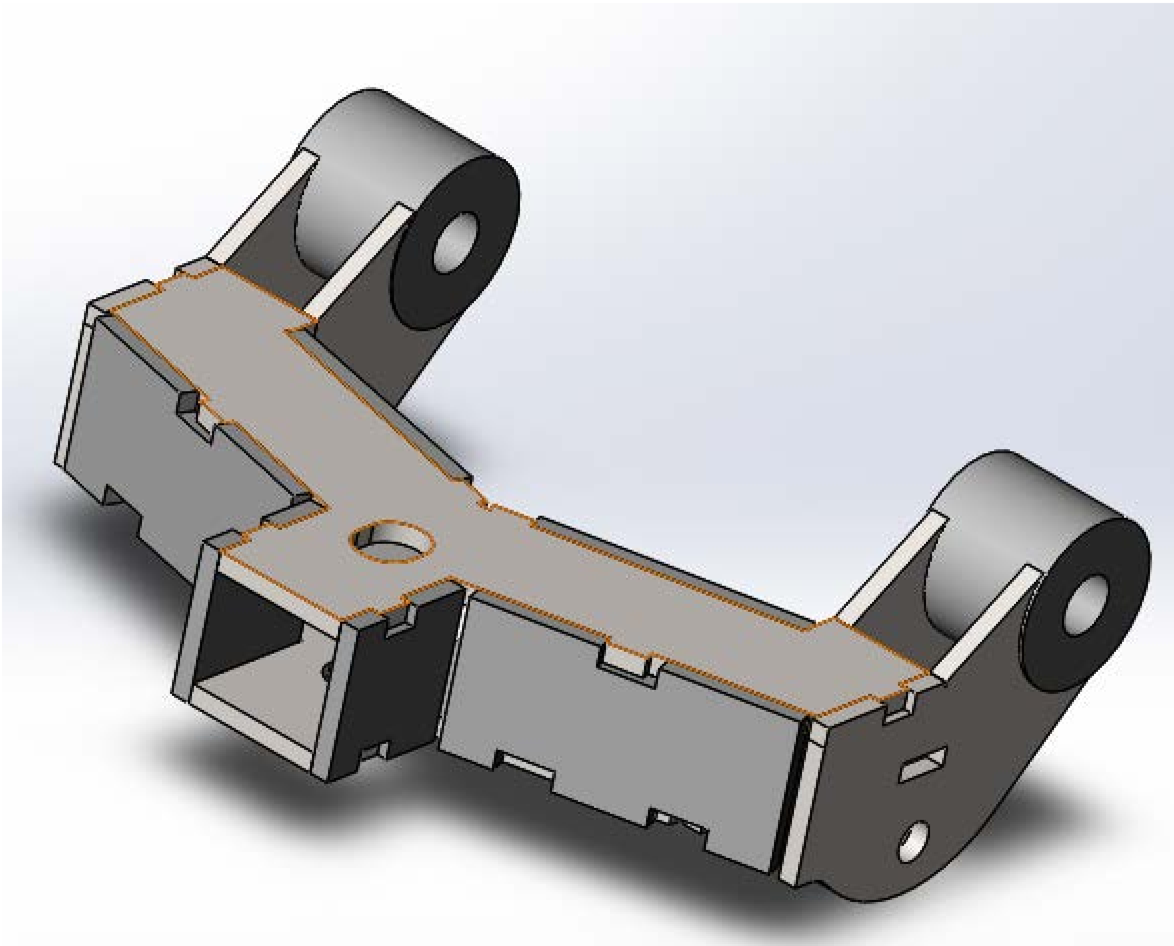


Figure 1- 53: Upper steering mechanism control arm

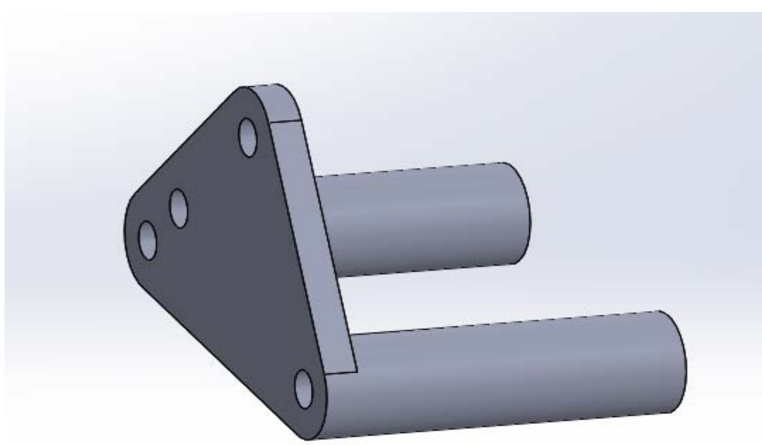


Figure 1- 54: Triangular link

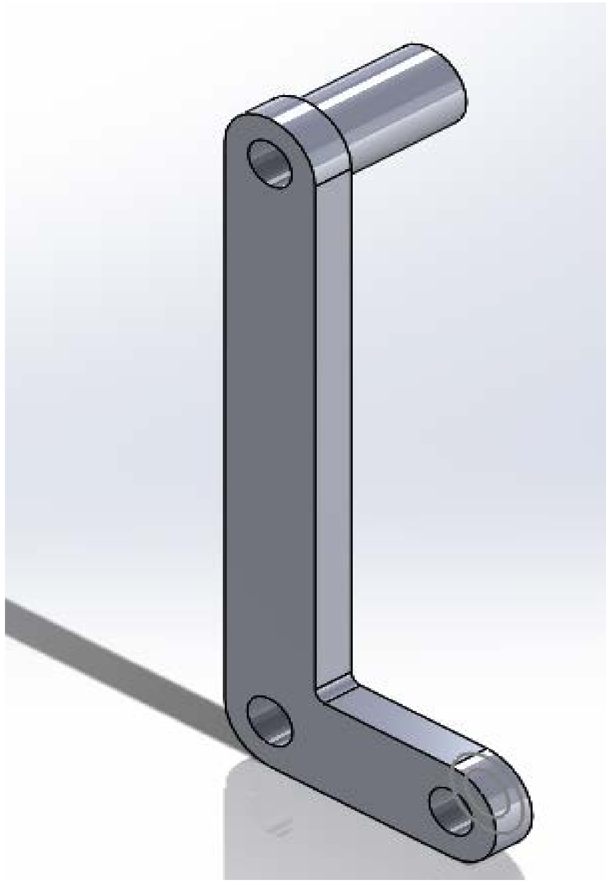


Figure 1- 55: L-bracket

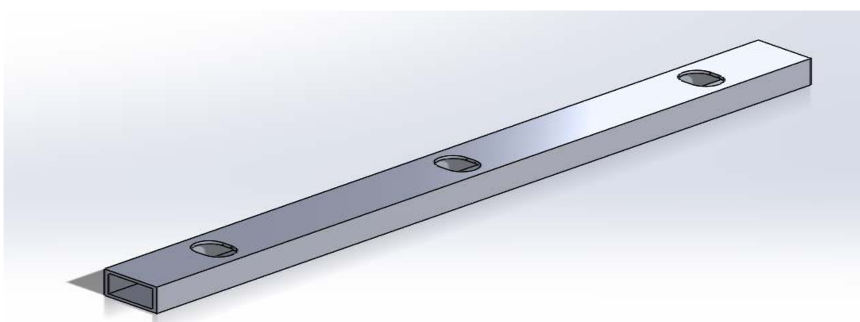


Figure 1- 56: Control Bar

The location of the braking system was critical since it determined the braking force, surface and stopping power. Initial suggestion was to place a brake system between guiding wheels but the vertical space was limited. The brake was then placed on the outer sides of the guiding wheels since braking power would be directly distributed on the guiding wheels with larger braking surface which would make it more effective in controlling speed of the vehicle. Brake bracket set up right above the guiding wheels would provide the main support for the rotor mount and caliper for braking. However, the brake mounting position was relocated to the hub motor due to the changes in design of the bogie. The main loading wheels cannot provide the smooth surface to mount the rotor and narrow space on the bogies limited the space of mounting bracket for the caliper. The hub-motor have just small space for the brake system, therefore, it required lots of modifications and fabrication step to make the brake system fit perfectly on the hub-motor. The brake rotor was mounted on the right side of the hub-motor. The Y-bar handle was bolted down on the side of the hub-motor mount to support the brake caliper. The design required lots of precision because the hub-motor had very little space on the side. The space between the caliper and the huh-motor mount was roughly 1/16 inch after assembled together. The brake motor mount had an L-shape and are made out of A36 steel. The steel was picked to provide strong support and rigidity. The holes on the plate required lots of precision to correctly align with the motor's holes since I manually marked and drilled the holes.

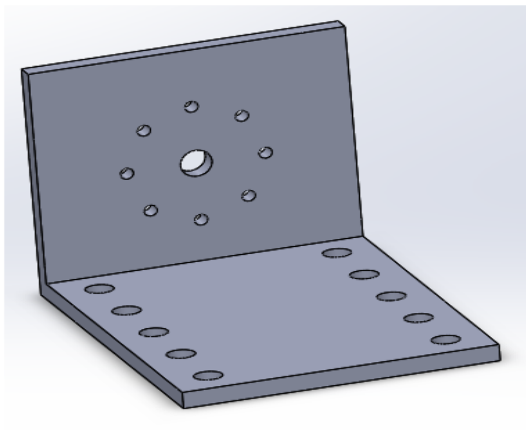


Figure 1- 57: L-shape motor mount: Front View

The designed also require a set of worm gear to reduce the RPM and increase the torque required by the brake system as shown in Figure 2. After 20 gear reduction, the motor had 9275.6 on-in and 327.8 RPM meanwhile calculated torque for brake was 1227.0768 oz-in as the entire system went down the 17 degree slope. the L-shape mount is made out of A36 steel, while the supporting block and shaft pulley are made out of aluminum 6061. They provide very strong backbone for the motor and the worm gear set. the worm did not have a key to tighten down onto the shaft, therefore, the shaft was sanded down and the worm was forced into the shaft using a tight clamp. In addition, this designed provided a very solid support to the brake system since the worm gear set would lock up the brake cable and prevent it from recoiling. The shaft pulley would be tied to a 60 lb fishing line that ensured smooth pulling. Brake housing for brake cable is necessary to prevent friction between contacting surfaces and damage the surface of the bogies.

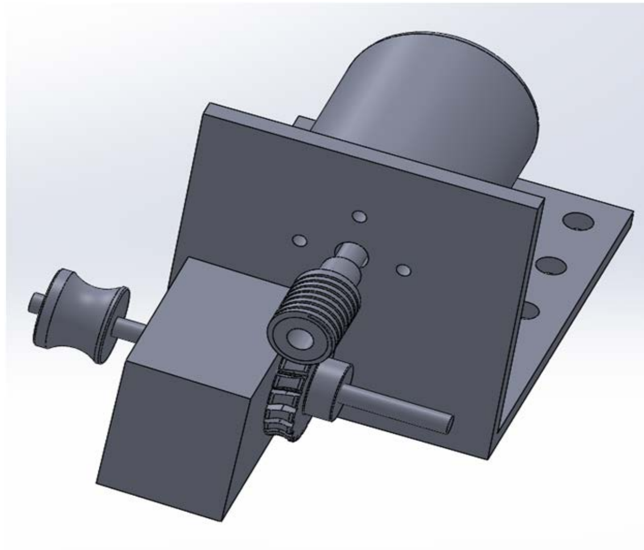
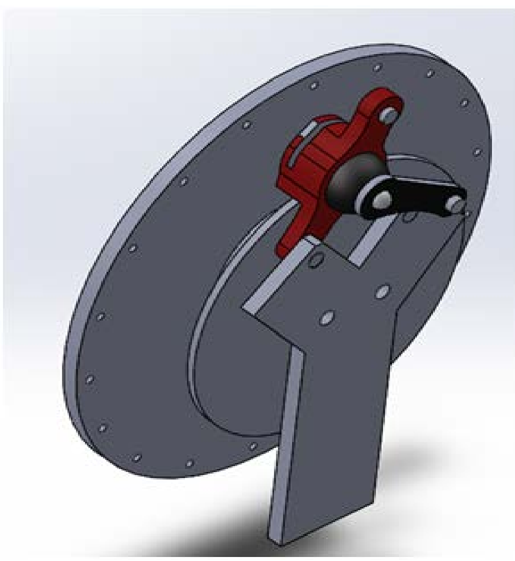


Figure 1- 58: Assembly of motor with worm gear and shaft pulley



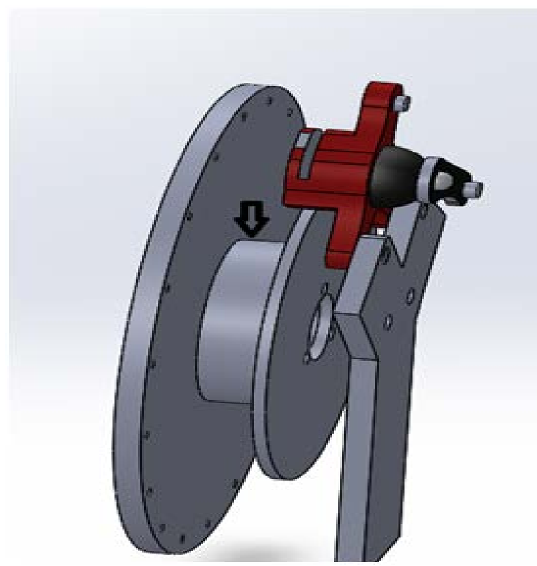


Figure 1- 59: Assembly of mount for hub-motor mount

Figure 1- 60: The brake mounted on the hub-motor

The main plate has 18 holes but only 9 holes were use to bolt onto the side of hub-motor as shown in Figure 3 above. The holes on the hub motor were drilled, threaded and size fit with the plate to make sure everything line up perfectly. The spacer (arrow pointed at) was handmade and probably wasted lot of time fabricate due to lack of tools. The holes needed thread and the tab kept on breaking inside the holes, which took lots of work to clean up and redo all over. A36 steel was used to made the mount, spacer and y-shape racket. The plates are about 1/8 thick and provided solid support to the rotor and the caliper. After running the motor and testing out the power of the brake, the mount could withstand the full torque to close the gap between brake pads.

Analysis and Concept Selections

The team carried out the stress analysis on some of the major parts of the steering mechanism in SolidWorks and our results show that the parts are designed in such a way that they can handle the stress caused by the stepper motor and the guideway. All the parts have a safety factor above 1 but through the stress analysis our team is able to foresee some of the possible weakness in our parts.

From the stress analysis, the L-shaped bracket has the highest Von Mises Stress of 9.935*10^6 N/m2 at the inner radius of the joint and the bracket may bend for 1.65mm under such load. The design can be changed to have a fillet with bigger radius. For the triangular support, there may be chances that the cylindrical part for the screw will bend when they are subject to heavy load from the linkage. The Von Mises Stress at the edge of the cylindrical parts is 5.594*10^6 N/m2. Ribs can be added for reinforcement on both the cylindrical part.

L-bracket S.F. = 2.5164

Triangular link S.F. = 44.6872

Brake bracket S.F. = 38.1128

Analysis was performed on sloped part of the guideway. From the Solidworks FEA simulation it was found that maximum deflection occurred at the top rail where the yellow wheels apply a normal force. The maximum deflection is 0.39 mm.

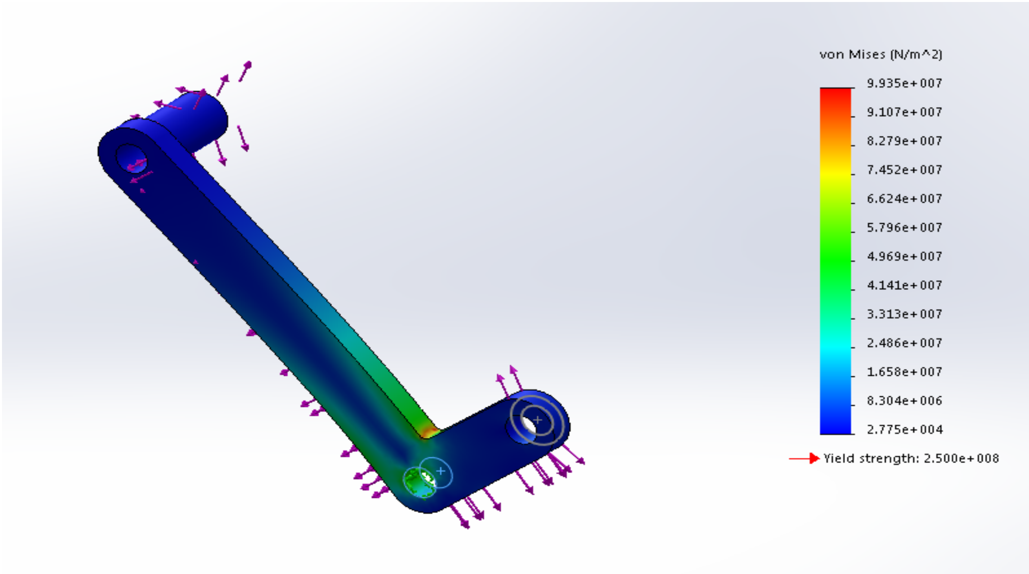


Figure 1- 61: L-bracket Von Mises stress

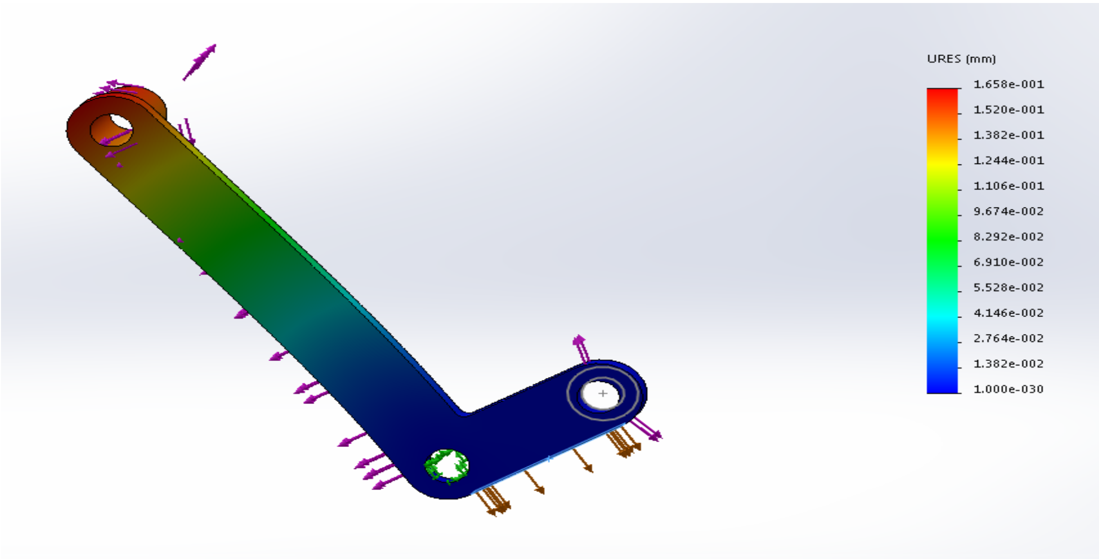


Figure 1- 62: L-bracket deformation

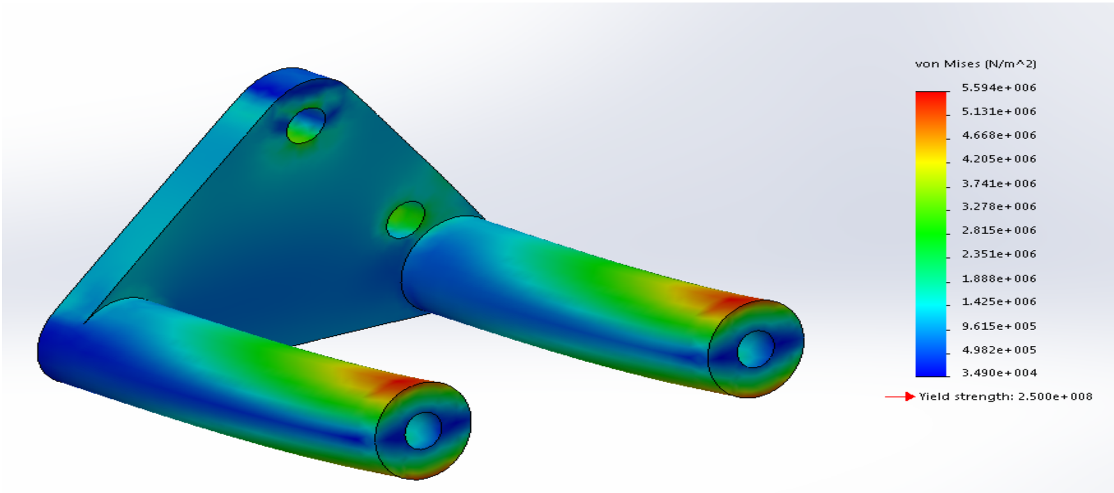


Figure 1- 63: Triangular link Von mises stress

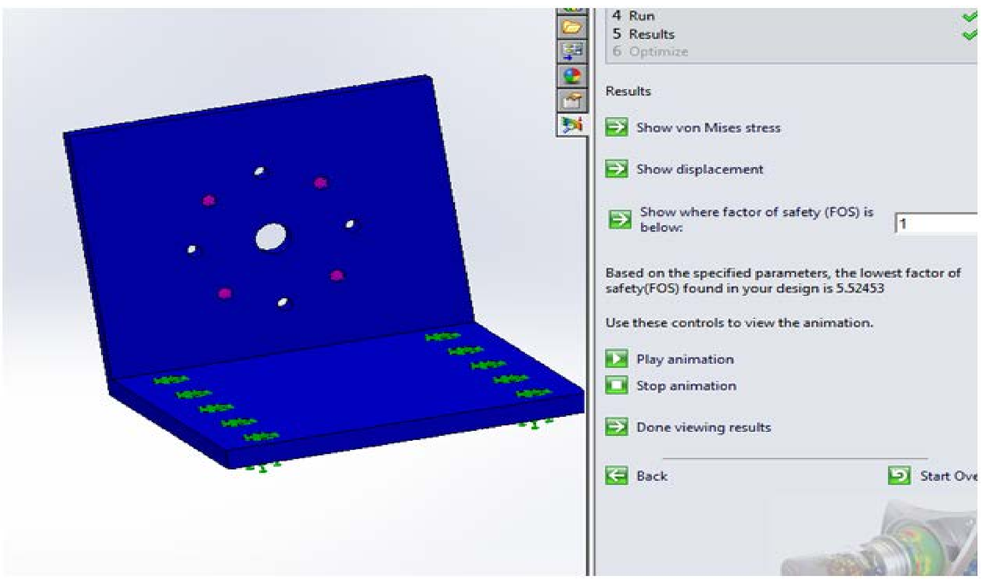


Figure 1- 64: Motor mount

<u>Testing and Validation</u>

The steering mechanism utilizes two stepper motors to actuate the control arms, one for each bogie. For the upper and lower control arms to be fully engaged against the guideway, the angle of rotation of L-linkage is about 45 degrees, which translates to about 66 degrees for both the upper and lower control arms. According to the torque curve, the maximum torque output of the stepper motor is 1696 oz-in (12.0 Nm) between 0 and 10 rpm. The torque would then exponentially drop as speed increases. A speed of 5 rpm was sufficient to have an actuation time of 1 second. The stepper motor might have been oversized at torque, but the 36:1 gearhead was necessary due to the huge moment of inertia of the control arms. Because the control arms are made out of steel, the motor needs a strong rotor inertia. A one-piece clamp-on rigid shaft coupling was chosen to connect the stepper motor shaft to the L-linkage due to providing excellent grip and holding power, preventing the chance of slippage.

The steering mechanism was tested first without putting it on the guideway. The control arms switched successfully in a smooth motion. However, it took multiple tries to physically align both upper and lower steering arms in the correct position and have them make contact to the guideway. Because the stepper motor lacks an encoder, it only knows the amount of rotation it needs to take and does not remember its starting position. As a solution, the Tiaihua switch was mounted onto the bogie with the purpose of reading the starting position of the control arms whenever the switch is pressed. With the switched pressed, the stepper motor stops rotating, which means the stepper motor has been initialized and can now turn the specified angle of rotation reliably. Another reason a switch was installed was due to possible power cutoff. It is possible that power might cut off during switching. If that is the case, the stepper motor has to reinitialize its position because when the power is back on the stepper motor wants to move the number of steps it was assigned to do.

Problems were encountered when testing for initialization. The code is written in a way that after every power cutoff, the stepper motor re-initializes itself. However, when the switch is already pressed, the motor forces to turn against the switch for a split second, which puts a lot of stress on the rigid shaft coupling. Since it is desirable to find out what the problem was, our team kept testing by changing the code slightly with no success. Because of this, the shaft coupling sustained wearing and lost grip with the output shaft of the stepper motor. This is remedied by welding on the L-shaped bracket with the coupling to increase its holding power.

Figure 1- 65: Two bogies connected to propulsion and suspension with control arms engaged

For brake system, a servo was used to test the ultrasonic code and what it does . When the threshold distance was met, the servo would go 180 degree close wise and when the threshold was not met, the servo would rotates 180 degree counterclockwise. In addition, a wii nun chuck was used to figure out the RPM of the brake system need to stop the vehicle. At rest, the clamp force of the caliper to close the gap completely was roughly 1450 rpm but with 20 gear reduction, the RPM would be 72.5 RPM and the amount of torque would be 6,956.7 oz-in. The motor had a maximum torque of 463.78 oz-in, therefore it can increase to 9275.6 oz-in. The calculated torque for the brake system going down a 17 degree decline was 1227.0768 oz-in. Therefore, the brake motor can safely produce enough torque for braking.

Since the motor was a brushless DC motor, it needed the 24V DPDT relay to change the direction since the esc was for RC aircraft and it can only go one direction. A MOSFET/transistor was used to amplify the signal for the relay coil control. Unfortunately, the test for the motor could not be carried out since the motor was broken down during the process. The causes consisted of manufacturing defect and bad wire connection which was common problem that caused a dead short. In addition, the ESC also broke due to dead short since the MOSFET was trying to drive a dead short and it would get very hot until it failed.

Fabrication Methods

The team decided that most parts of the bogie are going to be fabricated out of A36 steel due to its low cost and easy machinability. Furthermore, A36 steel is a very common structural steel as it is used in many applications such as buildings, bridges, and automotive parts, is available in variety of forms, and exhibits great mechanical properties. This type of steel also can be galvanized to provide increased corrosion resistance. There will be a lot of welding done to assemble the bogie, so A36 steel was chosen since it is easy to weld using any type of welding methods, and the welds and joints formed are of excellent quality.

The upper and lower control arms were first built in order to test fit them with the main body built by the fail-safe team. The Solidworks files are scaled down to half the size before these parts were cut by a water jet cutter. Total of 48 metal pieces were cut for the 4 upper control arms and another 8 pieces were cut for the lower control arms. The metal used for making the control arms was ⅛ inch thick A36 metal plate with size of 2 feet x 4 feet. Thicker metal, which has a thickness of ¼ inch, was used for making the L-shaped bracket and linkage connecting the left and right control arms. Total 2 L-shaped bracket and 2 Upper control arm linkage were made.

The pieces were then welded together using a MIG-welder because of its simple application and strong welding between contacting faces. Different wooden templates were made to align different faces and brackets. ⅜ inch diameter holes were drilled on the pivot joint of both the upper and lower control arms and various ⅜ diameter bolts would be used for these pivots. 4 motor mounts were also made using water jet cutter and they were later on welded on the side plates of the main body by the fail-safe team. 2 short linkage and 2 long linkage for connecting the upper and lower control arms to the L-shaped bracket were made using ¼ inch diameter tie rod and ball joint, with 28 threads per inch. The bolts for mounting the tie rod linkage were ¼ in diameter. The steel coupling was eventually welded onto the L-shaped bracket since the coupling failed to grip the shaft of the bracket firmly.

For the brake system, the parts for the mount are designed by solidworks then drilled and cut by drill press and powered friction band saw. The shaft pulley was customized in a machine shop while the hub-motor plate and caliper y-bar were water-jet in the tech-shop. The worm gear set were purchased from Boston gear.

Outcomes

The CAD model of the steering mechanism successfully synchronized the motion of both the upper and lower steering links. However, a lot of position adjustments were made to the L-bracket and tie-rods to ensure both steering links were perfectly in sync and pressed against the track equally. The length of some parts needed to be altered. The length of the linkage connecting both the upper control arms was changed from 6.17 inches to 7.22 inches in order to avoid possible toggle position of the short tie rod and L-shaped bracket ar dead end position. The longer part of the L-shaped bracket was extended from 6 inches to 6.18 inches. The lengths of the tie rods remain the same. Portion of the bogie side plates needed to be cut out to allow clearance for the motion of the mechanism linkage. The stress analysis on the steering mechanism shows that the L-bracket and tie-rods are able to handle the stresses generated during switching. The safety factors of all parts analyzed are well above the requirement.

The SolidWorks motion tool was used to simulate the motion of the steering mechanism, which successfully switched in both directions. Although the team met its goals by getting the CAD model to work successfully in SolidWorks, a lot more work needs to be done to get the prototype to work in real life situations.

The Finite Element Analysis on the brake bracket showed the lowest safety of 38.1128 with 1000 lb-f applied, which indicated that the design was very safe due to thickness of the beam. However, brake was an important safety feature therefore, it would be recommended to have a large margin of safety in case of extreme accidents.

Discussion

There were a number of substantial challenges that needed to be overcome when designing both the steering and braking mechanism. In the beginning of the semester, a lot of different ideas were iterated from all team members and sketches were made to display our ideas. A lot of these ideas displayed a lot of potential, but in the end many of these ideas were discarded for being too complicated to manufacture and adding too much complexity to the system. Because simplicity is key when designing the prototype of the bogie, it was decided in the end to modify last year's bogie design instead of designing a completely new prototype as its design appeared relatively simple. Modifying last year's bogie proved to be a challenge because the bogie offered limited space for modifications.

When making progress on the prototype design, the challenge was to also keep track of the designs of the fail-safe to ensure none of the designs interfere with each other and are compatible. The hinge on the lower switching link was extended to allow enough clearance for the fail-safe team to add their upstop wheels. In addition, the upper switching arms were extended a bit to fit the fail safe hooks. Frequent communications were also made between the steering and guideway members to discuss about how thick the guideway and how much clearance there needed to be between the steering wheels and the center wheels to ensure the wheels are securely pressed against the track.

Fabrication process was very time consuming for the steering and braking system. The bogie design was scaled down to half-scale and that made everything to be very compact. There were lots of components added upon the previous design of the bogies and the fabrication goal was to make sure everything fit well together. Lots of grinding and surface sanding were done to make sure the surfaces are not scratching and rubbing against each other on the bogies. The steering arms were nicely surface-finished with lots of sanding. When the bogies were mounted on the guideway, there were swaying due to the weak support from the bogie frame. Therefore, support components can be modified to ensure the frame is rigid. In addition, the steering were adjusted many times at the techshop to make sure all the parts are free of tight connections at the bolts and hinges.

Conclusion / Suggestions for Future Work

The design of the steering mechanism met the specifications. The torque needed to actuate the control arms is 5 Nm. The stepper motor, rated at 12Nm, far exceeded the calculated torque. Furthermore, the motor put out the speed desired to actuate the control arms. At just 5 rpm, both control arms were able to rotate in sync with an actuation time of just one second, which exceeded our expectations of having an initial switching time of 3 seconds.

However, there is rooms for improvement in our design and fabrication process. First of all, our team has noticed there is excessive play in the pivot point of control arms, which could be the result of improper size of drill bit used or larger tolerance in the size of drill bit. The play can be further reduced by using a lathe to cut holes for different pivot points with much careful measurement and load bearing or ball bearing can be used instead of just bolts on the pivot points for smoother and more precise motion. Secondly, the coupling is not able to grip the shaft of the L-shaped bracket firmly and it is recommended that a key for a positioning a set screw should be made on the shaft. Our solution is to weld the coupling onto the L-shaped bracket. Lastly, the upper side wheels seem to be pressed against the railway too firmly and there is very little space for them to maneuver. A pivot point can be added to the support of the side wheels so that the whole assembly is allowed to rotate and follow the railway more easily.

The design of brake system met the specs since the power needed for the brake system was far exceeded the calculated needed. Calculated power without friction was 0.284 horse power and the motor could provide three horse power. The maximum RPM of the motor was 6556 which could significantly improve the response time of the brake since the vehicle was going down a decline. The worm gear set was designed in a way that prevent the cable brake from recoil since the worm wheel cannot drive the worm but the worm could drive the worm wheel.

We learned so much throughout the project from designing the parts on solidworks, fabrication process, machining parts and familiarizing ourselves with all the tools and equipments. The fabrication could be done in timing manner with better equipments, tools and professional help from machinists. Central shop has good resource from machinist Kyle that can help students get the metal parts drill, cut, tab and trim down. For our sub-team, we did improve the bogie steering mechanism with an efficient design. The brake system consists of hub-motor mount, worm gear set mechanism and motor mount. Unfortunately, the main motor broke down due to bad wire connections and manufacturing defect, therefore, the testing of the brake was not carried out properly. However, the motor and worm gear mechanism was able to clamp the caliper brake pads together with 1450 RPM which is 72.5 RPM and 2051 oz-in torque after twenty gear reduction. The braking system could used a power-off brake to make sure the wheel from roaming if the power line is cut.

What should be done by the next group of Super way engineers to improve upon your work and take it to the next level?

The stepper motor could be mounted into a better position as it was very hard work within the tight space of the bogie and its looks rather awkward with the motor sticking out of both ends of the bogie. Although the stepper motors did the job, the motor was most likely oversized too much. In the future a motor with lower specs could be used. Due to time constraints, not enough time was spent sizing for the ideal motor.

For the brake system, a stepper motor can be easier to work with since it can be programmed to go forth ward and reverse with good holding torque. However, the stepper can be slow since it is designed to give a higher torque at a lower RPM and the higher RPM can costed weaker torque. The fail-safe brake can be purchased online from the different companies such as Warnerelectric and Ogura industrial corp. The fail-safe brake will need more space on the bogies since there is very limited space to work with. For fabrication, having a solid plan is very important since it will save you lots of time instead of keep failing in making a part. It will be very important to work with all other sub-team to get an accurate data and correct dimensioning when building the parts that need to fit onto the bogie and propulsion.

Overall project conclusions, broader impacts, and recommendations

The project can be improved in many aspect in term of sub-teams. There should be a cap for each sub-team and each sub-team needs to contribute evenly amount of work in the project. There are many areas of the project where some people can provide supports by creating a spreadsheet on the fabrication plan and sign up for it. The project is a great way to build leadership skills and teamwork by communicating between the sub-teams. If the sub-teams were divided up evenly in the beginning, there would not be so many miscommunication between the sub-teams and the building plan to meet the deadlines.

Intermediate Active Suspension

Objectives

Due to the many axes of excitation in transportation, our suspension system needs to be able to adapt to a variety of situations, and satisfy the following key points:

1. The suspension system must isolate any vibration in the vertical axis due to the bogie wheels rolling against the overhead track. Vibration can come from irregularities in the track such as seams and transitions or unevenness in the rail construction.
2. The suspension system must allow for the cabin to tilt front to back and stay level with the ground when ascending or descending rail grades of assumed 17-degree angles. At

the same time, the suspension system must stop the cabin from swaying front to back when it experiences an abrupt start or stop.

3. The suspension system must allow for the cabin to remain parallel with the ground and even with the platform when at a station, as well as counteracting the load/passenger weight to keep the cabin entrance same level as the platform. This will ensure easy access to the wheelchair users.
4. Since these conditions require that the suspension system be active, the suspension system must have sensors monitoring the motion and the track of the system, as well as a control system to interpret its current state and make the appropriate adjustments.
5. The system must be able to interface with the bogie and cabin in a compact design that is easily concealable for aesthetic purposes

Design Requirements and Specifications

The active suspension team is a completely new addition the Spartan Superway project. Integrating an active suspension into the bogie and cabin system is another feature that complements the forward thinking design of the project as a whole. In the context of this project, an active suspension was once thought of as only a luxury feature that could be omitted. However, with changes in track angle and elevation between stations, a means of controlling the cabin angle was found to be a necessity. Upon further investigation, it was determined that there are a number of design requirements that would be demanded of the active suspension in order to produce and safe and comfortable ride for Spartan Superway passengers.

In general, the active suspension system will need to satisfy the following six design requirements:

1. The cabin must be must maintain a horizontal angle (parallel with respect to ground).
2. The suspension system should constrain the movement of the cabin such that there are only two degrees of freedom (2 DOF).
3. A damping system will be needed to isolate the cabin from vibrations and oscillatory motion.
4. The suspension system must be capable of leveling the cabin to the station platform.
5. The suspension system must interface to both the cabin and the bogie.
6. All components and hardware must have a sufficient safety factor associated with the forces and stresses imposed by static and dynamic loading.

Design Specifications:

The cabin angle must be controlled such that it will be able to negotiate a 17^{o} change in angle of the guideway. The rate at which the guideway angle changes, and the velocity of the cabin during transit, will dictate the angular velocity at which the cabin must rotate in order to maintain a horizontal orientation (Eq.1). The required angular velocity of the cabin can be determined using the following equation:

$\omega = vr = d\theta dt$ (1)

Where:

ω=angular velocity of cabin about the pitch axis

v=linear velocity of cabin

r=radius of rotation

d/dt=change in angle of cabin with respect to time

It was determined that that the cabin's motion be constrained to 2 DOF, vertical translation, and rotation parallel to the guideway (pitch axis as seen in Figure 1-66). Adding a third degree of freedom to the roll axis was considered, but was eventually considered unnecessary. While the cabin will be negotiating turns on the guideway, the radius of these turns and the velocity at which they will be traversed are both small enough that the radial component of acceleration can be considered negligible (Figure 1-67). However, to compensate for the small amount of torque generated from the angular acceleration, flexible bushings should be used to lessen the possibility of fatigue failure of rigidly mounted hardware and components.

$\alpha=d\omega dt$ (2)

$at=\alpha r=d\omega dtr$ (3)

$ac=\omega 2*r=v2r$(4)

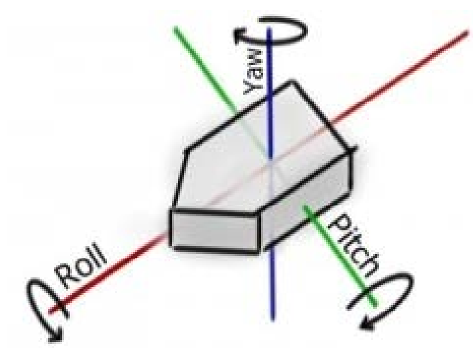


Figure 1- 66: Pitch axis

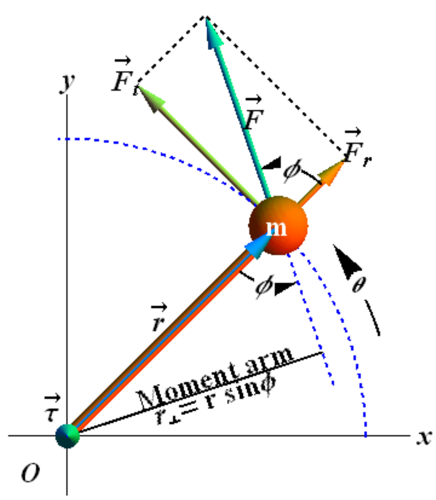


Figure 1- 67: SEQ Figure* ARABIC \s 138: Torque and Angular Momentum of a Ridgid body

$\tau=I\alpha$(5)

Where:

α=angular acceleration

a_t=tangential acceleration

a_c=centripetal acceleration

r=radius of arc

τ=torque

I=angular momentum

For the ¼ scale suspension design, an estimated 650lbs was accounted for in the weight of the cabin plus the weight of the passengers. This figure will dictate the damping parameters of the suspension system (Figure 1-68). To provide vibration isolation and oscillation control, the spring constant and damping coefficient should be chosen such that the suspension system is in a slightly underdamped state. An overdamped system would certainly limit any oscillations from occurring, but it would likely inhibit the suspension's ability to cycle and result in rigid ride quality. While critically damped systems return to equilibrium the fastest without any oscillation, this would still result in a stiff or harsh ride for the passenger.

Choosing a slightly underdamped system will allow for some oscillations; however, the benefit will be more comfortable ride characteristics. Ideally, the oscillation will be dissipated and the system will return to equilibrium in 2 cycles or less (Figure 1-69). The damping ratio ζ is a function of the system's spring stiffness, damping coefficient, and sprung mass, and should be around 0.4-0.8 to achieve the best balance between damping and rider comfort.

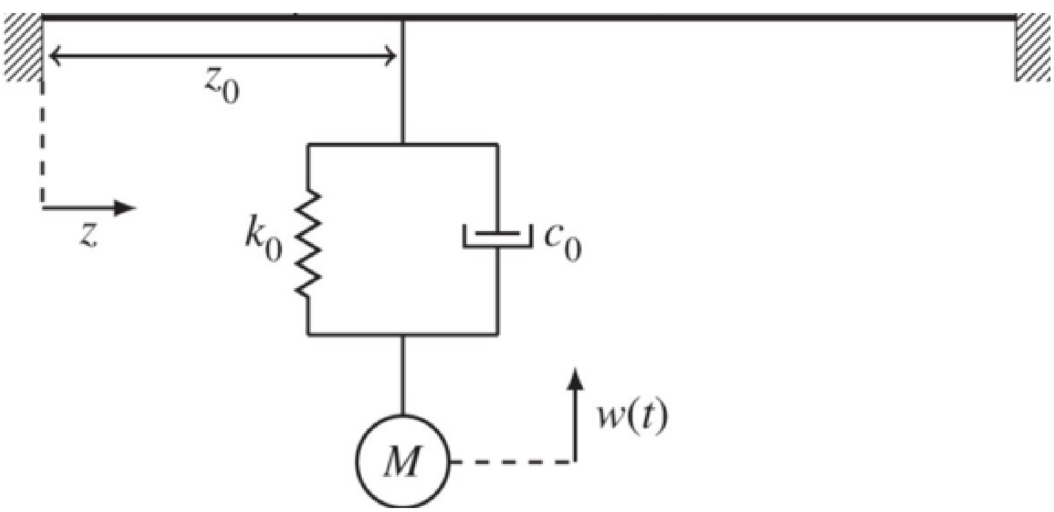


*Figure 1- 68: SEQ Figure *ARABIC \s 1 39 Dampled spring mass system with vertical motion*

*Fs=k*x (6)*

*Fd=c*v(7)*

$\omega n=km(8)$

$\omega d=\omega n1\text{-}\zeta 2 \;(9)$

$\zeta=c2*m*k \,,\; 0.4<\zeta<0.8(10)$

Where:

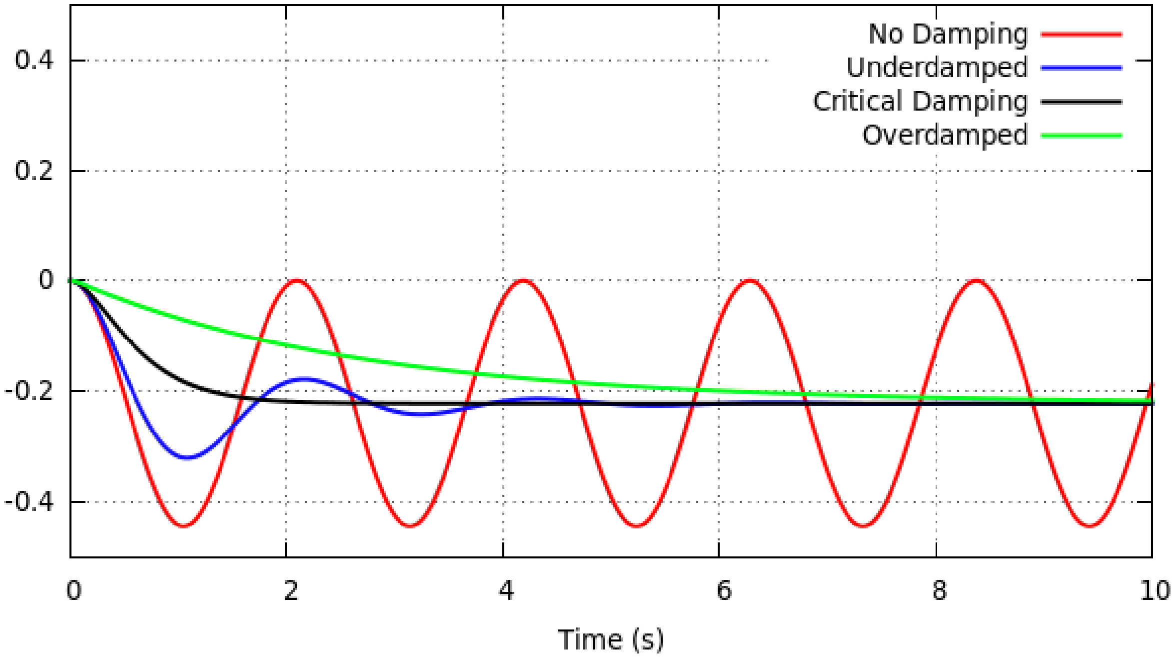


*Figure 1- 69: SEQ Figured * ARABIC \s 140 Different damping systems scenarios*

k=spring stiffness

x=spring displacement

c=damping coefficient

v=velocity of spring displacement

F_s=spring force

F_d=damper force

$_n$=natural circular frequency

$_d$=damped circular frequency

ζ=damping ratio

The addition of a suspension system to the cabin inherently adds some complexity to the overall system. One problem that will arise from the suspension system is the deflection of the springs when loaded. When the springs compress, the cabin will be displaced vertically, leading a misalignment with station platforms when loading and unloading passengers. In order to cope with this problem, the active suspension system will need to alter its position to maintain alignment with station platforms, which is especially important for disabled persons who depend on wheelchairs for mobility (Figure 1-70). The best approach to solving this problem will involve changing the position of the cabin relative to the platform without further causing a displacement of the suspension system. This way, leveling the cabin does not work against the spring and damper through compression or extension, and the two systems can operate independently of one another.

Figure 1- 70: The position of the cabin and station platform must be level in order to ensure passenger safety and convenience

When designing the suspension system, many ideas and concepts were proposed, some more complicated than others, and each with its pros and cons. Part of working with many sub-teams on a large scale project such as Spartan Superway, requires the consideration that many systems will need to come together and be integrated into a seamless final product. Designing a suspension system that has adaptability as well as flexibility when it comes to interfacing to the bogie and cabin will be crucial (Figure 1-71).

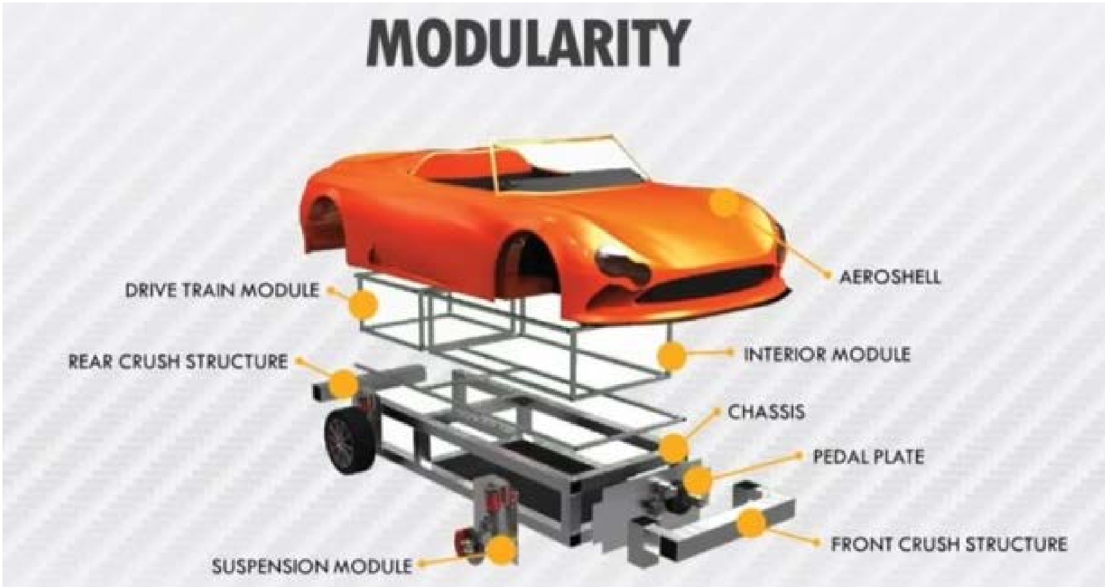


Figure 1- 71: An example of utilizing a modular design approach where parts are built around certain specifications, ensuring compatibility even after small changes are made

The best approach will be a modular one, where components can easily be resized or changed without needing to completely redesign the system. In a large group it is natural for there to be some uncertainty in the final dimensions or configuration of different systems, therefore, it may be best to choose a design that is simple yet effective.

Perhaps the most important design requirement for any mechanical system used or operated by humans is the factor of safety. Due to the nature of suspended cabin, the factor of safety of the suspension components is the last line of defense between the cabin and bogie. Hardware and components must be selected such that there is a high margin of safety with the mindset that “a chain is only as strong as the weakest link”. On this particular system, some components may be overdesigned in terms of strength, as unpredictable failure could lead to catastrophic results. The materials used will dictate the ultimate yield strength of different components. Failures due to axial loading, shear stress, transverse shear stress, and bending will need to be considered.

Safety Factors in General:

$$Factor\ of\ Safety = \frac{\sigma_{yield}}{\sigma_{max}} \quad (11)$$

$$Margin\ of\ Safety = Factor\ of\ Safety - 1 \quad (12)$$

Stresses to be considered:

$$Axial:\ \sigma_a = \frac{F}{A} \quad (13)$$

Where:

F=applied force

A=affected area

Bending: $\sigma b = M*cI(14)$

Where:

M=resultant internal moment

c=perpendicular distance from neutral axis to extreme fiber

I=moment of inertia of cross section about neutral axis

Shear: $\tau = V*QI*t(15)$

Where:

V=internal resultant shear force

Q= y'A' where A' is the area above or below where t is measured, and y' is the distance between the neutral axis and centroid of A'

I=moment of inertia of cross section about neutral axis

t=width of cross section where is measured

<u>State-of-the-Art/Literature Review</u>

Many organizations and companies around the world are working hard to solve the traffic congestions and accident problems by bringing in a new age transportation system. Even though it has been more than twenty years, we are yet to perfect the design. While there are many small scale offline transportation systems such as Morgantown PRT (Figure 1-72), it still uses large railway and infrastructure as that of BART trains.

Figure 1- 72: Morgan Town Public Rail Road Transit System

As one of the problems we have tried to solve, having a gigantic infrastructure as seen above is not space saving, and very costly. Which makes the design irrelevant to our design, and the suspension system was not considered. On the other hand, there are many small scale in-town transportation systems that suspend from guideways. Such motorized elevated tram systems include: Wuppertal Suspension Railway Figure 1-73, and the Chiba city Suspension Railway Figure 1-74.

Figure 1- 73: Wuppertal Suspension Railway

Figure 1- 74: Chiba Suspension Railway

The fault with these types of transportation system suspension design is that they simply use the suspension system that resembles closely to that of a train Figure 1-75. They do not incline or decline, and the suspension is definitely not actively controlled. As one of the design requirements, we are to solve this issue by creating an active suspension system that puts the comfort of the rider first.

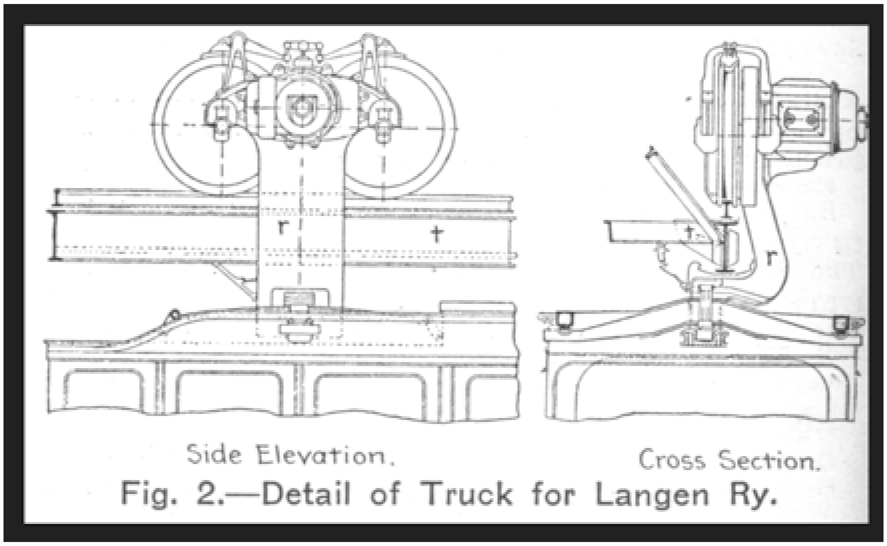


Figure 1- 75: Suspension System of a Typical Suspended Railway Transit System

So these systems so far were no help in designing our suspension system. Our search for the previously designed products continued. During our research, it became clear that no other suspended guideway system that actively controls its ride has not been invented yet, and we are in an uncharted territory. However, this does not mean there are none being developed. For example, in Secaucus, New Jersey Jpods are being developed (Figure 1-76). They are suspended offline transit system that closely resembles ours. But they have not yet come up with the solution of leveling, and providing comfort to the cabin. Similarly, there is Swift, a slightly larger system being developed for Boulder, Colorado (Figure 1-77).

Figure 1- 76: JPods

Figure 1- 77: Swift

As it can be seen from the pictures, the current design only includes suspending the pods from the bogie with direct connections that translate every vibration and imperfection directly to the cabin for the rider to feel. They are currently being developed but they have not come up with the final design yet. Lastly, the most relevant design, that seems to resemble our system the closest is the Metropolitan Individual System of Transportation on an Elevated Railway (MISTER), that utilizes small pods for transportation (Figure 1-78) and is being developed to be able to elevate up a slope of 45 degree angles (Figure 1-79). It appears there has not been much information released on the design of the suspension system.

Figure 1- 78: MISTER pod design

Figure 1- 79: MISTER at a decline of 45 degrees

Because of the suspension system has not been fully developed yet, we are privileged to be the pioneers in developing the first active suspended suspension system, that self-levels and controls the ride tilt to provide comfort during ascent and descent of the cabin.

Design Concepts and Final Design

As soon as we started the project, our work had been cut out for us and it was clear what the suspension system needed to accomplish. As stated in the design specification section, we needed our suspension system to do:

- The cabin must maintain an orientation that is parallel to the ground
- Allow only two degrees of freedom
- Isolate the vibration caused due to the track and traveling motion
- Capability of leveling the cabin to the platform under different loads

During our team meetings to come up with the different ideas to solve the problems, and few of the important designs worth mentioning are shown. Many other design concepts did not make it in the report. All of the sub team members were required to come up with 5 different concept drawings and the voted as a team to choose the best design. Following are few top designs:

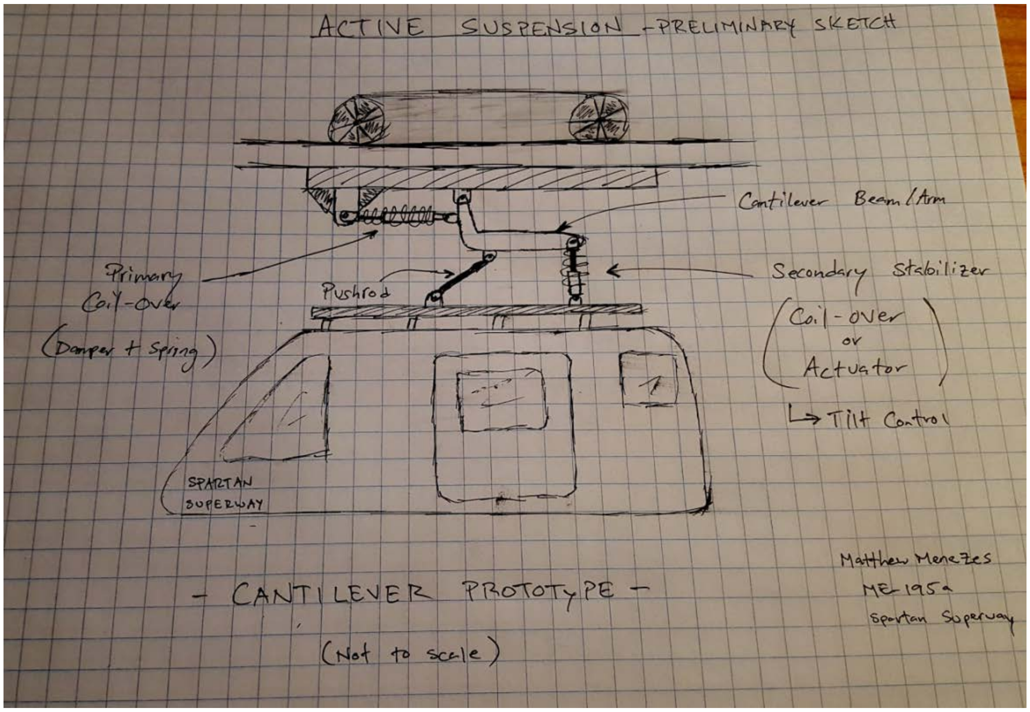


Figure 1- 80: Cantilever Design Suspension

This design (Figure 1-80) was a good start for us. Cantilever style links and coil overs were used to control and assist the tilting and the isolation of vibration. While this design would have helped to bring the cabin close to the guideway, giving more ground clearance, did not address the issue of lifting and lowering the cabin to allow easy access to the wheelchair users.

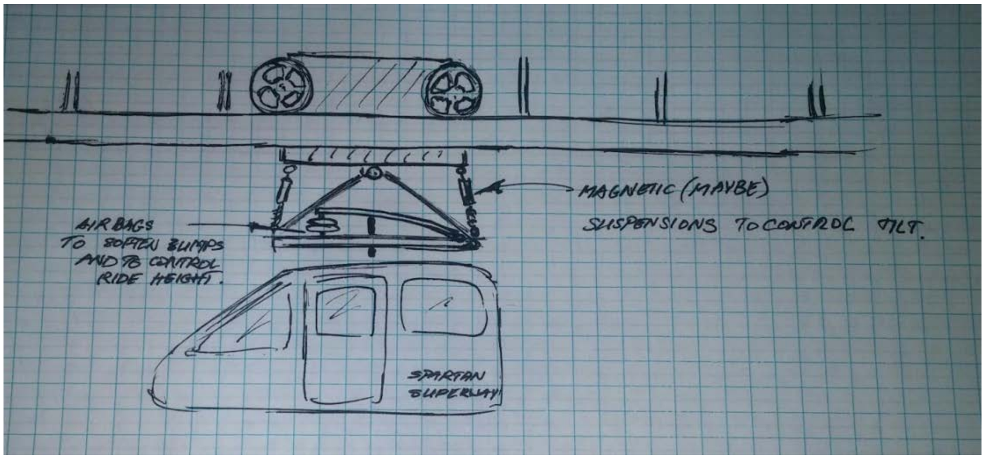


Figure 1- 81: Utilization of Air Bag and Magnetic Dampers

A Above design (Figure 1-81) utilized the help of an air bag system that is found commonly on modified cars, and high-end luxury cars to control ride height, as opposed to the previous design that lacked the ability to do so. Hall effect sensors would have been used to sense the position of the cabin as it arrives at the platform, and the airbag would raise or lower the cabin to align the cabin perfectly. Magnetically controlled dampers are used to control the tilt as travelling through the sloped section of the guideway. This was a good design but it seemed to be tilting the cabin as it lowers or raises the cabin, and would take many complicated parts to solve the problem. For that reason, this design concept was deemed not sufficient.

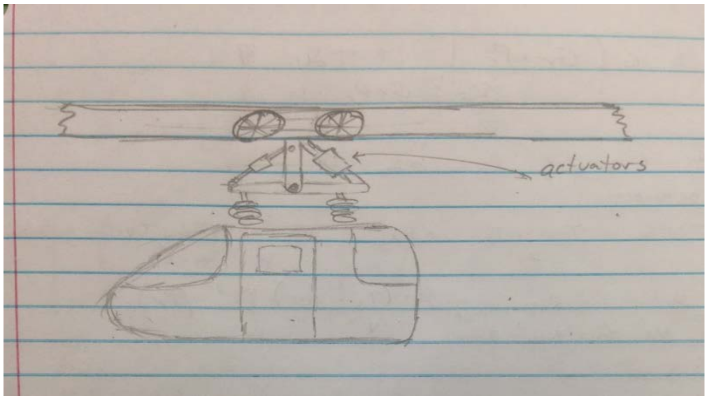


Figure 1- 82: Utilizing Actuators and Coil Overs

This design was one of the highest rated design, utilizing linear actuators to control the tilt of the cabin, and the set of coil over to dampen the vibration. By far this is the closest design to our winning design concept. Figure 1-82 shows how the suspension would look like while the guideway is level to the ground, and Figure 1-83 below shows how the suspension handles different slopes.

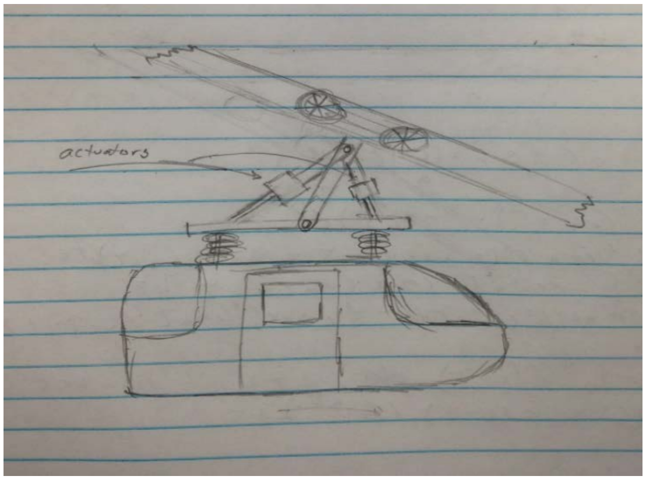


Figure 1- 83: Actuators and coil over to keep the cabin level

Our members' process of design evolution can be seen from the previous figures. These have been just the concept drawings to determine the feasibility of our system. While we were choosing the best design, we have also taken into consideration that our suspension system should take up less space, giving the overall design a slick and futuristic look. The design we have chosen can be seen in Figure 1-84 below.

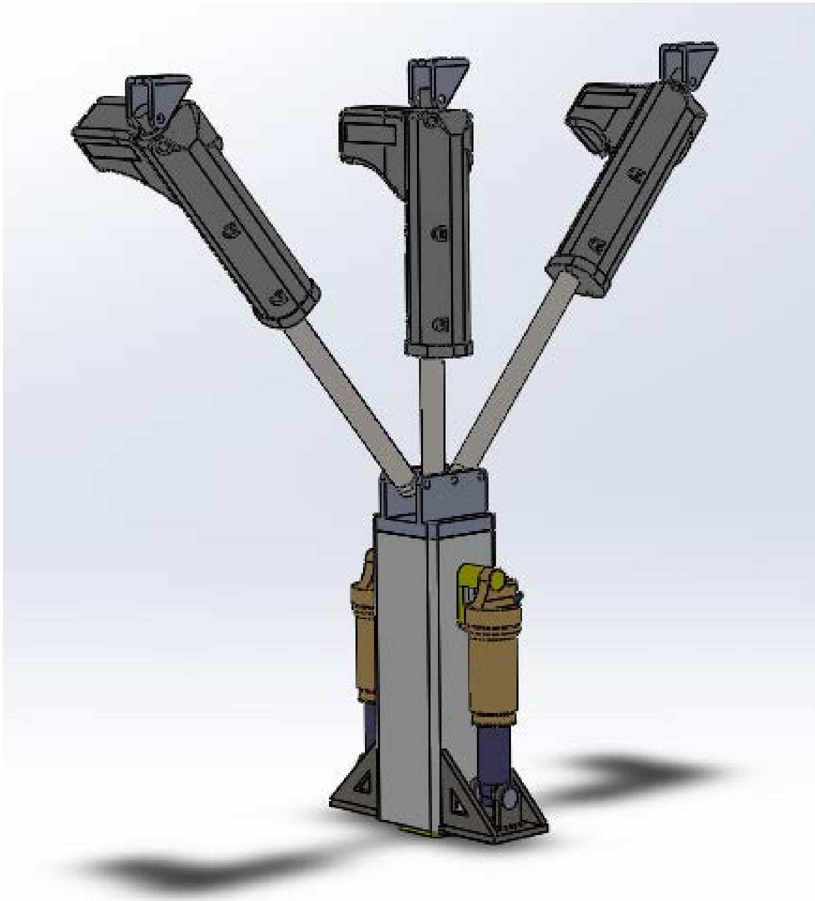


Figure 1- 84: Final Design

This design uses two nested square tubes to turn a system in tension into a system in compression. The inner tube, seen in Figure 1-83 below, connects to the cabin and is pulled down due to the mass of the cabin and cargo. The shock pin then pushes down and compresses the shock absorbers against the supports connected to the outer tube. The outer tube, seen in Figure 1-84, is supported by the top connection plate, seen in Figure 1-85, which connects to the three actuators above which connect to the bogie.

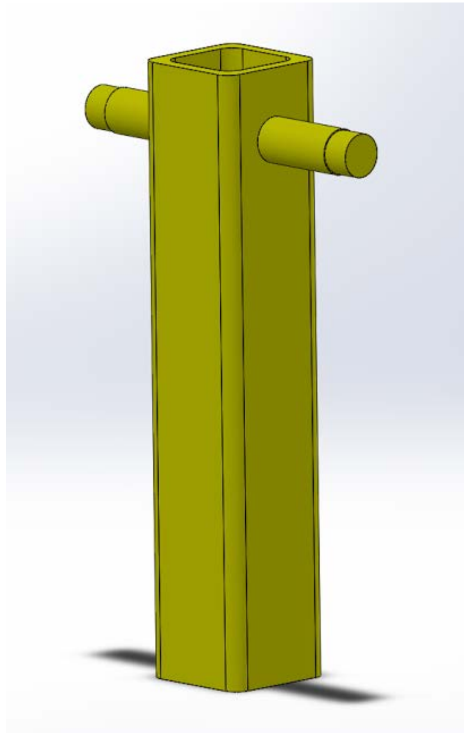


Figure 1- 85: Inner Tube with Shock Pin

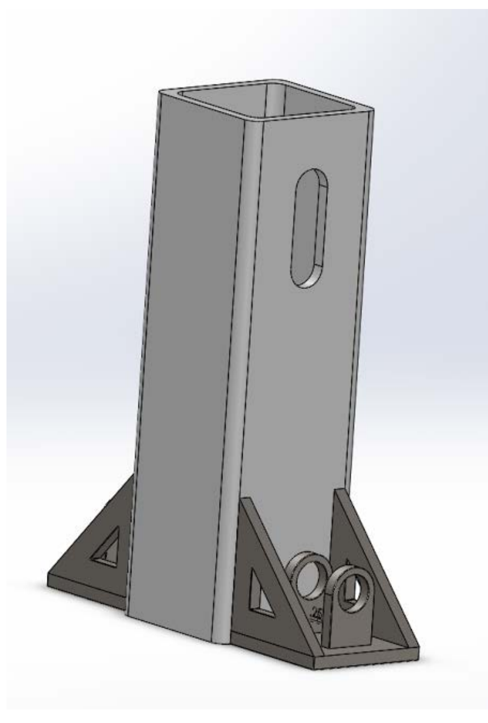


Figure 1- 86: Outer Tube with supports

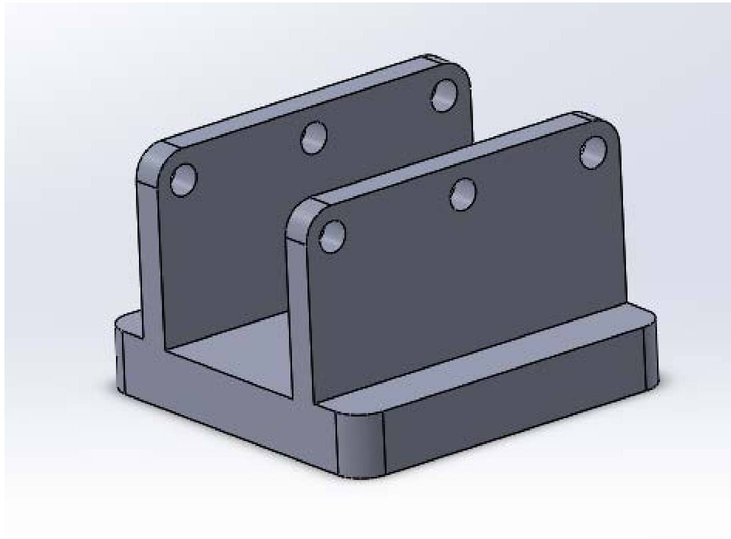


Figure 1- 87: Top connection plate

The two shock absorbers work in parallel to support heavy loads while also keeping the loading symmetrical throughout the system. The three actuators are used to allow the cabin to tilt during ascension and descent as well as raise and lower the cabin while loading and unloading passengers. In order to control the three actuators with regards to tilting, an IMU (Inertial Measurement Unit) is placed inside the cabin to measure acceleration and radial velocity of the cabin. This information, with correct interpretation, is used to determine the orientation of the cabin with respect to the ground. Additionally, three hall effect sensors are spaced vertically on the cabins outer wall to sense a magnet on a known location of the station platform. The sensors can detect the presence of the magnet and the different readings can be used to determine the cabin's height with respect to the magnet. This information is used to then adjust the cabin so that the floor of the cabin is flush with the floor of the station platform.

<u>Analysis</u>

The components of the vibration isolation system needed to be evaluated to ensure the quality and performance of the design. The analysis was iterated in an excess of ten times and design changes were made appropriately. Only the analysis of the final design is represented here. In order to begin the evaluation process, an appropriate loading needed to be determined. The loading was determined from an estimated absolute maximum "Full Scale" loading in Equation 16.

$$F_{FullScale} = 2,500 lbf \qquad F_{\frac{1}{4}scale} = \frac{F_{FullScale}}{4} = 625 lbf \tag{16}$$

The loading was then appropriately applied to components of the vibration isolation components of the system.

The Bottom Tube assembly consists of the Bottom Tube, which connects to the cabin, and the Main Pin, which connects to the shock absorbers. The loading was applied to the Main Pin of the Bottom Tube of the assembly. The loading was applied to the very ends of the pin to produce a more conservative simulation. The Main Pin experiences the maximum von Mises stress of 17,990 psi. Although von Mises stresses are commonly used to determine the Factor of Safety (FOS) of a system, one must consider normal and shear stresses as well. The Main Pin has a minimum FOS of 3.1 due to normal stress. The Bottom Tube experiences a maximum von Mises stress of 17,690 psi. The Bottom Tube has a minimum FOS of 2.0 due to normal stress. The Bottom Tube assembly has an overall FOS of 2.0 due to the normal stress in the Bottom Tube. See Figure 1-88 for the distribution of von Mises stresses in the Bottom Tube assembly.

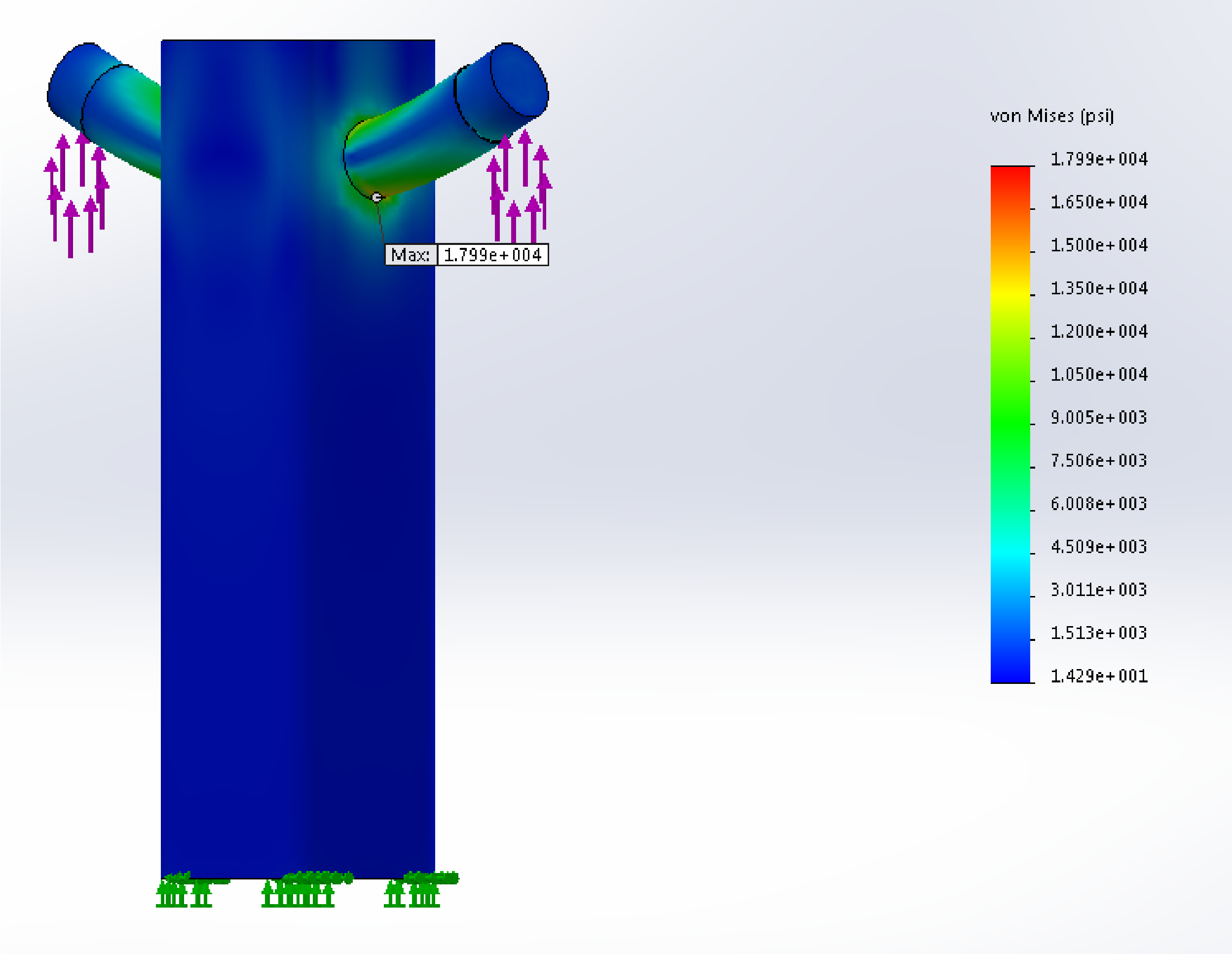
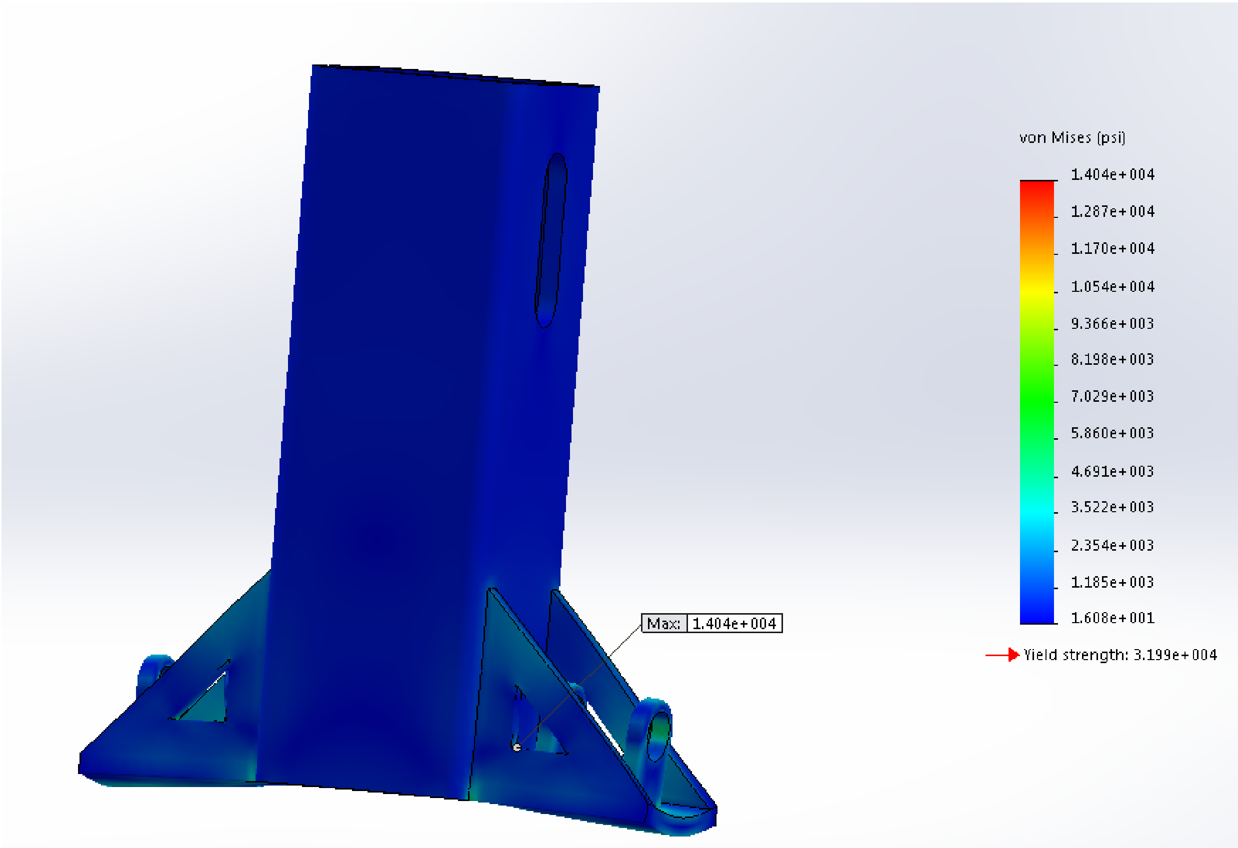


Figure 1- 88: This figure represents the distribution of the von Mises stresses in the Bottom Tube assembly.

The Top Tube assembly consists of the Top Tube, which connects the suspension system to the actuators, and a few other components that work in conjunction to connect to the shock absorbers. The loading was applied to the Tabs of the Top Tube assembly. This is the component that eventually connects the bogie to the shock absorbers. The loading was applied to the inside faces of the Tabs to produce an accurate simulation. The Brace experiences the maximum von Mises stress of 14,040 psi. When evaluating the Top Tube assembly as a whole, the Top Tube assembly has a minimum FOS of 1.7 due to the normal stress in the Tabs. This is a conservative FOS since the simulation software does not have the ability to account for the filet-like characteristics of the welds that hold the tabs to the rest of the Top Tube assembly. Therefore, the Top Tube assembly has a FOS greater than 1.7. See Figure 1-89 for the distribution of von Mises stresses in the Top Tube assembly.



The Top Connection Plate is used to connect the Top Tube assembly to the actuators. The loading was applied to the inside faces of the holes in the Top Connection Plate. The loading was applied along multiple axes to represent the non-vertical loading in the two outside holes. The Top Connection Plate experiences maximum von Mises stresses in the outside hole at a magnitude of 1,883 psi. Due to the normal stress in the Top Connection Plate, the part has a FOS of 2.0. Thus, the entire vibration isolation portion of the active suspension system has a FOS of greater than 1.7. See Figure 1-90 for the distribution of von Mises stresses in the Top Tube assembly.

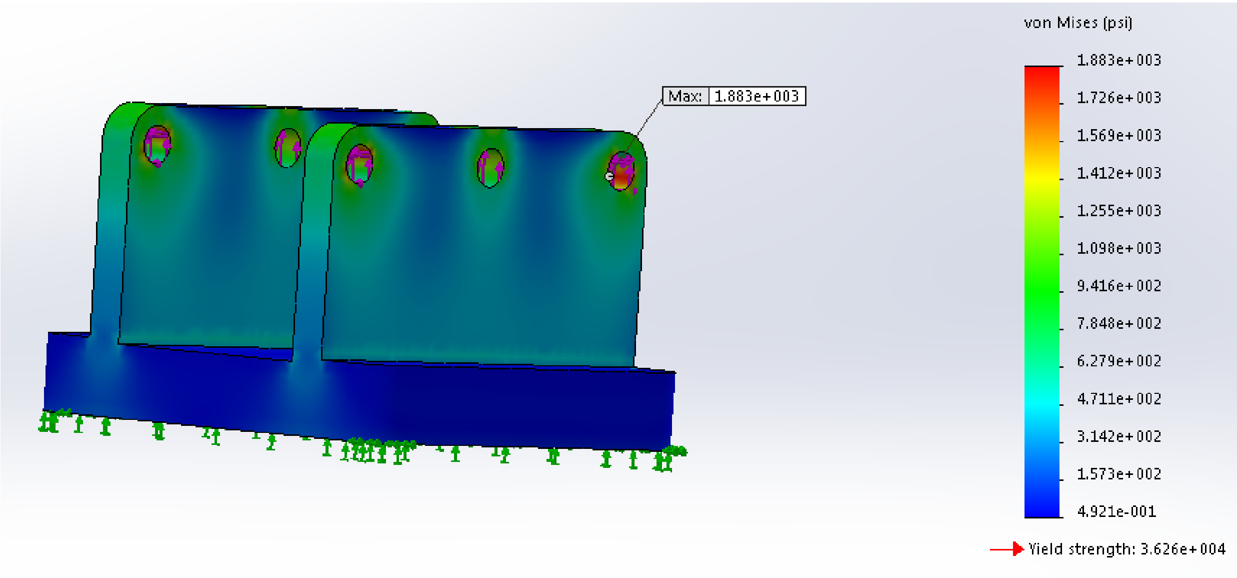


Figure 1- 89: This figure shows the distribution of von Mises stresses in the Top Connection Plate.

The shock absorbers that have been chosen to utilize in this design are air shocks. Thus, that the spring rate of the shocks is progressive. That means that as the shocks are compressed, the spring rate increases. This makes it difficult to calculate the natural frequency of the system. Using estimated dimensions of the shocks and the Ideal Gas Law, the force provided by the pressurized air in the shock could be calculated. Utilizing Microsoft Excel, the assumed loading, the calculated spring rates, the expected quarter of an inch of displacement, and an assumed damping ratio of 0.3, the transmissibility ratio was calculated and plotted versus a range of excitation frequencies from 0-20 Hz. If the estimated dimensions of the shock are near correct, and a damping ratio of 0.3 is achievable, then the vibration isolation system will have a transmissibility of less than 2. Equations 9 and 18 were utilized to calculate the transmissibility ratio. See Figure 91 for the relationship between transmissibility ratio and excitation frequency.

$$TR = \sqrt{\frac{1+\left(2\zeta\frac{\omega}{\omega_n}\right)^2}{\left(1-\left(\frac{\omega^2}{\omega_n^2}\right)^2+\left(2\zeta\frac{\omega}{\omega_n}\right)^2\right)}} \quad (17)$$

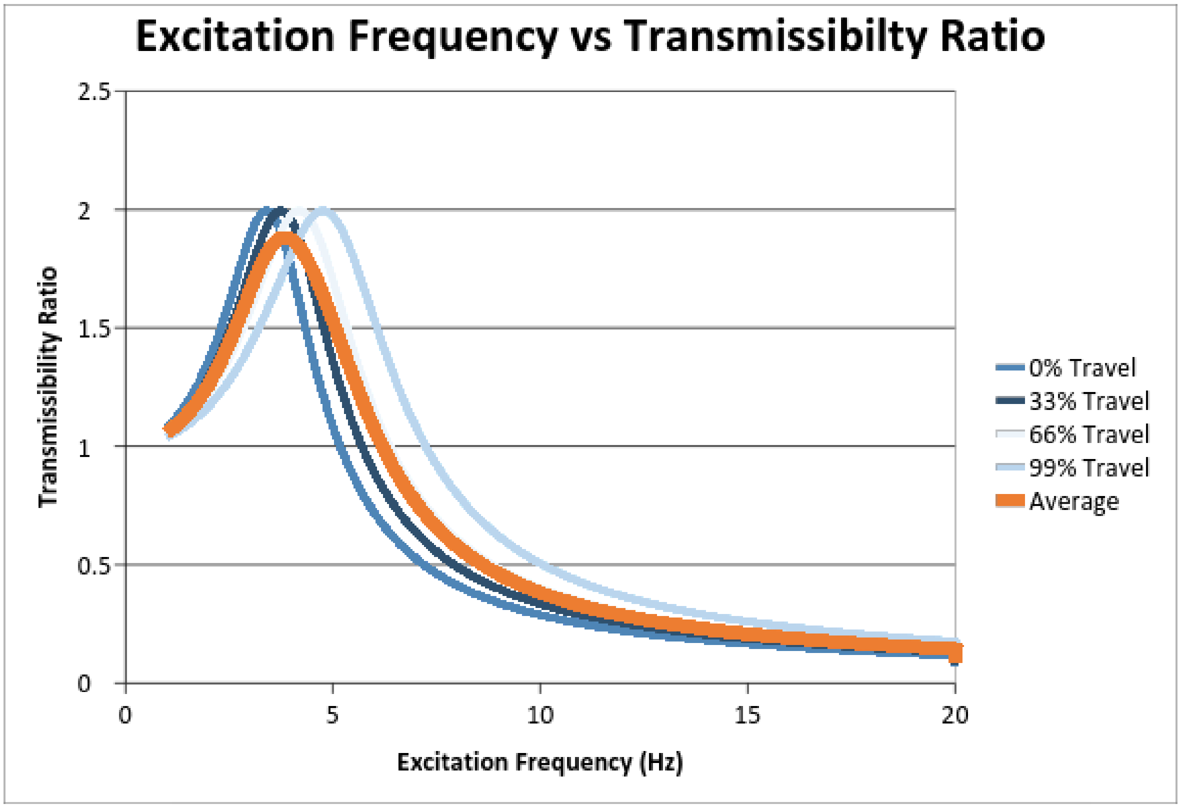


Figure 1- 90: This figure shows the relationship between the transmissibility ratio of the suspension and the excitation frequency.

Once the Suspension system was complete, a standalone structure was built such that it could be used to test the performance of the shock absorbers and the actuators. The vibration isolation assembly was connected to the frame we had built, which was then bolted to a vibration table that simulated a typical railway vibration spectrum. An apparatus that would allow the attachment of several large weights to simulate the expected load on the system was also built and attached to the bottom of the vibration isolation assembly. The setup that was used to test the vibration can be seen in Figure 1-92. Accelerometers were placed on the framework and the base plate in order to be able to compare the input and output vibrations that were experienced. With the adjustable damping settings at their lowest positions and with the air pressure set to 40 psi, it was determined that the shocks performed well and reduced the input vibrations to a reasonable level. The response plot from the vibration testing, Figure 1-93, shows that the transmissibility ratio of the system is less than two throughout the railway vibration spectrum

Figure 1- 91: Vibration testing apparatus

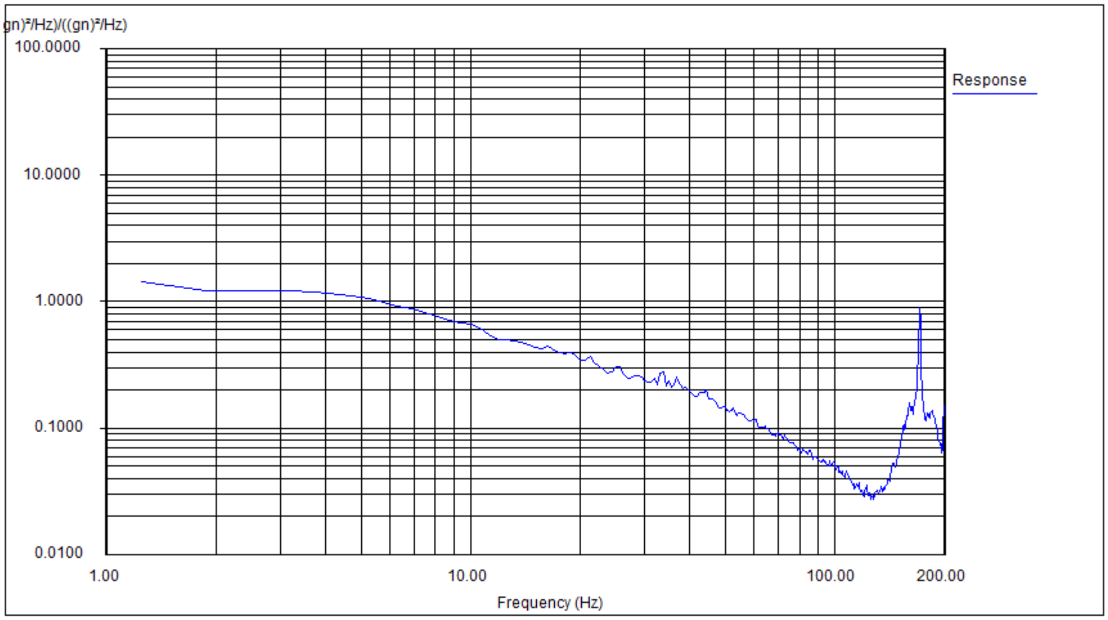


Figure 1- 92: Response plot of the system during railway vibration simulation.

To test the performance of the actuators, a second crossbar was added to the framework. This crossbar had brackets that the actuators could attach to which could then support the vibration isolation assembly. Once the actuators were powered and the IMU was attached to the base plate, the framework would be tilted to simulate the system ascending an incline or descending a decline. This process was repeated until the performance and behavior of the actuators reacted in an appropriate manner in response to the gyro and accelerometer inputs. The modified framework can be seen in Figure 1-94. The control Code can be found in Appendix.

Figure 1- 93: Actuator testing assembly

<u>Money Spent on the Project</u>

Overall, the Active Suspension Team was able to save over $1000 dollars from its initial estimates of the required budget. This was accomplished primarily by getting actuators that would not perform quite as quickly, or be able to support as much weight, but would still be able to perform to an acceptable standard. Additionally, some of the items and/or services were obtained for free or donated, and additional research revealed cheaper sources for other various parts. The amount of money that was saved was then used to help other team procure their parts. Not only did the cost savings reduce the cost of our project, but it made up for deficiencies in other teams' projects.

Total Budget

#	Item	Quantity	Unit Price	Shipping/Misc Fee	Sub Total
1	Actuator (4inch)	1	$139.99	$0	$139.99
2	Actuators (6inch)	2	$139.99	$16.54	$295.52
3	Shock Absorbers	2	$179.50	$0	$359.00
4	Steel Outer Tube	1	$15.57		$15.57
5	Steel Inner Tube	1	$12.13	$13.16	$25.29
6	Plate Steel	1	$25.82	$16.24	$42.06
7	HDPE Lining	1	free		free
8	Nuts, Bolts, and spacers	1	$20	$0	$20
9	Arduino Mega	1	$13	$0	$13.00
10	Gyro Sensor	1	$5.87		$5.87
11	Hall Effect Sensors	3	$21.45	$0	$21.45
12	4 Channel Motor Driver	1	$50		$50
				Grand Total	**$987.75**

Results and Discussion

Through hours of vibration simulation testing and adjusting the shock absorbers, we found that the vibration isolation portion of the active suspension system performed extremely well. The active suspension system isolates the bulk of vibrations that are experienced through the use of adjustable air shocks and fluid dampers. This keeps the cabin in a pleasant riding state for passengers and also extends the lifetime of any components stored within the cabin. After hours of code writing and PID tuning, we found that the actuators could be accurately controlled and adjusted. The actuators of the active suspension system are able to keep the cabin level with the ground through the use of actuators. This will allow the Spartan Superway to be used in a larger variety of situations where keeping the track on the same plane for the entire course of its operation may not be feasible. Some of these situations include implementations in cities like San Francisco and/or traveling over freeways or under overpasses. The active suspension system has largely increased the abilities of the Spartan Superway and the comfort of its riders.

Conclusions and Suggestions for Future Work

Despite the valiant efforts put forth by our team, we weren't able to meet all of our design requirements, but we were able to meet enough of them to provide a system that would showcase the possibilities of an ATN network. Some of the capabilities were cut down in order to save on money. For example, the actuators that were chosen could only support 250 pounds, when initially the design requirement was 600 pounds. This decision was made because it saved nearly $1000, and after talking with the other teams, we discovered that the weight that would actually be experienced in the completed model was much lower than 600 pounds. As well, the feature of the system raising and lowering the cabin at the platform was not fully developed. This was due to other teams needing help and our efforts were more valuable helping them get presentation-ready. We saw it more pertinent to help them finish so that there is something to show at Maker Faire rather than having a fully developed Active Suspension that has nothing to connect to.

In the future, Spartan Superway engineers should be aware of the all the ideas and designs that have already been created. Even if the system is completely redesigned, much can be gained from learning what groups before you have worked on for a year and dissecting their successes and failures. That way, the best ideas can be bolstered, and the weak ideas thrown out. The vibration isolation portion of our system turned out well, but the actuator set up could be improved. Getting the dimensions smaller would be a bonus, and changing the geometry to utilize more leverage may also be some promising directions to take. It is also possible that actuators are not the best solution at all, so other devices to aid leveling should be explored. An area that could have been improved this year would be communication. Going forward, this project should focus on keeping in contact with other groups to make sure each team knows how the other teams are going to integrate their designs together. By using a Google Drive folder or something similar, everyone could share their most updated files for anyone to see, so there would never need to be a question if something will fit together or if the sizing has changed. The vast scope of this project makes it imperative that everyone is aware of how their design affects those around them.

Intermediate Cabin

Background and Context

The cabin team is responsible for designing and improving cabin designs that were created from past Superway teams. The cabin is very important as it accommodates the passengers when the system is running. The cabin must be able to hold 4 passengers, have acceptable safety features, and have a streamlined shape as to reduce drag. The cabin team will be making overall adjustments to past designs, as well as taking inspiration from other cabins already in use to accomplish the objectives listed below.

Objectives

The objective for the cabin team is to design and improve on past cabin designs, more specifically the 2015 Swedish summer team. Our specific objectives are to design a larger cabin shell that will provide adequate dimensions for wheelchair space and accessibility while maintaining its aerodynamic and aesthetically pleasing form. We want an interior layout that will allow passengers to store their bike in a safe and compact way. The design will also have added features to secure wheelchairs.

Once the team has a final design of the cabin, we will be fabricating two scale wooden models that will display our design. One of the models will be completely hollowed for the intermediate scale to place electrical component and other housing needs. This model will be connected to the intermediate scale system that will be fully functional. A quarter scale model will act as a diorama. Using a hinge mechanism, the diorama will display the shell of the cabin as well as the interior.

Design Requirements and Specifications

The cabin designs are regulated by ADA standards to serve those with special needs and general public needs. The doorways will be at least 72” high and 32” wide, to comply with ADA regulation §38.53. There will be a 32” by 48” opening for wheelchair mobility, as per ADA regulation §38.57. Also, the height of the cabin must be at least 70” to allow an average bike to be stored in a vertical position. Internal temperature of the cabin will be controlled at 70^{o}F to 72^{o}F and the humidity levels will be at 40-60%. The humidity and temperature will be regulated by the HVAC system, housed in the empty space of the cabin. Overall shape is to be based on its ability to reduce air drag as much as possible. The cabin will be expected to have a drag coefficient of between 0.8 and 1.8 when traveling at the believed max speed of 30 miles per hour. This drag coefficient goal is decided from the known examples for busses and trains. Drag is not a huge issue because the cabin will be traveling at such a nominal speed.

State-of-the-Art/Literature Review

The Spartan Superway is a student project to design an alternative system known as a Personal Rapid Transit (PRT). A PRT system is an alternative form of transportation that uses pod cars operating on a guideway. More specifically, the Spartan Superway will be using a suspended guideway and will consist of a bogie system that will use a switching mechanism for directional purposes. The whole system will be powered on green energy by adding solar panels to the system. Connected to the bogie will be the suspension of the cabin and will prevent any unnecessary movement to the cabin.

One of the famously known PRT system can be found on West Virginia University's campus. According to West Virginia University, the cabin, shown in Figure 1-95 has 8 seats but can accommodate a total of 20 passengers. The cabin has a rectangular shape and is designed for passengers to ride in a standing position. Their PRT system has been around since 1975 and can travel up to thirty mph. Due to its age, the reliability of this system has decreased to as low as 93 percent.

Figure 1- 94:The cabin used on West Virginia University's PRT system (writeopinions.com)

Another example of a PRT system can be found at Heathrow Airport in London. Called the ULTra, the pods can carry up to 4 passengers with adequate space for luggage (Ultra Global PRT). The pod cars travel by rubber tires and are powered by battery. ULTra had plans to add the same PRT system in Amritsar, India in 2011 but progress has not gone forward since.

Figure 1- 95: ULTra system found at Heathrow Airport (londonist.com)

With biking becoming a very popular form of transportation, we want to incorporate a design that will allow bike users to use the PRT system as well as biking. Bike commuting has increased by 9% in 2012 and will continue to rise (Snyder, 2013). The city of San Jose has adjusted to this increase by adding bike lanes around downtown. Also, programs such as the Bay Area Bike Share offer kiosks to allow anyone to rent bikes. According to Bay Area Bike Share, there are about 700 bikes and 70 stations across the bay area alone. Other forms of transportation such as Caltrain and VTA will usually have some form of bike storage for passengers. An example can be shown in Figure 1-97 of a bus using a bus rack. Having bike storage on the PRT system will keep up with the demand of bike usage.

Figure 1- 96: Similar form of bike storage on a public bus (cycle-works.com)

Description of Design

Exterior of Cabin

The exterior shell of the cabin, we incorporated our design with the 2015 Swedish summer team to prevent us from starting from scratch. The overall shape of the cabin shell is going to be very similar but with minor differences. Figure 1-98 shows a preliminary simple sketch of the cabin shell. The Swedish team design has curved side walls but our design will have vertical flat walls. This modification will allow additional space for the interior as well as allowing an easier manufacturing process. The positioning of the windows will be oriented differently in the final design, we want the passengers to be able to look directly forward and backward. The back of the cabin will be a simple round curve while the front will have a nose for aerodynamic purposes. Lastly, the doors will have a hinge mechanism that will allow the doors to open in an outward position, these can be seen in figures 1-99 and figure 1-100.

Figure 1- 97: Concept sketch of the cabin's exterior shell

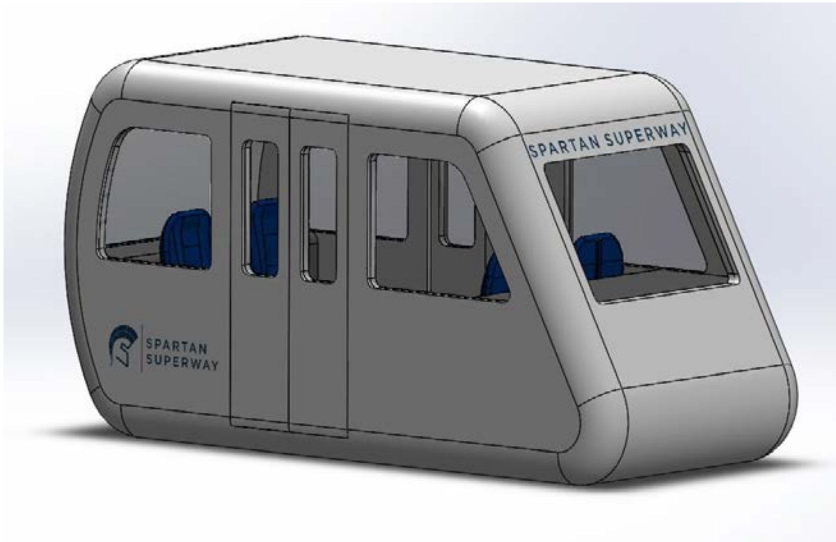


Figure 1- 98: Final design of cabin

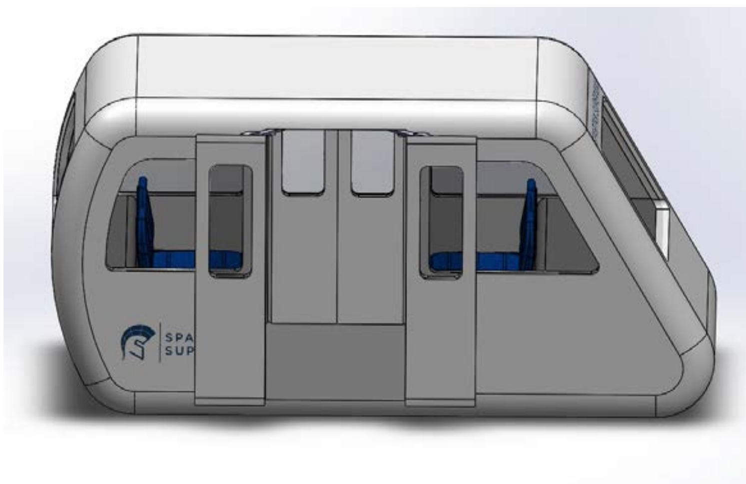


Figure 1- 99: Cabin design of hinged doors

Interior of Cabin

The interior of the final cabin will have a greater volume in comparison to the 2015 Swedish summer team. The interior will allow a maximum of four passengers, two in the front and two in the back. We want to make sure there is sufficient amount of space for wheelchair accessibility. Using a folding mechanism for the seats, there will be enough space to allow two wheelchairs to sit side by side. Also in the design, we want to allow bike storage for passengers that commute on bike. To allow bike storage, there will be two foldable hooks that will allow the bikes to sit in a vertical position. Figure 1-101 shows early sketches on how the interior will look when a bike is stored with a seat in a folded position.

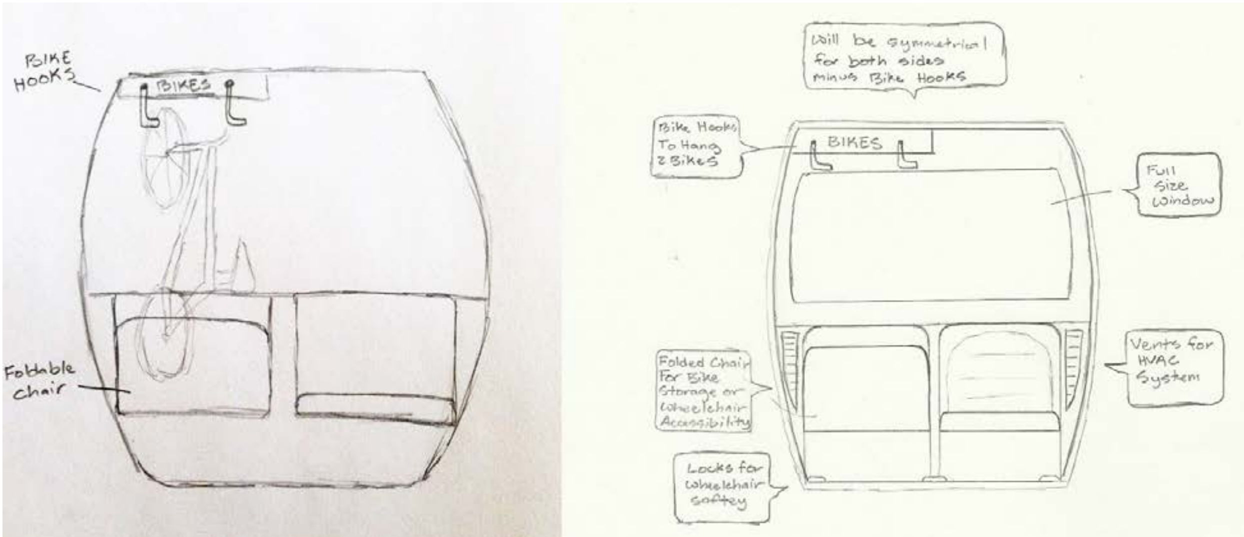


Figure 1- 100: Early sketches of the interior design

The width of the interior portion of the cabin provides different configurations for the wheelchair types. Two manual wheelchairs can be placed side-by-side, as shown in Figure 1-102. The configuration followed ADA regulations for the required movability of the wheelchairs. Powered wheelchairs and scooters are aligned with the front or back of the cabin wall, depicted in Figure 1-103. Manual wheelchairs and scooters have longer lengths and require more space, and thus cannot be placed side-by-side. This positions prevents the doorways for the cabin from being blocked, and will help the entering and exiting the cabin faster.

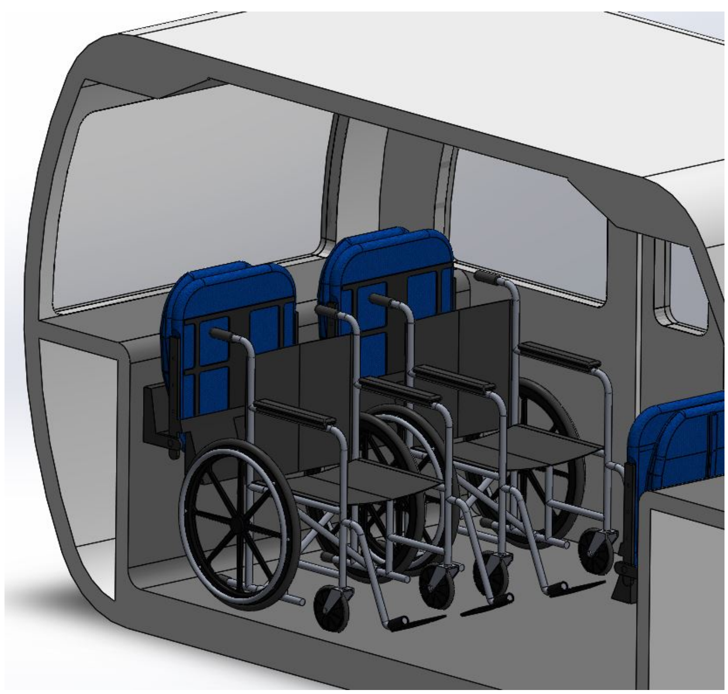


Figure 1- 101: Wheelchair cabin space visualization

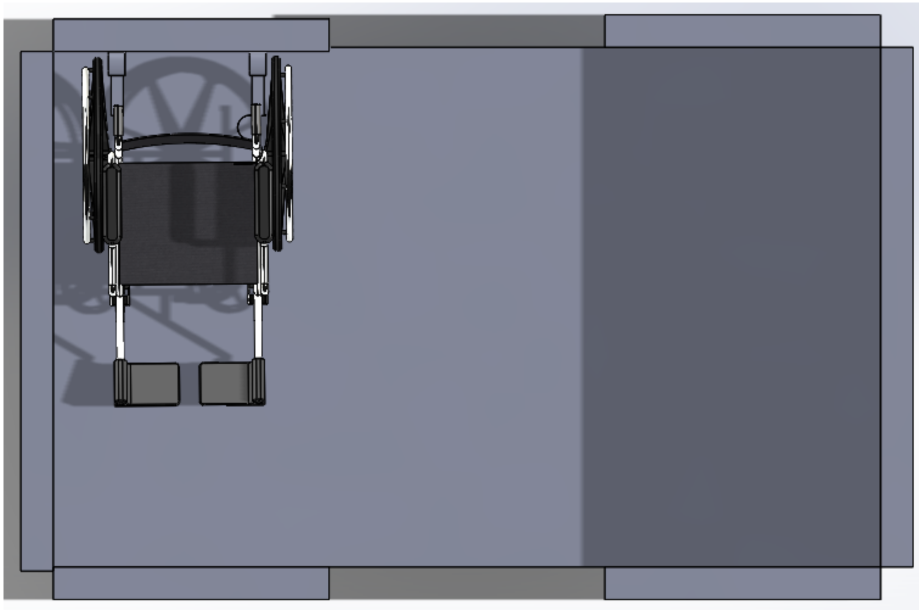


Figure 1- 102: Powered wheelchair cabin placement

Safety

The hooks have retractable belts and lock fully to secure the wheelchairs in place. Positioning of the belts changed by moving them up along the walls of the cabin. This is for the scenario when a person was riding a cabin solo, they would be able to secure themselves in without others' assistance. The new configuration can be seen in Figure 1-104, the belts are now at level with the arms of the wheelchairs. The straps would model the Sure-Lok retractable belts with S-hooks. Selecting the S-hooks as fasteners compared to clips was because no force is required to attach them to the wheelchairs.

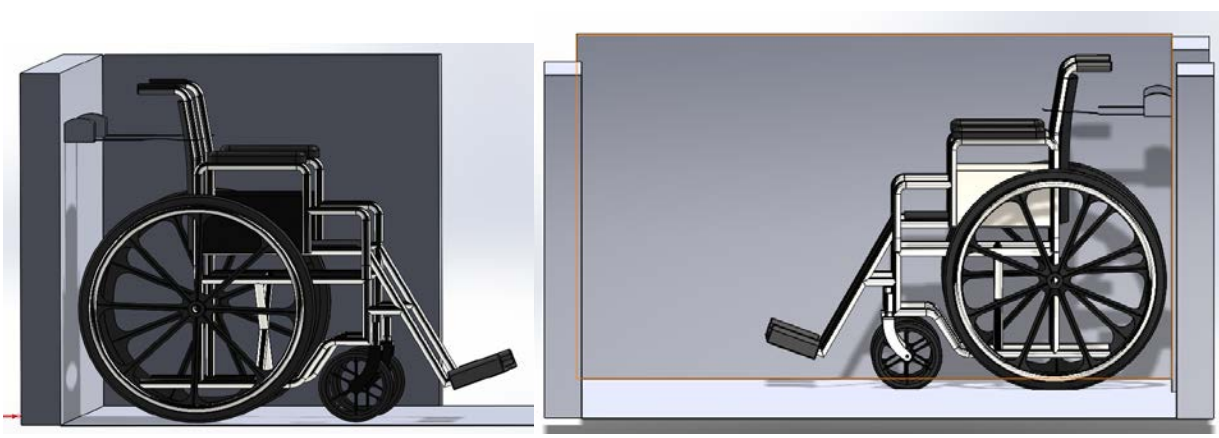


Figure 1- 103: Wheelchair restraint locations (Left: manual wheelchairs, Right: Powered and scooter wheelchairs)

The interior design will have foldable chairs to allow space for wheelchairs and bikes. Figure 1-105 shows a configuration of the interior when a wheelchair or bike is in a parked position. This configuration will be symmetrical to the front side of the cabin to allow a maximum of 4 passengers.

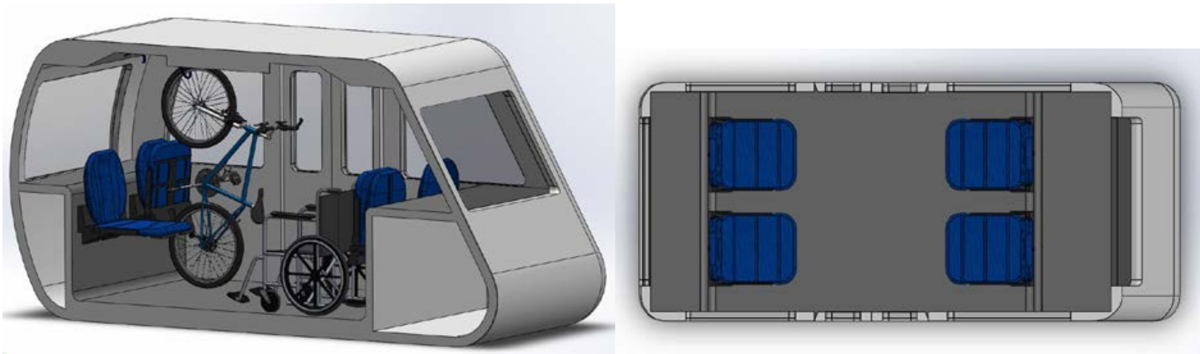


Figure 1- 104: Examples of how a wheelchair/bike will sit

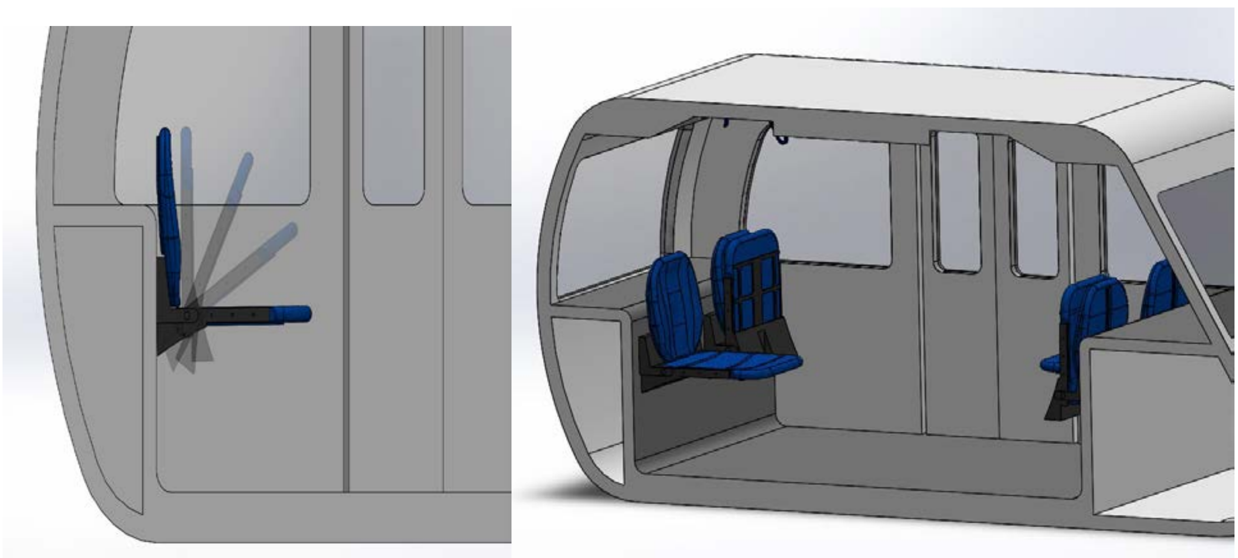


Figure 1- 105: Movement of foldable chairs in down and upright position

To allow storage of a bike in a vertical position, the roof will have a hook mechanism, shown in Figure 1-107, which will hold the rim of the bike. When not in use, the hooks can be folded to prevent any collision with the passengers. There will be a total of four bike hooks in the interior design, two on each side.

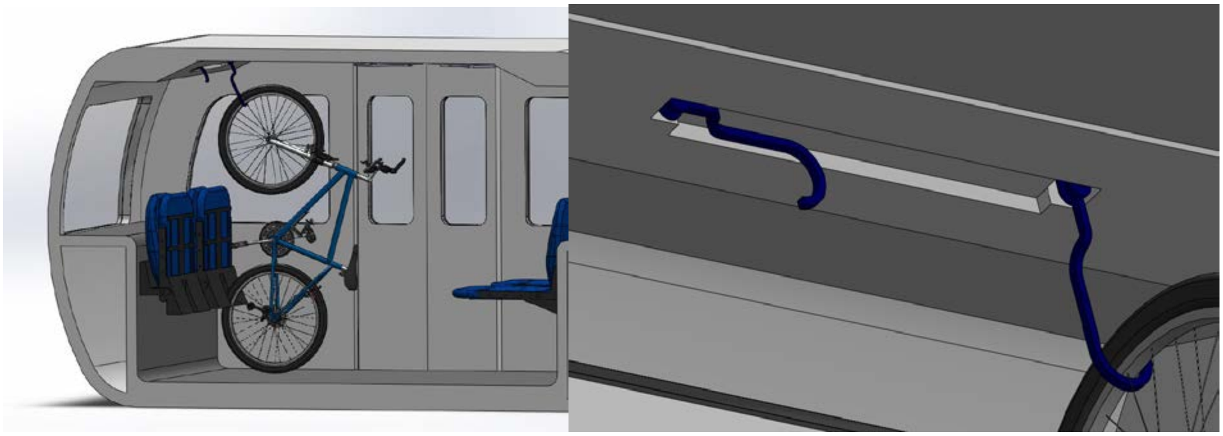


Figure 1- 106: Bike hooks that will securely store bikes in a vertical position

<u>Analysis/Validation/Testing</u>

Exterior Design

With some changes and improvements to our earlier sketched, we rendered our final cabin design shown in Figure 1-108. First, we added a second doorway on the other side; suggested by Bengt Gustafsson, the CEO of Beamways, we added the second doorway to allow a continuous flow of traffic. Secondly, we rounded off the edges that has a 15” radius to allow a smoother flow of motion. Lastly, we slightly lengthen the cabin size to prevent interference from the door opening and a wheelchair that is in a parked position.

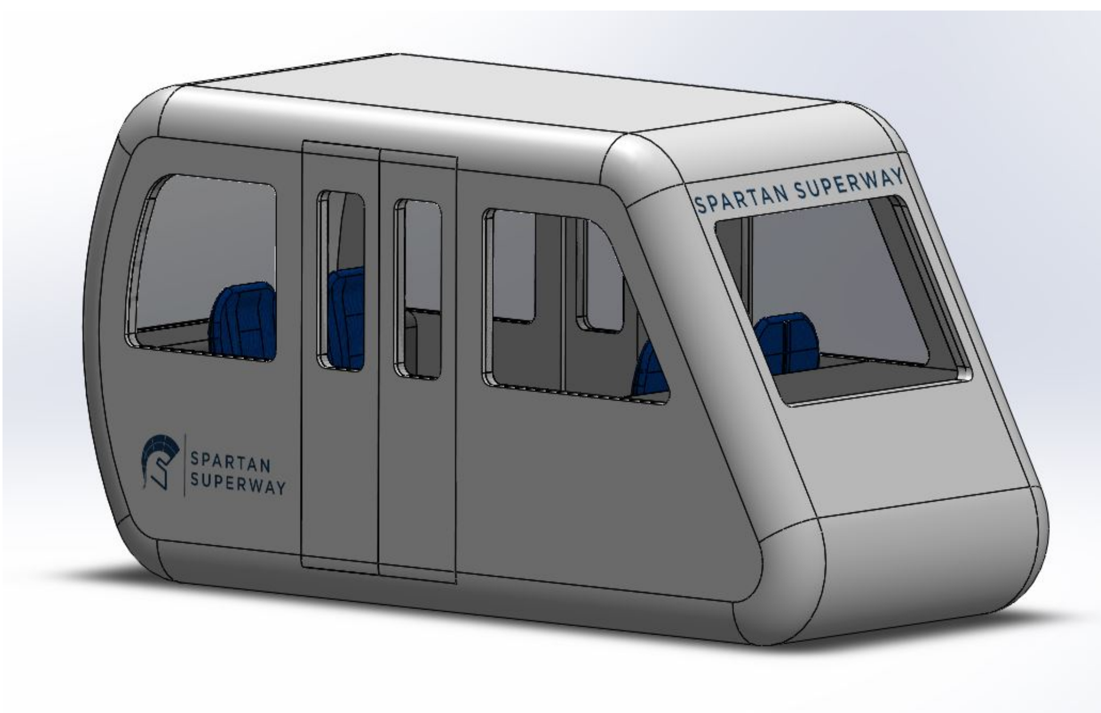


Figure 1- 107: Final design of the cabin’s exterior shell

The final dimensions of the cabin will be 6 feet by 12 feet and a height of 7 feet. The door openings will be 6 feet by 3 feet to allow excess space for wheelchairs. The front of the cabin sits at an angle of 63 degrees and the back is rounded using a radius of 63” from the center of the doorway.

The final cabin design was run through Solidworks Flow Simulation software. The goal of this test was to see if the final design met initial design specifications with a drag coefficient of 1.3. The simulation was run using air as the fluid and traveling speed as thirty miles per hour. When the program is run it simulates the flowing of air and calculates how it will impact the design. The design worked much better than expected so the tests were run using 30 m/s instead of 30 mph. All figures below show the cabin under higher overall wind conditions to better illustrate the aerodynamics of the cabin.

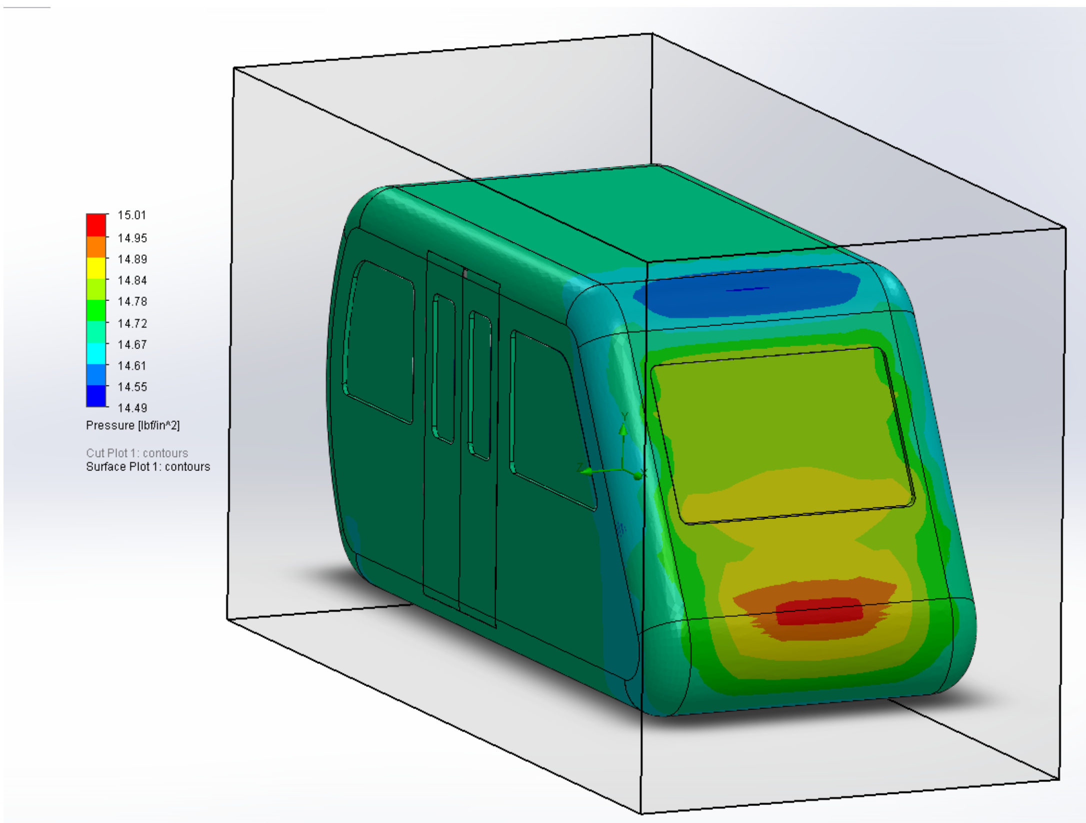


Figure 1- 108: Pressure contours on cabin design

The first iteration of the simulation shows simple pressure contours on the model. In Figure 1-109 the air flows from right to left and hits the cabin full in the front. It can be seen that the average pressure experienced by the cabin is about 14.7 psi and experiences a range of pressure of about 0.4 psi. The point of highest pressure (rounded red area) can be seen to occur at the very nose of the cabin. It was taken into consideration that changes could be made to alleviate this area, but the effects would be minimal and ultimately require more material in the design. It is also possible to see points of lower pressure near the top of the cabin. This is where a vacuum created by the wind bouncing over the front of the cabin which may result in more overall drag. Figure 1-110 is another visual to show airflow across the surface of the cabin. The cabin can be seen to cut through the air extremely well, guiding the air up and over the top.

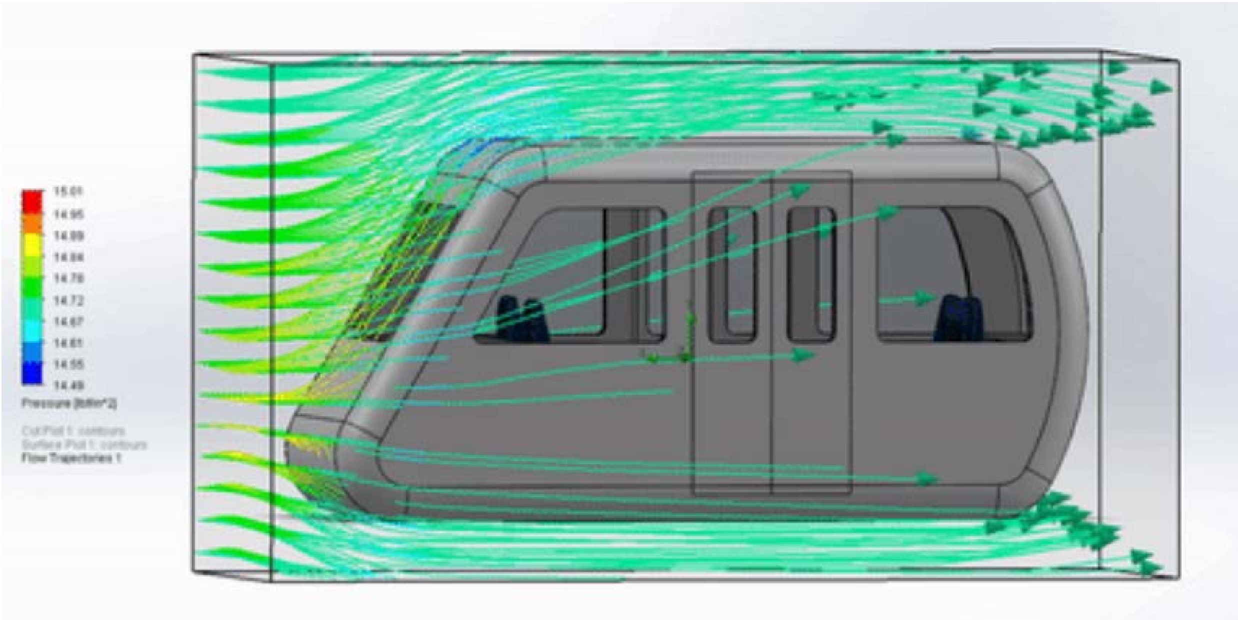


Figure 1- 109: Airflow model of cabin flow simulation

The Solidworks flow simulation can also run equations based on the data found during calculation. Using Equation 18 for drag force, it was possible to iterate the drag coefficient for the cabin model. This equation states that the drag force is equal to the drag coefficient times half the density of air times flow velocity squared times the front facing area of the model. Upon completion of the simulation it was found that the drag coefficient of the cabin model is about 0.19. This value is extremely successful and completely overreaches the expected drag coefficient. During testing it was found that at 30 mph the cabin experienced an average measly 6 N of drag force.

$$F_d = c_d\ 1/2\ \rho\ v^2\ A \qquad (18)$$

Cabin interactions with other teams was overall very limited. The main interaction was with the suspension team because that component is attached directly to the top of the cabin. When built the cabin was specially fabricated to securely attach to the suspension and provide a strong and sturdy base. When tested the cabin successfully attached to the suspension on multiple occasions, but it wasn't until Maker Faire that it was truly tested. At Maker Faire the cabin was finally connected to the suspension which attached to the bogie hanging on the track. This was the first time the cabin had been fully suspended while attached to the complete project and it passed the test triumphantly. No cracks were seen or heard, and overall it appeared sturdy and complete. The successful attachment can be seen in Figure 1-111 further below.

Money spent on Project

At the beginning of the semester the budget was increased to $303 because one model of the cabin needed to become intermediate size. Keeping in mind cost efficiency, we were able to cut manufacturing cost by $14 to have a total cost spent of $289.55 as seen in Table 1-9.

Table 1- 9: Manufacturing Cost for Spring 2016 designs

Item	Unit cost	Qty	Cost
Sandpaper 80-grit	$5.97 (3 pack)	1	5.97
Sandpaper 120-grit	$5.97 (3 pack)	1	5.97
Sand belt 80-grit	$6.97 (2 pack)	1	6.97
Bendable pile wood	$4.97 (1 sheet)	2	9.94
Plywood (6x8 sheet)	$31.95 (1 sheet)	5	159.75
2x12	$21.92(16 ft)	1	21.92
4x4 board	$10.33 (10 ft)	2	20.66
2X4 board	$2.97 (96 in)	3	7.02
Wood Glue	$6.27 (16 oz.)	2	12.54
Screen material	$5.24 (roll)	1	5.24
Magnets	$2.69 (8 magnets)	1	2.69
Paint	$20.75 (1 gal)	1	20.98
Wood Putty	$4.95	2	9.90
	Total Spent		$289.55

Results and Discussion

The Spring 2016 semester has been extremely productive with the completion of the quarter and intermediate scale version of the cabin, both externally and internally. Tests were successfully run to determine the cabin design meets previous design specifications in regards to a drag coefficient.

The main focus for the Spring 2016 is fabrication and completing the needed two models for demonstration. Since time allowed, there was the ability to overlap work between the two models. We made final decisions on all of the required materials and created a mock model of the quarter scale out of cardboard to gain some knowledge of a process to follow. Once completed materials were purchased at given times depending on development stages. Fabrication began by processing all of the plywood pieces: tracing, shaping, and cutting. All work was done in shop and primarily by the cabin team. Due to the high cost and lack of time interior pieces were not 3D printed, like the seats and hooks. The pieces were instead made by hand with wood for the chairs, and large binder clips for hooks (this required imagination). The physical models were successfully completed. They then demonstrated their intended purpose in figure 1-111 and figure 1-112.

There were some complications with the intermediate scale, because of its size and weight. The active suspension team's actuators were limited to 200 lbs, which meant the cabin needed to weigh less. Since there was no onsite scale, the weight of the cabin was estimated to be around 160 lbs including the components housed inside. There had been initiative to make a station, but this was not able to be accomplished.

For a complete schedule see in the Cabin Appendix.

Figure 1- 110: Completed intermediate scale model of the cabin

Figure 1- 111: Complete quarter scale model of the cabin

Conclusion and Suggestions for Future Work

Overall the design of the interior and exterior cabin was able to be accurately shown in both the quarter and intermediate scale models. This included the quarter scale model with a detailed interior and exterior. The intermediate scale provided a larger scale shell for the intermediate track as well as housing for electrical components. In the future, should time and cost permit, some elements of the quarter scale cabin should be 3D printed to provide nicer detailing. For future work within the intermediate scale cabin there should be more effort put into reducing the overall weight of the construction. Once the weight has been reduced steps can be taken to better organize the interior mounted components. As of now some components are correctly mounted and optimally located, but it is possible to make others follow those standards. A station setup can also be done for future work. This would help demonstrate human interaction and express the goal of one hundred percent solar power.

Intermediate Wayside Power

Background and context for the work of the sub-team

The wayside power team is focused on creating a power pickup system to that will be the interface between solar power and the vehicle for the intermediate scale model. Over the past years, the Spartan Superway models have been battery powered which requires charging. This defeats the purpose of having a sustainable mode of transportation. Solar power has not yet been integrated into the system. This year's wayside power team was responsible for being the bridge between solar power and the vehicle. To make the Spartan Superway a sustainable transportation system, the wayside team created a power collecting system, which enable bogies to obtain power from solar panels through the wayside rails. This idea would eliminate the hassle of recharging batteries. The environment would benefit by reducing the waste associated with recycling batteries and carbon emissions associated with burning fossil fuels.

Description of the Subteam and Objectives

Implementation of wayside power is the primary goal of the wayside power team. Over the past years that the Spartan Superway have progressed, there has been no team that worked on integrating power from solar panels into a power pickup system that would power each vehicle. As mentioned previously, the Spartan Superway models have been battery powered. This year's team focused on research and design of a power system that would be cost-effective, feasible, aesthetically pleasing, and safe. Research was done on how different transportation systems are powered such as third rail, fourth rail pickup, how trains and subways works, conductive materials, how to charge batteries, and materials that can be used for fabrication for the wayside rail system for the intermediate scale model of the Spartan Superway. After research on primarily the 3rd and 4th rail designs of train systems, the wayside power team decided that the fourth rail design proves to be the most feasible design given time constraints of the project, safe for an audience of all ages, aesthetically pleasing, and be durable.

The main objective of the wayside power team is to successfully design a wayside pickup system that will power the mechanical driving components of the bogie which include the propulsion motor, braking, steering and suspensions. Other objectives include having the wayside rail be aesthetically pleasing, be durable, and be easy to assemble. The power from the solar panels will supply power to the hot conductive rail of the wayside rails, which will then supply power to the components of the vehicle such as the motors. Moreover, the team's objective is to integrate solar energy from photovoltaic cells onto the rail system so the model can be powered by clean energy, which is the overall target of Spartan Superway. The solar panels will provide the energy that will make the Spartan Superway ATN sustainable.

Design Requirements and Specifications

In order to meet the objectives stated earlier, there is few design requirements needed to be meet. The main design requirements of the wayside power pickup system are to be able to provide the propulsion, steering and active suspension with 48V of power and be able to handle a current of 50mA. The design of wayside must meet the configuration of a fourth rail wayside system where there are two supporting rails that acts as the guide way while the other two separate are the wayside power rails where one would be for supplying current while the other would be returning current to complete the circuit.

Furthermore, the design specification for a collector shoe is that it does not interfere with the motion of the bogie and does not block access of any wheels or moving mechanism. The collector shoe must be in constant contact with the current and return rails at all times because losing contact would break the supply to the components and reset the system while running.

Finally, another design requirement of the wayside pickup system is that it must modular and mobile. Since the Spartan Superway model is likely to be transported to various locations for viewing, it is important that all the components can be disassembled and assembled for mobility for transporting. Following this specification the design of the wayside rails was made by breaking into ten feet sections so they can be attached and detached at ease.

State-of-the-Art/Literature Review for the Subteam’s Sphere of Work

Power Systems of Public Transportation

The first step in the state of the art literature review was to determine what technologies have been implemented and proven successful on a fully operational ATN system. In previous years work on the Superway ran with the assumption that wayside power was the best way to provide constant power to the bogies but didn’t have a fully developed explanation as to why this was the case. During the literature review there were four examples of ATN systems that were deemed fully operational. The first is the Ultra system in the London Heathrow Airport, which runs on battery power alone but only on a short 3.8 km track with downtime required to recharge (ULTra, 2014. Phenix, 2014). The second fully operational system that we identified is the 2getthere system in Masdar city with a similar battery powered model that only travels 800 meters at a time and also requires downtime to charge (Hill, 2011). The third system identified is the Vectus Skycube in Suncheon Bay Korea that operates on a third rail system and runs for 4.64 km ("Korea's First Personal Rapid Transit (PRT), SkyCube"). The final system is the Morgantown PRT system that runs on a 575-volt wayside rail for 13.92km of track (Historical Snapshot, n.d.).

Figure 1- 112: The Ultra PRT is fully operational in Heathrow London.

This system uses battery-powered pods to travel on a 3.8 km track (ULTra, 2014).

After determining that both wayside and battery powered ATN systems have been successfully implemented in fully operational systems, both power delivery technologies were analyzed further to determine the best fit for the Superway.

The main advantages of wayside technologies are reliability, power, and uptime, with the main disadvantage being the inability to operate in inclement weather due to submersion of live rails in water (Ande, 2012. "District Department of Transportation," 2014). Onboard energy supplies such as batteries, supercapacitors, and flywheels all have the benefit that they don't require a power infrastructure to run parallel to the track for it's entire length, however none of these solutions offer the required power and energy density to make steep grades or travel significant distances ("District Department of Transportation," 2014)]. For the distances that the Superway pods will need to travel, wayside power becomes the obvious choice for the main power source of the bogies. Onboard solutions remain a critically important design element in the development of the Superway but only as a redundant source of power for emergency situations. Additionally, the previously mentioned disadvantage of non operation in inclement weather is much less of a concern for vehicles traveling suspended from an elevated structure than for ground based vehicles due to the easy avoidance of a rail submersion scenario.

Third Rail & Fourth Rail Configurations

Some configurations of wayside pickup systems that are currently implemented are third scale and fourth rail configuration. The third scale configuration uses one rail to supply current and the running rail for the return current. This sort of configuration can be found on many heavy transit systems such as the Bart (Bay Area Rapid Transit) system and can also be seen in Figure 1-114. The fourth rail system is very similar, however, instead of using the running rail for the return current there is another rail devoted for the return current. This system is currently used by London underground system trains and can be seen in Figure 1-115. Both of these configurations use a collector shoe to obtain power from a supply rail.

Figure 1- 113: Forth Rail Configuration (SP Smiler, 2014)

Figure 1- 114: Third Rail Configuration (Lennart Bolks, 2014)

A critical goal in the development of the intermediate scale model is to keep it as true as possible to the full scale implementation of the Superway. This has been done so that the connection between the small-scale model which represents the controlling and movement of the system is more clear to visitors who are interested in Spartan Superway. To power all components of the intermediate scale bogie there is about 50 mA needed and according to OSHA 50mA can be a potentially fatal current and this current can be achieved between the hand and foot of a person with the 24 volt source proposed for running our wayside power rail (OSHA, 2006. Giovinazzo, 1987). So in order to allow a safe environment the fourth rail was considered due to the fact that the configuration allows the return current to go through a separate insulated rail instead of the structure itself.

Conductor Material

Conducting materials was researched in order to select the material for the wayside rail and the shoe collector. A favorable electrical conductor is a material where electrical charge carriers, electrons, can move with ease from atom to atom when a voltage is applied. In general, conductivity is having the capacity to transmit electricity. The most conductive materials are metals such as silver, copper, and gold. Although silver is a better conductor than copper, copper is cheaper than the other two materials as shown in Figure 1-116. Copper will be chosen for the wayside rails and collector shoe. The shoe collector is a current collector that slides along the rail, which is supplying power and then uses that power to energize all of the components that need to be energized.

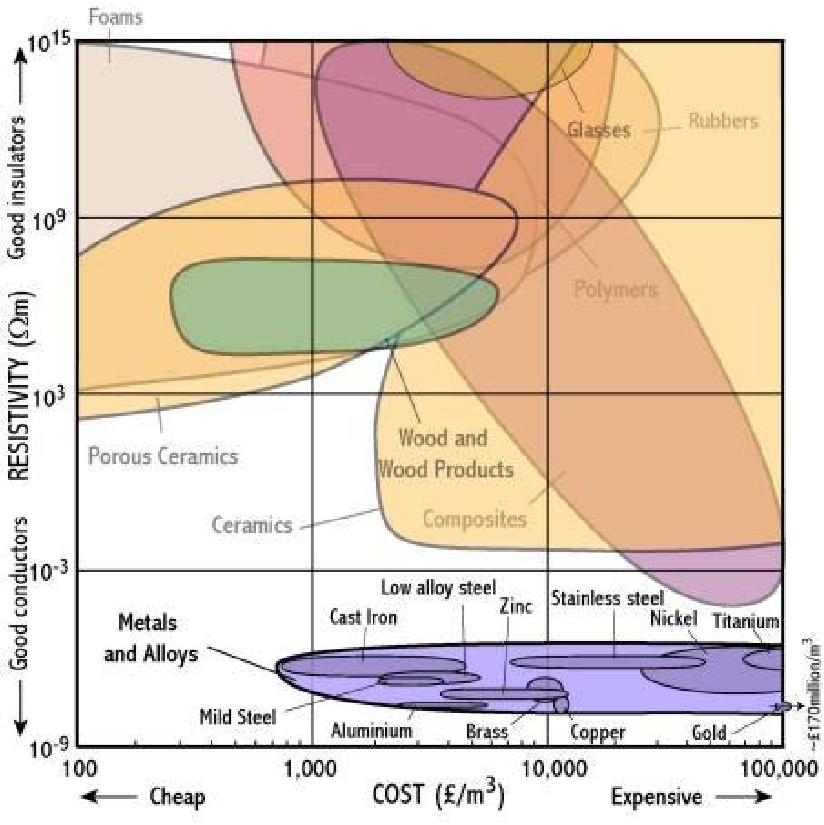


Figure 1- 115: A chart showing the relative cost of materials with respect to its conductivity ("Resistivity-Cost", n.d)

Description of Design

The design chosen from last semester followed a fourth rail configuration, which was implemented this semester to the intermediate scale model. There were several factors to consider when designing the location and the spacing of the conduit rails since there are many components in driving the vehicle that made less space available. The final design of the wayside rail onto the intermediate track can be seen in

Figure 1-117 and 1-118. The design allows a perpendicular extended collector shoe to slide across two rails that are upheld and attached to the frame of the track using brackets. The collector shoe has wire that is extended into the cabin where it is attached to necessary electrical components of the braking, steering and active suspension.

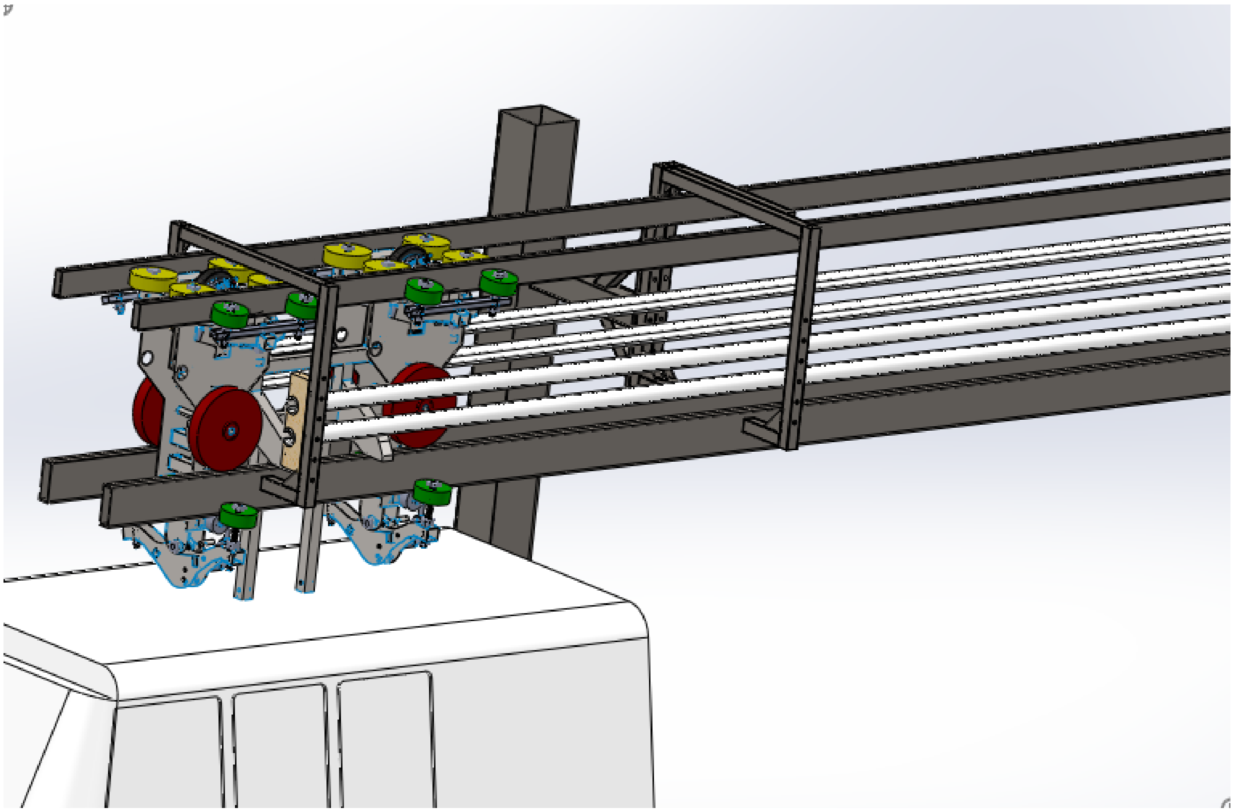


Figure 1- 116: Complete Model of the Intermediate Scale Model with Wayside

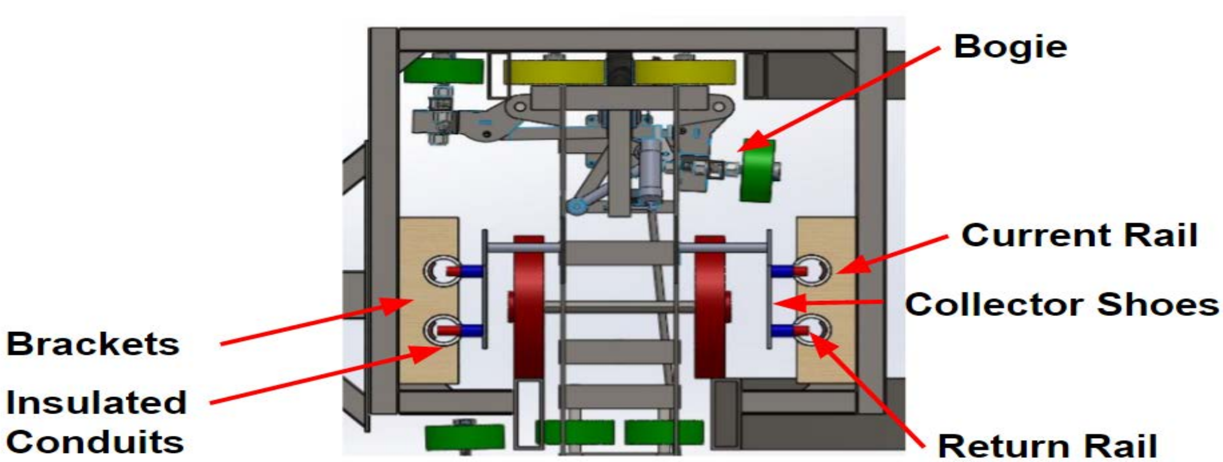


Figure 1- 117: Component Breakdown of the Intermediate Scale Wayside System

In order to meet the specification of providing 50mA of current a conductive material flat wire with an appropriate gauge was needed. For the design 6 AWG copper wire was selected to be appropriate to meet the requirement. However, due to the unavailability of flat copper wire of the gauge needed the team decided to fabricate the wire using solid bare wire of a smaller gauge. Using a metal roller available at San Jose State University's Material Engineering Laboratory did this. The wire that was fabricated was close to the cross sectional area of a 6 gauge wire. Figure 1-119 shows the fabricated wire that was used for the design.

Figure 1- 118: 4 AWG bare copper wires that has been flattened to around 6 AWG

To meet the requirement of preventing any shocks from happening there was insulated conduits used for the housing of the rail. The conduit pipes were cut using a table saw and pneumatic saw for openings of ½ inch to allow space for the collector shoe to enter and run along the conductive wires. A section of the conduit pipes that were fabricated can be seen in Figure 1-120.

Figure 1- 119: The flattened 6 AWG bare copper wire inside the schedule 40 conduit

The conduits were upheld and extended on the track with fabricated brackets, which had been spaced out every three feet on the track. The space between the two conduit pipes was 2.5 inches and the drawing can be seen in Figure 1-121 to prevent stress or turbulence of the pipe to crack the brackets. Originally the plan was to make the brackets using a 3D printer, however, to accelerate the manufacturing process the team decided to use wood as the material, which had resulted in a larger spacing to prevent failure of the bracket. The dimension drawing of the bracket can be seen in Figure 1-121.

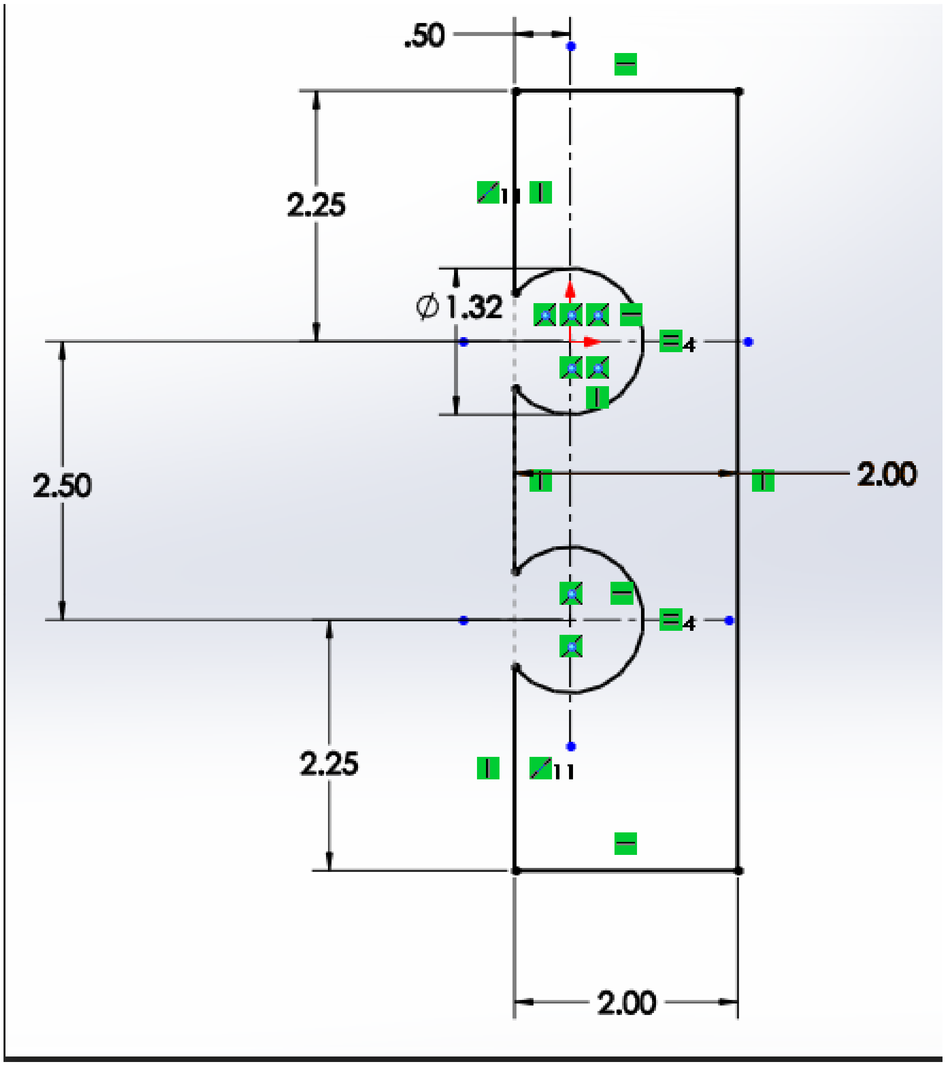


Figure 1- 120: Dimension of Fabricated Bracket

To meet the design specification and requirement of being in constant contact with the current and return rails at all times the collector shoe had small changes made to the previous design. The changes brought in by adding preloaded spring into all of the collector shoes so that during turbulence of the bogie the contact of the conductive materials would not be lost. Figure 1-122 shows an assembly breakdown of one of the collector shoes. The collector shoe are welded onto the first half of the bogie assembly in order to make sure that the wayside rails maintain the same motion of the track without a change in the vertical direction.

Figure 1- 121: Assembly breakdown of collector shoe (pre-welded)

<u>Analysis/Validation/Testing</u>

Once fully assembled, the four rail wayside system was tested in a modular fashion. First, the 6 AWG flat bare copper sections had to be tested for proper conductivity across the entire track. Applying 52.9 Volts at one end of the track, and then measuring that Voltage at the other end of the track did this. When tested, a reading of 52.9 Volts was recorded for both side of the track, showing that the wayside rails properly conduct electricity throughout the entire wayside rail system. With the rails proven to work the collector shoe was then tested, this proved more difficult due to the lack of a moving bogie. Still, the collector shoe was bolted on to the bogie (seen in Figure 1-123) and the wires were feed into the cabin and connected to the inverter.

Figure 1- 122: The collector shoe bolted on to the bogie

The inverter successfully received power, and in turn the power supply a successfully powered up. But, the collector shoe has not yet been tested in a dynamic way. So far, it has only been tested while stationary. In the next week, the collector shoe will be able to be tested in a dynamic way when the bogie is up and running.

Money Spent on your project

The total cost of the wayside pickup system on the intermediate scale came out to be $719.73. Most of the cost was applied into purchasing the conductive wire for the rails. The specifications given to the team by other sub teams called for a 6-gauge wire needed to accommodate all of the current specs. However, since copper wire is not easily available flat, the team had decided to buy solid round copper wire of a smaller gauge (4 gauge) and use a metal roller to flatten the wire to the equivalence cross section of about 6 gauge. However, as the wire of copper goes to a smaller gauge the cost increases and given the fact that there was a need of about 360 feet of conductive wire the team decided to buy copper in a bulk of 200 feet packages to save cost compared to by the feet. There was also about 360 feet of insulated housing needed for the conductive rails which was also a big part of the budget in the project. Finally, the remaining cost was spent on purchasing of material and hardware needed for the fabrication of the rail and collector shoe which were not available in the Spartan Superway Development Center. One of the extra costs was the purchase of a Pneumatic Saw, which was needed in order to cut sections of PVC insulating pipes. Table 1-10 shows the bill of materials for the wayside pickup system.

Table 1- 10: Bill of Materials

DETAILED BILL OF MATERIAL (BoM)						
No	MATERIAL	QTY	PRICE $	MANUFACTURER	SUPPLIER	TOTAL COST $
1	1" X 10 FT PVC SCHEDULE 40 CONDUIT PIPE	40	$ 3.17	JM EAGLE	THE HOME DEPOT	$ 126.80
2	FAST DRY 10.1 OZ. WHITE ACRYLIC LATEX PLUS SILICONE CAULK	8	$ 6.24	GE	THE HOME DEPOT	$ 49.92
3	200FT OF 4 GUAGE SOLID SOFT DRAWN COPPER BARE WIRE	2	$ 139.00	HOMEDEPOT	THE HOME DEPOT	$ 278.00
4	WOOD LUMBER FOR BRACKETS 1X3-8	5	$ 2.97	HD LUMBER	THE HOME DEPOT	$ 14.85
5	SPRINGS FOR COLLECOTOR SHOE	2	$ 2.87	OSH	OSH	$ 5.74
6	ETC HARDWARE	1	$ 100.00			$ 100.00
7	PNEUATIC SAW	1	$ 78.99	-	AMAZON	$ 78.99
					TOTAL COST	$ 654.30
					TAXES (~10%)	$ 65.43
					GRAND TOTAL	$ 719.73

<u>Result/Discussion</u>

Over the last year the team was successfully able to design and assemble a wayside pickup system for the intermediate scale model. This system enables power to be supplied along separate rails, which allows the mechanical components of the bogie to pick up power required through a collector shoe from the power rail instead of depending on a conventional battery as the main source to power the bogie. Wayside rail is a more convenient and effective way to power vehicles because it allows vehicles to run off power that is supplied on track without the need of stopping to charge batteries when they are low. However, there will be a backup battery on board of the vehicle which will be eventually be charged and used when energy is not being actively supplied to the rail. This system also opens the door for integration of solar energy onto the wayside, which is the ultimate goal of Spartan Superway.

In the previous semester the team had set a goal to create a functional wayside pickup system on the small 1/12 scale model. However, after reevaluation of the design on the scale model the team was told to apply the concept onto the intermediate scale model. This brought a challenge to the team because components had to be resized to meet the power demand for the mechanical components. Due to a budget change requested in the beginning of the semester many teams had to resize their components, which caused a delay in resizing our components due to the dependencies on all subgroups associated with the intermediate scale. The team ultimately decided to overshoot the size of the bare copper wire gage to ensure that current running through the rails would be safe for the system.

Some challenges faced in the fabrication of the collector shoe was the location and availability of space on the bogie. Originally, the team had planned to place the collector shoes in the midpoint of the bogie on the “H-bar” that connects the two bogies, however, soon the team realized that there would be an issue on the trackside where the decline will occur. The midpoint of the bogie does not follow the path of the track so there will be a change in the vertical direction as a decline occurs. To overcome this challenge, several ideas were discussed one of which includes the use of linear guides. However, the team did not go with this idea because this would create an issue when entering the switch portion when going in the straight track. Designing the shoe collector with linear guides would be more time consuming given the time constraints and would prove to be challenging. Although linear guides would solve the vertical fluctuations of the track, the team solved this challenge by finding a location on the front part of the bogie that would follow the track. The shoe collector was placed near the blue wheels of the bogie that runs on the bottom track, this ensures that the shoe collector follows the path of the running track. Another issue with the fabrication of the collector shoe was to maintain contact along the wayside rails. With unexpected turbulence or shifting of the bogie there was a possibility that the collector shoe would lose contact of the wayside rail. To accommodate this issue, the team concluded that it was necessary to use a preloaded spring for the shoe collector onto the wayside rail to maintain contact; this idea was inspired by the function of toilet paper roll holders.

The team also faced a few challenges in the fabrication of PVC conduit pipes. The pipes were purchased in straight sections of ten feet. However along the switch and drop section of the track there was the need to fabricate the straight pipes to the dimensional arc. Through research, the team discovered the techniques of using heated sand to cause bending of pipes, which stay firm after it is cooled down. The team first began by pouring sand into the pipes and then using heat guns on the exterior to heat the sand inside through conduction. However, this process turned out to be time consuming and inefficient. The team then overcame this challenge by pouring preheated sand into the pipe and bending it along guides made using the desired radius.

There were also few challenges faced in the fabrication of the brackets used to hold the wayside rail along the track. Originally, the brackets were to be fabricated using a 3D printer, however, due to the high cost and significant time investment. The team decided to fabricate the brackets using wood and hole saw. This method was originally difficult due to the small spacing between the two holes, which caused fracture of the wood due to the high stress in the spacing. This challenge was overcome by increasing the spacing of the holes to which there was a very low possibility of fracture.

Finally, the last challenge that the team faced was with the fabrication of the copper wire. As discussed earlier finding a flat copper wire with an appropriate gauge was difficult and expensive. This led the team to fabricate the flat wire using solid bare wire by using a cold roller to flatten the copper wire. When the team started this process the challenge was determining how low to have the metal roller set to roll the wire. The team first started off with a test section of 10 feet of wire. The test wire was rolled and lengthens to about 30 feet, which resulted in a lower gauge then desired. The team then experimented using trial and error to get the cross section of the flat wire to a desired dimension and gauge.

Overall, the team has overcome many challenges over the last two semesters. The challenges were solved using critical thinking and applying the theoretical knowledge and fabrication skills that the team members had acquired through their experience at San Jose State University.

Conclusion and Suggestion for Future Work

This year's wayside power team successfully designed and fabricated a working wayside power pickup and shoe collector. The wayside rails consisted of PVC pipes, copper wire, and silicone caulk. Silicone caulk was used as the insulator and the adhesive between the flat copper wire and the schedule-40 PVC conduit that was used for the wayside rails. Silicone caulk was chosen because bare copper wire is expensive and using silicone caulk would allow future teams to recondition the wayside rails as necessary.

Brackets that hold the wayside rails into place were made out of wood. Wood was chosen over 3-D printing due to time and cost constraints. The brackets that were made can fail if it is not handled with care. Future teams can work on designing a sturdier bracket or a different system to hold the wayside rails in place.

The collector shoes are flatten 8-gauge insulated wire that comes in contact with the wayside rail with the help of springs to work with deflections that may occur as the bogies travels through the track. The collector shoe that was designed this semester is reliant on the direction of the bogies and the wayside rails. This year's team designed the wayside rail in modular sections for ease of transport for occasions such as Maker Faire. The collector shoe is designed so that it can go in one direction so that it does not get caught on the slight inclines of the rails at the sections where two pipes meet. Future teams can improve the shoe collector design by making it be able to go in any direction.

During Maker Faire, the team was able to install wayside power onto the intermediate scale. The team learned about the importance of labeling, which insures proper installation after transporting parts. Unfortunately, the bogie was not working properly so the wayside rails were not properly tested. However the team was able to test for conductivity through the wayside rails after applying a voltage and observing the voltage with a multi-meter at the beginning and at the end of the wayside rail connected them all.

Communication between other sub teams is extremely important especially on a big project such as Spartan Superway because there are many dependencies and exposures that can act as a set back. For future teams, it would be very valuable to help other sub teams if their own team is dependent on other teams. Helping other sub teams other than your own team would prove favorable for all members of the team.

To take wayside pickup system to the next level, future engineers can improve the system by being able to take solar energy from the solar panels and supply the wayside rail with solar power. This would bring Spartan Superway a step closer to the ultimate goal and prove that sustainable mode of transportation can be developed for the use of public.

Power System

Abstract

The Sustainable Mobility System for Silicon Valley (SMSSV), also known as the Spartan Superway, is an interdisciplinary student-run project with the goal of developing a solar powered, rapid-transit system to be implemented in urban areas. The goal of the project is to design a system that will be able to provide a renewable energy-based transportation system to the public while minimizing the system's overall environmental footprint. As part of the SMSSV project, our team of electrical engineers has created a solar interface system that will supply power to the Spartan Superway and utilize solar energy to offset the environmental impact of the transportation system.

Introduction

At the beginning of the Fall 2015 semester, our project had two main objectives. The first objective was to replace the batteries that supply power to the 1:12 scale model with solar cells and a conducting wayside rail system. The second objective of the project was to create a solar interface system to provide power to the intermediate scale model via a combination of solar and grid power. Unfortunately, the 1:12 solar interface project was put on hold by project leadership at the beginning of the Spring 2016 semester, in order to divert all efforts to creating a solar interface system for the intermediate scale model. The ultimate goal of our project was to develop a system that will provide a reliable source of power to the Spartan Superway under all conditions and to aid in the creation and implementation of an economical and environmentally friendly public transportation system. Spartan Superway's enormous potentials and global impacts, which have been described in the next section, have inspired us to join this project and be a part of creating history.

Technological Impact and Uniqueness of Spartan Superway

The automobile transit in busy cities is rapidly becoming unsustainable due to the increasing population all over the world. The increasing number of automobiles are worsening the environmental impact of fossil fuel combustion in an alarming rate. According to a report published by EPA named 'U.S. Transportation Sector Greenhouse Gas Emission 1990-2013,' "transportation represented 27% of total greenhouse emissions in 2013. Within the sector, light-duty vehicles (including passenger cars and light-duty trucks) were by far the largest category, with 60% of GHG emissions." The diagram published in this report (shown below) is a clear indication of how the transportation sector is polluting the environment in an alarming rate:

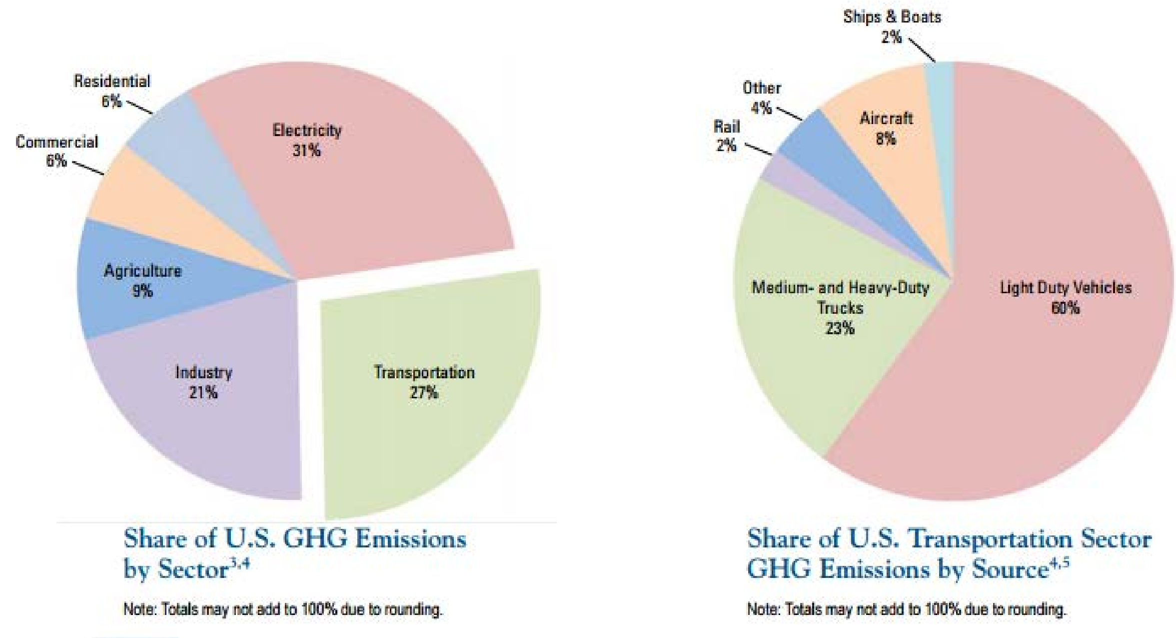


Figure 1- 123:Greenhouse emission due to transportation sector in the US (Image source: U.S. Transportation Sector Greenhouse Gas Emission 1990-2013, October 2015)

To remedy these alarming conditions, Spartan Superway is the ultimate solution that will provide the crowded cities of the world with an automated transit systems that harnesses one of the cleanest form of energies. By incorporating solar power into the system, this transit system can be proven to be a landmark of an environment-friendly public transportation.

The Santa Clara Valley Transportation Authority (VTA) is one of the main providers of public transportation in the San Jose area that provides bus and light-rail public transportation solutions to Santa Clara County. Even though VTA's goal is to provide community focused, environmentally responsible transportation solutions to San Jose and the surrounding communities ("About VTA"), SMSSV's potential to reduce overall traffic and greenhouse emission supersedes VTA. According to the VTA 2014 Sustainability Report, the total fuel usage was 4.3 million gallons of fuel and 30.1 million kilowatt hours of electricity during the 2014 calendar year ("Sustainability Report 2014"). Compared to this huge fuel consumption, SMSSV will be significantly more environment-friendly due to solar-power implementation. In addition, since the Superway will not be using any existing roads, it will not add to the existing traffic as well. Other public transportations include BART (Bay Area Rapid Transit) and Cal train, which are both inter city transit systems and does not create direct competition for SMSSV. Being fully automated and solar-powered, SMSSV is a definitely a more efficient, reliable, and environment-friendly choice for public transportation.

CCTV News, Bay Area, has published a short documentary on Spartan Superway and its enormous potential, which showcases the uniqueness of this whole project to the whole world. The video published by CCTV News is named "Are mini pod cars the future?" The video describes our project as "the world's largest pod car project." The video highlights the uniqueness of Spartan Superway by mentioning, "It's the only pod car in the world that rides suspended on a guideway." Finally, the video gives this project the ultimate stamp of approval by saying that is only a matter of getting the industry and the government together to turn this project into a reality. Overall, the Spartan Superway project is the gateway towards the most sustainable public transportation system that will lead the world towards a greener future.

Project Specifications and Methodology

At the beginning of this project year, two different scale models of the SMSSV were planned for production, a 1:12 scale model and an intermediate scale model. The 1:12 model will employ multiple pod car units. Each pod car model has a motor, a series of servos, a microcontroller, and a backup battery, all of which would be powered through an energized 3rd rail and wayside pickup system. The estimated electrical requirements of each pod car will be about 0.5 amps at 6 volts DC, or about 3 watts DC. To support multiple cars operating simultaneously on the model track, our team had to design a power conversion system using a combination of solar power and city grid power. However, earlier this year, the small-scale team and overall project leadership decided to forgo our solution for an all-battery power system. There will be a solar powered battery charging station for the pod cars, but we were only consulted on its design rather than being intimately involved.

For the intermediate scale design, we went in the direction of a commercial-off-the-shelf (COTS) modular design. This was done for several reasons. First, since we agreed that the transition from intermediate to 1:1 scales should involve simply increasing the ratings of the components, using COTS devices simplifies that task. Secondly, since this system involves both a photovoltaic (PV) system and public safety, we tried to follow all appropriate regulations that might apply to the final system. This would require that all components be listed with some approved agency, such as the Underwriters Laboratories. Finally, since we were working with multiple subsystem teams, we did not receive final estimated power requirements in time to complete a custom design solution. Add to that the variety of voltage levels and current demands that were proposed as the project evolved, and it became clear that a simple and scalable solution was required.

Project Details

The complete component list for the intermediate scale solar interface circuit can be found in Table 1-11. This system converts the captured solar energy to U.S. grid-compatible AC power, then to a lower voltage DC power to run the drive motor for the car, then back to AC power in the transport car. There, the AC will power another multiple-output power supply that will provide power to any secondary motors and controls. The block diagram for the overall system can be seen in Figure 1-125 shown in the next page:

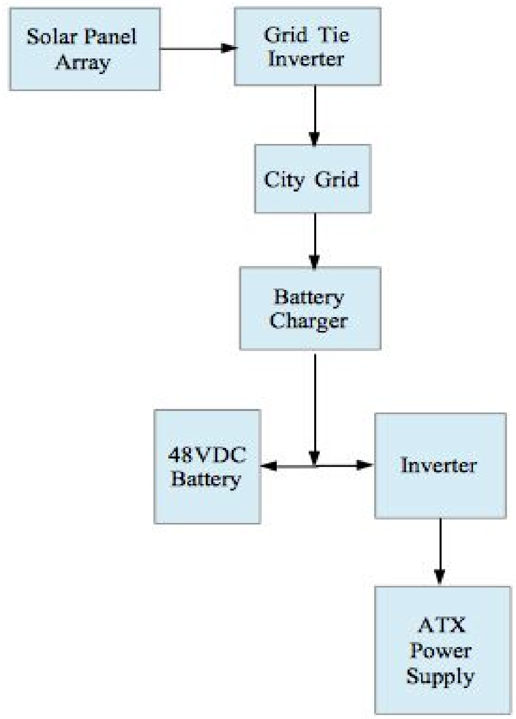


Figure 1- 124: Overall System Block Diagram for the Intermediate Solar Interface

In the current intermediate scale design, an array of 15 solar panels provides approximately 1 kW of peak power to a grid-tie inverter. This inverter has a synchronization circuit that produces an AC output that is phase-matched to the AC provided by the utility source. Connected to the utility source, along with the solar inverter, is a battery charger. The charger output is connected to the storage batteries and the wayside fixed conductor rail. The transport vehicles have a movable conductor which rides along the fixed conductor to provide an input path to the various loads in the car. The nominal 48VDC on the wayside rail will power the drive motor controller and a second 1500W inverter unit. This second inverter unit provides 120VAC at 60Hz for a 1250W ATX power supply, which provides 12VDC and 5VDC for auxiliary loads, such as the suspension and steering motors. Also powered by this end unit will be multiple microcontrollers that independently operate the various subsystems of the SMSSV. The complete intermediate solar interface system schematic can be seen in Figure 1-126 shown in the next page.

The estimated cost of the power conversion subsystem for the intermediate scale model is $1128.63, not including shipping and taxes. This cost does not include the solar panels, batteries, and battery charger, as those items were donated. The solar panels for the intermediate scale model have been donated by MiaSole, a local solar cell manufacturing and distribution company. The batteries and battery charger were donated by GMET, a manufacturer of rechargeable batteries sold in China and elsewhere. The remainder of the funding for this project has been provided via the Spartan Superway GoFundMe account. The complete bill of materials for the intermediate scale solar interface can be seen in Table 1-11.

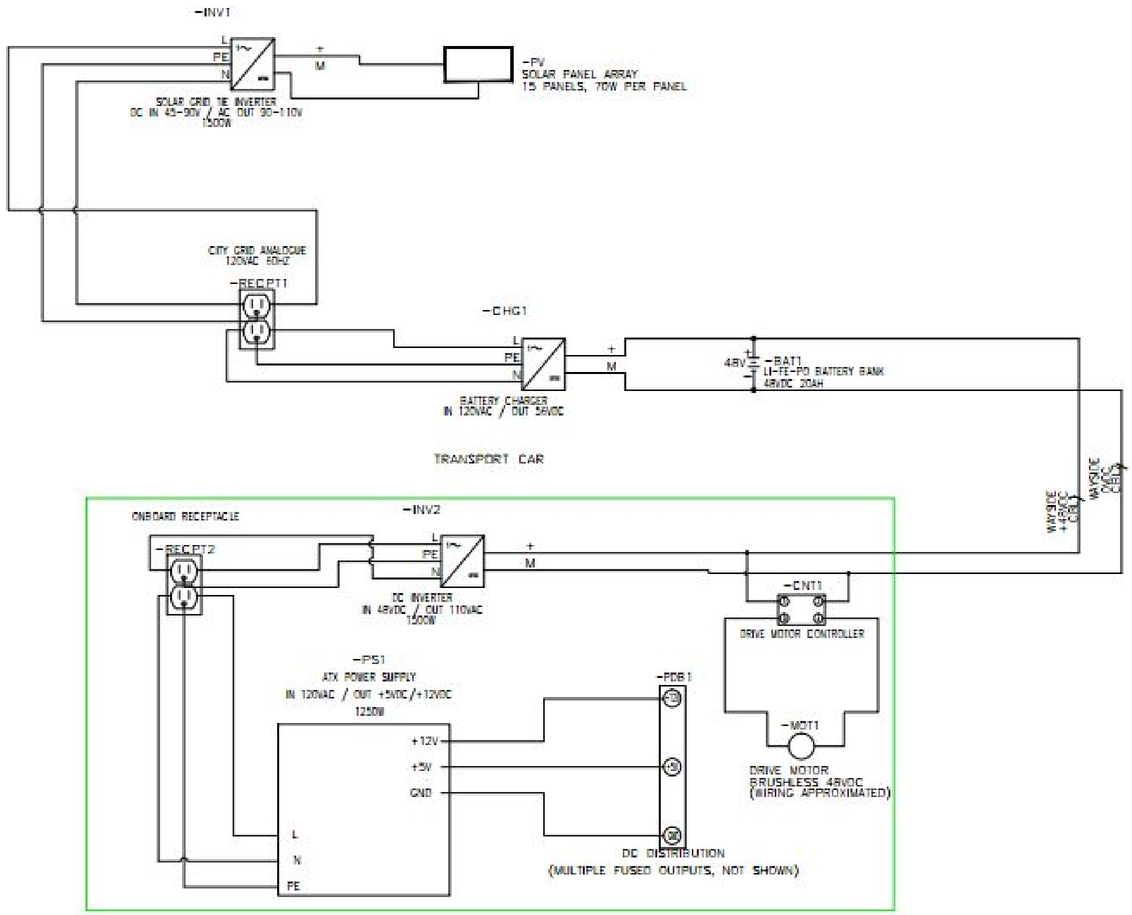


Figure 1- 125: Complete Intermediate Scale Power Conversion & Distribution System Schematic

The tasks for our team involved getting finalized load demand estimates from the subsystem teams, acquiring the required materials, and assembling the final system. Significant delays were experienced due to the lack of firm estimates for power requirements. Around the end of February of 2016, we were running out of time to get the necessary components and complete assembly and testing. As a result, we moved forward with a design that would have significantly more capacity than what was estimated. This was done in order to account for last minute changes from the other teams.

Our team was responsible for the acquisition and assembly of components for the intermediate scale model power conversion system. The components for the 1:12 solar interface were not purchased as changes in the overall plan moved away from the custom solution that we had designed near the end of 2015. This led us to focus solely on the intermediate scale system design. All components were ordered and paid for by the SMSSV project accounts. Assembly was completed by our team, as well as the cabin subsystem team. The cabin team was responsible for location and mounting of the components that would be installed in the transport vehicle.

Testing was done at the SMSSV assembly area, as the system could not have been adequately simulated without being integrated into the larger assembly. This testing involved measuring power supply input and output voltages and currents, as well as monitoring running temperatures to ensure long term operability and stability of the overall system. For the full system testing and display, both the handheld test equipment listed in Table 1-12 and installed power meters listed in Table 1-11 were used.

Table 1- 11: Parts List and Estimated Cost for Intermediate Scale Solar Interface

Quantity	Description	Cost Per Part ($)	Total Cost per Part ($)	Notes	Total Cost ($) (Less Shipping & Tax)
15	Solar Cell	0	0	Donated	1128.63
1	1500W Solar Grid Tie Inverter	489.99	489.99		
1	1500W 48VDC to 120VAC Inverter	285.00	285.00		
1	1250W Modular ATX Power Supply	215.41	215.41		
2	6 Circuit Fused DC Distribution Block	33.50	67.00		
1	ATO type Fuse Assortment	7.25	7.25		
2	60VDC / 50ADC Power Meter	31.99	63.98		

Table 1- 12: List of Equipment to be used

Quantity	Description	Obtained From	Use
1	FLIR C2 Thermal Camera	Personal Equipment	Monitor equipment during operation
1	Fluke 177 Digital Multimeter	Personal Equipment	Test and verify proper operation of system
1	Fluke 322 Clamp on Ammeter	Personal Equipment	Test and verify proper operation of system

<u>Completed and Current Goals of the Team</u>

Figure 1-127 below shows the progress of the of the project at the end of the Fall 2015 semester. As can be seen from Figure 1-127, the design and specifications for the 1:12 scale model were completed by the end of the Fall 2015 semester. It can also be seen that the design of the intermediate scale system had not yet begun, as the overall intermediate power specifications had not yet been determined. As mentioned earlier, the production of 1:12 scale solar interface was terminated at the start of the Spring 2016 semester. It should be noted that, although the Gantt chart in Figure 1-127 includes dates leading up to the end of the Spring 2016 semester, this schedule had to be revised to account for the shift in project priorities.

Figure 1-128 below shows the revised project Gantt chart for the Spring 2016 semester. As can be seen in Figure 1-128, our team began the conceptualization of the intermediate scale model at the beginning of the Spring 2016 semester. As stated previously, our team faced several difficulties in the initial design of the intermediate system, due to a lack of power requirements for the system. At the time of writing this report, our team is in the process of fabricating and testing the system. Table 1-13 below contains the deliverable descriptions and due dates for the intermediate solar interface system. It should be noted that, while we have been able to test some of the subsystems for functionality, we have not yet been able to test the entire system as a whole. However, we are confident that we will be able to implement and test the remaining system components once the construction of the wayside rail is complete.

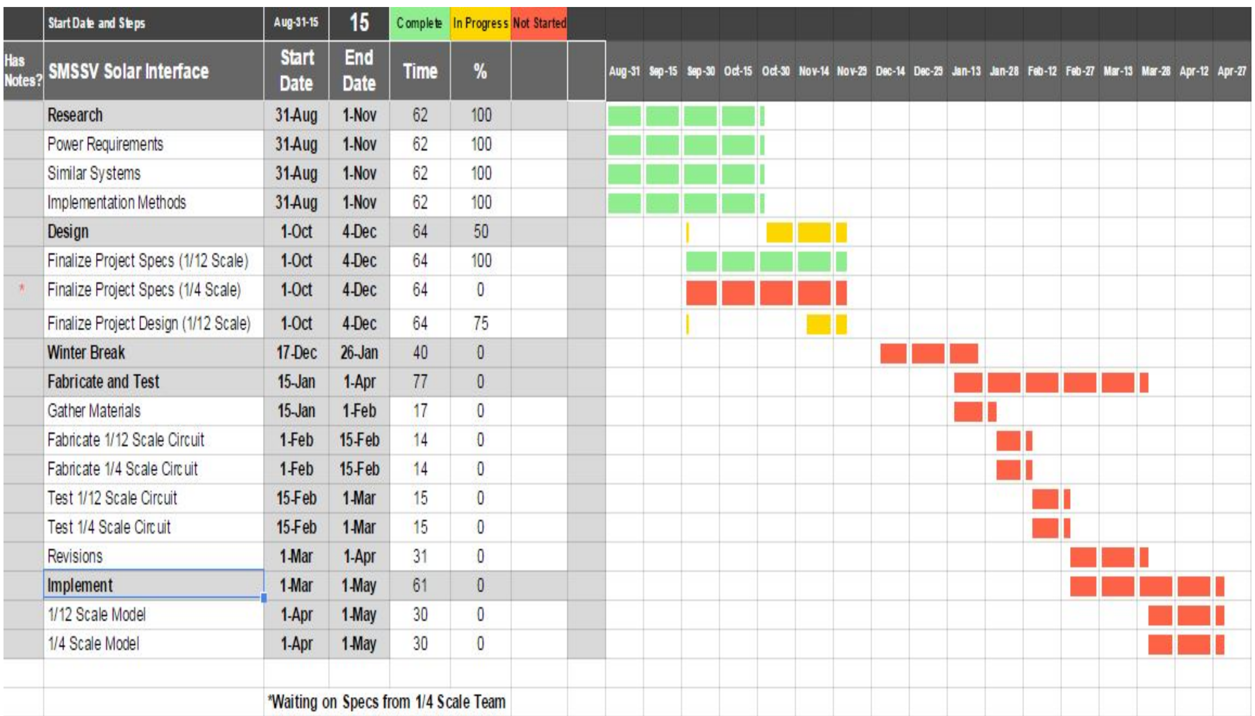


Figure 1- 126: Project Gantt chart Project Gantt Chart as of December 4th, 2015

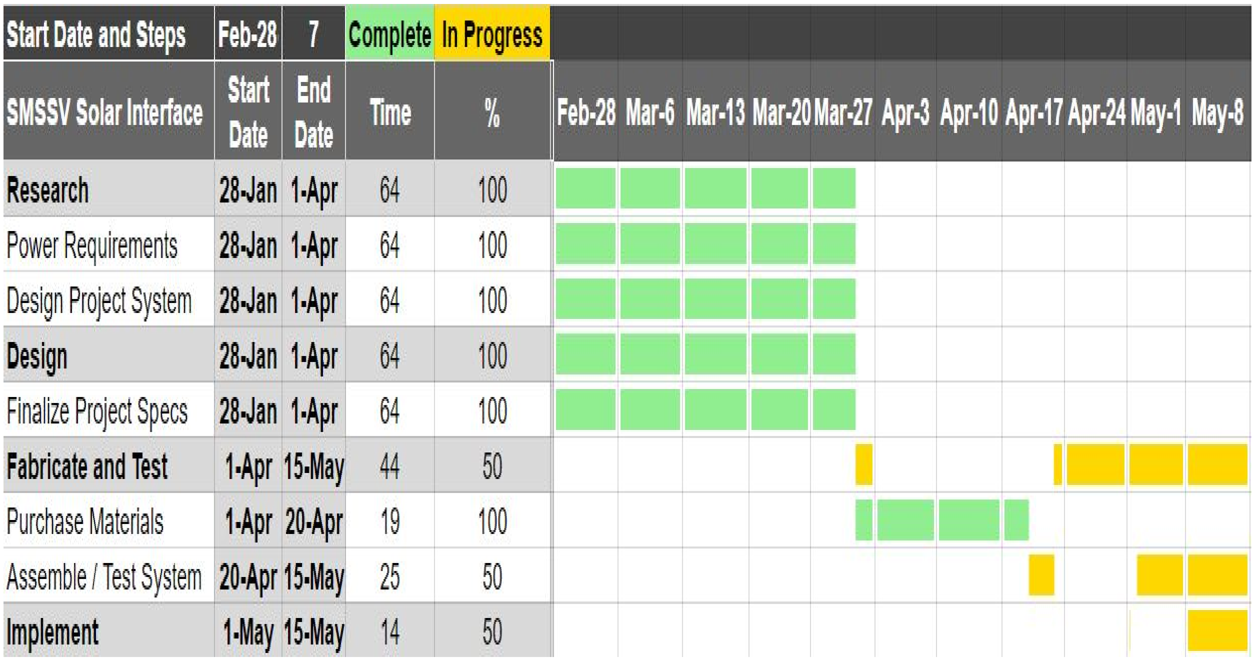


Figure 1- 127: Project Gantt chart Project Gantt Chart as of May 9th, 2016

Table 1- 13: Revised Project Deliverable Dates, Descriptions and Estimated Cost

Date	**Quantity**	**Deliverable Description**	**Estimated Cost ($)**
4/1/2016	1	Finalized Design of the Intermediate Solar Interface	N/A
4/20/2016	1	Complete Bill of Materials for the Intermediate Solar Interface	N/A
5/15/2016	1	Finalized Intermediate Scale Solar Interface Circuit	$1128.63

To finalize the project, our team will be attending the Bay Area Maker Faire, May 20-22, 2016, along with all the other Spartan Superway sub teams. Our final goal is to assemble our power system, place it on the final model, and run the pod cars at the fair. We are looking forward to presenting our work in front of the tech- enthusiasts of Silicon Valley.

<u>Team Management and Performance</u>

Overall, our team proved to be highly effective and adaptable when faced with design challenges, inconsistent and changing power requirements and upcoming deadlines. During the Fall 2015 Semester, our team had meetings each week to discuss the current and relevant details of the project design. In addition, at least one member of our team attended weekly meetings with the larger Spartan Superway team to collaborate on designs and keep informed of any important project information and deadlines. During the Spring 2016 semester, our team made a collective decision to attend the larger Spartan Superway meetings as a group. This decision enabled us to interact as a team with the other sub teams in the project. As our team was depending on power requirements from the other sub teams, we spent the first part of the semester in an advisory role aiding the other sub teams in component selection and determining power requirements. Any conflicts or clarifications that arose were addressed at the weekly meetings via small group discussions between our team and the participating sub team. Outside of the weekly meetings, email was used as the primary means of communication between our team and the other sub teams. In order to ensure that all members of our team were involved in group discussion and problem solving, each member of our team was included in all email responses.

Major Challenges Faced

One of the main challenges our team faced was the lack of data to move forward with our project. For example, one of the first pieces of information we needed to start designing our power system was the power requirements from the sub teams. Eventually, the sub teams resolved and finalized their own designs and came up with the final power requirements. We were able to get the final numbers from the sub teams in April 2016, which shortened the time frame for finishing the execution part of our project. However, our team did not stop planning and designing to finish the project in time. We predicted the power requirements beforehand based on our prior knowledge and talking to the sub teams as much as possible. We kept designing the circuit and looking for parts to buy based on our predicted numbers. When we got the final power requirements from the sub teams, they matched our predictions and we were able to move forward with our design and finish the project on time.

Conclusion

We joined the project with the hope of contributing to improving the Spartan Superway's overall potentials. Throughout this journey, we have not only acquired technical knowledge but also learned valuable skills of teamwork. One of the most important life-long learning for us was how to operate effectively within a large group of engineers. This experience will definitely prove to be an important skill at our future work place. Towards the end of the project and after a year of our dedicated team effort, we are very proud to be a part of a revolutionary public transport system that will ensure a better future for our world.

Torsion

Background and context for the work of the sub-team

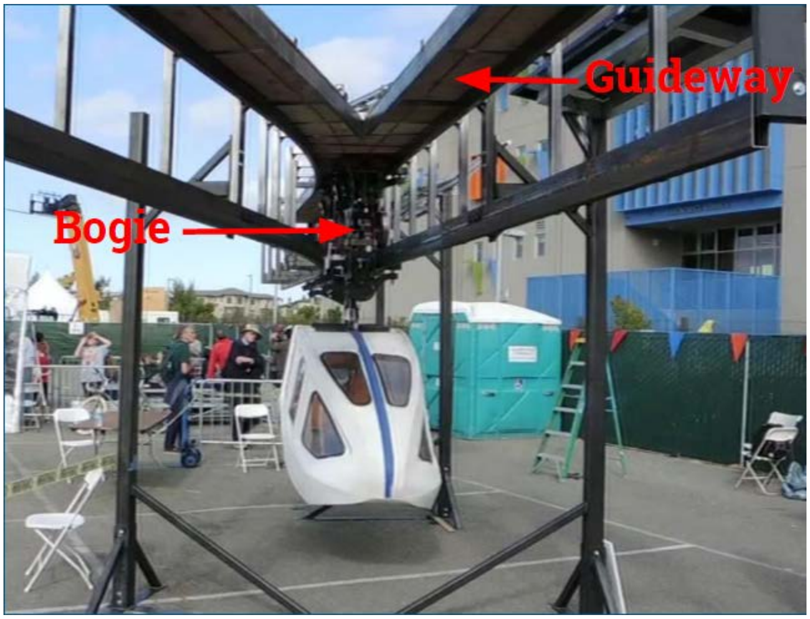


Figure 1- 128: Guideway System Scale Model

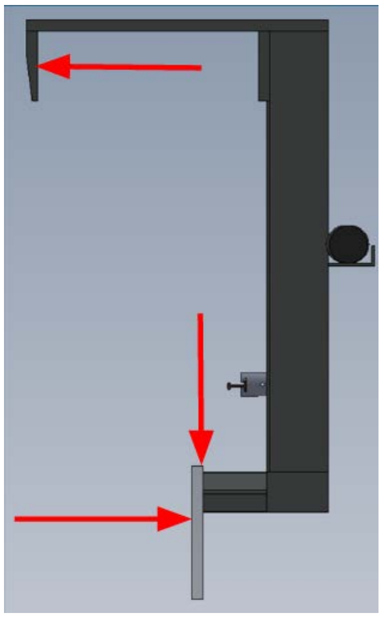


Figure 1- 129: Loading Due to the Bogie

As the Spartan Superway develops, it's important to optimize the design of the guideway for maximum strength while maintaining cost-efficiency. The loading from the bogie causes a net torque on the guideway due to the design of the bogie's guideway switching system (figures 1-129 and 1-130). For this reason, the guideway must be analyzed under torsional loading. Two methods will be used to analyze the most current track design: theoretical analysis and physical experimentation. Theoretical analysis is done through hand calculations and FEA modeling in ANSYS, and will be confirmed using experimental testing.

Description of the Sub-team and Objectives

The purpose of this sub-team is to investigate the precision of an ANSYS model by comparing the model's behavior to a physical specimen. Kriti Kalwad, a Master's student at San Jose State University, will work to optimize the guideway design using ANSYS. The sub-team will confirm her ANSYS results by comparing the behavior of the computer models to that of actual specimens when a torque is applied.

The first objective of the team is to calibrate the actual torsion testing machine. The machine was manufactured around the 1940s, and had not been used since 2008. To ensure the accuracy of the torsion machine's torque dial, the team will use stock pieces of steel for calibration purposes. Then, strain gages will be applied to different specimens to measure strain behavior, and will be compared to the behavior of Kriti's finite element models. These specimens should range in geometry and size to give more insight on how complex shapes will affect the predictability of strain behavior. The final goal of the team is to build and analyze a scaled model of the guideway design.

Design Requirements and Specifications for the Sub-team's Work Products

- Calibration Design Requirement
    - Test two circular cross sectional tubes to calibrate the torsion machine
        - The specimens must fit in the torsion tester (between the two chucks)
        - The specimens must give an angle of twist significant enough to accurately measure and compare to hand-calculations. This is relative to the machine's loading capacity
- Strain Specimen Design Requirement (Intermediate Specimens)
    - Test one circular cross section with a strain gage applied to it and compare results to ANSYS and hand calculations.
        - Strain must be significant enough to measure and to compare to ANSYS results
    - Test one square cross section for angle of twist and with strain gage applied to it. Compare results to ANSYS and hand calculations.
        - The specimen must be modified to fit in the torsion tester, since the chucks are triangular
        - The torque needs to be distributed evenly along the center of the pipe
- Track Design Requirements
    - Test a scaled down track, measuring strain for comparison to an ANSYS model
        - The specimen must fit within the length and width constraints of the torsion machine
        - Strain gages should be placed at multiple locations on the track
        - The strain and angle of twist must be significant enough to accurately measure

State-of- the-Art/Literature Review for the Sub-team's Sphere of Work

Although torsion test literature review was limited, the team did investigate other types of guideway systems and how they compare to the Superway. One of the simpler PRT designs is the Urban Light Transit (ULTra) located at the Heathrow airport in London. Similar to the

Superway it implements the use of offline stations to store the personal rail vehicles they are called upon. The guideway for this system, however, is beneath the vehicle. The bottom rail PRT is efficient and has good user feedback, but the infrastructure is not reasonable for city-wide use. The bottom mounting is for guiding the machine, and the actual support is a concrete pathway. This means the system requires more material and space to build a track separate from walkways and streets.

The Siemens People Mover H-Bahn is a suspended passenger railway system installed in Dortmund, an independent city in Germany. The system received various upgrades since its public opening in 1984 at the University of Dortmund, and the rail network is currently about two miles long. Similar to the Superway, its propulsion wheels rest on a type of support rail, and switching is done through horizontal guide wheels (although there are slight mechanical differences). It also differs in use from the Superway; the H-Bahn is for transporting a large amount of people similar to a bus system. Its guideway is designed to withstand much larger loads, and has a much different type of queueing system.

The final PRT the team looked at was the SkyTran, a transit system designed by NASA that has not yet been implemented in the US. The system uses magnetic levitation technology, which drastically decreases energy consumption. The current design is very similar to the Superway since it uses a queuing system, stands above traffic, and is a personalized vehicle. However, this system is still in development and will have a high cost of installation.

Description of Your Design

Calibration Set-Up

The two calibration specimens were cut from a stock circular pipe (donated by PDM Steel). The stock pipe is a hot-rolled 2”OD A513T1 steel tube with a 0.120” wall thickness. The first piece was cut to ~48”, and the second to 59”. The effective lengths were 42” and 53”, however, since each end had to be mounted into each chuck (about 3” a side). This report will refer to the calibration specimens by their effective lengths because the twist occurs between the two chucks.

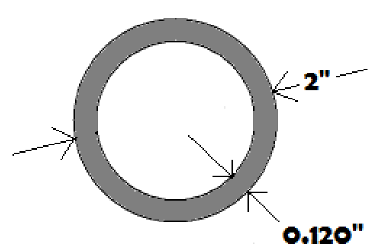


Figure 1- 130: Stock Pipe Dimensions

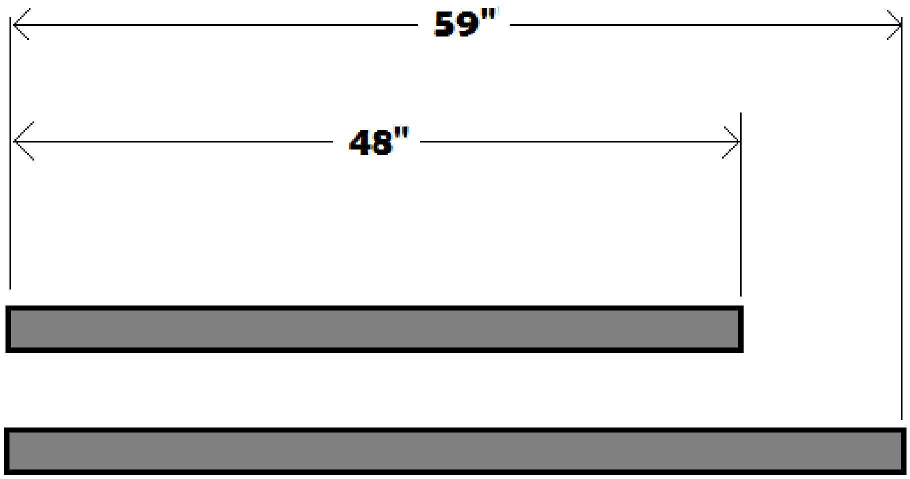


Figure 1- 131: Calibration Specimen Total Lengths

To calibrate the machine, the team decided to compare measured and calculated angles of twist. First, the team determined the torque at which the specimen would remain in the elastic deformation region, and chose to apply a maximum torque of 8250 lb-in. Starting at 0 lb-in and slowly increasing the torque (in intervals of 750 lb-in), the team will measure and record the bar's angle of twist using a clinometer mounted to a bracket each end of the specimen (figure 1-133). See the torsion team lab guidelines and report for a more detailed procedure.

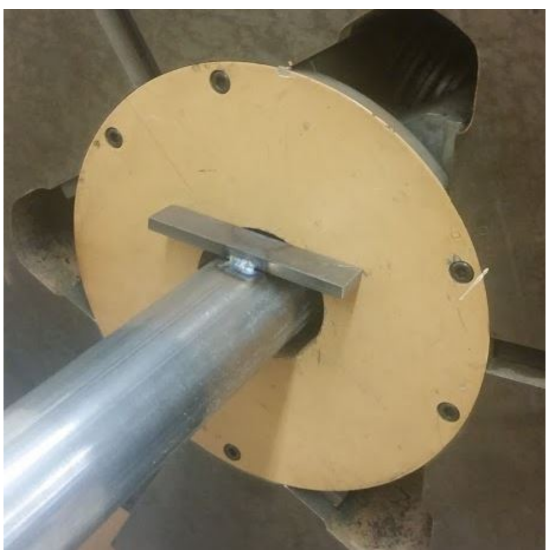


Figure 1- 132: Clinometer Mounting Bracket

This result will be compared with theoretical calculations for angle of twist of a circular hollow section, using equations 19 and 20 shown below.

Equation 19

$$\theta = \frac{TL}{JG}$$

Equation 20

$$J = \frac{1}{2}\pi(r_o^2 - r_i^2)$$

Within these equations, **Θ** is the angle of twist, J is the polar moment of inertia for a hollow circle, T is the applied torque, L is the length of the section, G is the modulus of rigidity for A513 structural steel, r_o is the outer radius and r_i is the inner radius. The measured and calculated angles will be compared by calculating the percent difference between the two values. The measured data will also be checked for linearity.

Intermediate Specimens

The first intermediate specimen was taken from the same material as the calibration pieces. To maximize angle of twist, the specimen was made significantly longer, and was cut to be 70” in length.

The second specimen was cut from a square tube in order to see what effect a more complicated geometry would have on ANSYS error. The square tube was made of A513 steel tubing, and was cut to a length of 63 5/8”. To mount the square tube into the testing machine, end plates need to be welded on to each end (figure 1-135).

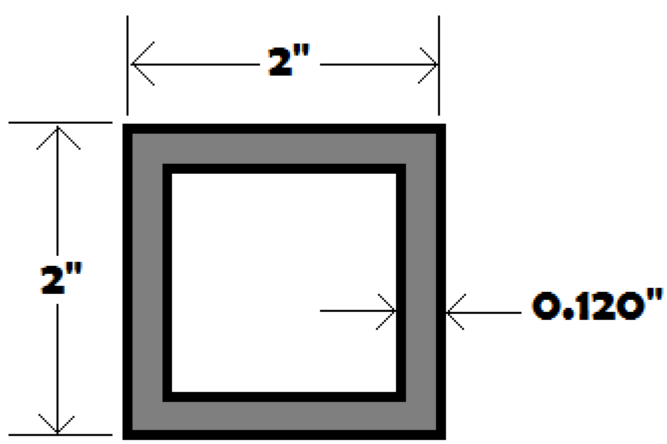


Figure 1- 133: Square Pipe Cross Section

Figure 1- 134:Square Specimen Plates and End Rods

The testing procedure for the intermediate specimens is almost identical to that of the calibration. However, strain gages must be placed at the center of each specimen to measure strain behavior under torsion. Again, a more detailed version of the procedure can be found in the lab guidelines.

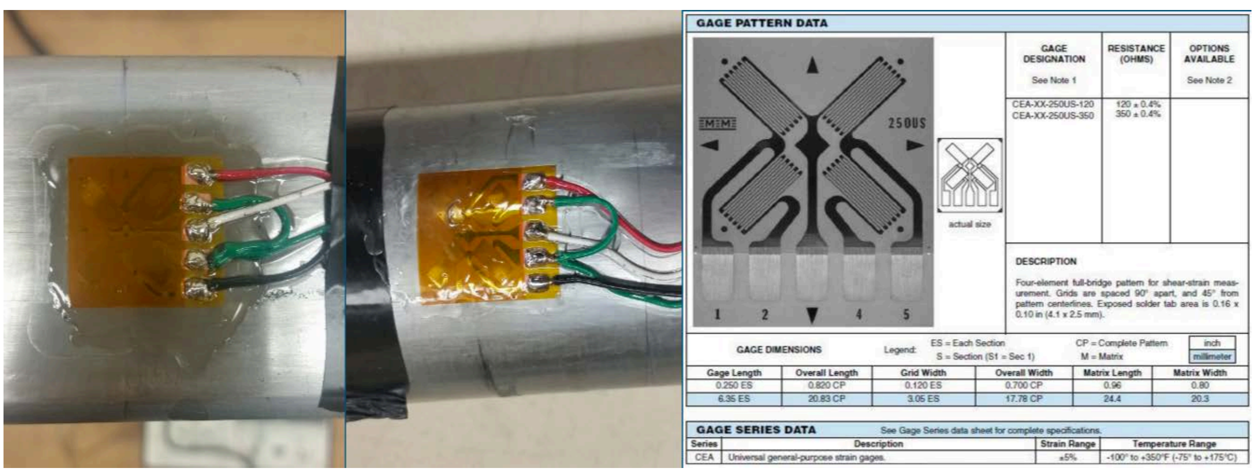


Figure 1- 135: 250US Strain Gages (donated by VPG Micro-Measurements)

The team will use 250US strain gages interfaced to a P3 DAQ (figure 1-137) connected to a computer to measure strain results (figure 1-138). These results will then be compared to ANSYS models created by Kriti Kalwad. Any type of deviation from experimental results will be noted to improve finite element analysis in the future.

Figure 1- 136: P3 Data Acquisition Device

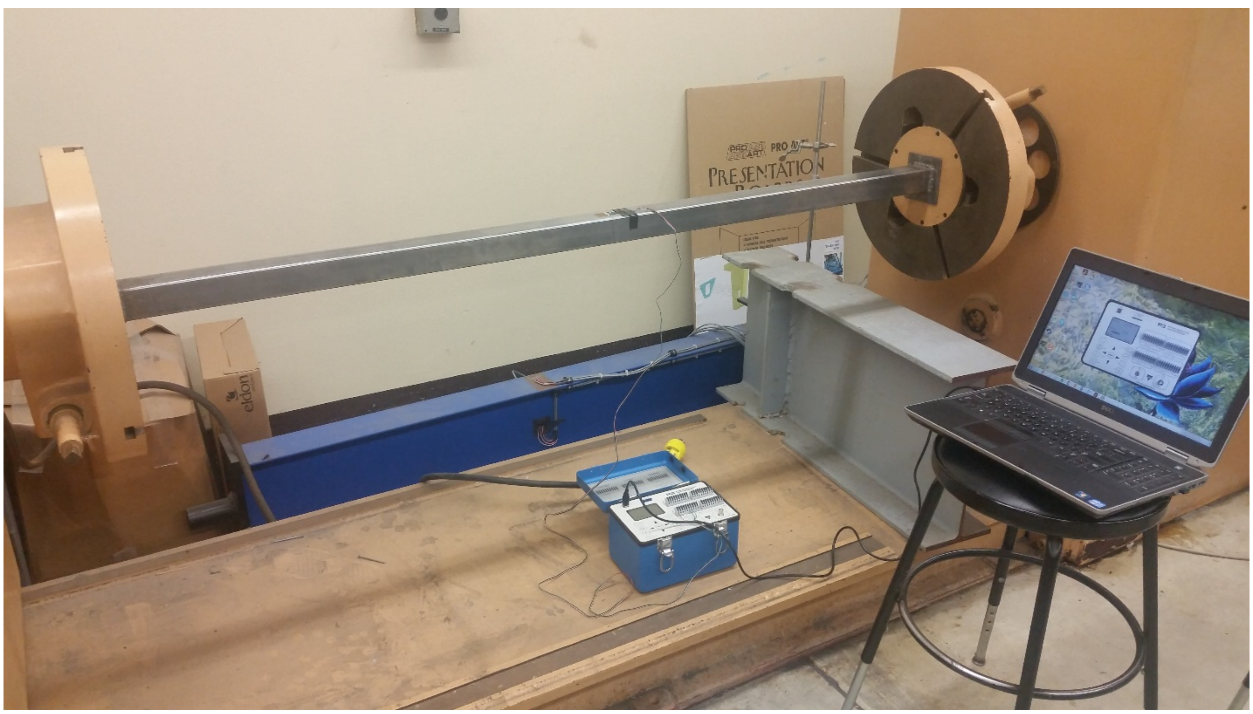


Figure 1- 137: Strain Test Set-Up

Scaled Guideway Design

The initial design of the guideway is shown in figure 1-139, and was created by Bengt Gustafsson. Bengt's design was somewhat complicated given the number of support joints connecting the support rail to the frame. Figure 1-140 shows an alternate model of the guideway created by Jake Parkhurst, a Master's student at UC Davis. There was an initial analysis on this specimen done by Kriti Kalwad in the summer, but this data was not used extensively by the sub-team. Both designs were determined to be too complex to construct for various reasons.

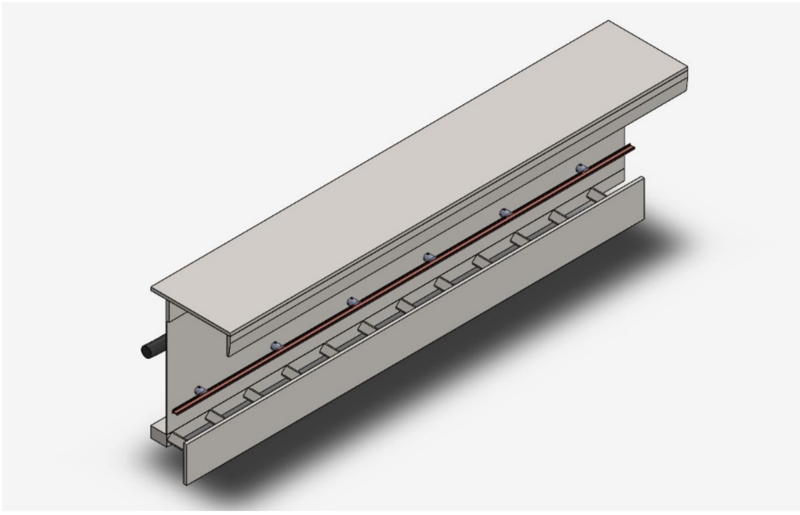


Figure 1- 138: Bengt Gustafsson Guideway Design

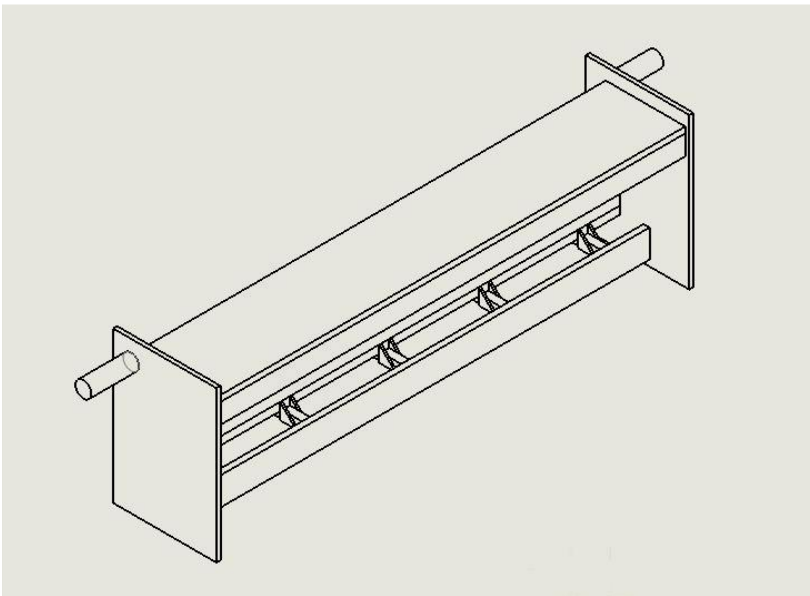


Figure 1- 139: Jake Parkhurst Scaled Guideway Design

<u>Analysis/Validation/Testing</u>

Calibration Specimens

The calibration specimens had significant error, but the data show slippage at the start of the test. As seen in graph a, there is a notable jump in twist angle as the torque goes from 0 to 750 lb-in.

Initially, the twist jumps from 0 to 0.5 degrees, but then shows a slope of ~0.3 degrees per 750 lb-in increment. Theoretically, the angle of twist is directly proportional to the torque applied as long as the bar remains in the elastic region. This initial jump in twist angle is not present at any other point in the data, therefore the team concluded an initial slip occurred, and that the chucks will not fully lock onto the specimen until the loading starts. To remedy this, the team decided to implement an offset of 750 lb-in. Essentially, the initial twist from 0 to 750 lb-in is ignored. This is only possible because of the direct proportionality of twist angle to torque.

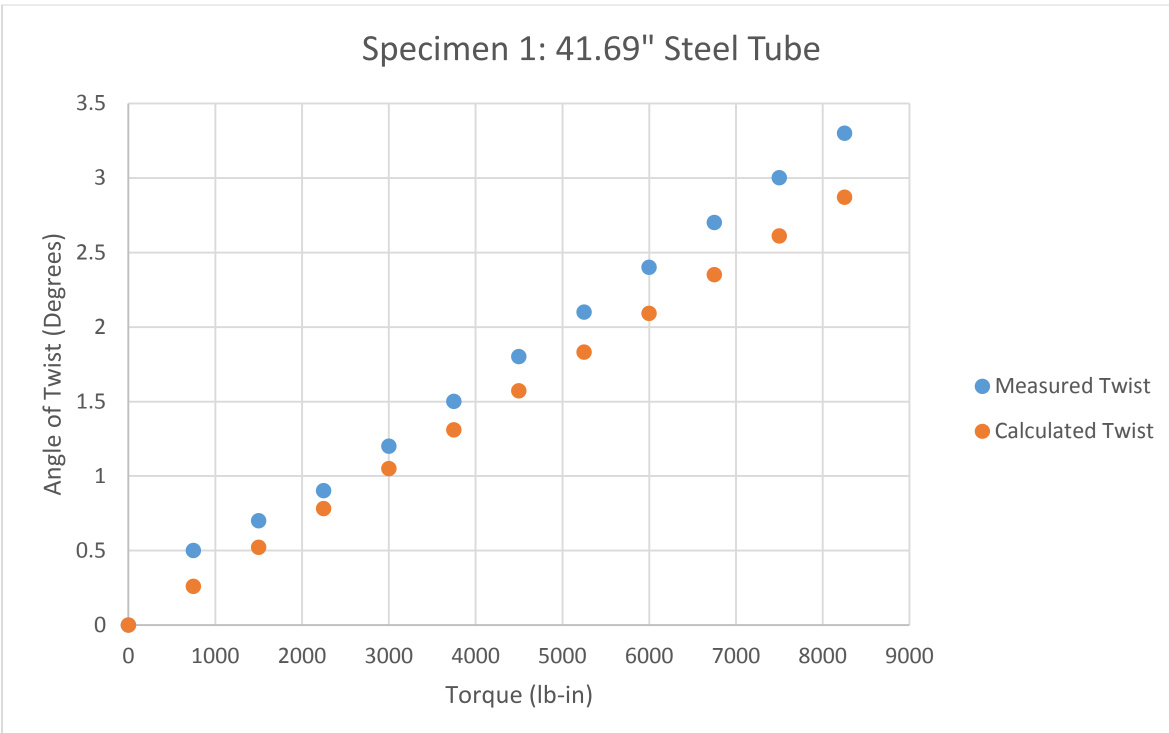


Figure 1- 140: Experimental and Theoretical Angle of Twist for a 42" Effective Length Steel Tube

After applying the offset to account for initial slippage, the error of twist was reduced. Tables 1-14 and 1-15 shows the error before and after the offset was applied. The team concluded that the torsion machine's dial was still calibrated, but that an initial slippage should be taken into account.

Table 1- 14: Angle of Twist Data for 42" Steel Tube

Torque (lb-in)	Angle of Twist	Calculated Twist	Error
0	0	0	0
750	0.5	0.26	-0.24
1500	0.7	0.52	-0.18
2250	0.9	0.78	-0.12
3000	1.2	1.05	-0.15
3750	1.5	1.31	-0.19
4500	1.8	1.57	-0.23
5250	2.1	1.83	-0.27
6000	2.4	2.09	-0.31
6750	2.7	2.35	-0.35
7500	3	2.61	-0.39
8250	3.3	2.87	-0.43

Table 1- 15: Angle of Twist Data for 42" Steel Tube with Offset Applied

Torque (lb-in)	Angle of Twist	Calculated Twist	Error
x	x	x	x
750	0	0	0
1500	0.2	0.26	0.06
2250	0.4	0.52	0.12
3000	0.7	0.79	0.09
3750	1	1.05	0.05
4500	1.3	1.31	0.01
5250	1.6	1.57	-0.03
6000	1.9	1.83	-0.07
6750	2.2	2.09	-0.11
7500	2.5	2.35	-0.15
8250	2.8	2.61	-0.19

Intermediate Specimens

70” Pipe

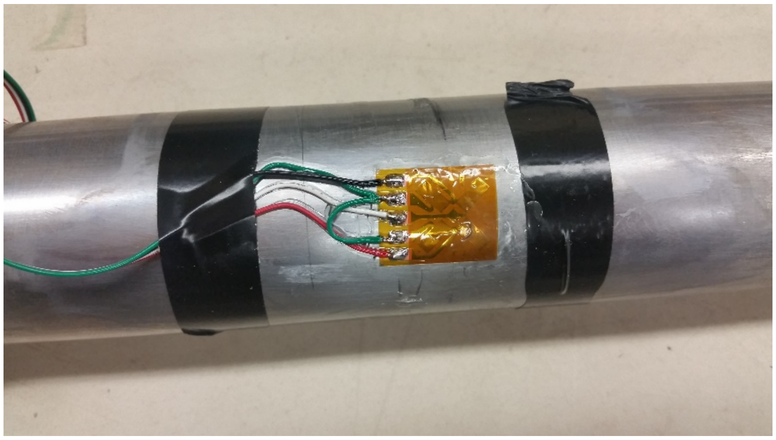


Figure 1- 141: 70" Circular Pipe and Strain Gage

The first intermediate specimen tested was the 70" hollow circular steel pipe. As with the calibration specimens, angle of twist was tested for machine accuracy just in case. After the offset was applied, the percentage error remained under 10% for the entire test, and the comparison can be seen in figure 1-143. This confirms the use of the offset and allowed us to move forward with strain analysis.

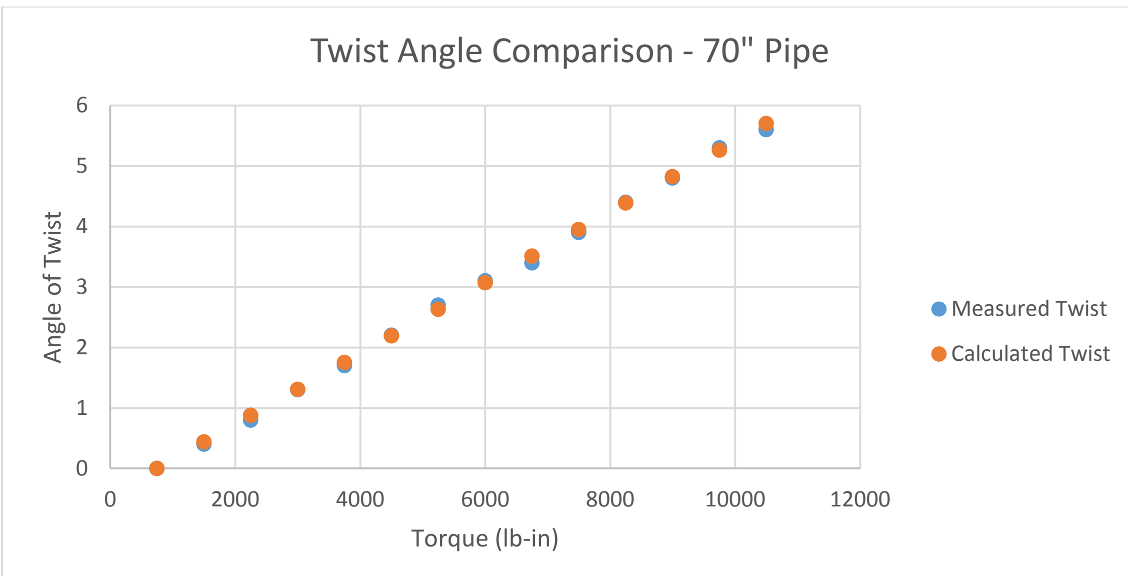


Figure 1- 142: 70" Pipe Calculated vs. Measured Twist

The picture above shows a 250US strain gage, which was used to measure the strains as the specimen was torqued from 0 to 10500 lb-in, in intervals of 7500 lb-in. In table 1-16, it shows a large starting error of 74.8%, however this is due to the low accuracy of the test and calculations relative to the size of the numbers. The error becomes lower, however the strain measurements remain about 30% larger than what ANSYS or hand calculations predicted. This is most likely due to imperfections of the steel beam, whereas ANSYS considers only an ideal model.

Table 1- 16: 70" Pipe Theoretical vs Measured Strain

Torque	Microstrain			
	[Measured]	[Calculated]	[ANSYS]	Error
0	0	0	0	0.0%
750	194	110	111	74.8%
1500	331	219	221	49.8%
2250	466	329	332	40.4%
3000	598	439	442	35.3%
3750	737	549	553	33.3%
4500	872	658	663	31.5%
5250	999	768	774	29.1%
6000	1144	878	885	29.3%
6750	1274	998	995	28.0%
7500	1408	1097	1106	27.3%
8250	1541	1207	1216	26.7%

30% error is significant, but this value can be used to predict the difference between theoretical and measured data. Figure 1-144 below also shows increasing divergence between theoretical and measured strain behavior, however the percentage error has become lower since the values become larger. The divergence can be attributed, again, to the non-ideal nature of the physical specimen and test. Also, as deformation reaches the plastic zone, this error is expected to become significantly greater.

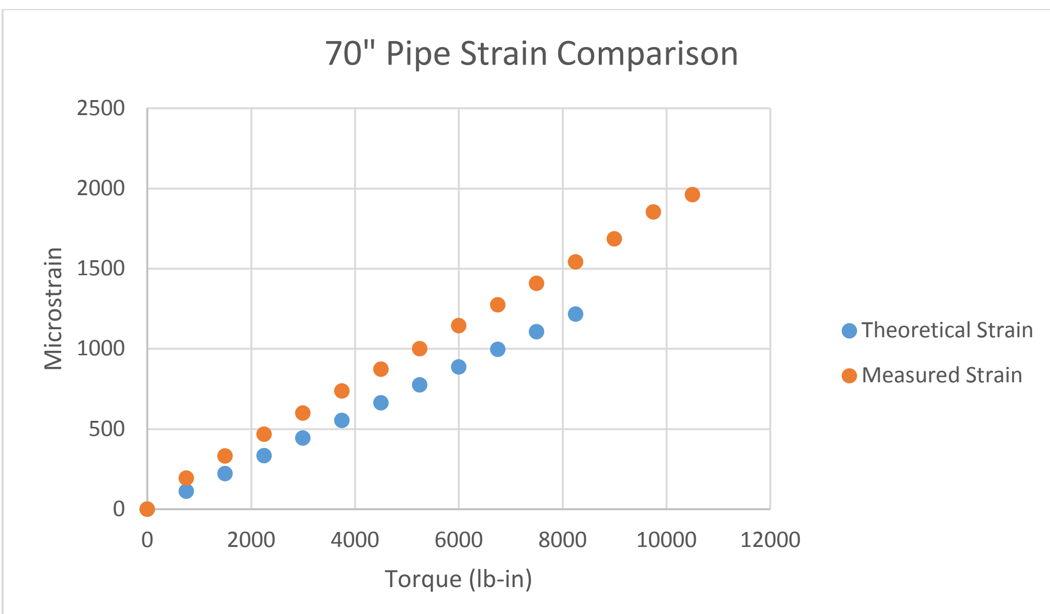


Figure 1- 143: 70" Pipe Calculated vs. Measured Strains

63" Square Tube

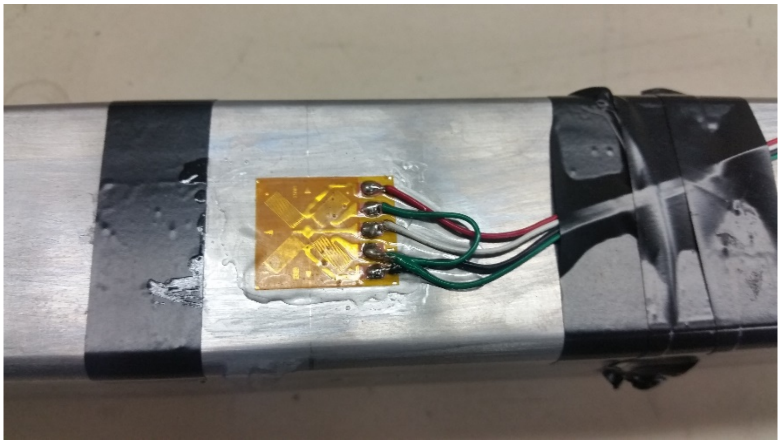


Figure 1- 144: 63" Square Pipe and Strain Gage

The second intermediate specimen tested was the 63” hollow square tube. For this bar, angle of twist was not calculated by the team due to the complex structure of the bar and inability to apply the same calculations to this specimen.

The strain behavior of this pipe was more accurately predicted in ANSYS than the circular pipe. This may be due to the increased stiffness of the specimen. As seen in Figure 1-146, the measured strain follows theoretical strain more closely than before. The team noted no diverging strain values as torque increased. The percent error started large as it did with the pipe, at 77.8%, but became drastically lower as the torque increased. At 8250 lb-in, the error had reached 14%, and had remained under 20% for previous 7 data points.

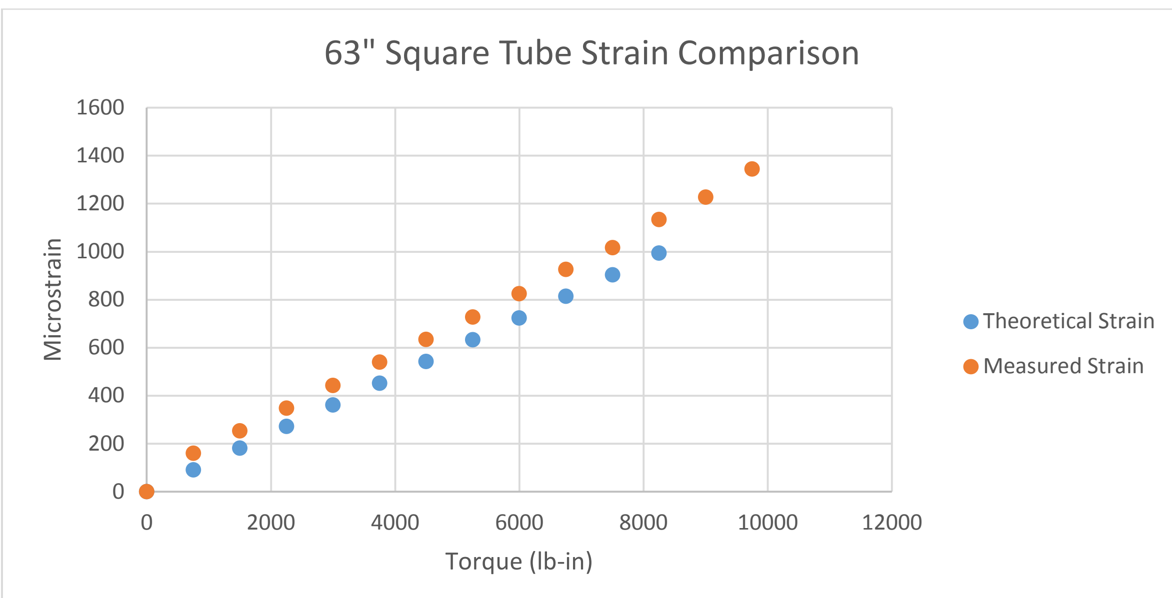


Figure 1- 145: Square Tube Calculated vs Measured Strains

<u>Money spent on your project</u>

This semester the torsion test team was fortunate enough to have most of its testing materials donated. PDM Steel has been a huge contributor by donating all the steel the team has used for its testing process. Also, VPG Micro-Measurements has agreed to donate the strain gages and its applications kit, in exchange for a case study write up about the torsion testing process. In all, there were ten 250US full bridge strain gages and the application kit included many items for surface preparation and adherence of the strain gages to the test specimen. This leaves the only expense being sandpaper and a band saw to cut the material, which came out to be $28 total. The team is very excited to have had the opportunity to work with these suppliers and appreciate all of their support.

The largest portion of our initial budget – the scaled trackway – was removed since we were unable to complete the goal of designing and building the model. The cost of materials would have been upwards of $1200 or more, and many of the parts were not stock material. Although it's unfortunate that we couldn't complete the model, the Superway budget was already drained by the end of the semester.

Table 1- 17: Torsion Team Expenses

Quantity	Material	Price	Notes
n/a	Metal Stock Pieces for Calibration/Testing: 2" OD x 0.120" HR Electric Welded Tube – 20' 2" C-1018 Cold Finished Bar – 20' 1/3 x 4" Hot Rolled Strip – 20' TS2x2x0.120" Square Tube – 20'	~ ~~$200~~	Donated by PDM Steel
	Material for Guideway	~ ~~$1200~~	Did not complete
10	10x Strain Gages	~~$500~~	Donated by VPG Micro-Measurements
1	VPG Micro-Measurements Strain Gage Prep Kit	~~$250~~	Donated by VPG Micro-Measurements
n/a	Sand Paper	$16	
1	Band Saw	$12	
	Total:	$28	

Results and Discussion

From our results, we conclude that using ANSYS for stress analysis on the Superway guideway is justified, but safety factors should be implemented to account for error. Strain deviation between the physical and theoretical specimens tend to become less as torque gets higher, but experimental strains are always greater than what is predicted with theoretical analysis. These errors are due to the non-ideal conditions of the experiment. Unlike the theoretical analysis, a physical specimen has imperfect geometries that can lead to an increased or unequal distribution of stress. Specimen slippage at the beginning of loading could also have been a significant source of error.

Based on the data, a factor of at least 1.5 is recommended be applied to ANSYS strain analysis. Measured results were always greater than what ANSYS or hand calculations predicted, although higher torques resulted in lower error. For more complex shapes, further testing is required. These errors occurred for relatively simple geometries, and weld behavior in ANSYS was not accounted for or researched in our testing.

Conclusions and Suggestions for Future Work

The team did not meet all of the initial design specifications that were set in the Fall due to time constraints and dependencies. The calibration and intermediate specimen design requirements were all met, however the team was unable to construct and test a scaled guideway section. The construction of the guideway was abandoned since the two submitted designs had several components and features that would be difficult to replicate with the tools and time available to us (extremely precise welding, several small non-stock pieces, complicated assembly etc.)

Over this last year, the team learned that communication is key. Although the team did a great job communicating with each other, it was not as successful communicating with some of the dependencies. It's better to take on as many responsibilities and be proactive to work around the schedule of other people rather than waiting for their results to move on to the next step. The team also learned a number of hard skills such as welding, basic ANSYS, strain gage installation, and DAQ operation and interfacing.

The team's major accomplishment was confirming that the torsion machine works well and has little discrepancy. During calibration, the comparison between theoretical and experimental angle of twist was within a small percentage error. This confirmed that the torsion machine works and has relatively good precision. Intermediate specimen testing also confirmed that the ANSYS strain data was within a reasonable amount of error, although physical models had consistently higher strains than predicted. Finally, the team has laid the foundation for future testing, and compiled a lab guide to help the next students operate and understand the torsion machine

The next group should first familiarize themselves with the torsion machine by running experiments on stock pieces of metal. The best way to do this is to design simple tests based on the lab guidelines compiled by this year's torsion team. They should then push to finalize the design as soon as possible in order to build the scaled guideway section and test it. Before scaled track planning, they may want to investigate the effect welds have on the discrepancy between ANSYS and physical models.

Chapter 2: Small Scale

Small Scale Guideway

Background

There are many different modes of transportation that people use everyday: driving a car, taking a train, riding a bike, etc. But a lot of people do not know about the Autonomous Transportation Network (ATN) system. The ATN can revolutionize the way people travel from one point to another and is already in use in some parts of the world but most Americans have never heard of it. That is where the small scale track team comes in. With the small scale track, we are essentially making a portable ATN system that we can take to events and show people what is and how the ATN system works. Being able to take our track to places can show potential investors, city council members, or contractors what the ATN system is capable of and how it can change our way of living for the better.

Description of the Sub-Team and Objectives

The purpose of the small scale track team is to design a model that can display aspects of the full scale system to be understood by the general public. We will be able to display an automated transit network where vehicles can continue to their destination on the shortest possible path, without stopping at intermediary stations. We will also be able to display a general idea of the switching mechanism and how the vehicle hangs from the track. The vehicles will travel smoothly along the rail.

Design Requirements and Specifications

In order to make the new track, we had some requirements that needed to be met. The first thing we needed to make sure was that the track should be modular. If we want to expand the track in the future, we should be able to attach whole sections with minimal work or modifications. Another requirement is that the track should be able to accommodate up to ten vehicles. The reason we are making a new track in the first place is that the existing track cannot fit or run ten vehicles at once. We don't want to change the track too much so other teams like wayside power pickup and small scale solar would be able adapt their design to the track. One big requirement we have is to make the track easier to disassemble and reassemble when we take it to out of the Spartan Superway Design Center (SSDC). The current track is very hard to put together and takes about 30 minutes for five people to put together. We want to improve that by making the track into solid sections by brazing parts together.

State of the Art/Literature Review

Reviewed last year's track and implemented most of the suggestions from previous teams.

Description of Design

Last semester, we came up with a four-loop track design as shown in figure 2-1. It has eight stations with supports at each station. The track now has five unique sections that are color coded to make the fabrication process much easier to implement. The red section pieces are the straight-way sections which have the same length at around 88.65 inches long. There are six straight-way sections for the two-loop. The top and bottom rails of the straight-way sections are welded on using guideway connectors to make a more robust section piece. There are four green outer curve sections of the track, four light blue inner curve sections and four purple station curves. The gray section rails are straight-way pieces that connect the two two-loop parts together. In total, there are 28 supports with 14 supports for each two-loop design.

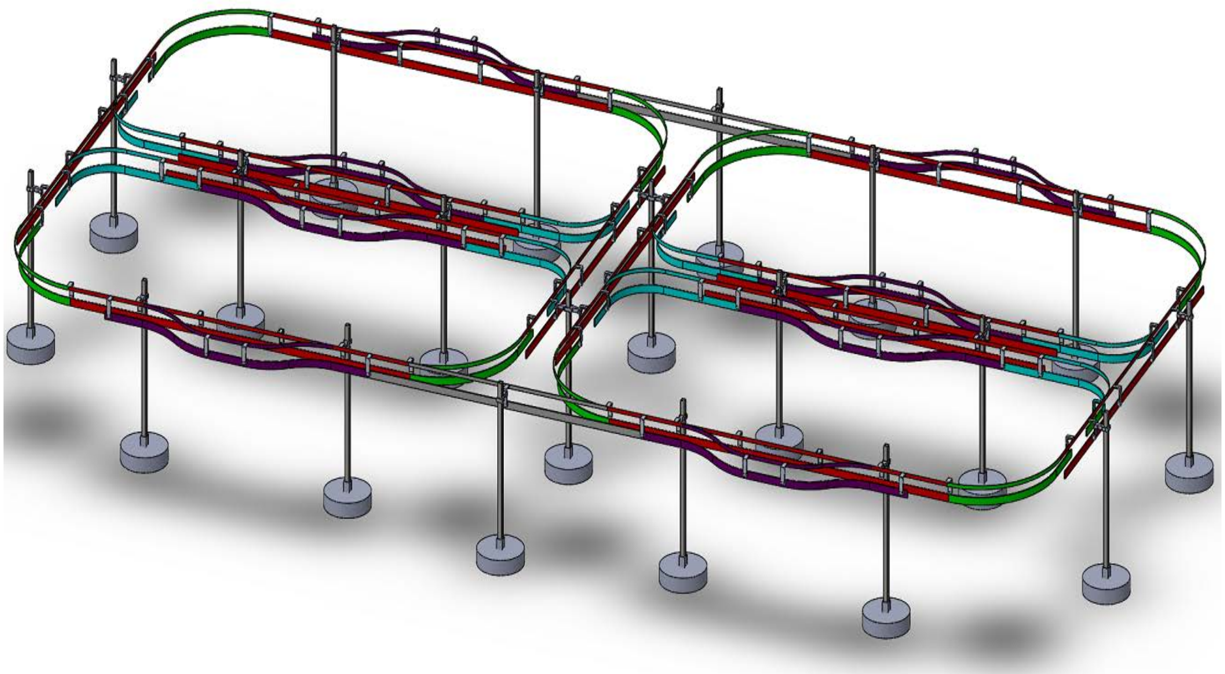


Figure 2- 1: Newly designed four-loop track.

We have made changes on the support design. The final design of the support is shown in figure 2-2. We replaced the last year's design of having round aluminum posts to a square inch steel tube that is three feet tall. For the summer team's design, they made a concrete base that was four inches tall and 12 inches in diameter. Their post mount design composts of a steel plate (colored in red on the left), four brackets, and multiple bolts to secure the post to the concrete base. However, to reduce fabrication time and material use, we simplified the design of the post mount. We will be using a square steel tube that is slightly larger than 1 inch which will protrude through the concrete base (in red on the figure to the right). The support post will be able to fall right inside the larger square tube. We also reduced the size of the concrete base to three inches height and ten inches diameter. This brings the weight of each concrete support down to 25-30 pounds from 40 pounds before which will make it easier to transport the supports.

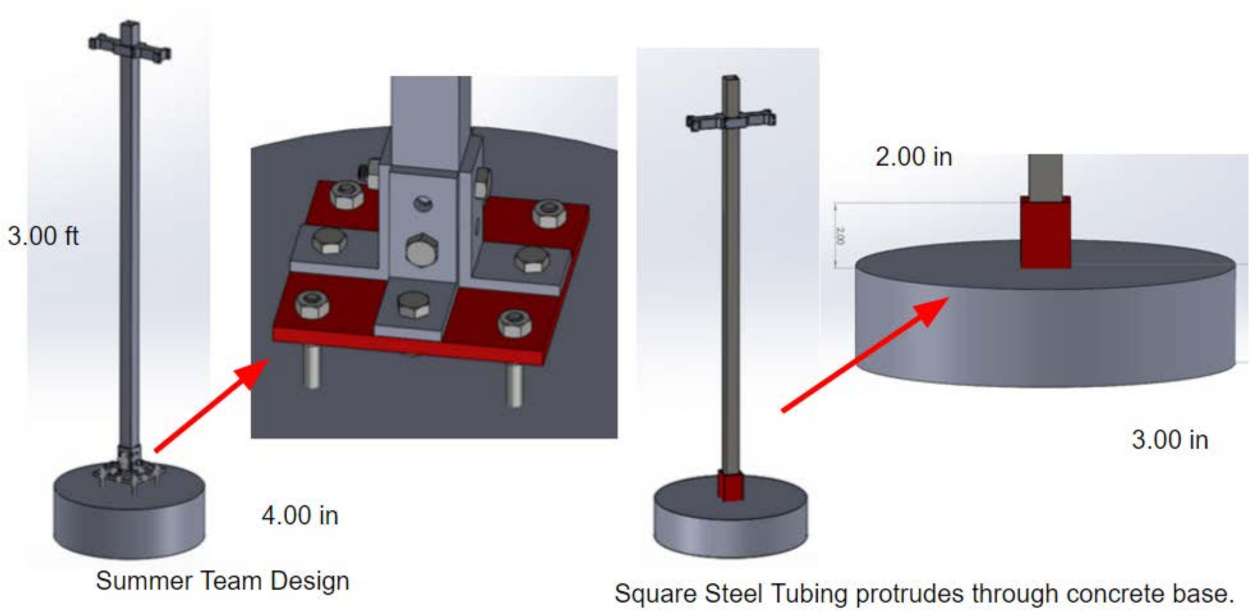


Figure 2- 2: Summer team support design (left) and simplified new support design (right).

We also simplified the support post connector design as shown in figure 2-3. The image on the left shows what it looked like in the summer 2015. The image on in the middle shows our current design that we have created. We simplified it to reduce the assembly time and cost of fabrication. The design uses an inch square steel tube that is an inch long which will act as a spacer that will separate the support post from the guideway connector. We used a half inch diameter steel bolt with a nut at the end to secure the steel tube in-between the post and connector. The guideway connector will have to be drilled for the bolt to fit through and the support post will have a inch slot that will be milled.

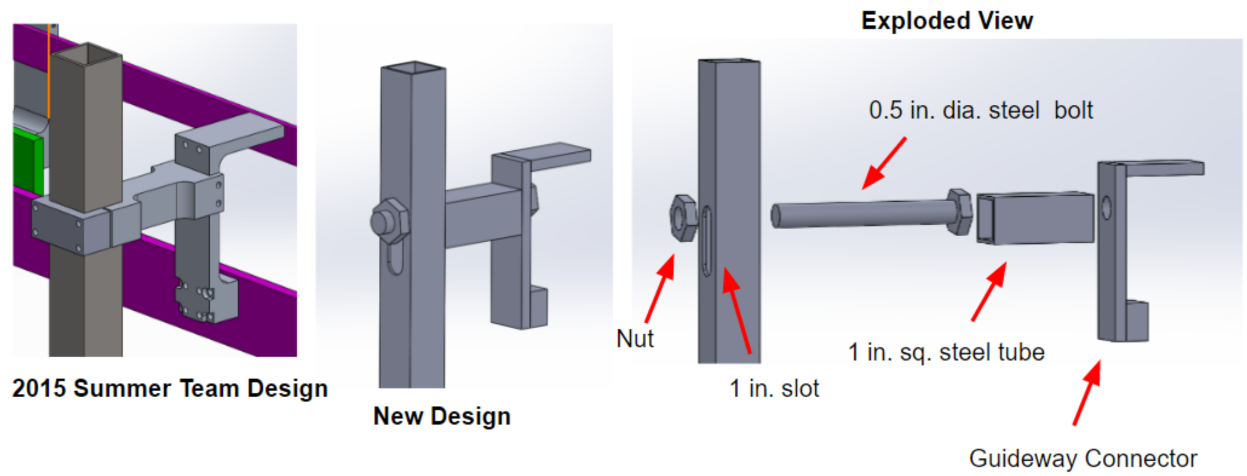


Figure 2- 3: Summer team post connector design (left), new post connector design (middle), and exploded view of the new post connector design (right).

Fabrication

At the start of the Spring 2016 semester, we decided to work on the two-loop track design first and finish its fabrication. If we had enough time, we would add the additional two-loop to complete the four-loop design. However, due to delays in acquiring parts, we are going to be unable to complete the four-loop track design.

In order to have the fabrication process to go by smoothly, we formulated a schedule of when and how the parts needed to be fabricated. We held meetings regularly to discuss the process and the current progress of the project. We found ourselves referring back to the main drawings constantly in order to have a better visual image in mind. We also printed out the drawing files of the top view of the drawing and the isometric view of the drawing. This helped in determining the locations of each connector and how each rails interacted with each other.

To keep the fabrication process simple, we separated the work into four different parts (Welding, Bending, Supports, and Assembly) and assigned the tasks to each member of the group. We helped each other in completing our tasks at hand, but we made sure we had our part taken care of. All of the progress has been documented by our spring presentations located on our subteam blog: http://littletrack12.blogspot.com/.

Welding

In the beginning of the fall semester, we were going to braze the sections together. After some tests, however, we found out that brazing took too long and wasn't strong enough for our specifications. So we decided to weld our track. Unfortunately, the welder in the SSDC does not weld in AC mode and couldn't deliver enough amperage. In order to combat this problem, we asked Professor Muntz for permission to use his welder in IS 199/122. He gave us shop access on Mondays from 12-3 PM and on Fridays from 6-8 PM.

When we first started welding, we had to take the small pieces from the old track and weld them together to create new longer sections to use them on our track. We used around 100 amps to weld the straight sections together. We created 3 sections of straight track that were 88.65 inches long.

After welding the straight rails, we moved on to welding the connectors to the bottom rails. Since both the connectors and bottom rails are fairly thick they required a higher current. In order to weld this quickly, we would need around 200 Amps but our welder could only deliver 130 Amps so it did take longer to weld the connectors. Each straight rail had four connectors and each station had two. The welds can be seen in Figure 2-4.

We were also planning to weld the top rail to the connectors as well but since the connector is a thicker metal than the top rail, the top rail would disintegrate before the connector would allow us weld it. So we decided to just screw to the top rail to connectors instead.

Figure 2- 4: Welded straight section (left) and station welds (middle and right) which are similar to straightway section welds.

Bending

To make a decent bend on the roll bending machine in E123 room, we laid out a full size drawing of the part as shown in figure 2-5. We superimposed the bends we have made onto the drawing to check for accuracy. For better results, it requires two people to operate the machine, especially for the bottom rail curves since it has a wider thickness than the top rails which makes it harder to bend. One will be in charge of cranking the crank handle on the left side of the roll bending machine while the other holds the workpiece and makes sure it is aligned to prevent bends in the horizontal axis. We found the top rails to be much easier to bend since the thickness and width of the piece was much smaller than the bottom rails and it could be bent by hand after it has been rolled through the machine.

Bending Roll Machine

Bending in action

Full scale printout of the outer (top and bottom) bends

Figure 2- 5: Bending fabrication processes of the inner and outer (top and bottom) curve bends.

Supports

Since we had no prior experience in concrete building, we looked up online tutorials and also recruited someone to help us with the forming the concrete base. A junior Civil Engineering major at SJSU, Marianne Medrano, offered her help in building the concrete blocks we needed for the supports. At first, we mixed concrete and stucco that were purchased by the summer team. We made a mistake of adding too much water to the mix so the mixture took a longer time to dry and the strength of the hardened concrete might have diminished as shown in figure 2- 6.

Figure 2- 6: Concrete base in the process of hardening in the yellow concrete round forms.

To ensure that the support posts were going to be vertical from the ground once the concrete dries, we made a large clamping system using a series of clamps and two long pieces of wood as shown in figure 2-7. We used a bubble level to check that the posts were vertically true. To prevent the concrete from sticking to the concrete floor, we initially used bubble wrap, but we later found out that this was causing the post mount to poke through the bottom of the concrete base causing the concrete to be unstable. The next time we made more supports, we reduced the diameter of the concrete form tubes from 12 inches to 10 inches to reduce the weight some more. We also used a plastic liner to create a flatter surface at the bottom of the concrete base. The second run through with concrete forming went smoother. We were better equipped with handling the concrete by having gloves, masks, and cups to transfer the concrete over to the concrete forms.

Figure 2- 7: Fabrication process in making the support concrete bases.

Assembly

After cutting all the sections to size and bending the curves for the top and bottom rails of the track, we categorized each section to its location of the track and labeled them. There were 6 straight sections, 4 outer curve sections, 4 inner curve sections, and 4 stations. We first had to drill through the top straight rails and connect them to the bottom straight rails with the connectors already welded on with the help of Ali. We used a handheld drill and acquired the drill bit from the summer team. Once the straightways were done, we moved on to mount two straight-ways on the support posts first and try to drill and tap the holes for one of the outer curved rail to connect the three sections as shown in figure 2-8.

Once we had everything laid out on the floor and have a general plan of where everything should go and be connected, it was a lot easier to put together. However, we still had to make sure that the bogie could pass through our curved rails with no problems such as having the distance between the bottom rails to be too narrow or having a gap between the top and bottom rail which would cause the top wheel of the bogie to slip and fall. We encountered these problems frequently but, we were able to fix the problem by cutting the top rail shorter to reduce the gap or fix the connectors so they are aligned straight and not crooked.

Figure 2- 8: *Assembly of the three straight-ways, two outer curves, and one station sections.*

We also had to make support connectors, which connects the support posts to the guideway connectors. We drilled holes to the support posts were the nut and bolt goes through to press fit the guideway connector to the post. These were done on the middle section of the track to hold the two middle straight sections. We assembled the outer loop first with all the outer curve sections and had all the straight sections mounted on the supports. Once everything was mounted, we finished the assembly by connected all the inner curved rails to the middle section and the straight ends. A completed image of our two-loop track design is shown in figure 2-9.

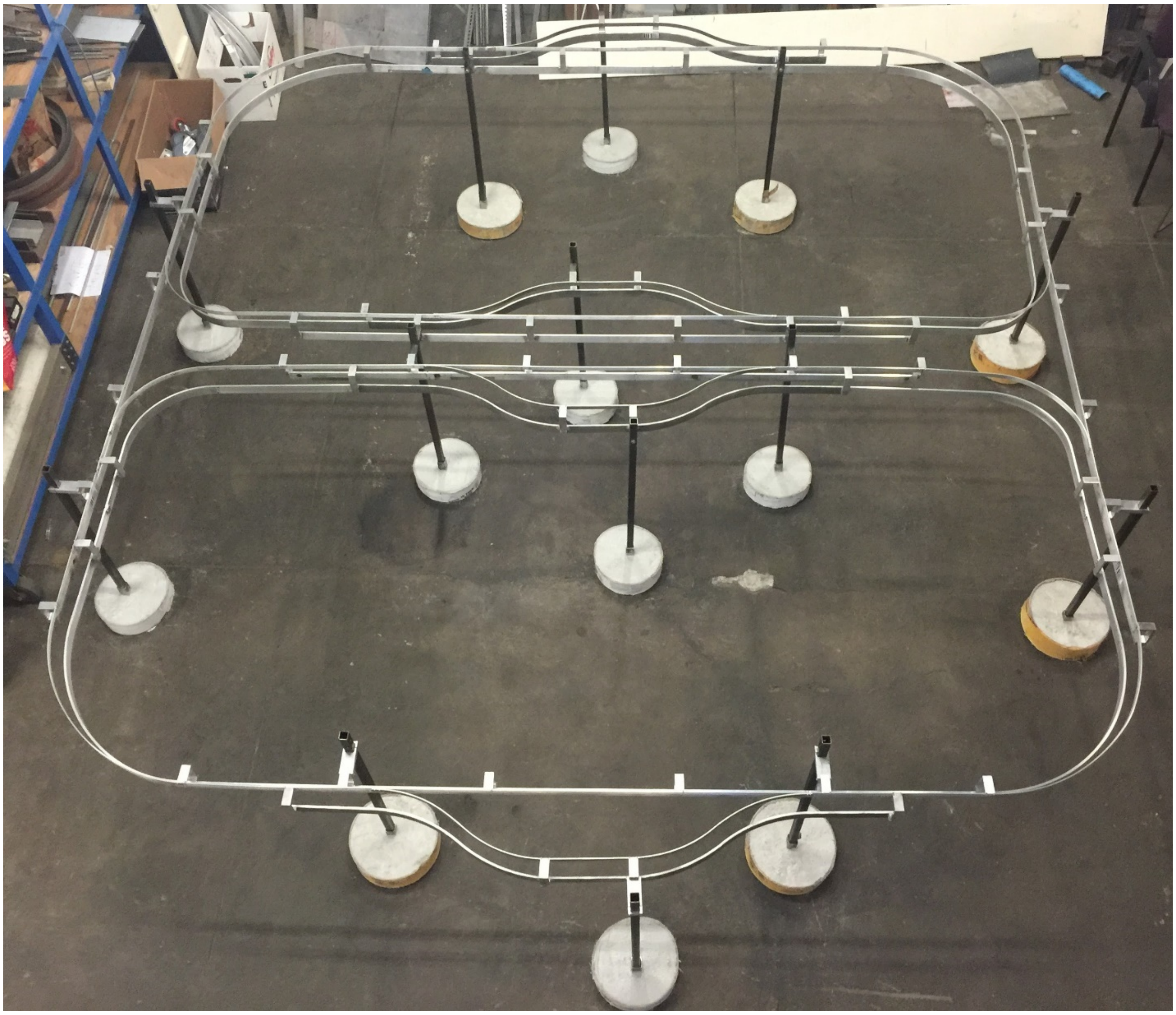


Figure 2- 9: Completed fabrication of the two-loop track design.

Product Analysis and Testing

In order to see our track met our design specifications, we had to test it. The first thing we did once the track was complete was to take one of the bogies and see if the bogies get caught anywhere or see if it wants to fall off the track completely. It turned out that some bends of the top rail were a little off, which made the bogie bind up in some places or would let the bogies fall off. Once we re-bent those rails to the correct radius, the bogie was secure. Another problem we found out was that some areas of the track would get too narrow or far apart so the bogie could not read the barcodes on the track. To fix this, we either bent the track to conform correctly or we added a spare piece of track to connect the gaps to ensure uniformity throughout the bottom rails. Another minor modification was to sand off some areas of the track to ensure a smooth transition to certain areas of the track for the bogie. After these modifications, the bogie went around the track nicely.

Finances

Last semester's summer team left us with material around the shop. We slowly found material and invoices that were pertinent to our project. Our choice of materials was mostly predetermined; we had station bends from Vanderbend, screws, and stock aluminum to work from. We decided to continue with most of the manufacturing choices that the summer team had suggested. We had originally priced out some new material, most of which we got donated or was already purchased by the summer team. Our first estimated budget for the track was $3,356.27. Our annual Associated Students budget was increased from $2,300 to $3,300, which allowed us to get our Vanderbend cost of $1,568.06 covered. We also had to buy the necessary supplies for the support posts like concrete mix and concrete form tubes. After switching our supplier from Metals Depot to TCI Aluminum, not only was the aluminum stock cheaper, it was donated by Thomas G. Schultz, Professor Emeritus of the Civil and Environmental Engineering Department at San Jose State University. We were able to find cheaper steel bars from Sims metals. Other hardware, such as a bag of machine screws was found in the design center, left by the previous team. After all of the purchases, we ended up using $48.78 from the Spartan Superway account.

Results

To test that our track was flawless, we pushed both, new and old bogies around the track by hand looking for places that needed adjustments. As soon as the new bogies were complete, the controls team was able to test that the vehicle could run autonomously. From this additional testing, we encountered and remedied new alignment issues. It is tedious to fix the small margin of error that is necessary for the bogie to operate. After many adjustments, we were able to reach a point where it worked well enough, despite the infrequent times when a bogie would bind up or experience some other undesirable symptom. In order to achieve a corner that is lower in the center of the arc, we needed to loosen the screw connecting the corner at both ends, this does not appear to affect the rigidity of the track. The track was fairly simple and quick to disassemble, the track is labeled so we know what fits best in a certain location. Set-up was first tested at Maker Faire and it went fairly smoothly. Most of the time was spent making sure each pole was aligned properly and the track spacing was nearly perfect in every location. After completing the visual adjustment, we pushed a vehicle around the track to make sure the bogie would not be pinched in any particular location and also to make sure the top rail was adjusted correctly. Some of the top rails require spacers and a loose fitting so that the center of the arc can be lowered. All in all, we have a fully functioning track for small scale that is ready to show what an ATN system is capable of.

Conclusions and Suggestions for Future Work

After a year of working on the Spartan Superway Small Scale Track, we are pleased to say that we have met our design specifications. We have successfully made a track that is ready to be taken events and show people what the ATN system is about. The track can be reassembled and disassembled quickly and is made out of big sections with the minimum amount of screwed on parts. The support posts are easier to attach to the track and are much lighter to transport. However, there were some things that we would've done differently. We would have liked to make sure that our ideas could be able to be achieved with the tools that are present in the SSDC.

When we decided to weld the Aluminum of the track, we didn't know that Aluminum needs certain welder requirements in order for it to be welded. Some of the welding requirements needed for the welder is that it should deliver high current and run AC. We thought that the shop welder could do that but it turns out it can only weld DC and at a moderate current only.

Over the past year, we learned a lot throughout the design and fabrication process. We learned that the student edition of SolidWorks files do not work with any other edition of SolidWorks other than just the student edition. We also learned that communication with other teams is very important during the design process. It is good to have a meeting whenever possible to discuss designs to see if they conflict with any other teams designs. During the fabrication process, we learned that Aluminum is a difficult material to work with. Its high heat conductivity make it harder and longer to weld which require special types of welders. Its high ductility makes it harder to shave down certain pieces since it can't be grinded like steel and must be sanded like wood. However, since Aluminum is soft, it can be cut quickly using wood miter and table saws. We also learned that scheduling team work days is very important in order to get things done in certain time tables. One of the biggest things we learned was take inventory of materials to see what the shop already had so we didn't have to order some things.

Some of our major accomplishments were being able to take design that we made on a computer and actually make it into a reality. Another accomplishment was to weld the track together even though Ali had never welded anything before in his life and learned how to weld through YouTube videos. Another accomplishment was David and Kenny being able to save the team a lot of money by bending the Aluminum themselves in the tech shop.

Even though we did a lot of work over the past year, there is some work for future Spartan Superway Engineers to do. The biggest thing they need to do is add another two loops to our track to make the four loop track we designed. In order for them to accomplish this, they will need to learn how to weld and bend the rails like we did this past year. Another thing they will have to do is, extend the length of the outer curves to fill in the gaps so they won't have to cut an extra piece out and screw it in. They can either extend the curve or they can weld in a filler piece to close the gap.

Small Scale Vehicle

Background

The 1/12th scale subsection of spartan superway is mainly used for demonstration purposes to inform and hopefully grab the interest of potential sponsors. The main problem with Spartan Superway and other Autonomous Transit Networks(ATN) is the lack of knowledge and understanding by the general public. For those who are unfamiliar of what an ATN is and what it is capable of, Spartan Superway 1/12th scale provides a physical illustration that can help explain the basic concept of an ATN.

Objectives

The Spartan Superway 1/12th scale vehicle teams focuses on the two vehicle components. The two components of the vehicle are the bogie and the cabin. The bogie is the top portion of the the vehicle that propels the completed vehicle along the railway. The bogie consists of the overall structural support for the vehicle, wheels, axles, motors, and switching mechanism. The cabin is used for both aesthetic and practical purposes. The cabin helps illustrate to potential sponsors what a real vehicle could potentially look like. The cabin also provides support and protection to the internal circuit components which act as a brain for the vehicle.

For these components, the objective for this project term from fall 2015 to spring 2016 is to simplify the vehicle by reducing overall components as well as creating a vehicle that more accurately represents what and actual vehicle will look like when the full scale Spartan Superway is implemented in San Jose.

The overall goal of the small scale vehicles team was to create 5 total vehicles in preparation for maker faire.

Design Requirements

The 1/12th scale vehicle team objective is to redesign the switching mechanism to be more reliable. They are currently held together by piano wire, and they tend to slip out of their joints which result in vehicle failure. We are finding the substitute to provide a better connection between servo arms and the steering arms. Also, the overall components of the bogie has to be reduced in order to reduce assembly time and provide easier support when there is a problem. The other objective of the vehicle team is to design a 3D printed cabin to holds all the electronics on the vehicle and act as a visual model of the large scale cabin. The cabin will be more solid and provide better protection on the electronics inside.

Design Concepts

The design concept for the Spartan Superway 1/12 scale model vehicle integrates the vehicle made by the Spartan Superway Summer 2015 team with the new design specifications. In order to incorporate the design specifications, the Summer 2015 teams design is inspected for design choices in order to generate a list of pros and cons. The list of pros and cons for the current design help the current vehicle team in redesigning components as needed. The concept of the cabin portion of the vehicle is to create a cabin that is similar to the large scale model for the cabin. It will help articulate the concept of Spartan Superway to potential sponsors at events such as maker faire.

Analysis

We have made some changes on the Summer 2015 team’s design. Instead of using many components to build the bogie parts, the new bogie design combines some components to reduce overall number of parts. Since we are using less screws to build the bogie, it is easier to assembly. The old cabin design was just serving solely as a support for the Arduino and other electronic components. The new cabin design is 3D printed and looks similar to the large scale model. During the Christmas holiday, we have asked the Cabin Team for their cabin drawing. However, after several discussions, we figured that their design may not meet our design requirements. Therefore, we have designed our own cabin for this project. The new design will have a good appearance to potential sponsors and better articulate the concept of the Spartan Superway project.

We also tried to find the alternative options for the switching mechanism. Piano wire is used in the summer 2015 team's design. Our team found that it is difficult to install and hard to replace. In last semester, we proposed using a ball and socket joints. However, we could not find one that would fit in that space. We also tried to design something and print it with the 3D printer. The designed part was too rigid and still required wires because the holes on servo arms are too small for screws. We figured it would better to use piano wires instead of others in this case.

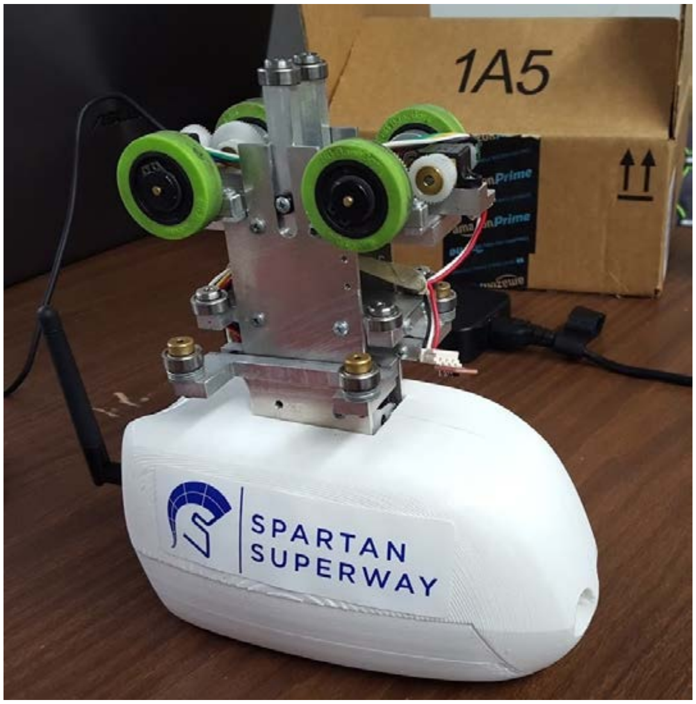


Figure 2- 10: New Vehicle Design

Figure 2-10. This is our new vehicle design. The bogie are redesigned to reduce the number of components. And with the new 3D printed cabin, the new design will be a better illustration of the Spartan Superway project to potential sponsors.

Money Spent

Several components for the small scale vehicle needed to be purchased in order to complete our goals. The main components that were needed for the vehicle includes the bogie components which are the side plates, pillowball bearings, servo mounts, top motor plate, switch sides, wheel holder plate, and lower switch wheel bar. Luckily these parts were donated by David Moal which saved us about $2000. Other components that needed to be purchased includes 3mm axles, bearings, wheels, and wheel hubs. The total amount of money spend for vehicle components is $308.43.

Table 2- 1: The table above shows the amount of money spend for purchased components.

Component	Price
3mm Axles	$36.36
Bearings	$80.00
Wheels/Wheel Hubs	$192.07
TOTAL	$308.43

Results

As a result of this semester's work, our team successfully created 5 vehicles to display and to demonstrate what the Spartan Superway is about. There are also enough spare bogie components to allow the next team to build 5 more vehicles making the total amount of vehicles equal to 10. The file for the cabin design can also be reused on the 3D printer if more cabins need to be made. Combining the vehicles with the track and controls will help demonstrate the main idea of the Spartan Superway ATN.

Conclusion

Based on the work that we have done this semester, we have successfully created new bogies, and new cabins. As a result, we were able to create the 5 vehicles that we had planned on creating at the start of the semester. Although we were able to meet this goal, we were unsuccessful in redesigning the turning mechanism which uses piano wires. The plan for the turning mechanism was to create something more simple and easier to install. In order to successfully meet this design specification, we would have redesigned parts of the bogie itself in order to accommodate a better mechanism. We would also have modified the servo horn to allow the use of something other than a servo wire. Overall the majority of the vehicles team goals were successfully met.

Future work

It is highly recommended that future teams find a better switching mechanism for the vehicles. Other than that component, the future teams should create more vehicles and implement them with the work of the controls team and the track team. It is also recommended that the 3D printed cabin design to be redesigned in a way that would allow the cabin to be printed more quickly.

Small Scale Controls

Background and Design Requirements

As previously stated, the conceptual goal of the Spartan Superway is to create an autonomous transportation network. The purpose of the Spartan Superway Small Scale Controls team was to create a mechatronic system that would illustrate the autonomy of the 1/12th scale vehicle network. Through both hardware and software design, the Controls team was responsible for creating the “brains” for the small scale vehicles.

There were three areas of concern that the team wanted to address. Initially, we wanted to improve upon the previous team’s work by increasing the number of small scale vehicles that could be functioning on the track at one time. Specifically the original goal was to enable 10 vehicles to function autonomously on the track. The next area of focus for the team was to refine the location and tracking system to further illustrate efficient and autonomous routing for our vehicles. The specific goal set forth by the team was to change the original design of using magnets and hall effect sensors to a barcode system along with a nodal location algorithm. Finally the last area of focus was the design of the hardware components. In conjunction with the goals of the Small Scale vehicle design team, the small scale controls team would have to design a compact controller system that would fit in the space provided by the 3D printed cabins.

The specifications and requirements of our designs were relatively simple. For the multiple vehicle communication we required that our design enable exactly 10 vehicles to function on the track simultaneously through one computer. THis would include starting, stopping, switching, and routing any of the vehicles at any time. For our location/ track pathing objective, our system would be required to take in the user input of the desired location. Then, it would read the next immediate barcode. Through the algorithm it would then create the most direct route to the desired location. As for the hardware design objective, the requirements would be to create a compact system of hardware components that would fit within the space of the cabin.

Design Overview

Graphical User Interface Redesign

One of the first things we had to do was to rewrite the software created by previous teams, the reason we had to do that was because it was not written to be expandable. One of the first things we realized was that the code on the Arduino and in Processing was designed for just one vehicles, though they did have the intentions for multiple vehicles, it wasn’t implemented properly. Our current program allows for vehicles to be easily programmed and uses a more robust communication method. To do this we used a similar messaging protocol to the Korean teams from last summer, it includes the receiver, sender, message type, status, and message content or payload. To also make our program a little more robust we wrote a function that is used to send out the different messages and calculate the checksum that is included to the end. Due to the low message variations from the vehicle to control, the messages sent from the vehicle are essentially predefined and sent a character at a time.

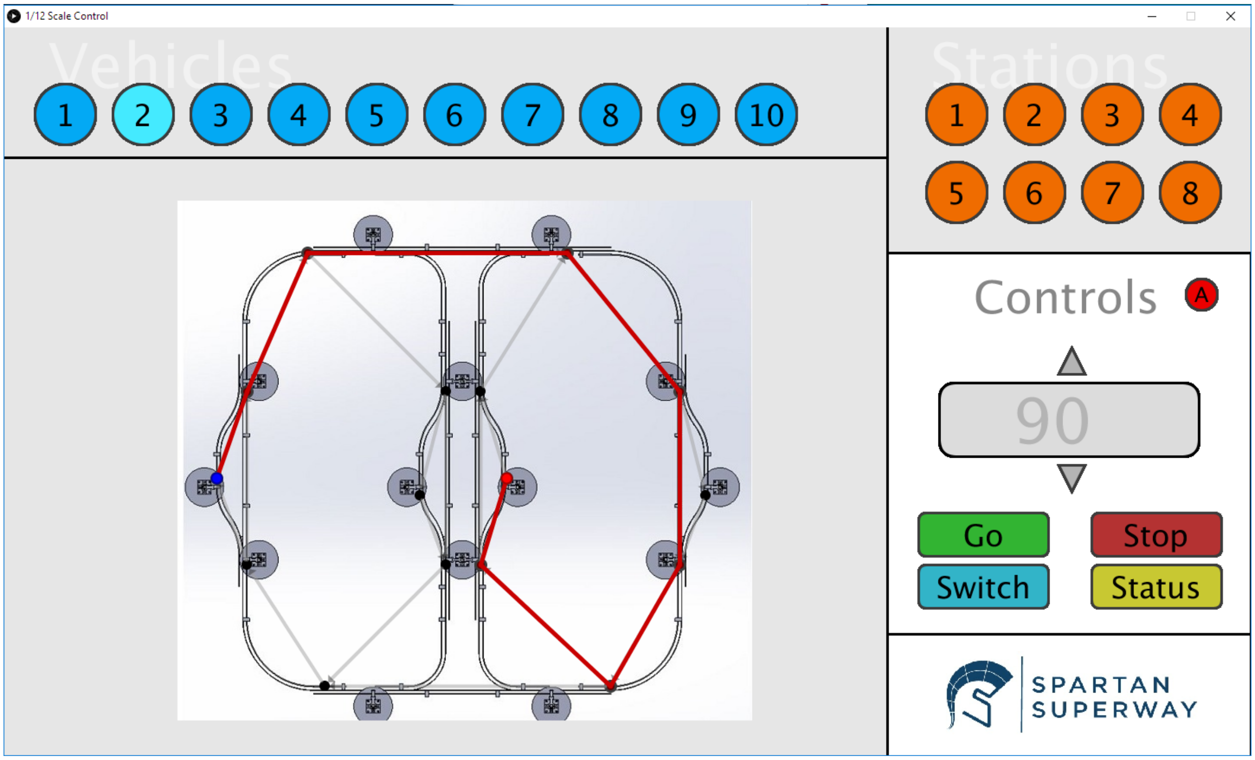


Figure 2- 11: New small scale control graphical user interface

Some other notable features we also implemented into the new code was the use of an actual checksum digit which allowed us to verify the integrity of the message that was sent. As it turns out the XBees did get some messages wrong, and in that case we will know if we needed to send the message again or not. We also added a heartbeat to check if the vehicle is still connected, and the instructions protocol which is how the vehicle receives the instructions on what it needs to do to get to its destination.

Barcode Node Design

One of the first topics of discussion was about the type of positioning system we were going to used for our project. Using GPS would have been a great option, for the full scale system, for our 12th scale model GPS would not have the resolution we would need to accurately position the vehicles on the track. A simulation of GPS was also considered, by using 2.4GHz or WiFi signals we would be able to triangulate the position of the vehicles based on the relative position of those antennas. Though this option would have made it more interesting we could not have used it since developing such a system would be a project in itself, and we did not have the knowledge or resources to create it in time. The final option we opted for was a barcode based nodal positioning design. The reason we used barcodes was because they are cheaper to produce and provided us more information than magnets used by the previous team. A consideration was also made for RFID scanners, though we thought they were too large for the scale of our model. RFID tags would also have to be held up momentarily for the reader to register it which would be we would have to stop the vehicles for them to work which was undesired.

Our barcode design was the solution we came up with for this problem. Barcodes were easy and cheap to produce, and they provided us with as much information as sections we put into them. The simplest format for our barcodes was binary which meant each bar either represented a one or a zero and that would simply be parsed as an integer on the Arduino, this was done to keep calculation time to a minimum and allow the CPU to be used on more important tasks. In the next image we have an example of how our barcodes are scanned, an assumption we made was that the barcodes are being read at a constant speed, however we know this is not true and a speed compensation can easily be implemented.

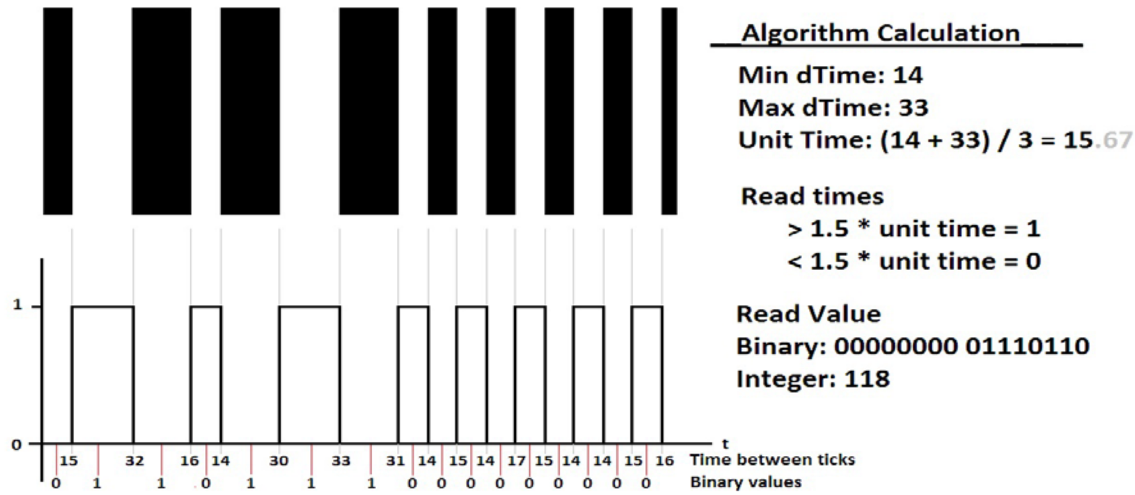


Figure 2- 12: Visualization of calculating barcode values

From the image above we see the barcode in question, and below the barcode we have the visualization of the sensor output, and the information we get out of it. The line labeled time between ticks is the time it took for the Arduino to trigger an interrupt change from the last time it was interrupt. Those times are then recorded into an integer array and then after we have all 16 bits they are sent to a calculator to be parsed as an integer. To calculate them the first thing we do is use a for loop to run through all of the recorded times and look for the largest and smallest value, summing that up and dividing by 3 gives us the unit time, that is the time it took for one short bar to pass. The bars are designed to have a wide bar be twice the width of a thin bar. Using that information we have a threshold of 1.5 times the short bar, so anything less than that is registered as a 0, and anything large is registered as a 1. In our program we used bit manipulation to shift each 1 or 0 over as many times as we need to form one integer which is registered as the location our vehicle is at.

Pathing Algorithm

With the implementation of the barcodes and barcode sensors as our new vehicle tracking system, changes to the overall control system had to be made in order to set up the new system. The user interface was changed with the addition of an image of the track overlaid with nodes at specific sections of the track. (Refer to Figure 2-13)

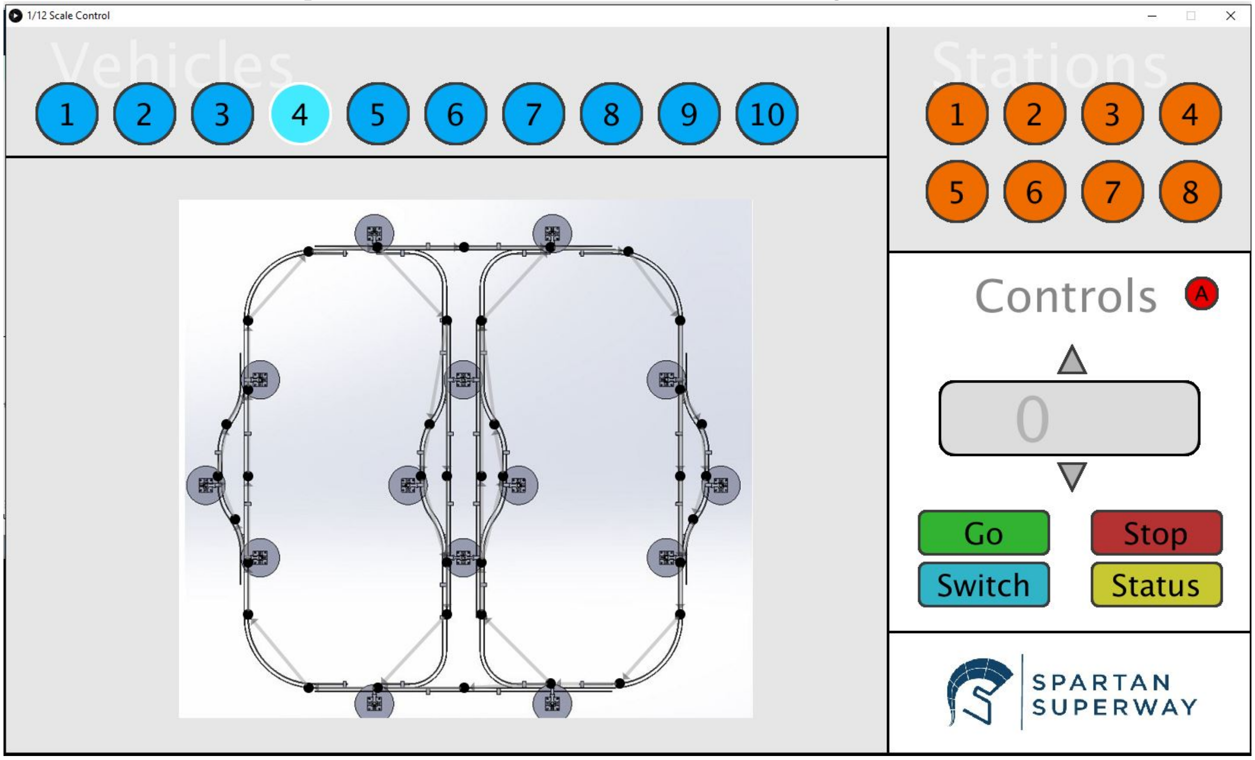


Figure 2- 13: User interface with map of the track overlaid with nodes

The nodes were programmed with properties such as an ID value and coordinates to correspond with the barcodes on the real track. Alongside with the nodes, edges were also programmed into our system, which act as connectors between each nodes. These edges also had properties that allowed us to manipulate the pathways that the vehicles can take in order to reach its destination. Properties such as the "from" node ID, "to" node ID, and the cost to move between the two nodes. Originally, there were complications with developing a robust system for the vehicles to know when to switch its steering mechanism based on the track geometry. This problem was counteracted by adding another property to the edges that was either a zero, one, or two, which tells the vehicle to stop, switch left, or switch right respectively. (Refer to Figure 2-14)

```
<edges>
104 107 50 2
107 206 50 1
206 205 50 2
205 202 50 2
202 120 50 2
120 114 50 1
114 113 50 2
113 104 50 2

204 201 50 1
201 209 50 1
209 206 50 1
```

Figure 2- 14: Image of Edge Properties (1st number - "From" node ID, "To" node ID, Cost between each node, and servo side)

Once the nodes and edges were set up, a pathing algorithm was used to plan the overall route of the vehicles based on its last known coordinates and its destination. The use of a pathing algorithm was inspired by video game design, which often implement these algorithms to move characters and enemies around obstacles in the most efficient way. In terms of this project, we implemented the breadth-first search pathing algorithm, which evaluates the costs neighboring nodes throughout a system starting from the first node to the last node. Based on the costs to travel from node to node, the program stores the list of nodes along the path into an array. Given this information, we were able to not only able to move the vehicles along the right path, but track their locations as well.

Circuit Design

So here you can see the original design of the previous team's work. It is a three layer system consisting of the Arduino Microcontroller, the Xbee Wireless communication shield, and an intermediate layer that wired the electromechanical components of the system with the Arduino.

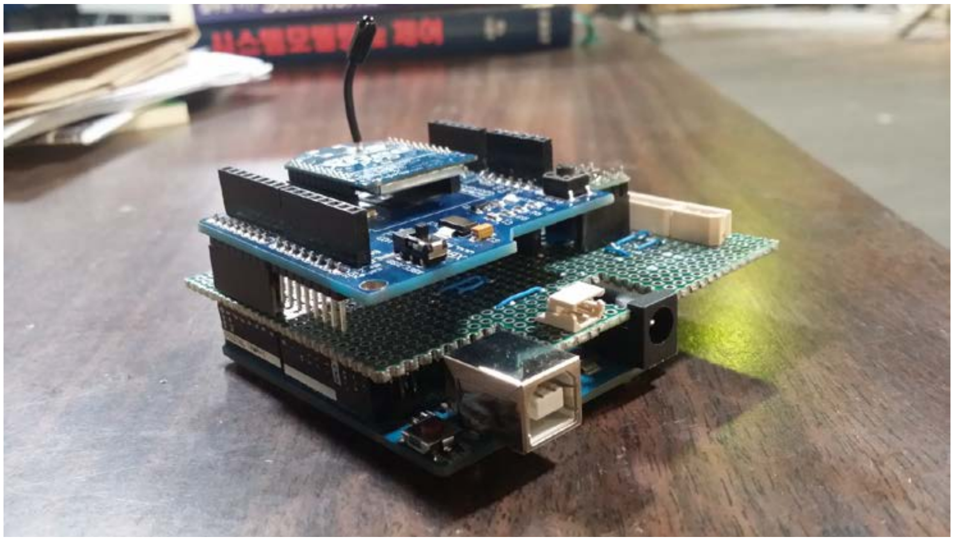


Figure 2- 15: Original Arduino System consisting of three layer

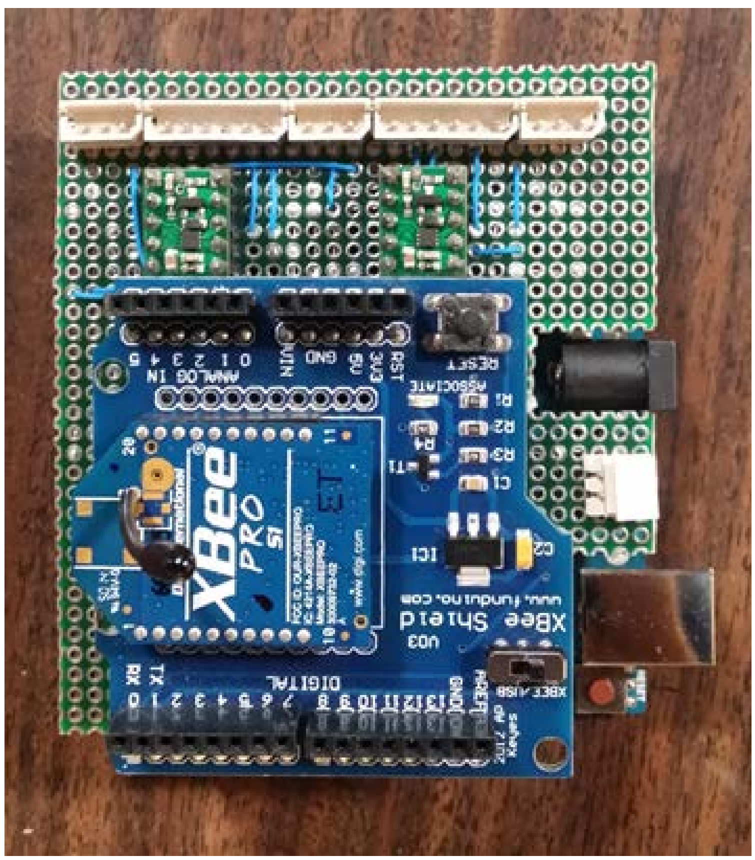


Figure 2- 16: Original System consisting of three layers top view

Given that the specific goal of the hardware design task was to create a compact system that would fit within the 3D printed cabin, we needed to find some way to reduce the size without compromising any components. Our first design iteration was based on the idea of creating a middle layer that was the same size as both the Arduino and the Xbee communicator layers. The resulting prototype can be seen in the following figure.

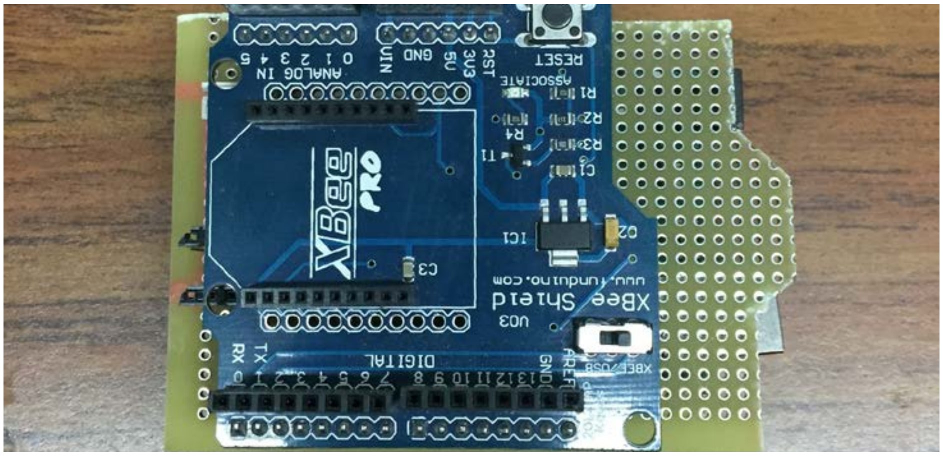


Figure 2- 17: First Iteration of Circuit Board redesign

While we did manage to reduce the size of the system, it was still however, too tall to fit inside of the cabin. So we moved into our second iteration of the design with the idea that it would be best to remove the middle layer completely. In order to accomplish this task, we would need to purchase new Xbee communicator shields that would give us the space to solder on the header components from the middle layer. The following image depicts the different types of electric components that we needed on our shield which includes, two motor driver headers, 3 headers for our servo and ultrasonic sensors, and two headers to power the motors themselves.

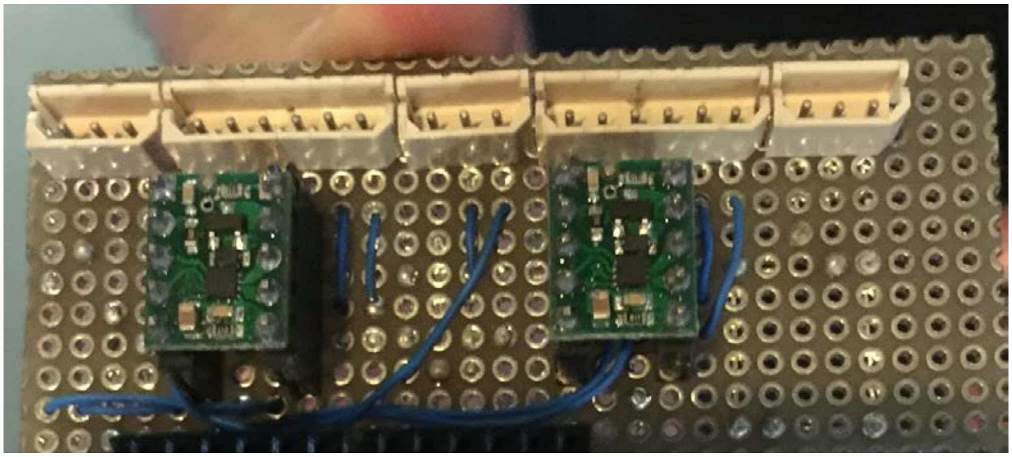


Figure 2- 18: Electric components required on new Xbee shield

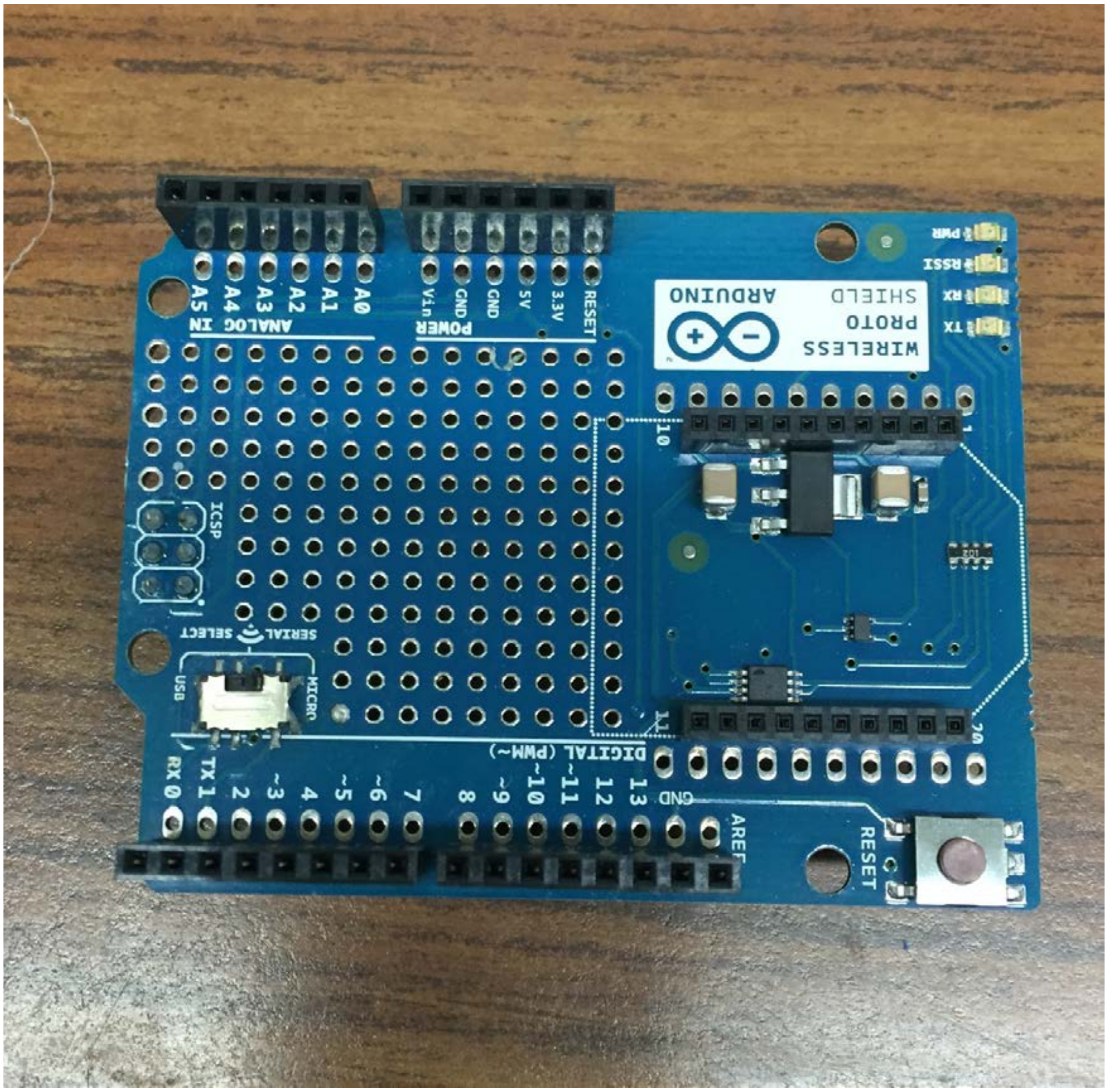


Figure 2- 19: New Xbee communicator Shields

In order to successfully and efficiently accomplish the task of soldering the components onto the new board, we devised a layout schematic in order to have an organized and repeatable means of creating multiple boards. We also needed to create further documentation regarding the pin layout

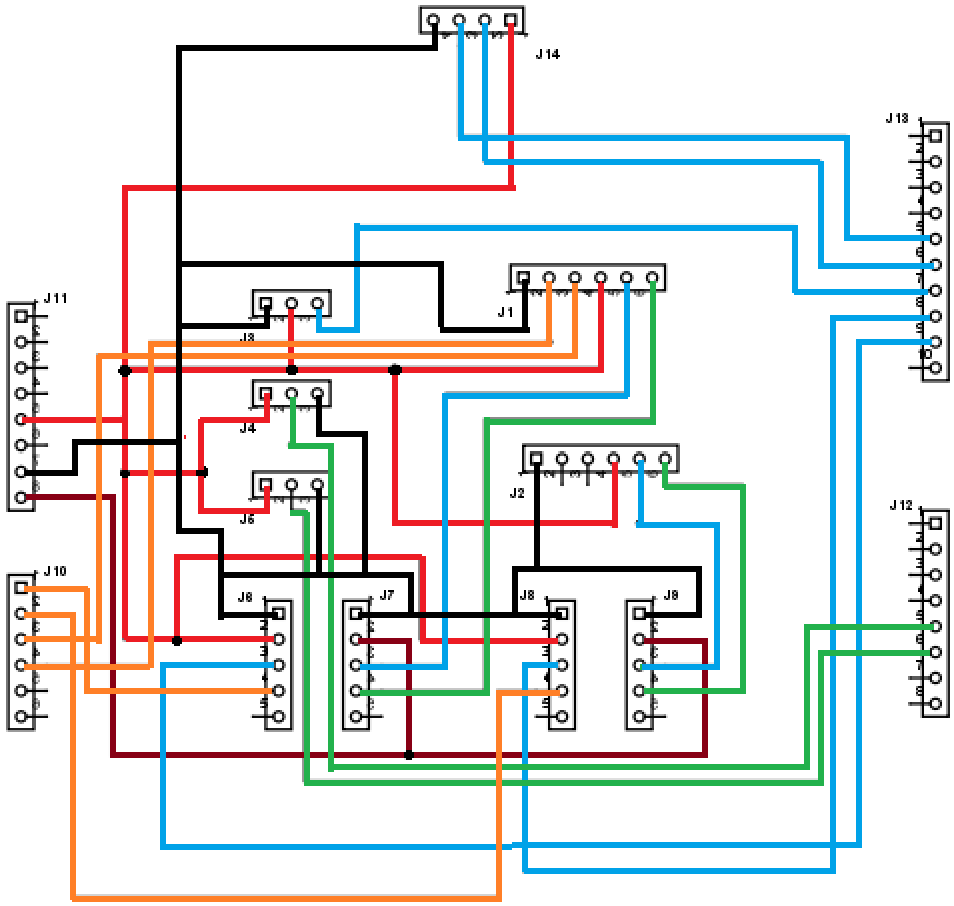


Figure 2- 20: Circuit Board Schematic (Top View)

Finally, the following image depicts the functioning result of the second iteration design. Physically you can see the difference in size between our final iteration and the previous two design. It is considerably smaller in all aspects (Length, Width, and Height).

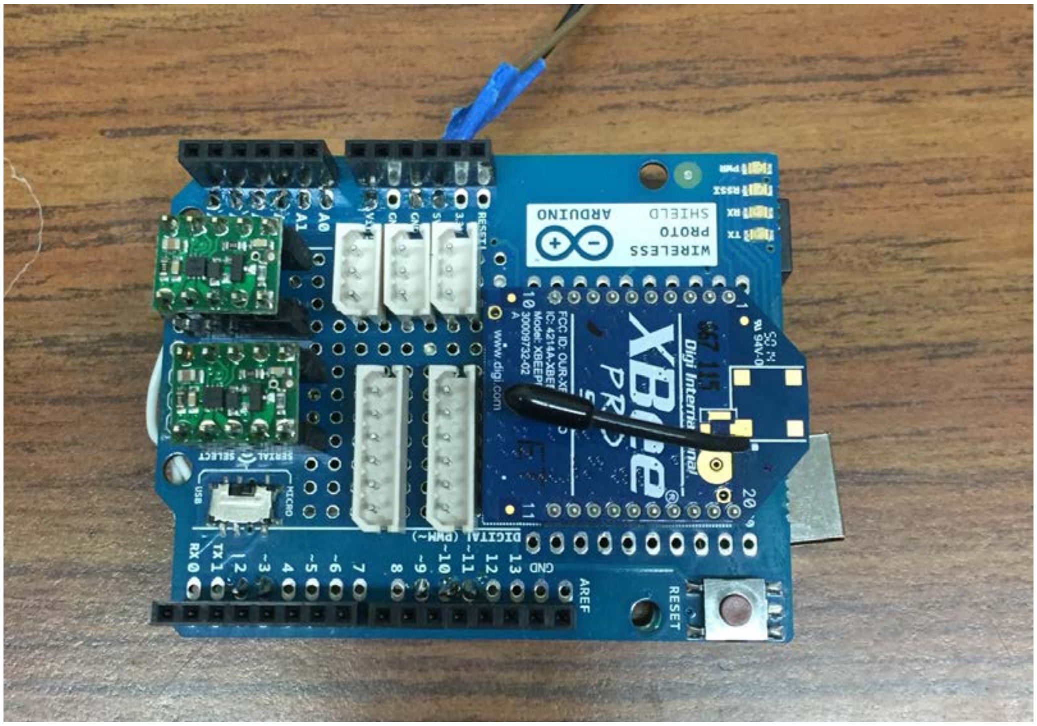


Figure 2- 21: Final Circuit Board from second design iteration

<u>Verification and Testing</u>

In order to test our design for multi-vehicle communication we simply ran the program with two vehicles to see if they could be communicated with individually. We found that we were successful in our design and the program had no problem sending information to the vehicles individually. In order to very that our barcode system and path tracking system worked, the team would first observe the output on the computer screen before the barcode sensor ran over the barcode. This can be seen in the following figures.

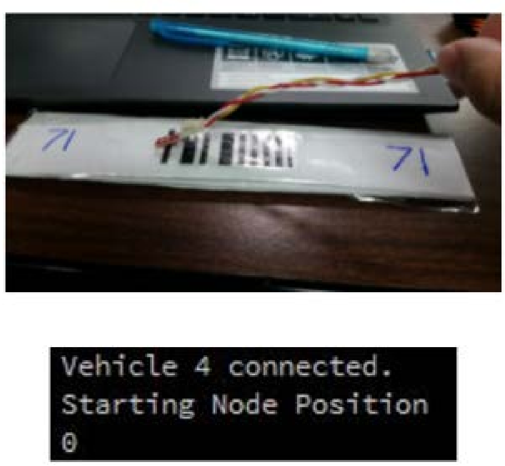


Figure 2- 22: Output status pre-barcode scan

From the figure, we can see that the vehicle is not given a starting nodal position because it has not read a barcode. The next figure shows the output of the program after the barcode sensor has scanned over the barcode

Barcode Sensor Mounts

One of our greatest challenges of this project was to get the barcode scanners to work on the track. Since the tolerancing on the track was not as tight as we would like it, we needed to come up several design iterations of the mount for the barcode scanners. Initially we thought simply having the sensor on the vehicle was enough, though it prove it was not and we had to add some flexibility to our sensor mounts which led us to add a curve into the mount which allowed it to flex side to side. This hardly improved our results though it was an improvement. Eventually we came up with our final design to have an S bend along which gave us almost three degrees of freedom. It was then able to tilt not just left and right, but also tilt up and down, and it also had some translational degrees of freedom left and right. In the final design you can also see a sled shape in the front of the mount which allowed it to enter the track more easily, and also allowed for the flat section to place the sensor at a consistent distance from the barcode it is reading.

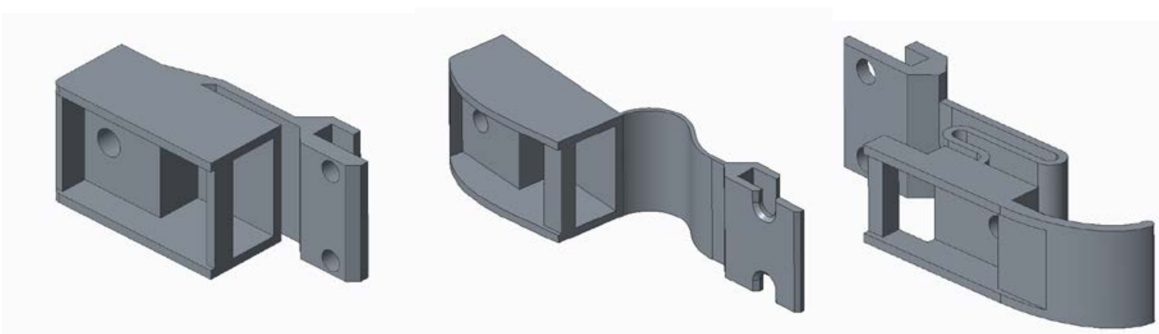


Figure 2- 23: Barcode sensor mount design iterations

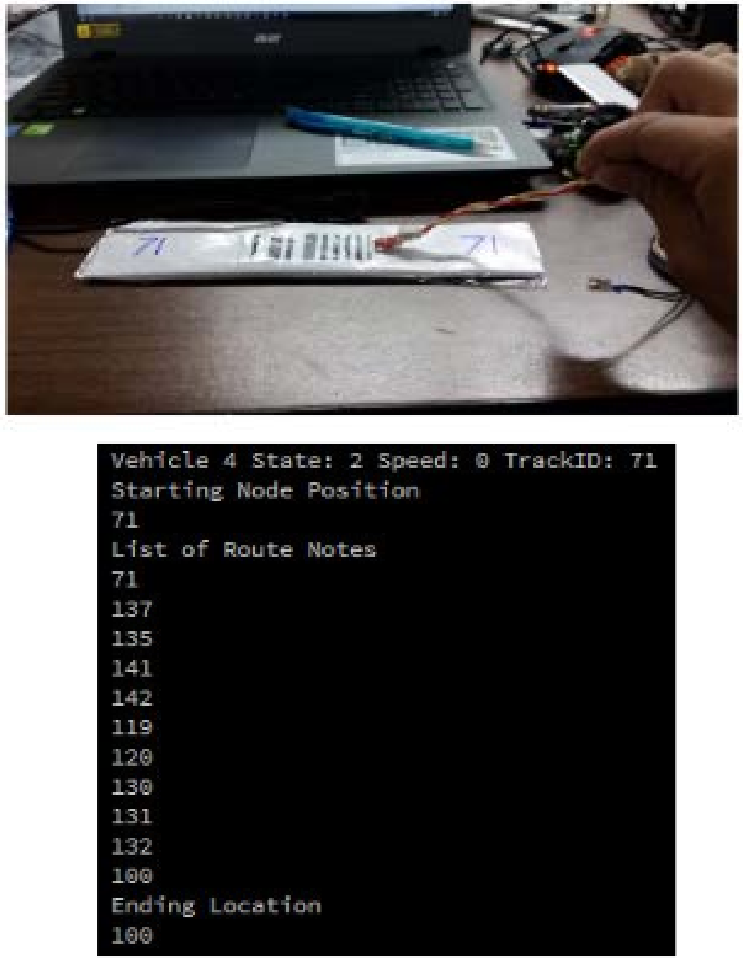


Figure 2- 24:Output status post barcode scan

As you can see, after the barcode sensor has scanned over a barcode, it not only determines the nodal location, but it also utilizes the breadth-first search algorithm in order to create the most efficient pathway to the desired station. In order to verify and test the newly designed circuit board, the team utilized a multimeter that had a continuity function. The team would place the contacts on various components of the board and a ring would sound if the component was successfully soldered and connected to the necessary components on the board. In order to verify the size specification of the design the team simply placed the Arduino system in the 3D Cabin and enclosed it to ensure that it would fit as seen in the following figure.

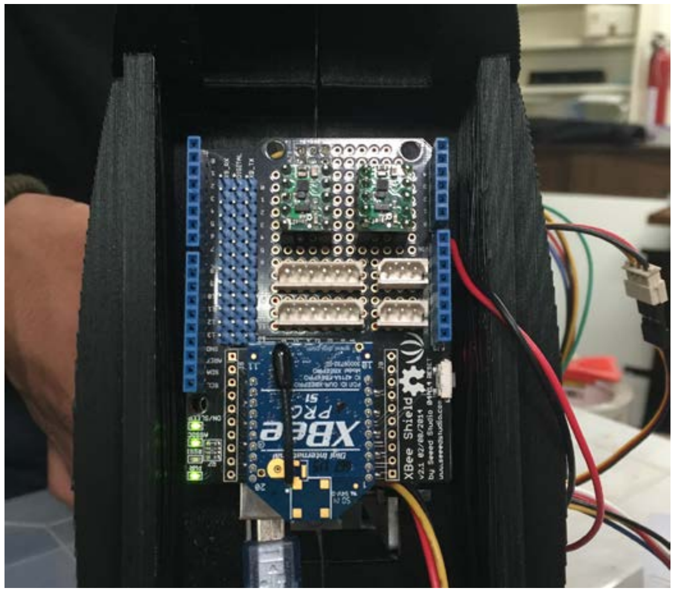


Figure 2- 25: Verification of Arduino System Design

Cost of Project

Table 2- 2: Cost Summary for Controls System

Supplier	Description	Amount
Pololu	Micro gear Motors	30.12
Pololu	Motor drivers	15.34
Pololu	Motor mounts	31.90
SparkFun	Reflective encoders	38.20
RobotShop	Wireless ProtoShields	124.90
	TOTAL	239.47

Given that the team already had an inventory of components which included Arduinos, Ultrasonic Sensors, all of the connection headers, solder, wire etc. the overall cost of the project was only $240. The team was also fortunate enough to receive a 20% discount on the products purchased from Polulu after mentioning that the parts would be used for the Spartan Superway project.

Results and Implications

With all of our designs fully functioning, the team's work would bring together all of the elements of the small scale. With functioning vehicles that can act autonomously, the small scale controls team would now be able to provide a functioning demonstration at Maker's Faire.

Although, a working model of the autonomous network was successfully demonstrated at Maker's Faire, there were many complications that occurred during the demo. For example, there were moments where the barcode sensors did not successfully scan the barcodes. This would cause potential problems such as the switching mechanism not engaging due to a misread in the barcode's ID.

Conclusion and Recommendations

While the Small Scale Controls team was overall successful in meeting their design specifications, there are various improvements that can be made in the future in order to further refine the Controls System. For the Barcode System, the team would recommend using higher quality sensors with a greater working range. This would allow the barcodes to be read more reliably. The team would also recommend using higher quality printer and paper to produce barcodes so that again the system will be more accurate. Additionally, different sensor mounts could be designed to help maintain a direct reading of the barcodes. For the Pathing algorithm, future improvements include generating a new code that would work in conjunction with the four-loop track design as well as refining the algorithm to be more robust in terms of having vehicles autonomously switch. For example, making use of the encoder counts based on the known distances between node to node would serve to solve the issue of missing a barcode. For the hardware design aspect of the controls team, one major improvement that could be made is exploring the concept of printed circuit boards. Utilizing printed circuit boards would allow for more easily manufactured boards that do not require extensive amounts of soldering.

Chapter 3: Solar

Intermediate Scale Solar Power

Objectives

The objective of the Intermediate Solar Team is to develop a means to supply power to the Spartan Superway and further the ability of the group to design an adequately powered system; this includes: theoretical design for a full scale network, design and implementation of an intermediate scale solar solution, and development of a Spartan Superway solar calculations spreadsheet. The team will supply power through solar cells to the grid so that whatever power is being drawn from the grid is offset. The delivered objective was a working system that partially powered the intermediate scale model at Bay Area Maker Faire 2016. The final list of design objectives is as follows:

- Design a Spreadsheet Calculator to ease future solar work
- Design a modular, easy to install, solar mounting solution at Full Scale
- Integrate Solar into the Intermediate Scale System
- Design and Build a modular, easy to install and transport solar mounting solution at the Intermediate Scale
- Power the Intermediate Scale System for the MakerFaire showcase using an appropriately scaled array

Design Requirements and Specifications

The stationary modular frame's design requirements are as follows:

- Modular- easy to assemble and take apart
- Design a frame that would eliminate the need a tracking system on the full scale model
- Able to fully power the intermediate solar scale track
- Structurally sturdy and aesthetically pleasing
- Light enough that the solar modules do not distort the shape of the guideway

The design must be modular and easy to install, both for the theoretical Full Scale and the implemented Intermediate Scale. This is because it will need to be assembled with the modular track at Full Scale and the Intermediate Scale will need to be transported and set up or broken down multiple times for Maker Faire. While modularity is important so are aesthetics and structural stability; these were both taken into account while designing as well. Changing building material when scaling down was important; it made the structure light enough to be mounted on the intermediate track with no issue. Lastly, in the vast array of a citywide system dynamic tracking would increase maintenance cost and cause more issues so the implementation of an efficient, static system is a very important design specification.

Unfortunately, the Intermediate Solar team fell short of fully powering the intermediate scale system using solar power because of size restrictions on the implemented array. This will be discussed in detail in the Results and Discussion section of this sub-team's report.

State-of-the-art / Literature Review for the Subteam's Sphere of Work

Currently, we have three main solar panels that are widely used throughout the world. There are monocrystalline silicon solar panels, polycrystalline silicon solar panels, and thin-film solar cells. Each solar panels has its advantages and disadvantages depending on the application for which it is used for. Specifically for the Spartan Superway, the intermediate solar team decided to select the types of solar panels based on "cost, efficiency, lifespan, simplicity of manufacturing, and the amount of space allowed to installed the solar panel" (Spartan Superway, 2014).

Monocrystalline silicon solar panels are made with high purity silicon as shown in Figure 3-1. High purity means that the solar cells are packed and aligned extremely well. As a result, the precise alignments will help convert solar energy to electricity better. "Monocrystalline silicon solar panels has an efficiency of 15-20%, it has the highest efficiency of the different types of solar panels, a long life span, and produces the most efficient result under low light conditions" (Spartan Superway, 2014). Unfortunately, it is the most expensive amongst the three types of solar panel due to the amount of work to produce precise alignments.

Figure 3- 1: Monocrystalline silicon solar panel (Image retrieved from: http://www.borgenergy.com/monocrystalline-solar-panel/)

Polycrystalline silicon solar panels utilizes raw silicon, they are manufactured by pouring raw silicon into a square mold. As a result, polycrystalline silicon solar panels are easier to manufacture and cost less compared to monocrystalline silicon solar panels. Polycrystalline silicon solar panels has an efficiency of 13-16%, in this case, there needs to be more polycrystalline silicon solar panels in order to produce the same amount of power output compared to a monocrystalline silicon solar panel. A polycrystalline silicon solar panel is shown in Figure 3-2.

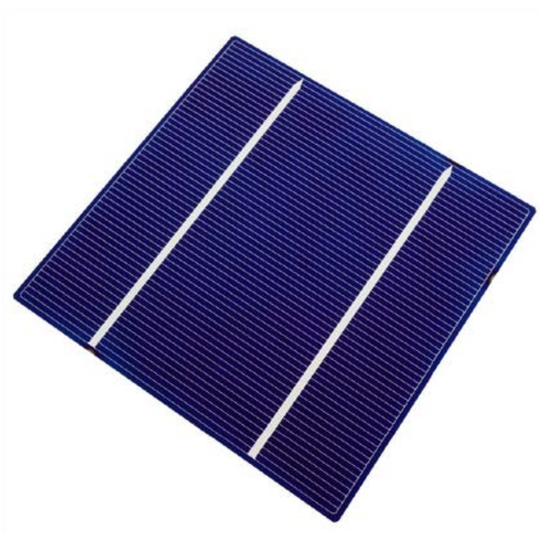


Figure 3- 2: Polycrystalline silicon solar panel (Image retrieved from: http://www.aliexpress.com/item/20pcs-125-125mm-Polycrystalline-Silicon-Solar-Cell-for-DIY-Solar-Panel/32439726826.html)'

Thin-film solar cells are made from "depositing one or several layers of photovoltaic material onto a substrate" (Spartan Superway, 2014). Thin film solar cells has an efficiency of 7-13%.

They require more space in order to produce the same amount of power output. Thin-film solar cells are easier to mass produce and they are aesthetically appealing due to the ability to bend. Unfortunately, thin-film solar cells degrade faster compared to polycrystalline and monocrystalline solar panels. A picture of a thin-film solar cell is shown in Figure 3-3.

Figure 3- 3: Miasole Flex 02 thin film solar cell (Image retrieved from: http://miasole.com/products/)

The intermediate solar team decided to utilize the Miasole's thin film solar panel for the full scale design. The Spartan Superway project was fortunate to have many sponsers and one of them included Miasole. Miasole's flex thin film solar panel that was donated to us has an efficiency roughly 16% and outputs 340W (Miasole, 2015). Miasole's thin film flex solar panel has many benefits that include: lightweight, bends, it is designed for high wind resistance and seismic zones, and etc. One of Miasole's successful application of thin film solar panel is located in Missouri, Columbia. Located in Missouri, Columbia is 3M Corporation, they are one of Miasole's partner that designed the protective film around the solar cells. The thin film solar panels were installed in December of 2013 and as of today, they are still functional and needed less maintenance compared to many solar panels produced by other companies (Miasole, 2015).

As the semester progressed, the intermediate solar scale team discovered that the intermediate track will be made and a new solar mount design will be created for it. The intermediate solar scale team decided to use the SoloPower solar panels that was kindly donated for Spartan Superway. A picture of the SoloPower solar panel is shown in Figure 3-4.

Figure 3- 4: SoloPower SP1 flexible solar panel (Image retreived from http://solopower.com/products/solopower-sp1/)

Design Concepts

We created a power calculator that will help determine some required specifications. The calculator uses basic arithmetic and dimensional analysis. We collaborated with all of the other sub teams, to determine the power they required for their systems. The calculator also takes into account the specifications of the solar panels, as well as the specifications of the intermediate spartan superway. The way the calculator would function is if one of the inputs were changed then all of the outputs would be altered as well. If the power required for pulsion was adjusted, all of numbers involving the propulsion would be adjusted. For example if the power required for propulsion was decreased, the number of solar panels would decrease as well. The power and track requirements are determined, by the values that are inputted in the colored boxes. Some power and track requirement include power output per foot of track, number of panels required, and the number of modules.

We wanted to improve last years full scale design, and eliminate the need for a tracking system. Initially, we did research on cylindrical solar modules, which can be arranged in an array to eliminate the tracking system. We discovered the company that made solar modules Solyndra, went bankrupt. This meant the solar modules were very difficult to find as well as, very expensive. We decided to use the given Mia Sole flexible solar panel in a curved orientation either in concave or convex fashion, to fulfill our requirement of eliminating the tracking system. The three were: Planar (figure 3-5), concave (figure 3-6), and convex (figure 3-7). We were able to use these designs because we had thin film solar panels that were donated to us from Miasole. We wanted the mounting system to be aesthetically pleasing as well as efficient and we felt that one of these three designs would fit the criteria.

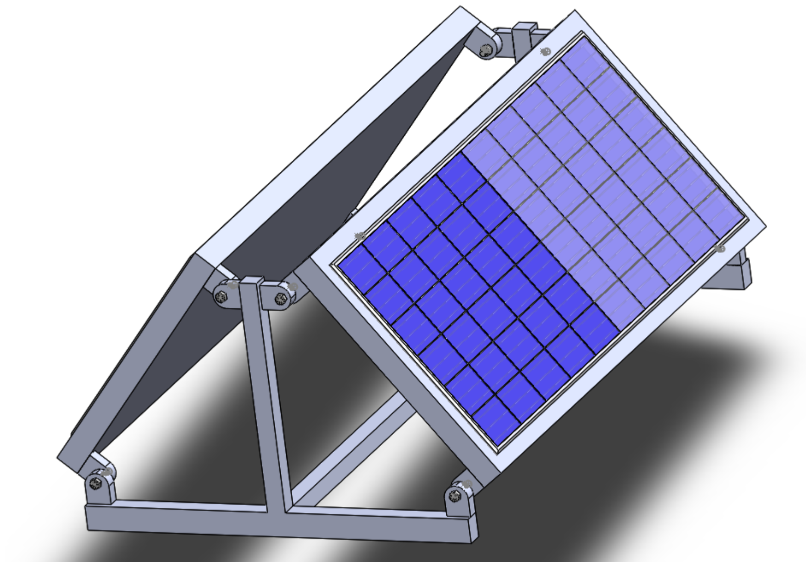


Figure 3- 5: Initial planar mounting design. This is the design chosen that was later improved.

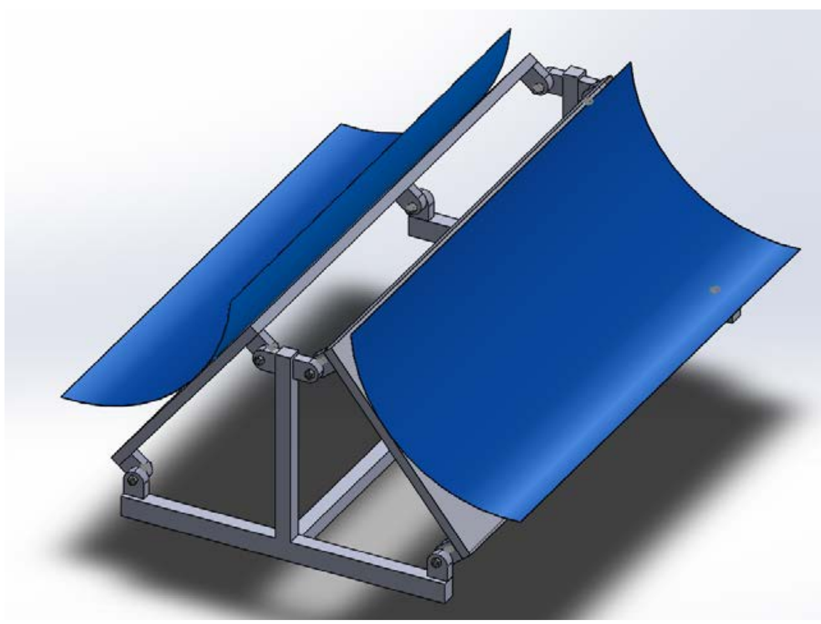


Figure 3- 6: Initial concave mounting design. This design was least appealing to us compared to the other two.

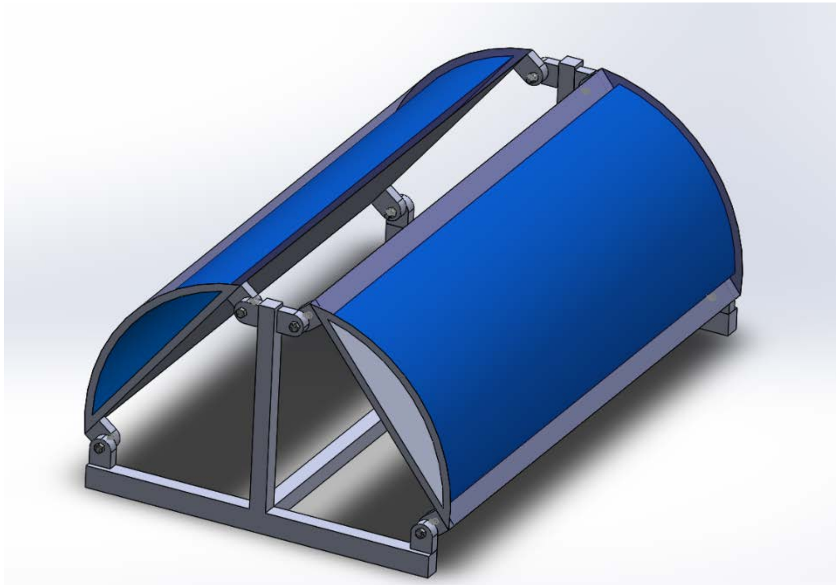


Figure 3- 7: Initial convex mounting design. This will be looked into next semester to see if it can be improved to succeed the planar design.

After some calculations and discussions, we decided on the final design mounting system to be the planar design, it provides the efficiency as well as looking aesthetically pleasing. With the final choice being planar, there needed to be two versions of the design to be made. One design was created to be mounted on track going East to West, and the second version was created for a North to South track, these designs are displayed in figures 3-8 and 3-9 respectively.

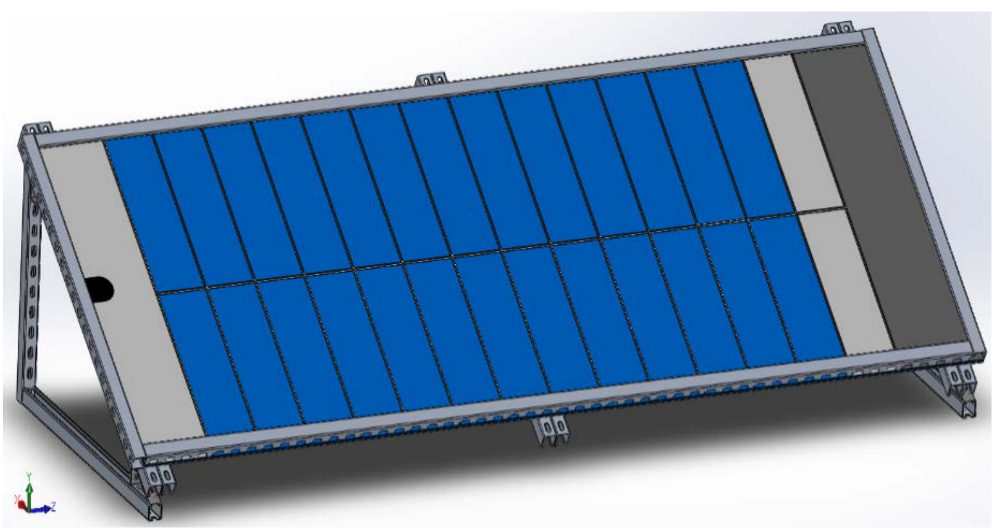


Figure 3- 8: East to West track mounting design. Made from strut channel, it is light-weight and easy to fabricate.

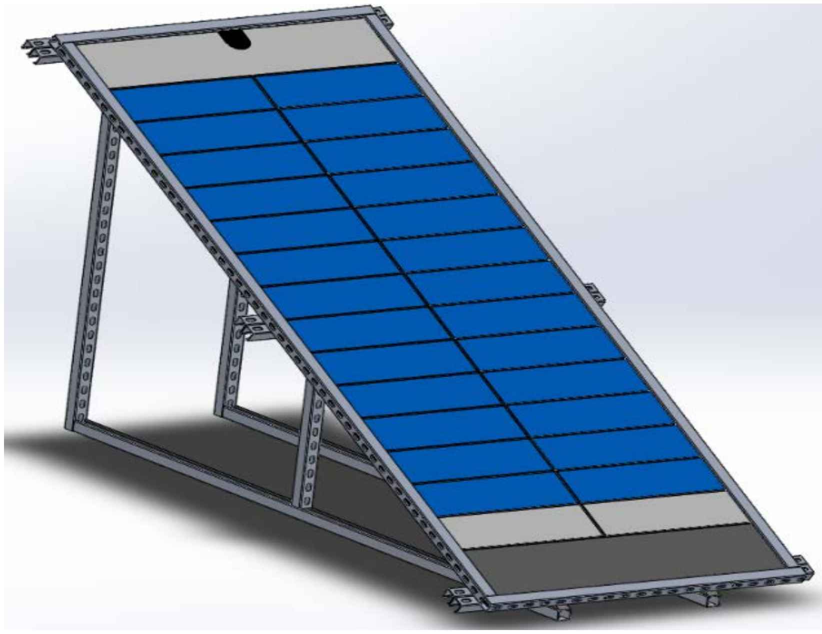


Figure 3- 9: North to South track mount design

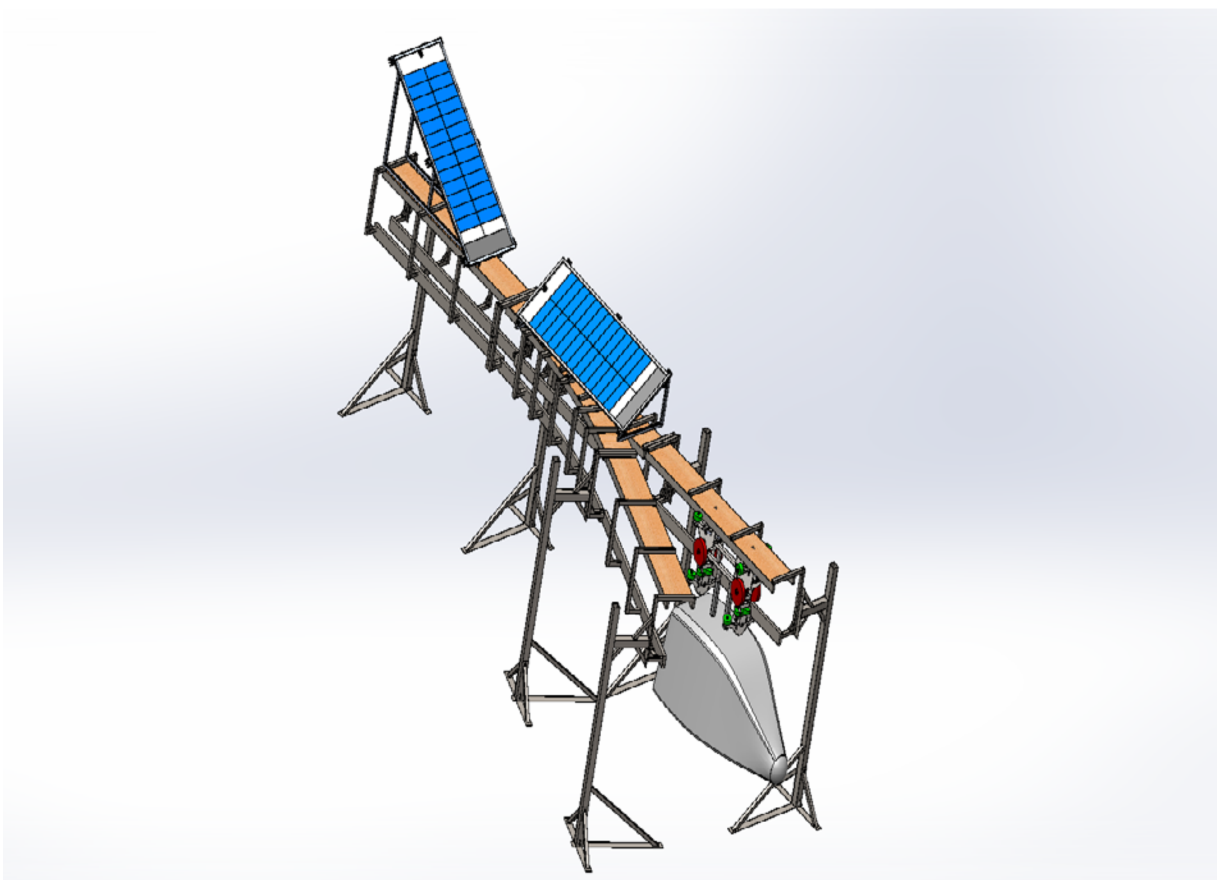


Figure 3- 10: Mount system on full scale model.

After completing the solar mount solution for the full scale, next was to design and build a solar mount for the intermediate scale. The guidelines for this build were similar to the one to full scale. The solar mount needed to modular for easy transportation, aesthetically pleasing, and be easy to install.

Figure 3-10 displays the solar mounting solution that was created. The solar mount solution is made of wood which is easy to build with and has two main components that make a module, the solar panel and the solar base. The overall dimensions of the module are 120.5in length, 30.76in wide, 10.8in high, and weighs less than 100 pounds. The features of the solar panel are: slotted end plates help curve the solar panel, ribs provide support for the flexed solar panel, runners help keep the curve and provide support to the solar panel, door hinges allow the panel to fold in half to make the panel easy for transport. The solar base was designed into a trapezoid so that three solar panels can be mounted together which looks aesthetically pleasing, which can been seen in figure (3-11). The features from both components combined fulfill the design requirements of having the solar mount being modular, aesthetic, and easy to install. Thus, this was the solar mount solution.

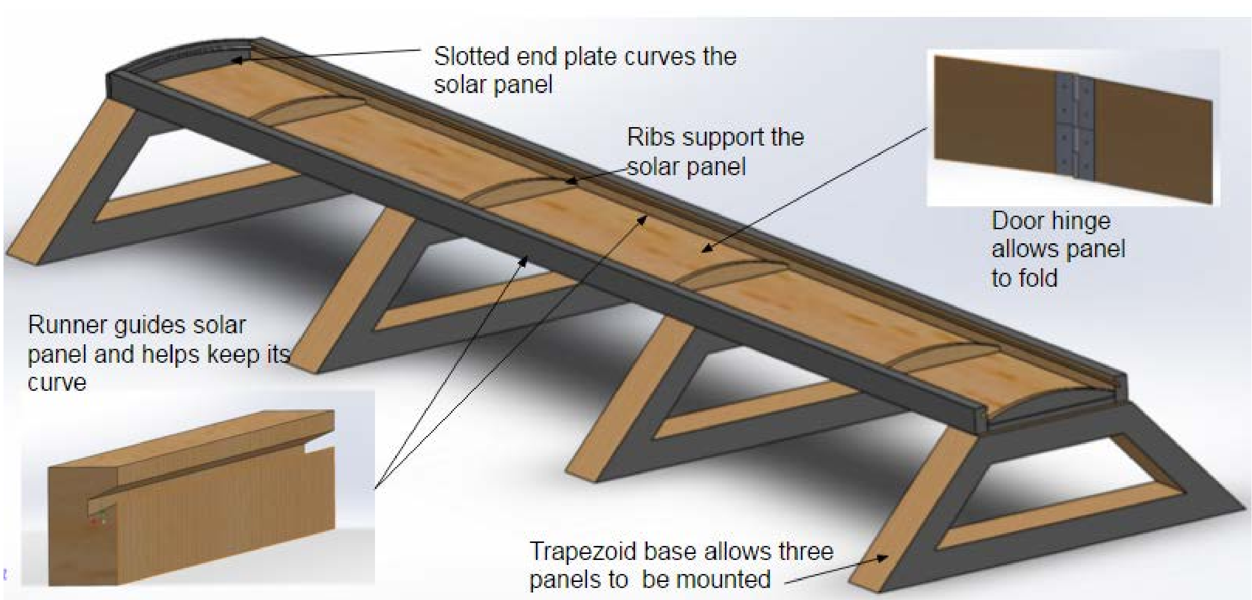


Figure 3- 11: description of solar mount solution

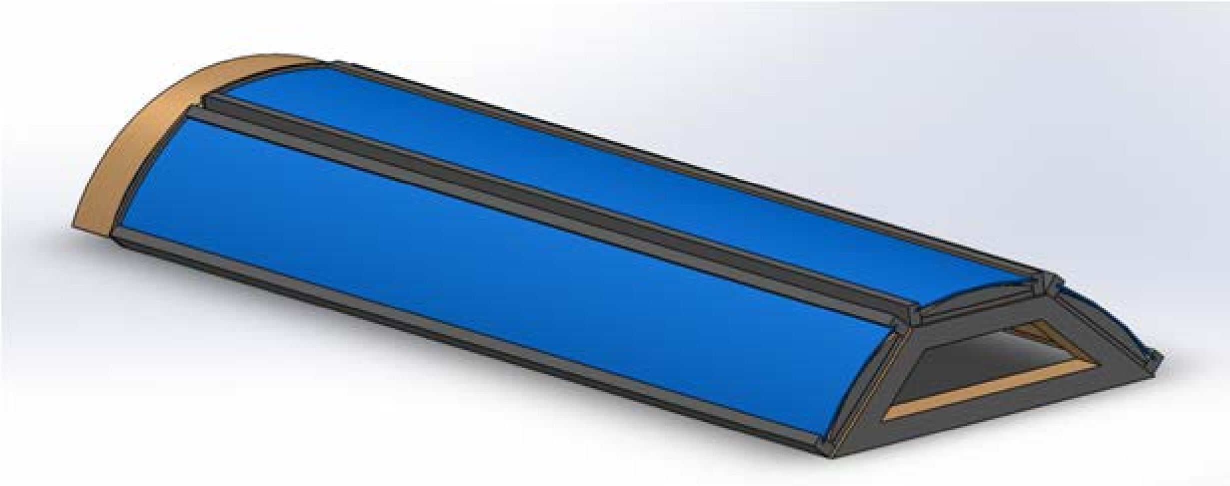


Figure 3- 12: Three panel module

Figure 3- 13: Completed solar module

Figure 3- 14: Fully completed solar mount module.

Five modules were made and are mounted across the straight length of track on the intermediate scale which is displayed in figure 3-15.

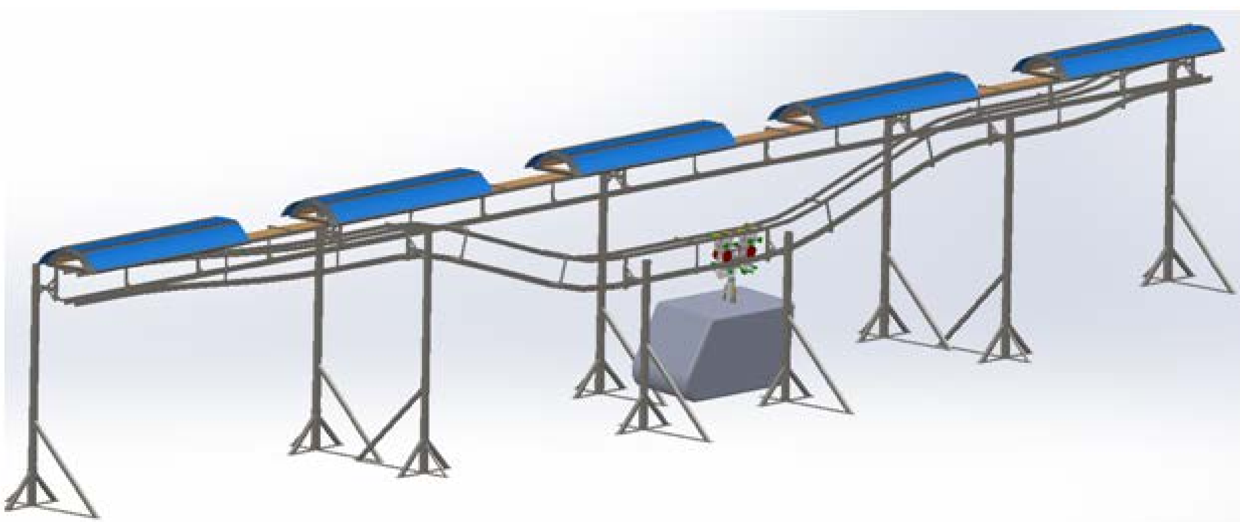


Figure 3- 15: modules mounted on intermediate scale track

Analysis and Concept Selections

The solar team was able to utilize some of information from the year 2014-2015 Spartan Superway report, this include the amount of load applied to the full scale bracket, which is 200 lbs. This value was used to perform majority of the calculations. We designed a calculator to help make our calculations easier. The power requirements that were provided were from a full scale model, the calculator would take the full scale numbers and provide the proper requirements to a quarter scale. If the power required for pulsion was adjusted, all of numbers involving the propulsion would be adjusted. For example if the power required for propulsion was decreased, the number of solar panels would decrease as well. The power and track requirements are determined, by the values that are inputted in the colored boxes. Some power and track requirement include power output per mile of track. The power output per mile of tack is the power required for a certain mile of track. Within the mile of track along with the given power, the calculator also determines the number of pods within the mile of track. In order to fully power intermediate scale with the solo-flex panels 63 solar panels will be required or 21 modules. A shot of our power calculator is shown in below Figure 3-16. To fulfill the design requirements of the solar mount, calculations were made to understand how much solar panel is needed, which will determine the amount of solar frame needed as shown in **Figure 3-18**.

	A	B	C	D
3	Power Requirments			
4	Propulsion (kW)	2.9828		Inputs
5	Suspension (kW)	0.18		
6	Braking (kW)	0.44742		Outputs
7	Steering (kW)	0.1		
8	Hours of Operation	12		
9				
10	Total Power Required For Each Pod (kW)	3.71022		
11	Total Power Required For All Pods (kW)	3.71022		
12	Total Power Required For Hours of Operation (kWh)	44.52264		
13				
14				
15	System Specifications			
16	Number of Pods	1		
17	Length of Given Track (ft)	70		
18				
19				
20	SoloPower SFX1-i70 Specifications			
21	Length (ft)	10		
22	Width (ft)	1		
23	Nominal Power (W)	0.0593		
24	Maximum Power (W)	0.07		
25				
26				
27	Solar Team Module Specifications			
28	Number of SoloPower Panels Used	3		
29				
30	Nominal Power of Solar Team Module (kW)	0.1779		
31	Maximum Power of Solar Team Module (kW)	0.21		
32				
33				
34				
35				
36	System Requirements			
37	Power Output of Hours of Operation per Panel (kWh/Panel)	0.7116		
38	Power Output of Hours of Operation per Module (kWh/Module)	2.1348		
39				
40	Number of Panels Required for Required Power	62.567		
41	Number of Modules Required for Required Power	20.856		
42				
43	Power Output per foot of Track (kWh/ft)	0.6360		
44				

Figure 3- 16: A screenshot of our calculator with showing our power and track requirements.

The solar mount solution was used to provide some power to the intermediate system specifically wayside pickup. Due to the lack of efficiency of the solar panels that are installed in the modules, they were not able to fully power the intermediate system. When testing the panels, the array they were put in were: panels connected in series in a module, and have all the modules connected in parallel which is displayed in figure 3-17. The results of the test were each panel in a module provided about 27 volts at 2 amps. The overall system tested, provided 80 volts at 10 amps.

Figure 3- 17: Modules connected in parallel

Solar PRT Performance					
50	km/hr, operating speed		31	mph	
8.0	kw at operating speed including cabin loads		226	miles per gallon equivalent	
4.3	sec podcar interval				
25%	podcars empty ("deadheading")		**Compare assumed solar insolation to:**		
4.0	hrs at peak operation equivalent (defines vehicle capacity)		942	108%	Stockholm
2.8	hrs of peak sun equivalent. SE = 2.8, Coast = 4, Desert = 6		1,022	kWh/kw/year solar assumed	
$ 3.00	$/watt for solar system		1,825	56%	Silicon Valley
2.0	people/podcar				
$ 2.20	/liter fuel price		$ 8.33	per gallon	
Cost and capacity based on above assumptions					
0.91	meters wide: solar panel to meet capacity as specified	$ 358,804	/km	**5,023**	**passengers per day** at any given point in one direction
Cost and Capacity based on podcar standard solar canopy width					
2.0	meter wide solar panel as podcar standard	$ 784,615	/km	10,985	passengers per day
Cost and Capacity for other canopy widths					
0.46	meters wide: solar panel to meet capacity at right	$ 179,402	/km	2,512	passengers per day
0.23	meters wide: solar panel to meet capacity at right	$ 89,701	/km	1,256	passengers per day
0.11	meters wide: solar panel to meet capacity at right	$ 44,850	/km	628	passengers per day
1.00	meter wide: specified panel's manufactured width	$ 392,308	/km	5,492	passengers per day
Compare to Automobile					
5.5	liter/100 km, average fleet consumption	43	mpg		car
2.1	years payback time for solar system vs. auto fuel	1.3	people/car	48,672	passengers/lane/day
	Input Variables -- can be modified for analysis				
	Key assumptions				
	Key results				

Figure 3- 18: Calculations of cost, efficiency, etc of solar panel

By utilizing the calculations, the intermediate solar team decided that 7 solar panels can be placed in series or 7 solar panels can be placed in parallel, or 6 solar panels can be placed in combination of series and parallels. With the amount of solar frames decided, our team believe that the ideal material used to build the solar frame would be to use aluminum because aluminum are lighter than steel, aesthetically appealing, and has corrosion protection. Steel has three times the modulus of elasticity of aluminum, but given the benefits of aluminum, aluminum is selected as the primary material for the strut channels. However, the strut clamps, closed angle bracket, and clamps are made of steel because the fasteners needs to be strong to hold the frame together.

<u>Budget Analysis</u>

In order to build the solar mounts, the intermediate solar scale team brainstormed the materials needed. During the design phase of the solar mounts, the initial design was to create a solar mount for the full scale. As shown in Table 3-1, majority of the materials are picked out due to cost, availability, and material description.

Table 3- 1: Initial design full scale bill of material list

Vendor	Vendor part number	Description	Quantity	Price per item	Total Cost
McMaster	3230T36	10 Ft Aluminum Strut Channel Slotted, 13/16" x 1-5/8"	13	$30.34	$394.42
McMaster	2233K19	Strut Channel Clamping Nuts	18	$2.00	$36.00
McMaster	33125T156	Strut Channel Accessory 30°Closed Angle Bracket, 2-Hole, Green-Paint Steel	10	$2.52	$25.20
McMaster	1815T16	I-Beam Clamp, Bottom Mount, Low Profile, Zinc, 13/16"-3 1/4" strut	4	$3.09 per pack of 2	$12.36
				Total	$467.98

As the semester progresses, the intermediate solar scale team discovered that the initial design for the full scale model could not be used for the intermediate scale. Therefore, a new design was created and a updated bill of material is created as shown in Table 3-2.

Table 3- 2: Updated bill of material for intermediate solar mount design.

Ideal Materials List					
Name	*Description*	*Quantity*	*Location*		*Price*
12-foot 2" x 4"	2 in. x 4 in. x 12 ft. Standa	10	Home Depot		$4.51 each
4' x 8' x 1/2 inch	Fir Sheathing Plywood 1!	8	Lowe's		$26.27 each
Door Hinges	12-Pack 3.5-in H Satin Ni	30	Lowe's		$21.98 / 12 pack
Various Screws	#6 x 1-1/2 in. Philips Driv	100	Home Depot		$6.97 / 315 pack
Solar Panels		15			Provided
				TOTAL	$ 328.17

Upon receiving the donated solar panels, we found out that there were residue behind the panels. We purchased materials to remove the residue behind the solar panels and another updated bill of material was created as shown in Table 3-3.

Table 3- 3: Updated bill of materials for intermediate scale solar mount for residue

Name	Quantity	Location	Price	Total	Purchased?
12' x 2" x 4" Lumbar	10	Lowe's	$4.18 each	$41.80 *$45.46 w/ tax*	✓
4' x 8' x 0.5" Plywood	6	Lowe's	$23.80 each	$142.80 *$155.30 w/ tax*	✓
4' x 8' x 0.5" Plywood	2	In house	Provided	0	✓
Door Hinges	30	Home Depot	$24.12 each box / 12 pack	$78.87 w/ tax	✓
Solar Panels	15	In house	Provided	0	✓
Goo Gone	6	Lowe's	$3.40 each	$20.40 *$21.93 w/ tax*	✓
Taping Knives	2	Lowe's	$2.50 each	$5.00 *$5.44 w/ tax*	✓
3/8" Bolts	1 box (100 bolts)	Lowe's	$29.99 each	$29.99 *$32.61 w/ tax*	✓
3/8" Nuts	1 box (100 nuts)	Lowe's	$14.99 each	$14.99 *$16.30 w/ tax*	✓
3/8" Washers	2 boxes (100 washers)	Lowe's	$7.99 each	$15.98 *$17.38 w/ tax*	✓
			Total	**$373.29**	

With the help of the Electrical Engineering team, we needed to include connectors to connect the solar mounts to the power inverter. The intermediate solar scale team decided to paint the solar mount to have it more aesthetically appealing. The final bill of materials to fully build the intermediate solar mount is shown in Table 3-4.

Table 3- 4: Final bill of materials for the intermediate solar mounts

Name	Quantity	Location	Price	Total
12' x 2" x 4" Lumbar	10	Lowe's	$4.18 Each	$45.46
4' x 8' x 0.5" Plywood	6	Lowe's	$23.80 each	$155.30
4' x 8' x 0.5" Plywood	2	In house	Provided	0
Door Hinges	30	Home Depot	$24.12 each box / 12 pack	$78.87
Solar Panels	15	In house	Provided	0
Goo Gone	6	Lowe's	$3.40 each	$21.93
Taping Knives	2	Lowe's	$2.50 each	$5.44
3/8" Bolts	1 box (100 bolts)	In house	0	0
3/8" Nuts	1 box (100 nuts)	In house	0	0
3/8" Washers	2 box (100 washers)	In house	0	0
MC4 Connectors	40	Amazon	$23.86 each	$47.42
MC4 Branch Connectors	4	Unlimited Solar, Inc.	$4.99 each +S&H	$19.96
Solar PV MC4 Cable Extension	8	Unlimited Solar, Inc.	$11.99 each + S&H	$95.92
S&H + Tax for MC4 Connectors and Branch Connectors	N/A	Unlimited Solar, Inc.	N/A	$24.39
Primer, Painter's Tape, and Trash Bags	N/A	Orchard Supply Hardware Store	N/A	$30.20
			Total:	$524.89

Outcomes

The Intermediate Solar Team has completed an Excel based calculator that can be used to design systems for intermediate and full scale Spartan Superway. Upon continuation of development for both scales the calculator can be updated to reflect changes in design. This calculator uses design parameters and values to produce output values for the system and other parameters that will help with the design of a full size network. Additionally, a modular mounting design in full scale has been designed for future use. An intermediate solar mounting solution that was used to partially power the Intermediate Scale Model at Maker Faire was produced; the team fully prepared and completed fabrication early and began assisting other teams in the weeks leading up to Maker Faire. The team provided partial power to the grid tied inverter and displayed the capability of the track as a solar farming option.

Discussion

The power calculator is fairly simple to use. The inputs are placed in the colored regions, and the power and track requirements are outputted. As of right now the power calculator inputs, are set for the intermediate scale model and the available modules for Maker Faire. The power calculator can be adjusted to predict power requirements that will be needed for the intermediate scale or full scale at various sizes.

The Full Scale solar mounting solution was designed to full size specifications and can be manufactured at a later date using the available solar panels donated from MiaSole.

The change in design to adjust to intermediate scale was successful. An Intermediate Scale Solar Solution was implemented in time for Maker Faire and provided partial power to the system. Although the system did not generate sufficient power to completely negate the draw from the grid, it did serve to lighten the load and prove that a solar farm was viable and useful while mounted on the guideway. Given a larger section of track and more efficient panels an array similar to the one used at Maker Faire could provide enough power to offset the draw from the grid. Approximately one third of the needed power was supplied through the solar cells atop the Spartan Superway Intermediate Scale at Bay Area Maker Faire 2016.

Conclusion

The Intermediate Scale Solar Team succeeded in many ways this year and developed a lot of useful outcomes for the future of the Spartan Superway. The Solar Calculator designed by the group will be useful in the future and provide all coming iterations of the Superway with a strong base for their solar and power calculations. There is a legitimate Full Scale Solar Mounting Solution ready to be refined or implemented based on future needs. The Intermediate Design is accessible and ready for future teams to take advantage of or display. Besides advancing the state of the Spartan Superway as a Senior Project at San Jose State University, the Intermediate Solar Team also had a strong display to showcase the solar power and renewability of the Spartan Superway at Bay Area Maker Faire 2016.

Suggestions for Future Work

We are hoping to make the intermediate scale fully solarized, as opposed to only being partially powered by solar panels. In order to fully power the intermediate scale more powerful and efficient solar panels will be required. The solo-power ones that were used for this year’s intermediate scale were descent, but they are out dated. Also, improving the power calculator to include more of the other sub teams power requirements in greater detail.

Small Scale Solar Power

Objectives

Many of the objectives have changed as the design process continued. After finalizing the parts design for the solar panel, new goals were created as the solar design took an alternative direction. Donations of 10 feet solar panels from Mr. Ron Swenson allowed for an unanimous decision to use as the primary component to the assembly. This decision enabled for budget to be used in other areas of the project. The main goal remained to keep an effective design of a solar panel array assembly in order to properly represent the full-scale Spartan Superway. With the use of the two 10 feet solar panels, an accurate representation could still be achieved with minor setbacks that could be easily overcome in future projects. Calculations determined that a minimum of eight solar panels was needed to power the full track for a 10-bogie system. Initially, the track team proposed to expand to a 4-loop track and utilizing all eight solar panels within the track. However, due to complications during the beginning of the semester, the track team was unable to expand to a 4-loop track. With the size restraint on the 1/12th solar scale design, only two solar panels could be implemented within the track design. The third objective was to find an efficient way to provide power to drive the bogies in the track design.

Out of the three types of solar panels on the market today, thin film solar panels are the only panels that are flexible. To take advantage of this key feature, the third objective was to design a frame in which a curve could be implemented to potentially increase efficiency as well as visualization. Lastly, the 1/12 scaled model will be transported to different locations at different times, thus changing the optimum tilt angle. Although the fixed optimum tilt angle can be calculated for any location, the model was made for demonstration purposes. The last objective was to create mounts that will allow the angles of the complete assembly to be changed to various angles.

Design Requirements and Specifications

In order to effectively meet the objectives stated earlier, a few design requirements must be met. Due to the concern of stability within the track, the complete solar panel assembly must be designed with lightweight components along with even geometry to avoid tipping of the track. As explained earlier, the selection of the solar panels did not allow for the whole track to be completely powered off solar panels. However, another design requirement was to provide at least 11-18V and 1A of usable power to the track. Even though the track itself will not receive power due to the lack of wayside, power will still be generated and used in the form of charging the bogie batteries. Next, the adjustable mount that allows for various angles to be achieved must be able to reach important angles determined by location as well as 0 and 90 degrees. The angle resolution for this initial design could be further increased, but for the purpose of this year's design, optimum angles must be able to be achieved. With the angles able to be dialed in, another requirement was to test the solar panels' ability to be shaped by applying a curve of no less than a radius of two feet. Lastly, all components must be easily assembled and disassembled. Transportation must be kept in mind when designing a model.

State-of-the-Art/Literature Review for the Subteam's Sphere of Work

Three types of solar panels

In order to power the track, there are a few options to consider when choosing a type of solar panel. Currently on the market, there are three main types of solar panel, which are the monocrystalline silicon solar panels, polycrystalline silicon solar panels, and thin film solar panels. Each solar panels have their own advantages and disadvantages which were taken into consideration for the 1/12 scale Spartan Superway.

Monocrystalline silicon solar panels are unique and are commonly known as crystalline silicon or single crystalline silicon. Monocrystalline solar panels are created from thin cuts of wafers from a singular continuous crystal, which ensures high purity silicon. Due to the high purity of silicon, monocrystalline solar panels have the highest efficiency rates and tend to perform better than the two. Monocrystalline silicon solar cells have been in the market for over 50 years and have proved to be known for their longevity. However, monocrystalline solar panels are the most expensive, and tend to be more efficient in warm weather.

Unlike how monocrystalline silicon solar cells are made, polycrystalline silicon solar cells are created from melting silicon material and poured into a mold. The efficiency compared to monocrystalline are much lower, but they are also cheaper. The efficiency ranges around 13 to 16% due to the less purity of the silicon. Polycrystalline silicon solar cells do have a lower temperature coefficient than monocrystalline solar cells. This will result in generating more electricity over the years when compared to monocrystalline solar cells.

Thin film solar panels are usually made from materials such as glass, plastic or metal. Thin film solar panels are used less in residential areas due to their deteriorating material. Because of this, they are the cheapest from the two. They are also easily mass-produced and can be made flexible for many applications. Temperature also does not play a factor in these type of solar panels. However, thin film solar panels are considered the lowest efficiency from the two. Even though thin film solar panels have a low efficiency, companies such as SoloPower have made great improvements with increasing efficiency. Figure 3-19 shows the different types of solar panels currently available.

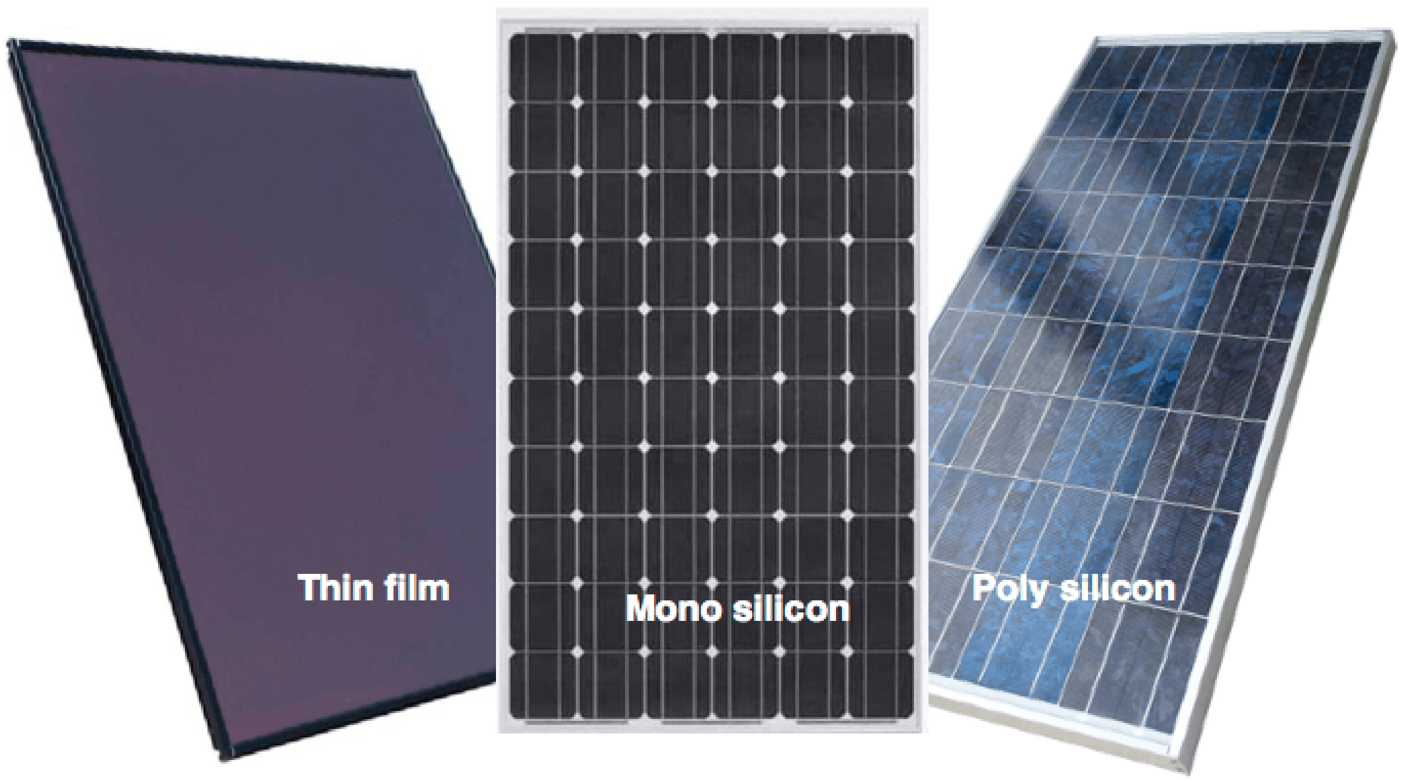


Figure 3- 19: The comparison of the three types of solar panels.

There are clear advantages and disadvantages between the three types of solar panels out in the current market. Thin film technology has progressed through the years with companies closing the efficiency gap between the three types. With the large donation of thin film solar panels, the panels were able to satisfy this year's design specifications. The donated SoloPower SFX1-i70 model has around 8% efficiency with electrical ratings of a maximum power of 70W, Max Power Voltage of 21V and Max Power Current of 3.3A. The SoloPower solar panels are made with Copper Indium Gallium Selenide solar cells (CIGS), which are one of the three mainstream photovoltaic technologies in the market. The panels are backed with plastic and are able to be flexed.

System Advisor Model (SAM)

The System Advisor Model (SAM) is a program provided by the National Renewable Energy Laboratory. It is a program that creates performance predictions throughout the month using various renewable energy projects. SAM also allows specified inputs of angles, locations, cost of installation, cash incentives and many more to further increase the accuracy of predictions. Using the photovoltaic array project imbedded in the program, solar panel specifications were inputted into the program (i.e. power, angle, and tilt). The goal upon using SAM was to maximize the energy harvest from solar panels at any given day and location through the alteration of the optimum angle of tilt provided by the program. For future and ongoing solar panel analysis and predictions, SAM is a useful tool that is capable of optimizing the system as a whole.

<u>Design</u>

Mounting Assembly Design

There were many variables to consider when designing the mounting assembly for solar panels, which might include weather, time and location. A tracking system may solve these issues by adjusting the angle for optimal results regardless of the conditions. From the previous year, a solar tracking system has been implemented as a standalone project, detached from the 1/12 scale track. With further consultation from advisors and deliberation from the sub team, an adjustable mounting assembly was favored over a tracking system because of the potential maintenance and installation costs. An adjustable mounting assembly will allow for potential calculations from SAM to be used in order to find the optimum angle without additional power to run the tracking system.

With the scaled solar team's objectives in mind, a dual three-bar mechanism was chosen for the adjustable mounting assembly design. The simplistic design required minimum fabrication while providing a sturdy base to support the panels. Shown in Figure 3-20, the mounting mechanism can be adjusted through the pre-existing holes with the use of bolts and nuts. Another advantage of this design was the availability of in-house materials needed for the fabrication of the mechanism. Slotted aluminum pieces used for the top and bottom rails were cut to 10 inches in length. ¼-inch bolts and nuts were used in conjunction with washers to hold the assembly at a desired angle.

Figure 3- 20: Completed mounting assembly.

Base Mount

The base of the mounting assembly will house both three-bar mechanisms as well as rigidly attach the whole assembly to the available one-inch steel posts. The base plate consisted of five components: three lightweight aluminum plates and a sturdy steel base welded onto a piece of rectangular tubing. With the aluminum sheets provided in-house, the pieces were cut using the table saw with dimensions shown in the Appendix. An aluminum base was formed by TIG welding the three aluminum plates into an "H" design shown in Figure 3-21. Once the base was made, ¼ inch holes were drilled in order to attach the steel base and the three-bar mechanisms.

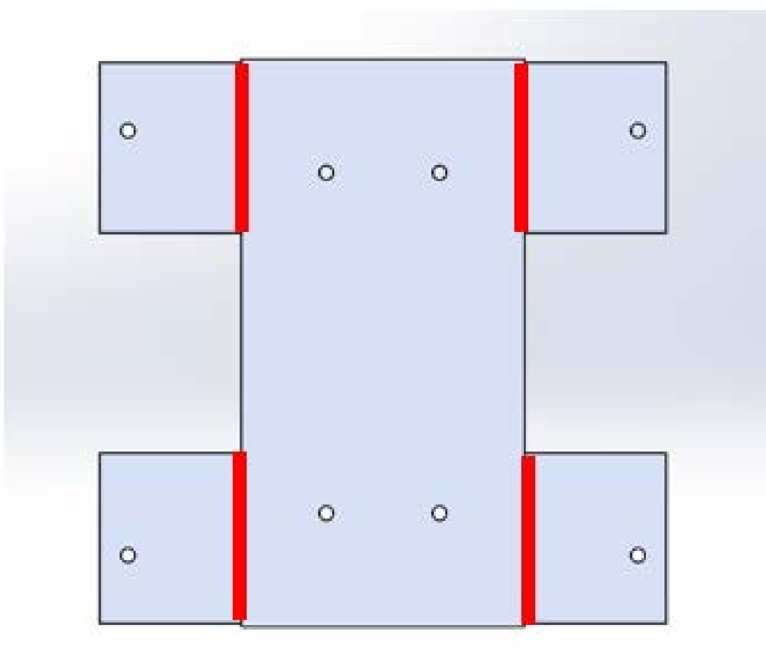


Figure 3- 21: TIG welded locations for the combination of aluminum plates.

Due to the ductile nature of aluminum, the TIG welded aluminum plate was reinforced with a steel plate. Since aluminum and steel cannot be welded together, ¼ inch bolts were used to secure the steel plate onto the aluminum plate. Before securing both plates together, the 1.2 inch by 1.2 inch steel rectangular tubing was MIG welded to the steel plate. With both plates completely welded, ¼ inch bolts were used to attach both plates together. Two ⅜ inch holes were drilled on either side of the tubing to ensure stability upon attaching the mounting assembly to the steel posts. The tubing can be easily fitted on the one-inch steel track posts using bolts. The additional four ¼ inch drilled holes were used to attach both three bar mechanisms onto the base. Figure 3-22 shows the complete base mount assembly without the bolts included.

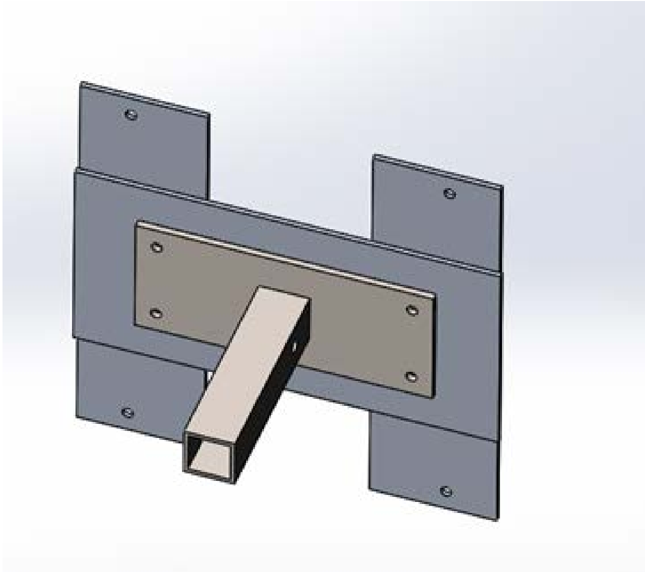


Figure 3- 22: The completed base mount are able to support the weight of the solar panels and frames.

Solar Panel Frames

Due to the unique dimensions of the donated solar panels, a lightweight custom frame design was needed to be attached on top of the mounting assembly. The frame was broken down into two five feet sections made from Pinewood 2x4's acquired from Spartan Superway. The base of the frame consisted of two five feet long one inch by one inch wooden rectangular beams fabricated from the 2x4's. Rabbet joints were cut on both ends of the one-inch wooden beams. The joint allowed for 12.38 inch in length wooden support to be fixed on either side with wood glue. These four components made a sturdy base for the ribs and the rails to be attached. The ribs were cut from painted wooden panels found from Spartan Superway on the band saw with a radius of 2 feet. The purpose of the ribs was to provide a curved base for the panels to form on. Rabbet joints were cut on the ends of the ribs using the table saw in order for easy installation to the frame base. Lastly, the wooden rails were cut to size as well as the groove was cut on the table saw. The table saw blade width easily created a groove for which the panels could ride along. The dimensions of the ribs, rails, and the frame base are found in the Appendix. A prototype was made in the early stages to test the design flaws.

Initially, both rails on either side were stationary, attached using brad nails. The panels were then pushed through the rails along a groove that was cut from the table saw. After testing, a few flaws of the design surfaced. First, the rails made it difficult for the panels to be pushed in. Secondly, the brad nails did not offer enough holding strength and resulted in the rails becoming loose. The design was improved through the implementation of a detachable rail as well as widening the rail for more room to attach with screws. Screws and wood glue was used to secure the stationary rail. With a detachable rail, the panels could be aligned first before attaching the second rail to secure the panels onto the frame. Figure 3-23 shows the rigid frame without the detachable rail.

Figure 3- 23: Bare frame setup without the detachable rail.

Using three ⅜ inch bolts evenly spaced on the detachable rail, this feature provided a clamping mechanism within the frame. Since the rail can be detached, the solar panel can be easily lined up along the groove and the rail can be attached to the side of the frame. A top piece on the detachable rail was glued together so the extra material can contact the panel and push the panel onto the curved frame. A wooden support cut from the table saw was used to join both five feet frames together to make a single 10 feet frame. Figure 3-24 shows a diagram of the simple design with two five feet frames. Through future use at Maker's Faire, a few issues caused the frame integrity to decrease. First, the strain on the middle support through improper lifting of the frame caused the grooves on the stationary rails to break around the middle section. This can be remedied by allowing more material on the top of the groove for a sturdier rail. Secondly, due to the lightweight nature of the frame, the middle section is subjected to more strain. A compromise can be reached by adding more material on the weaker section of the frame.

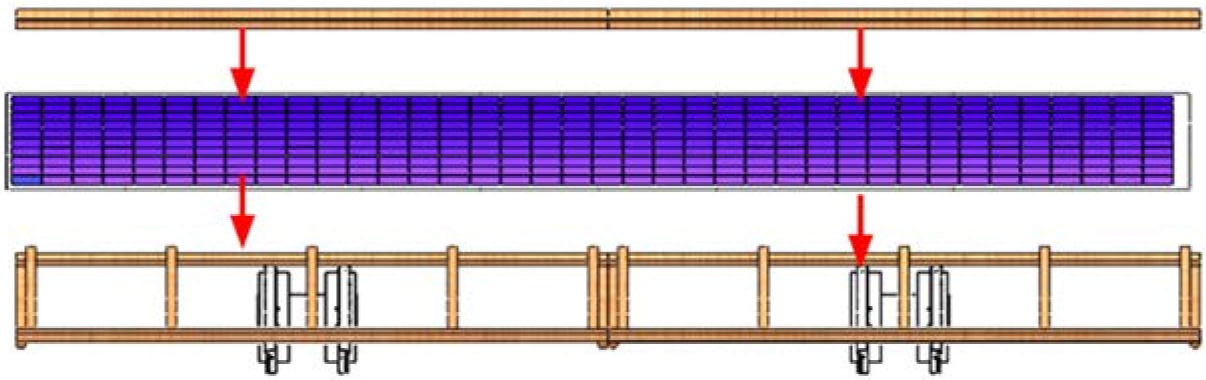


Figure 3- 24: Installation of frame, solar panels and detachable rail.

Electrical Schematic

The electrical configuration for the solar panels was extremely crucial in the design phase. In order to show full functionality of the solar panels, the panels would be required to power something of significance. However, since both wayside and electrical teams were removed from 1/12 model, on track charging/powering was considered unrealistic due to time constraints and low DC power. Many options were considered, such as powering LEDs or creating a display using the power from the panels. However, to show maximum functionality of the on track panels, the 1/12 solar team chose to power battery chargers which could charge the batteries used for the bogies. The battery charger that the electrical schematic would be designed around was the iMAX B6AC V2 Dual Power battery charger. This battery charger was chosen because it had the ability to accept DC power, negating the need for a DC/AC inverter. Inverters are crucial in some electrical schematics, but draw a significant amount of current resulting in a drop in the efficiency of the inlet power source. A charge controller was considered. However, through the guidance of Mr. Swenson, it was concluded that charge controllers were only predominantly used to charge larger batteries and not DC loads. The iMAX battery charger was later concluded to be a charge controller itself. To power the battery chargers, the voltage of the SoloPower panels need to be drop down from 21 V to 11-18 V. Through research, a DC-DC buck converter was considered to be the most suitable component to lower the voltage of the solar panels. With further research, the use of a diode was highly recommended, preventing the solar panels from drawing power from the battery or battery charger when insufficient power was produced by the solar panel.

<u>Analysis/Validation/Testing</u>

Using Solidworks, a model of the three-bar mounting assembly was created and estimated angles were recorded on Excel by varying the placements of the smallest bar. In Figure 3-25, the placements of the top and bottom slots are shown along with the angle produced. The angles achieved from the slotted three-bar mechanism can reach the angles needed for this semester’s goals. However, having a rail system without slots can increase the angle resolution. The current three-bar mechanism and the labeled slots that correlate to the graph in Figure 3-25 are shown in the Appendix. For more specific angles pertaining to this assembly, refer to the table shown in the Appendix as well.

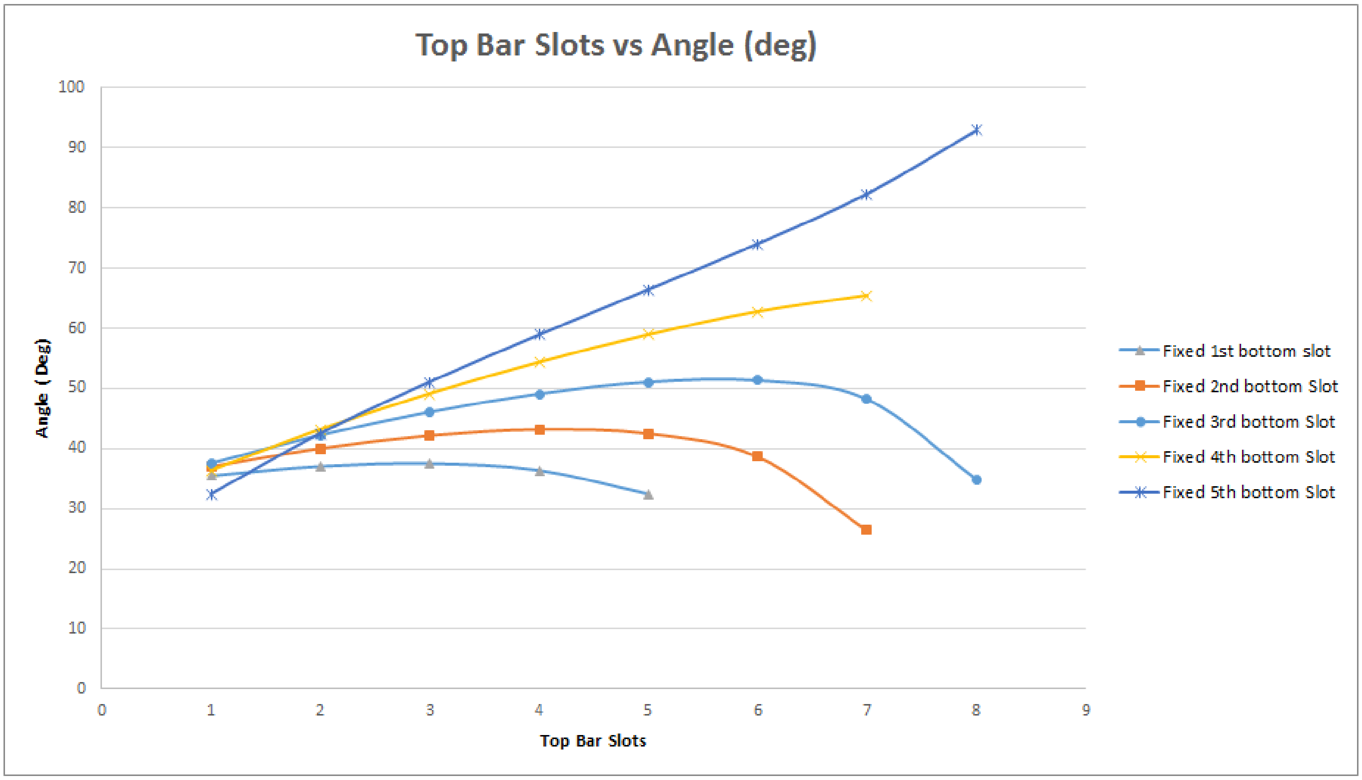


Figure 3- 25: Line graph gives estimations of possible angles the three bar system can achieved.

Figure 3-26 shows different angle results as the months vary. The program SAM was used with specifications of the SoloPower solar panels inputted within the program. The maximum power of 70 W as well as the location of San Jose and the angle specification gave the parameters for the simulation. The use of SAM further proves the significance of an adjustable angle mounting assembly. As shown in Figure 3-26, different months yield different results. With the data from different angles, an optimal tilt angle can be chosen for a specific month.

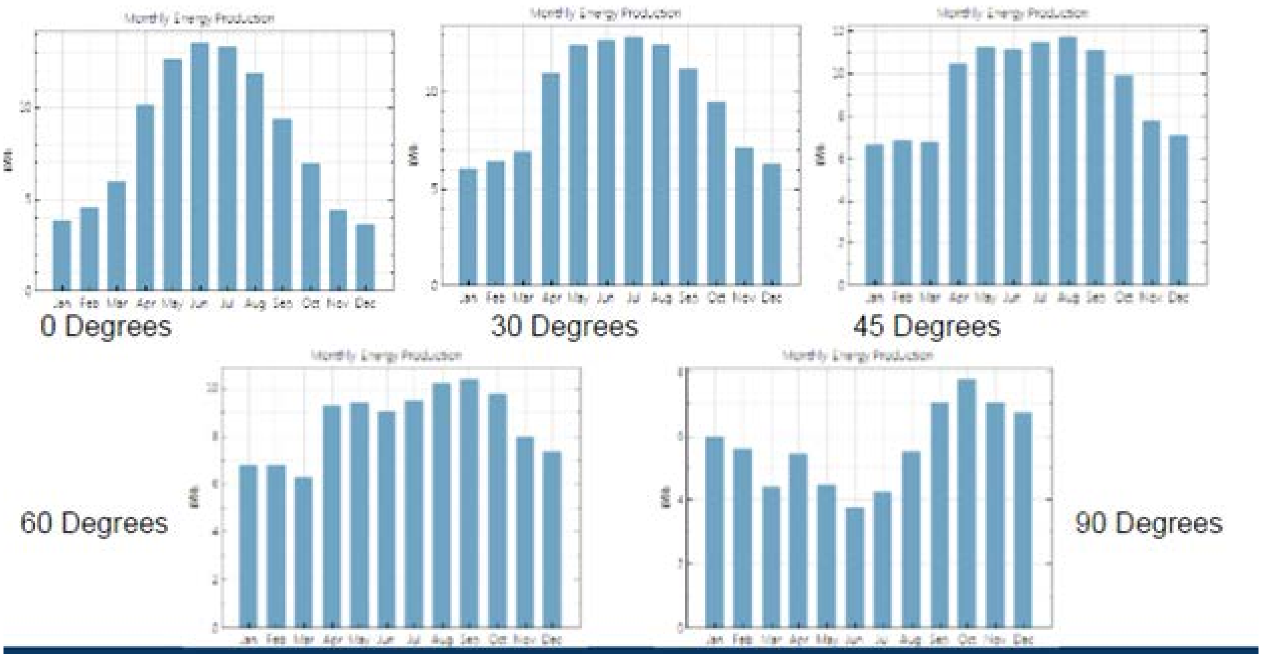


Figure 3- 26: Energy production(kwh) model throughout the months according to tilt.

<u>Outcomes</u>

Throughout the year, the design plan of the 1/12 scale solar team has been constantly evolving. The initial plan was to implement the 2014-2015 solar team design of the solar tracker design and improve upon it. However, this initial concept was abandoned when solar tracker complications involving often failures and malfunctions, programming, maintenance, low lifetime, and a high investment cost arose upon research and communication with advisors. Though many modifications were made throughout the 2015-2016 year, these modifications allow many options and ideas to be explored that else wise would not be researched. The excess of research allowed the designers of the 1/12 scale solar team to create a greater final product; this final product can be seen in Figure 3-27.

Figure 3- 27: Complete solar panel assembly implemented on 1/12 scale model.

The 1/12 scale solar team has designed a fully functional and on-track solar panel system that will power the 1/12 model and that accurately represents a full-scale Spartan Superway model. Using thin film SoloPower panels provided by Spartan Superway advisor and sponsor Ron Swenson, an adjustable mount and curved frame were created. The adjustable mount allows the angle of the solar panels to be adjusted at any time to better suit the time and location of the 1/12 model. The angle of the panel can drastically alter the power the solar panel can generate as seen in Figure 3-26. With the ability to range from 0-90 degrees, the solar panel assembly will be able to closely match any angle provided by SAM to produce optimal power for any given day or hour. Adjustable mounts also provide a simpler and more cost effective design when compared to solar trackers, yet offer similar advantages of solar trackers in comparison to fixed solar mounts. Adjustable mounts were able to offer a simple and easy to replicate design that requires little to no maintenance. Advisors Anuradha Munshi, Ron Swenson, and Dr. Furman, who have all had past experience with solar panels recommended a curved solar panel frame to increase efficiency and appearance. The 1/12 scale solar team was able to produce a 2 feet radius convex frame that promotes the recommendation from advisors Anuradha Munshi, Ron Swenson, Dr. Mokri and Dr. Furman.

With the use of two 11.5” x 60” SoloPower panels, a solar panel assembly was created to produce enough power to successfully power two iMAX B6AC V2 Battery Chargers. The battery chargers could be operated by the generated power from the SoloPower solar panels and transmitting the current to a diode. The current then flows through a DC-DC converter to lower the voltage to match that of the allowable DC voltage for the iMAX B6AC V2 Battery Charger. The electrical schematic can be seen in the Figure 3-28.

Figure 3- 28: Electrical schematic for 1/12 Solar Team.

The iMAX battery charger will then be able Ni-MH batteries that are used to power the 1/12 model bogies. The specs of the SoloPower Panel, iMAX battery charger, and Ni-MH batteries can be seen in Table 3-5.

Table 3- 5: 1/12 Solar Team Power technical specifications including current, voltage, and power. Bogie measurements provided by 1/12 scale team.

1/12 Solar Team Power Calculations			
	SoloPower Panel Specs	**iMax B6AC V2 Battery Charger**	**Ni-MH Bogie Batteries**
Current (Amps)	*3.3*	*5 maximum*	*2.2*
Voltage (Volts)	*21*	*11-18*	*7.2 V*
Power (Watts)	*69.3*	*5-90*	*15.8*

These calculations prove that the SoloPower can easily power the iMAX battery charger which will power the bogie batteries. When testing the electrical schematic, the 1/12 solar team concluded that these power calculations were accurate and could easily power the Ni-MH battery at a recommend 2 A and 7.2 V. While conducting testing, an average reading of 18 V and 1.3 A was recorded for the solar panel. Because of this reading, a splitter will be added to the iMAX battery charger outlet which will allow the battery charger to charge two Ni-MH batteries at 2 A and 7.2 V simultaneously.

Discussion

The initial goal was to create a functional and on-track solar system that could completely power the 1/12 model. Additionally, the team sought to create a lightweight and cost-effective model that could better represent the Spartan Superway and could easily be reassembled and disassembled at any moment. While all initial design specs were mostly fulfilled, one spec was not accomplished. Providing full power to the 1/12 model was a goal that we were unable to accomplish. This setback was due to the transition of the wayside and electrical team to focus more heavily on the ¼ Spartan Superway model. The removal of wayside on 1/12 Superway track signified that bogies could no longer be powered on track with power generated from the SoloPower panels. However, an additional contributing factor was also the limiting amount of current the SoloPower panels could produce. For example, to power 5 bogies, the panels would need to produce a minimum of 11 A. In order to meet a current of 11 A, a total of four SoloPower would be required. Yet due to 11.5” x 60” SoloPower dimensions, it would be far-fetched to fit four panels on track. Due to a fully solar powered 1/12 model being out of reach without the use of an external DC power source or solar farm, the 1/12 solar team then created a design to power Ni-MH batteries on site.

With a total expense of $272.86 out of a projected $350 budget, the 1/12 solar team was able to create a cost effective design that was able to further drive the idea of solar as viable energy source. By creating on track and fully functional panels, observers were able to witness the full capability of solar panels that prior to the 2016 year could not see. Figure 3-29 shows a comparison of the final track way for both 2014-2015 and 2015-2016 Spartan Superway team and highlights the impact of solar panels.

Figure 3- 29: Spartan Superway 2014-2015(left) and 2015-2016(right) 1/12 model.

Being able to overcome the challenges that were met, the 1/12 solar team was allowed to explore and study various solar concepts. The SAM program allowed the 1/12 solar team to explore how the effects of location, system design, solar lifetime, wind speed, heat and electricity load has on energy production, cost and electricity savings.

While the 1/12 solar team was able to make several accomplishments throughout the 2015-2016 year, some design improvements could still be made. Since on track and functional solar panels have been added to the 1/12 Spartan Superway model, the next major step would be to implement the use of on track charging. On track charging could quickly be implemented to the current 1/12 model with the addition of wayside. Wayside could either be implemented on the whole track or charging stations could be created. If future Spartan Superway teams chose to implement wayside to the whole track, panels might need to be replaced/added or an external DC power source must be added. However, if future Spartan Superway teams choose to rely solely on the solar panels occupied, a minimum of two charging stations could be added. These charging stations would offer the same ability as current 2015-2016 electrical schematic, yet batteries would no longer need to be removed and bogies would be able to stay on track. Prior to focusing exclusively on the ¼ Spartan Superway model, the 2015-2016 wayside team created a design that can be implemented to the current 2015-2016 1/12 track, this design can be seen on Figure 3-30.

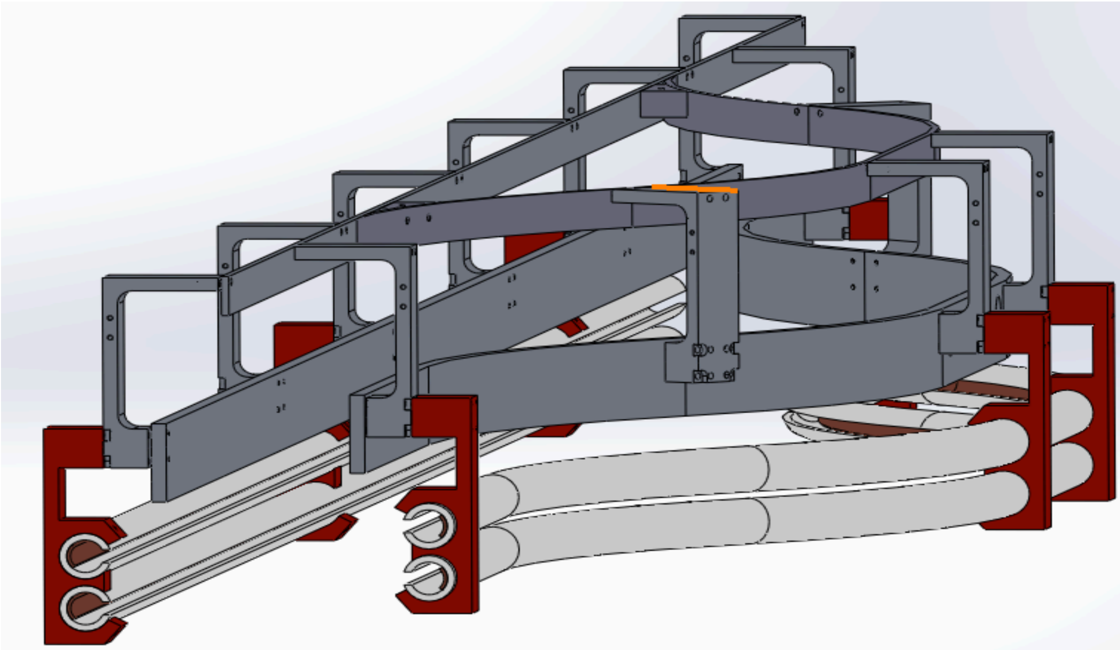


Figure 3- 30: Wayside design for 1/12 Solar Team.

The design of implementing charging stations to 1/12 model was studied by the 1/12 solar team. Due to time constraints, limited bogie space for a collector shoe, track conductivity, and the lack of completed of bogies, the 1/12 solar team felt that implementing wayside at a late stage in the 2015-2016 year may of produced a faulty and inferior design. Nonetheless, the 1/12 solar team felt comfortable that a wayside could be implemented to the 2015-2016 1/12 model.

Future Spartan Superway teams can slightly alter the design of the 1/12 solar frames. Current frames use one slit rail and one detachable rail as seen in Figure 3-24. These frames call for solar panels to be initially attached to the slit rail and the detachable rail is then added to hold the panel and create the curve provided by the ribs. However, the new design would call for 2 detachable rails. The dual detachable rail frame will provide the same ease of assembly and disassembly of the current frame, while allowing panels to better match the ribs attached and would also allow Superway teams to change/replace the ribs of the frame. The design of this frame can be seen in Figure 3-31, as seen in the figure, solar panels will initially be put on the frames and then detachable rails would then be attached to the frame.

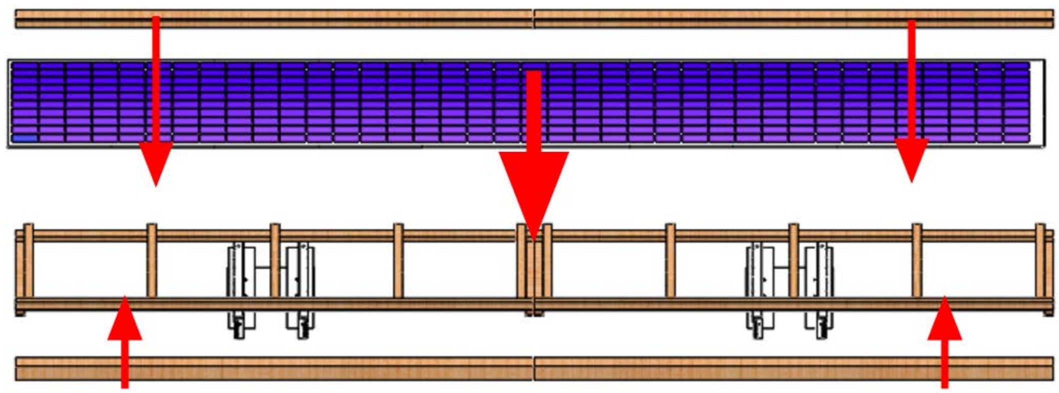


Figure 3- 31: 1/12 Solar Team future frames.

Conclusion and Recommendations

The goal of completing an intermediate scale guideway, bogie, suspension, and cabin were accomplished. Unfortunately, at Maker's Faire, the goal of moving the bogie and cabin along the guideway did not occur even though the groups worked very hard to make it move. The twelfth scale model was able to complete small cabins to travel along the track and demonstrate batteries being charged by solar power. The bogies would sometimes fall off the track at turns or from the switching mechanisms. The project received 3 Editor's Blue Ribbon Choices award at Maker's Faire. Some recommendations for future work is to stress the need for communication and sense of urgency. This would provide teams accurate knowledge at all times and working busily to finish work. Next year's team has a very good start based on the accomplishments of the 2015-2016 team. Future teams will also be able to access the works of this year's team in the archive drive provide by Professor Furman.

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Appendix A: Intermediate Scale

Intermediate Scale Guideway

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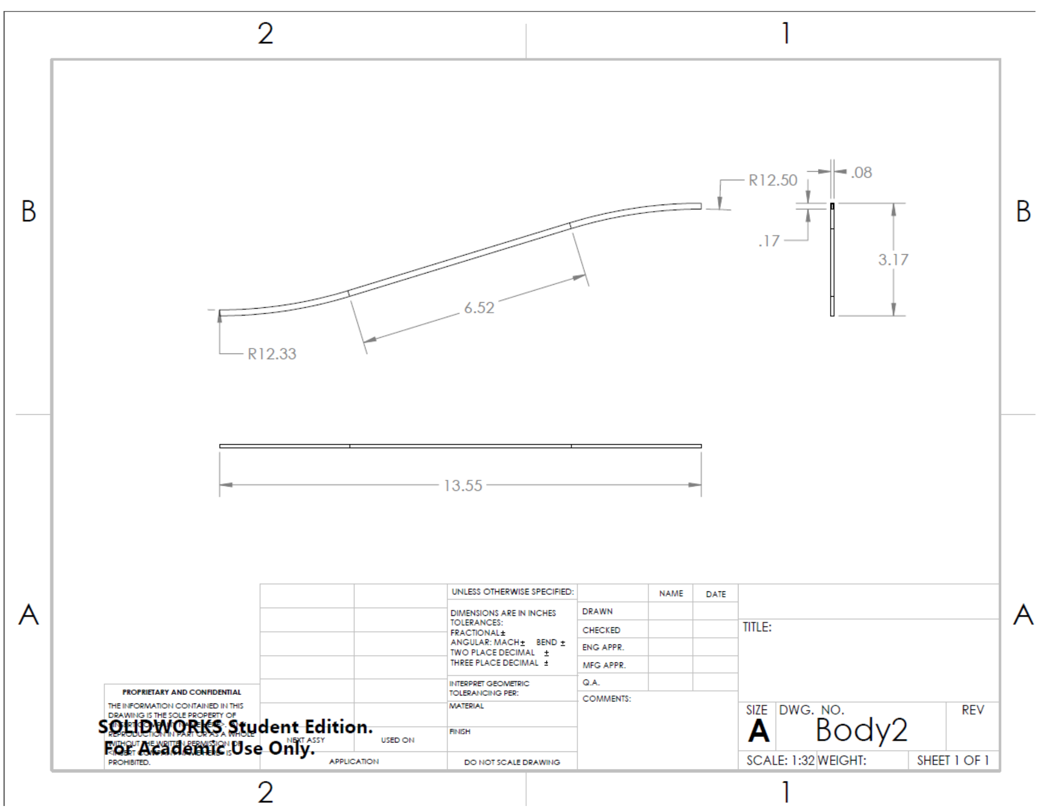
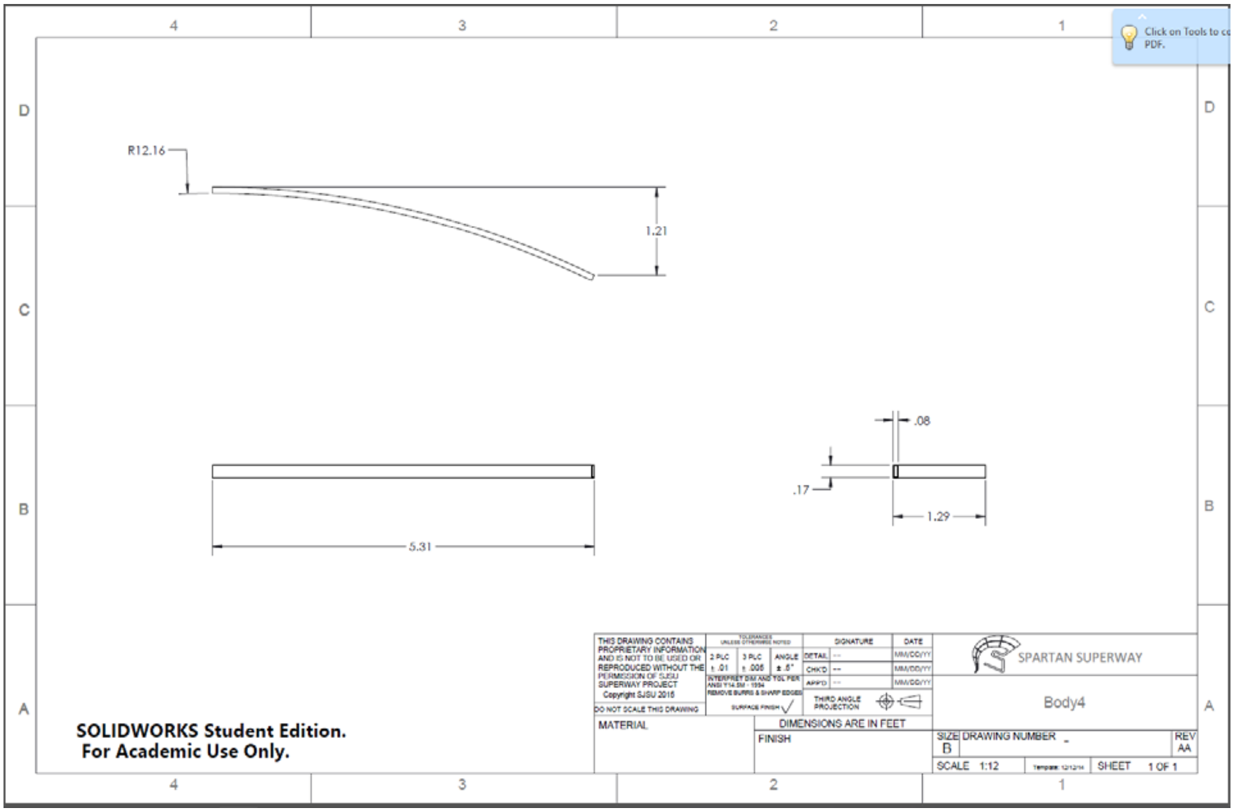
Drawings for curved sections

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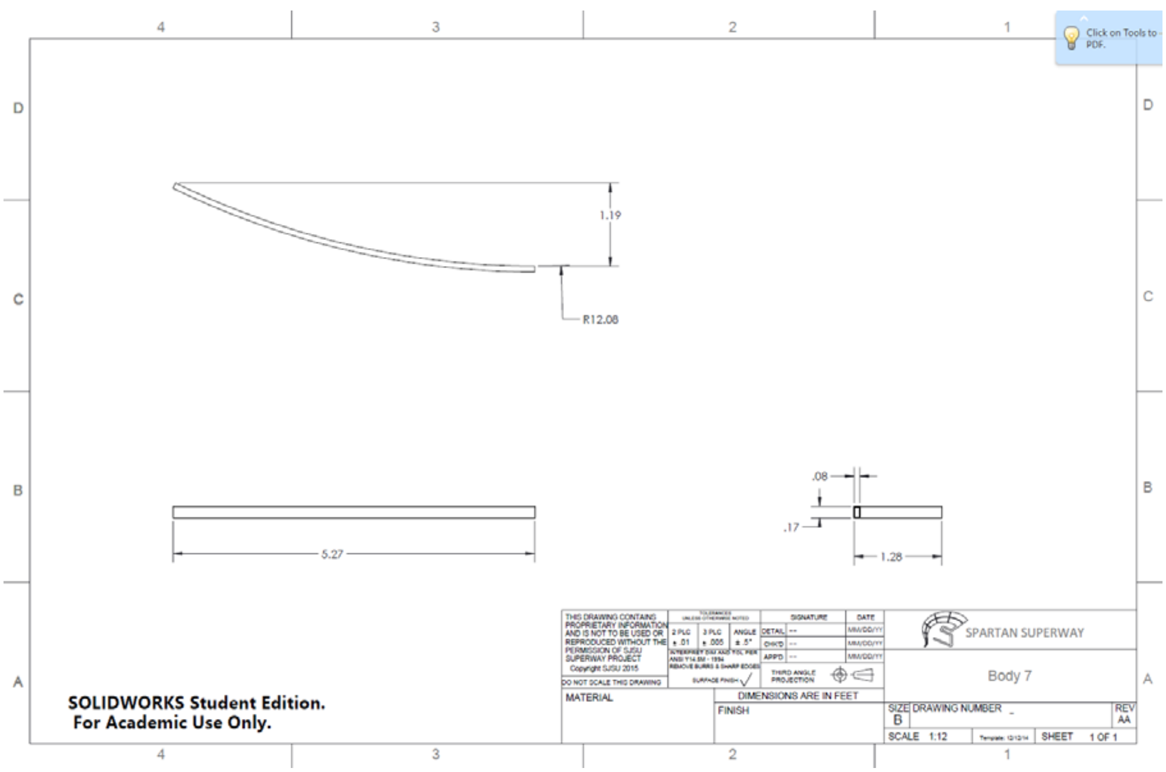
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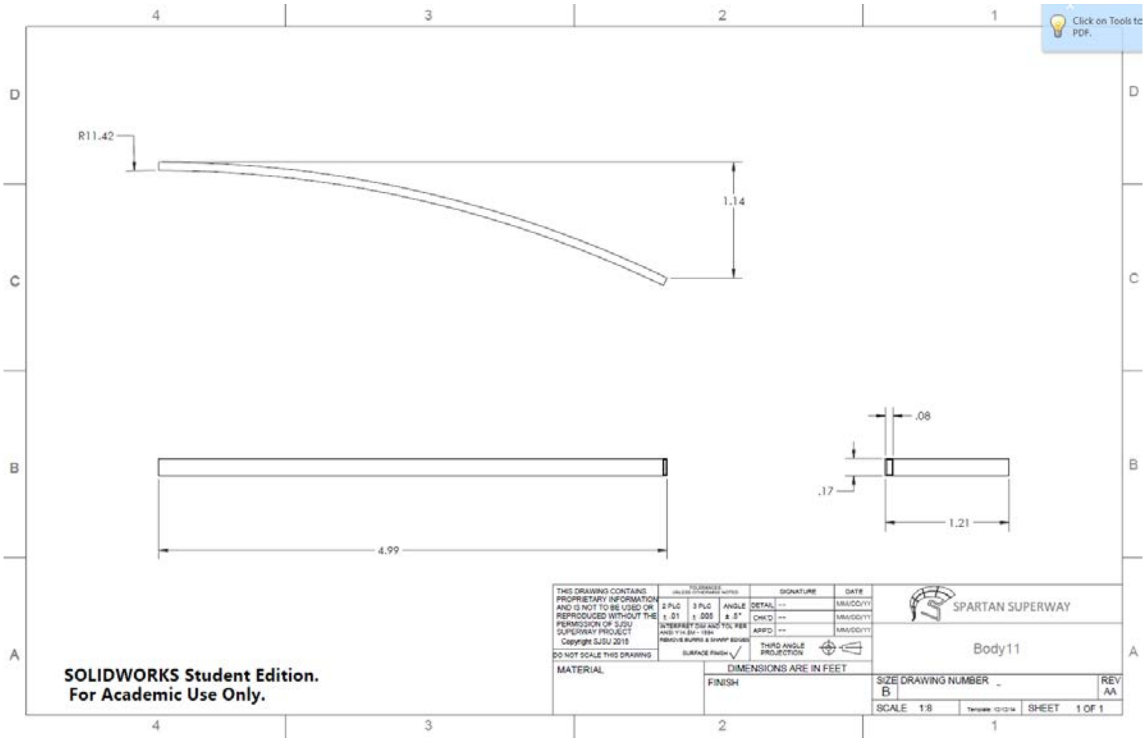
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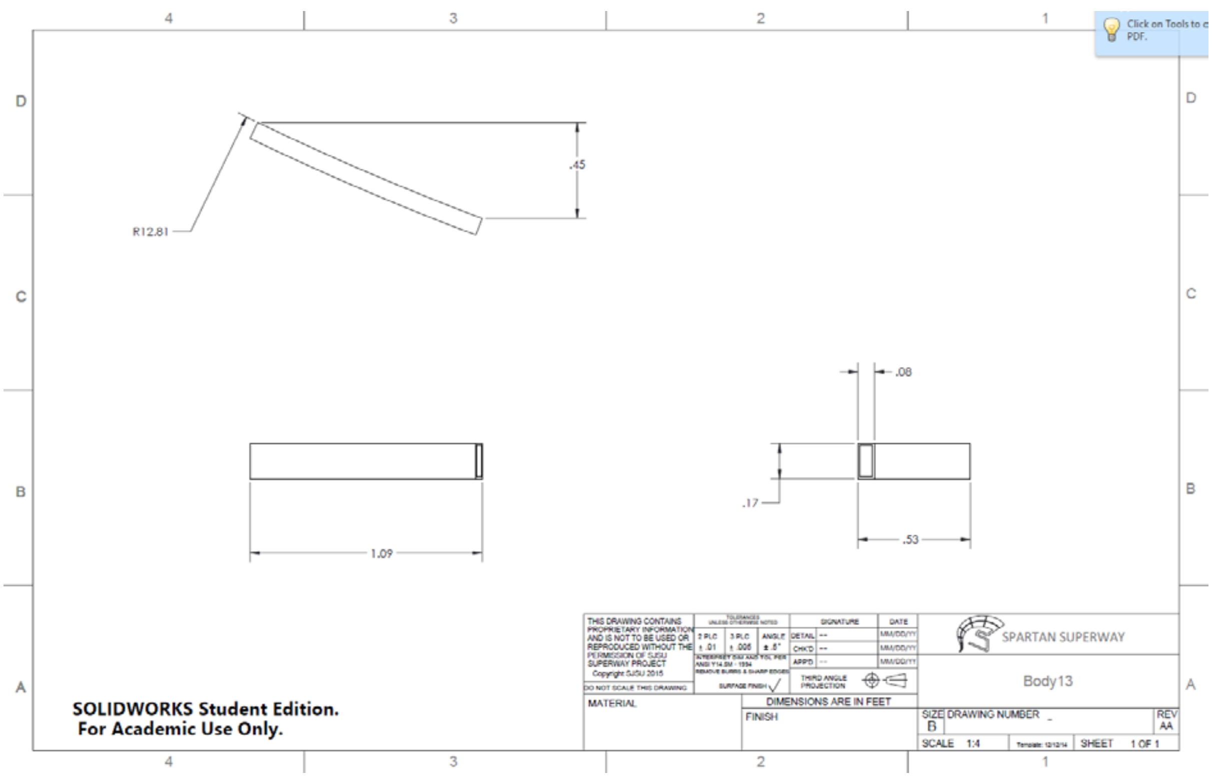
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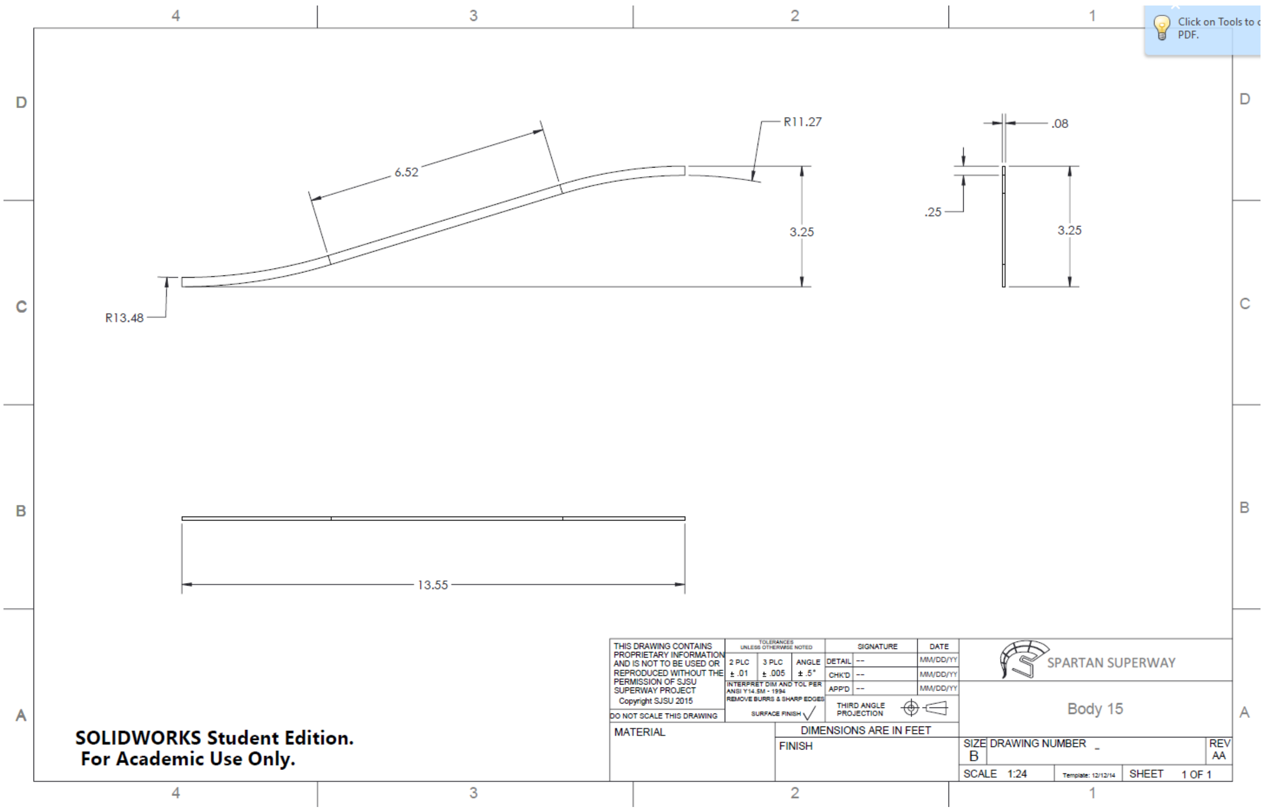
R11.27
6.52
.08
.25
3.25
3.25
R13.48
13.55
SPARTAN SUPERWAY
Body 15
DIMENSIONS ARE IN FEET
SIZE B
SCALE 1:24
SHEET 1 OF 1
REV AA
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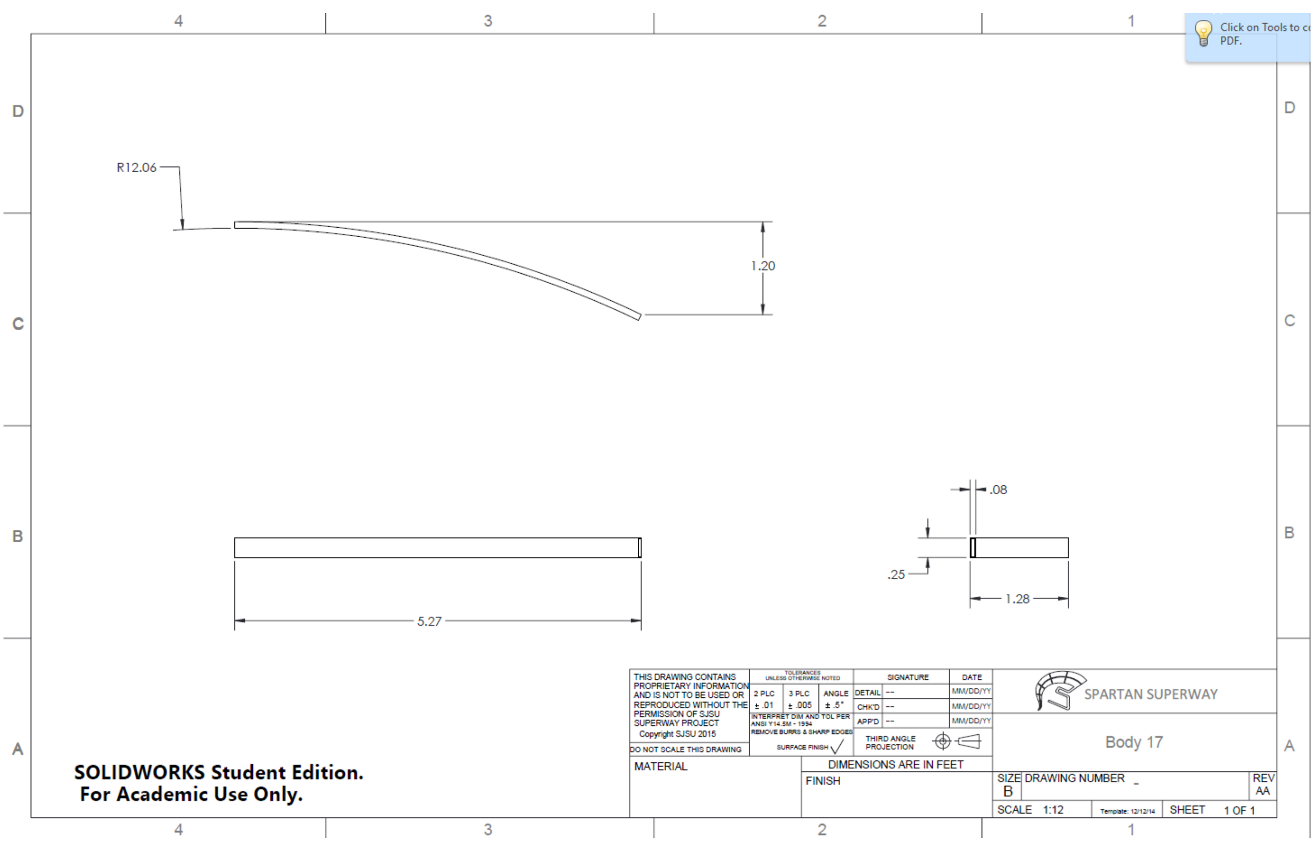
R12.06
1.20
.08
.25
1.28
5.27
SPARTAN SUPERWAY
Body 17
DIMENSIONS ARE IN FEET
SIZE B
SCALE 1:12
SHEET 1 OF 1
REV AA
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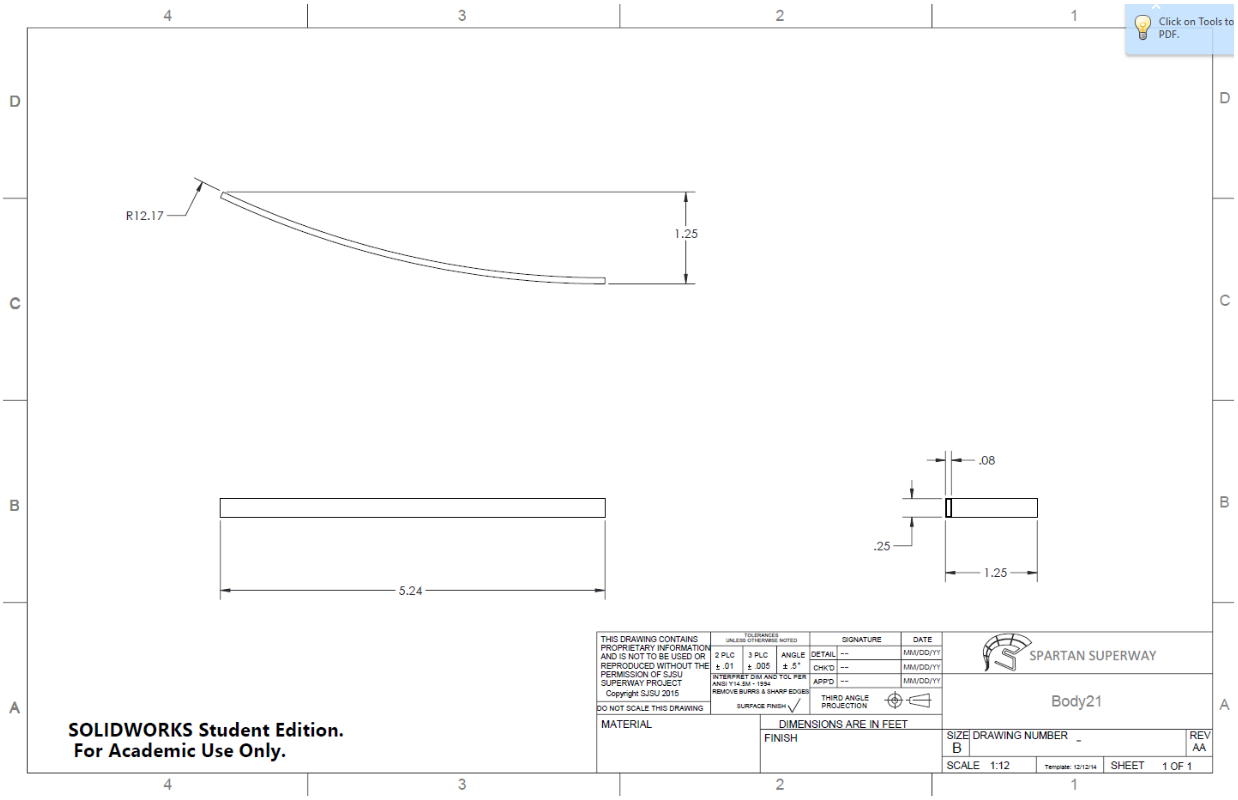
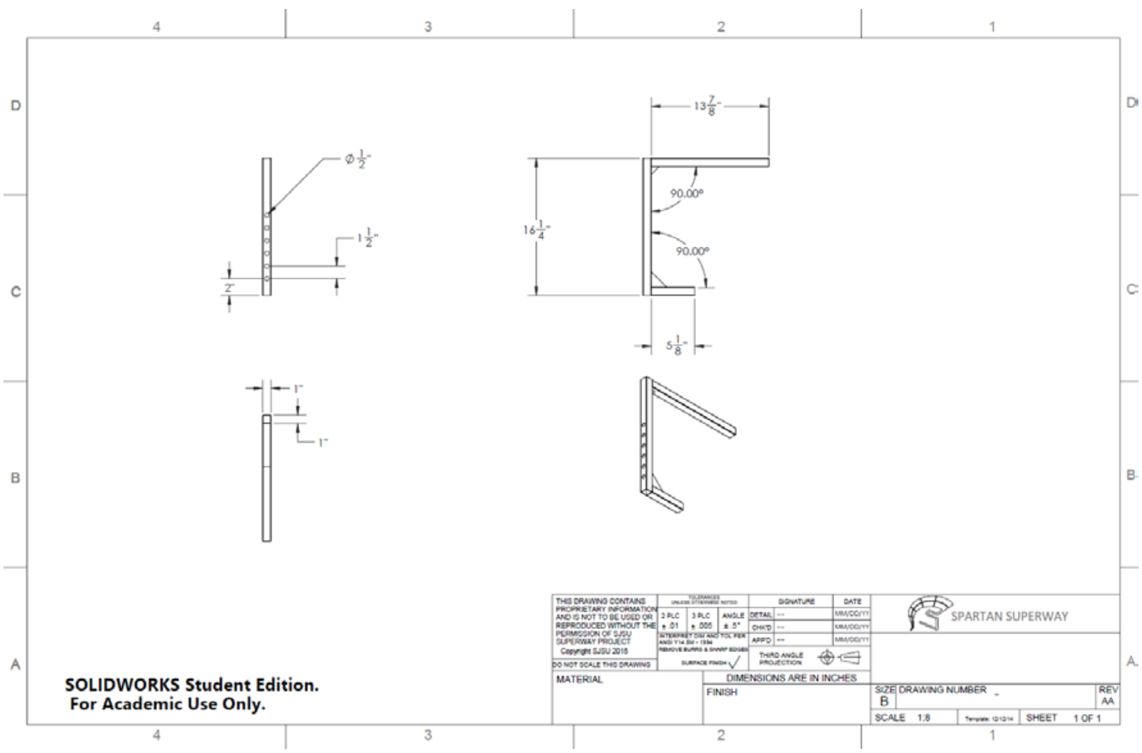
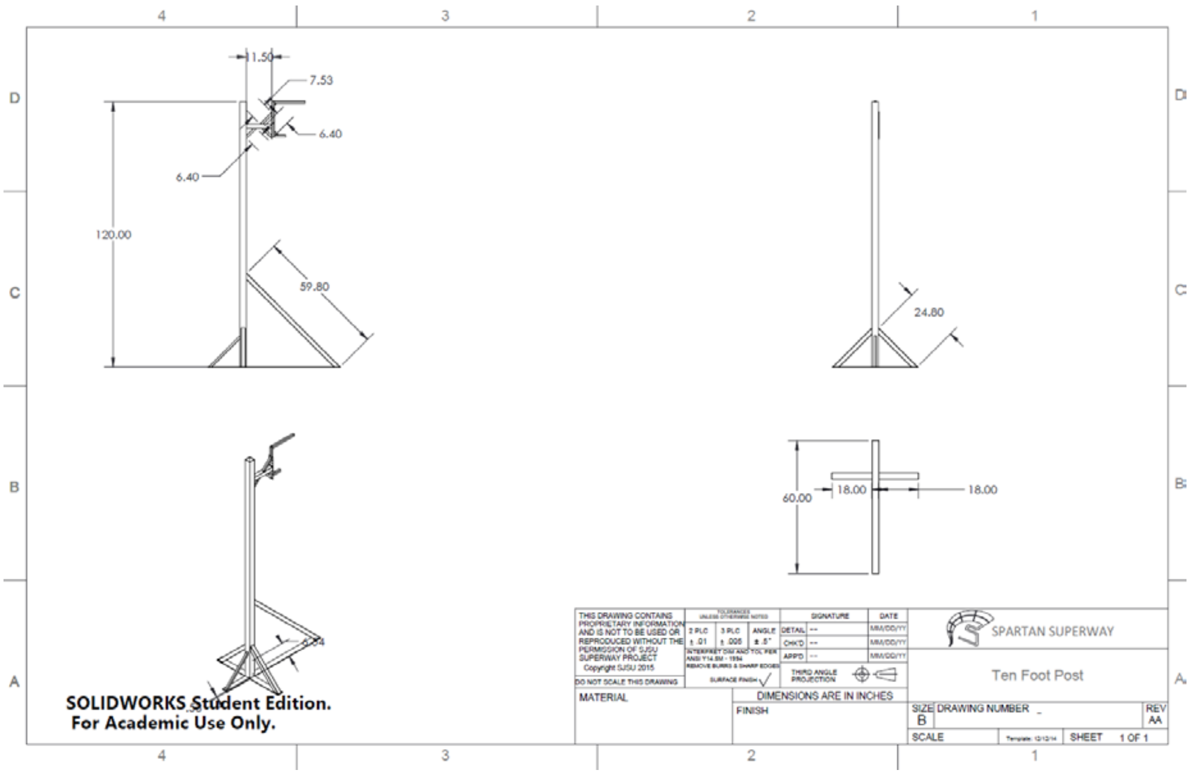


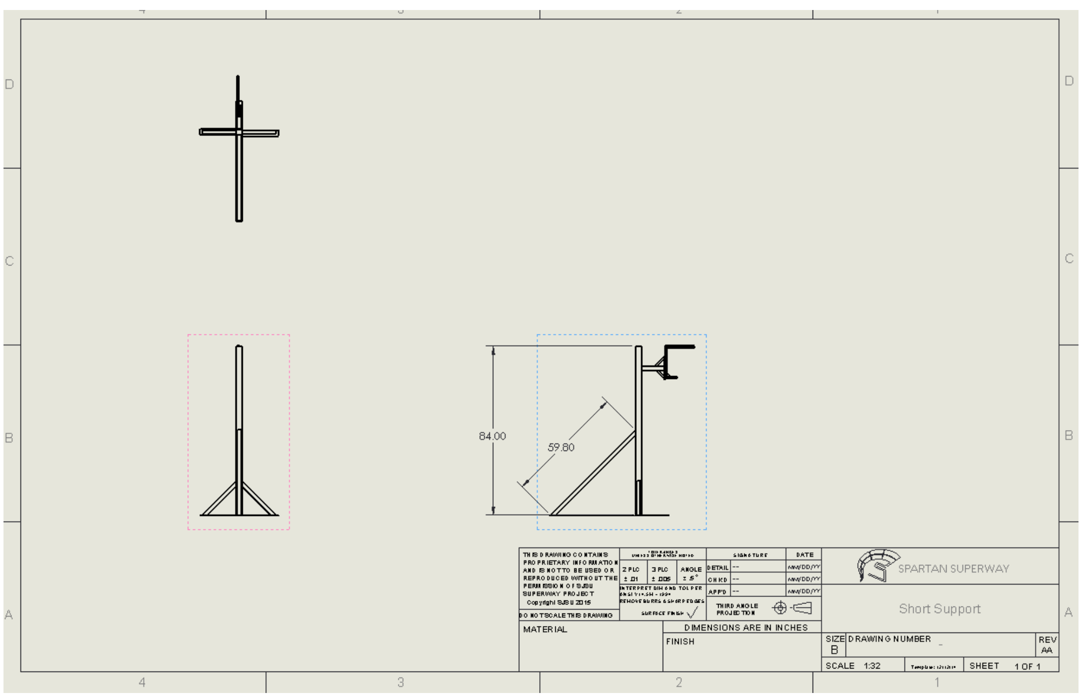
Drawings for Ribs



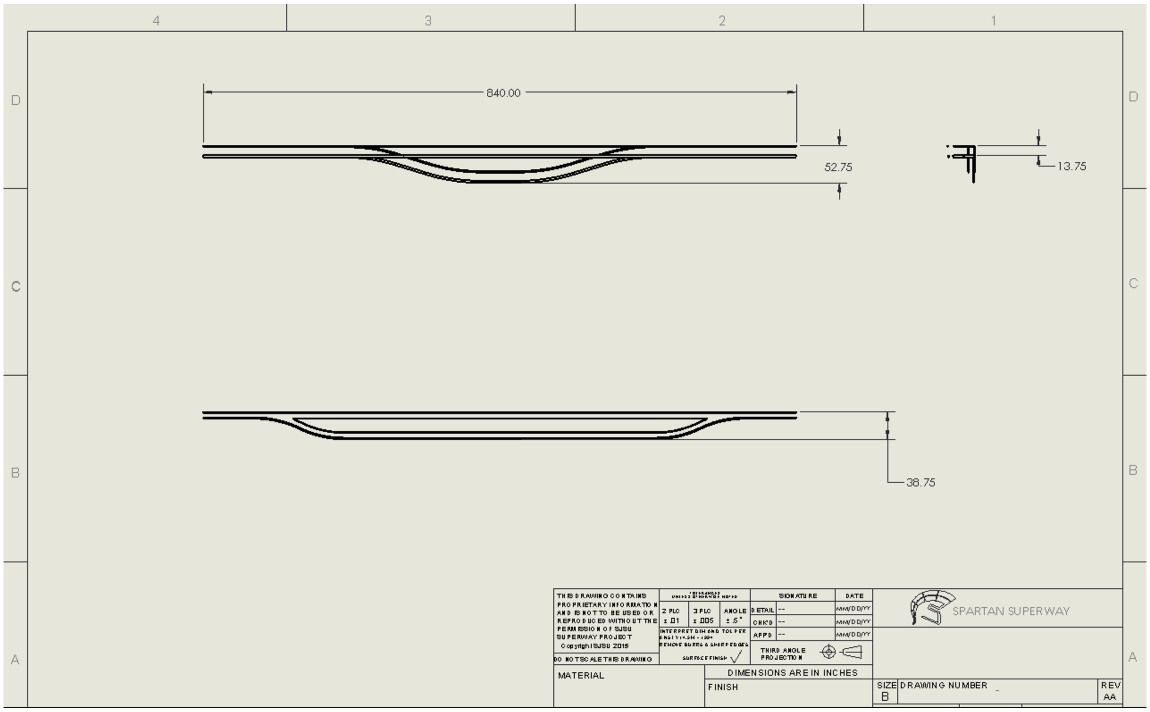
Drawing for Tall Support



Drawing for short support



Drawing Track

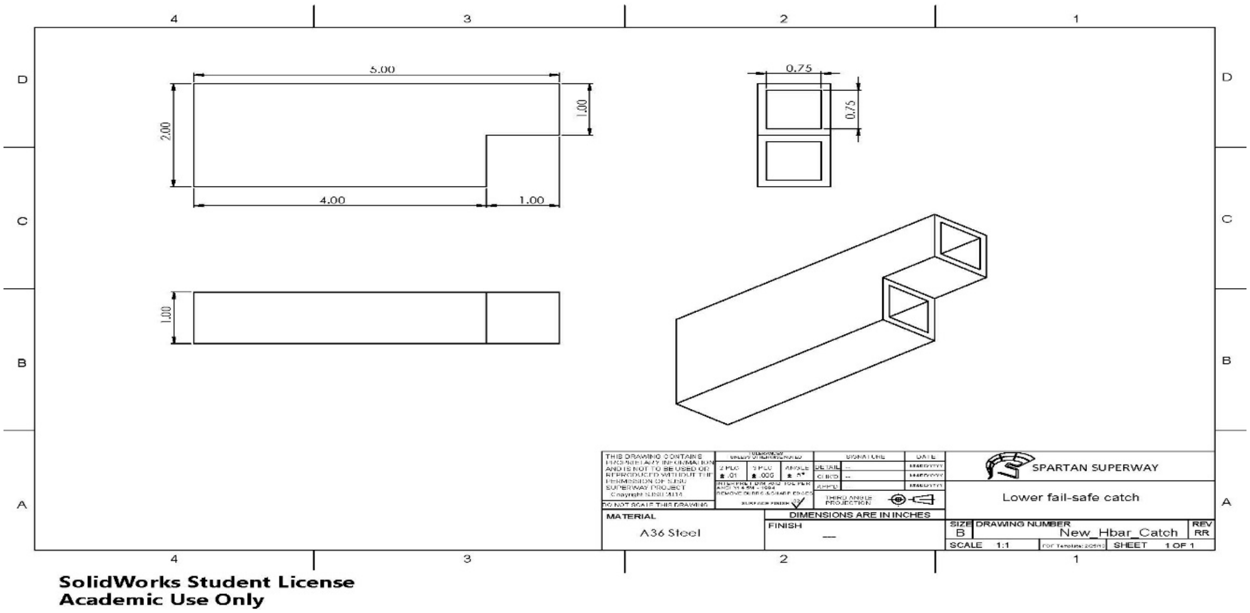


Intermediate Scale Bogie

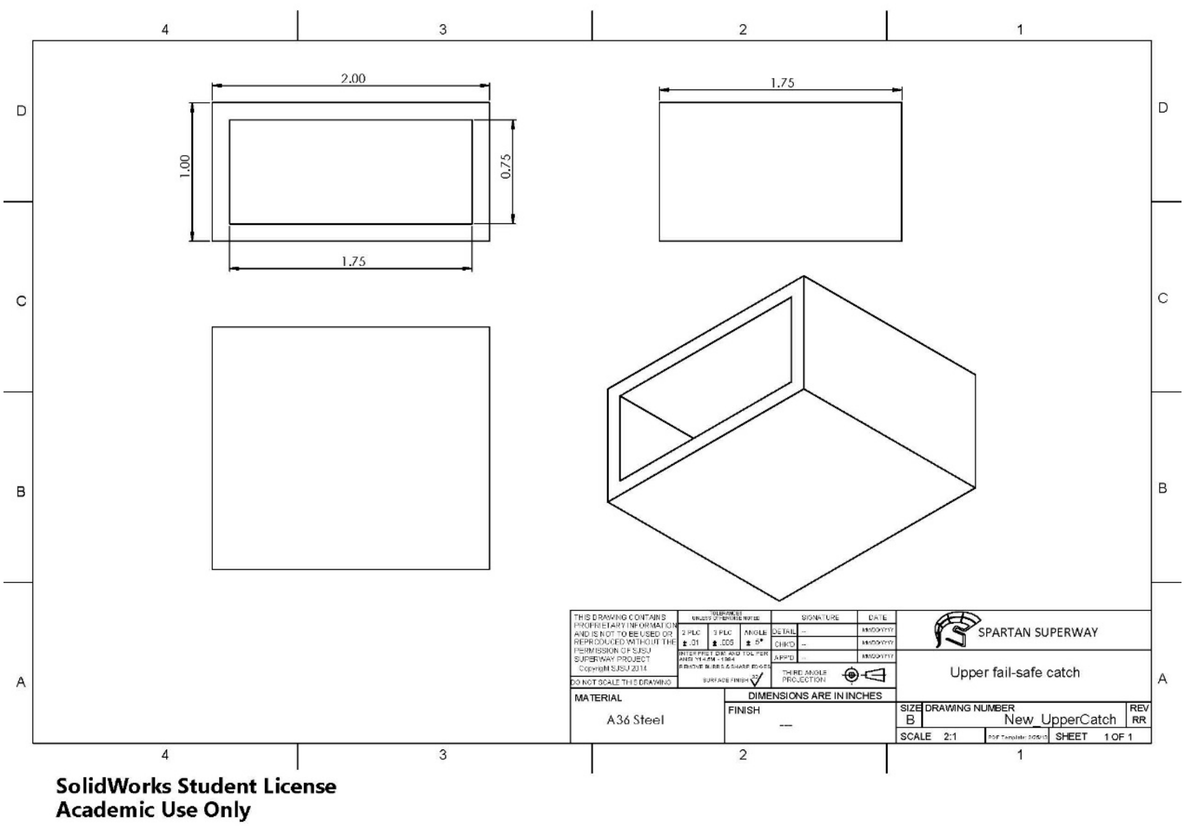
Acknowledgements

Special thanks to Techshop San Jose and College of Engineering for providing the team with free access to TechShop equipment and classes, allowing for the team to fabricate key components of the bogie and fail-safe mechanisms. Thank you to Matt Menezes for allowing the team to use his MIG welder. Thank you to David De Ocampo for helping load the bogie onto the guideway. Because of the weight of the entire bogie, this was not an easy task! Finally, thank you to Alejandro Valenzuela for helping weld parts of the bogie and provide feedback on fabrication.

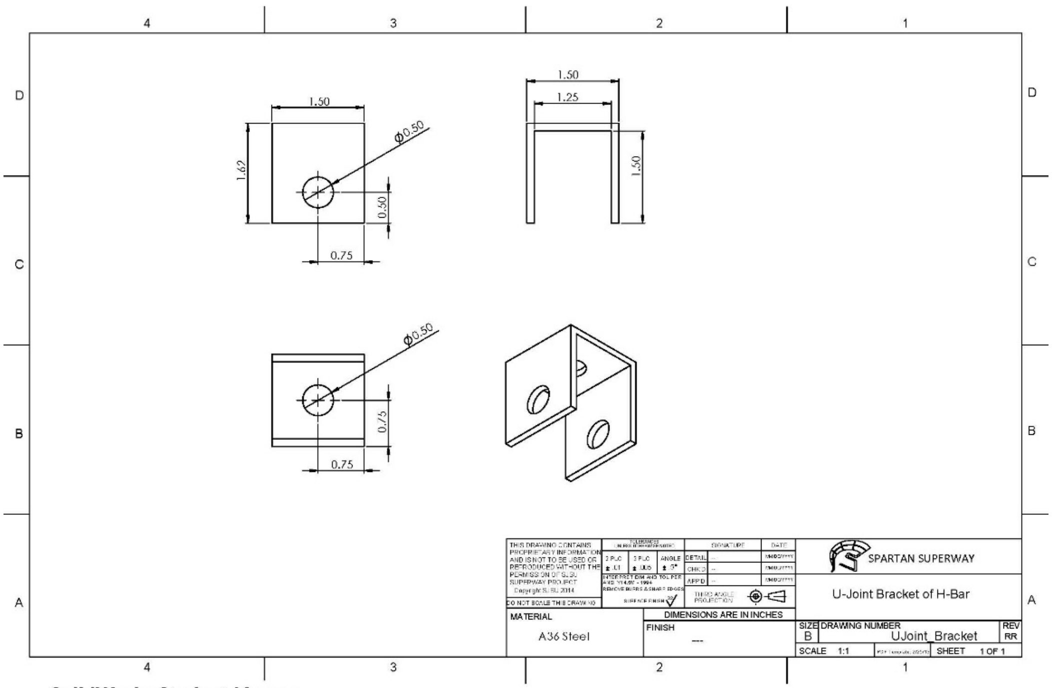
Lower Fail-Safe Catch



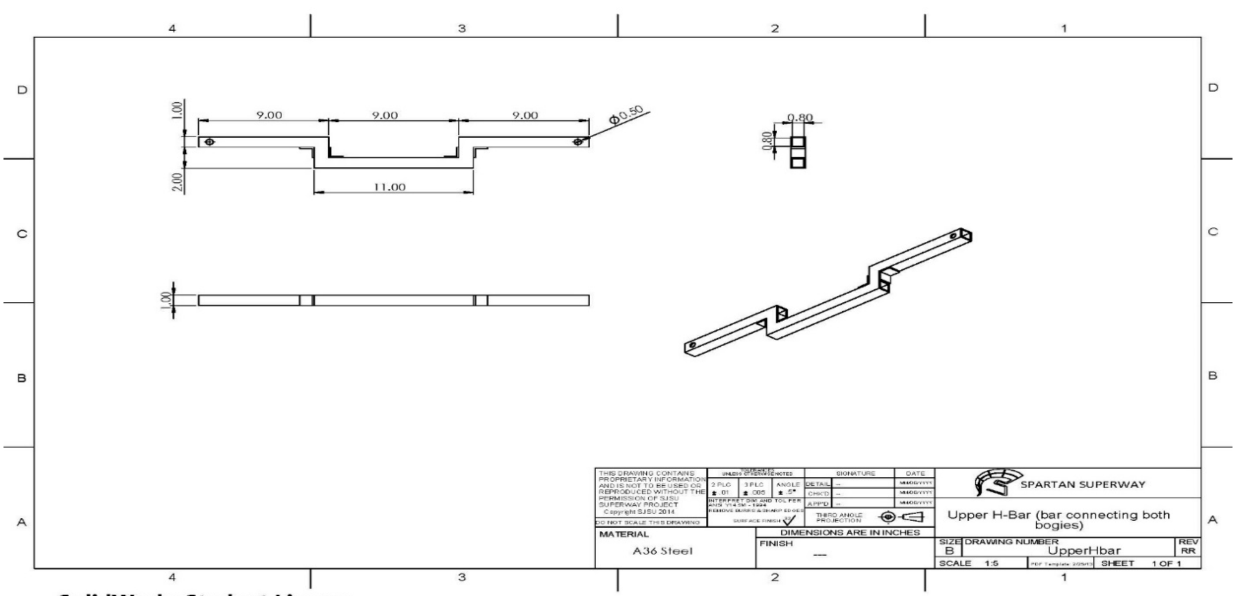
Upper Fail-Safe Catch



U-Joint Bracket for H-Bars



Upper H-Bar

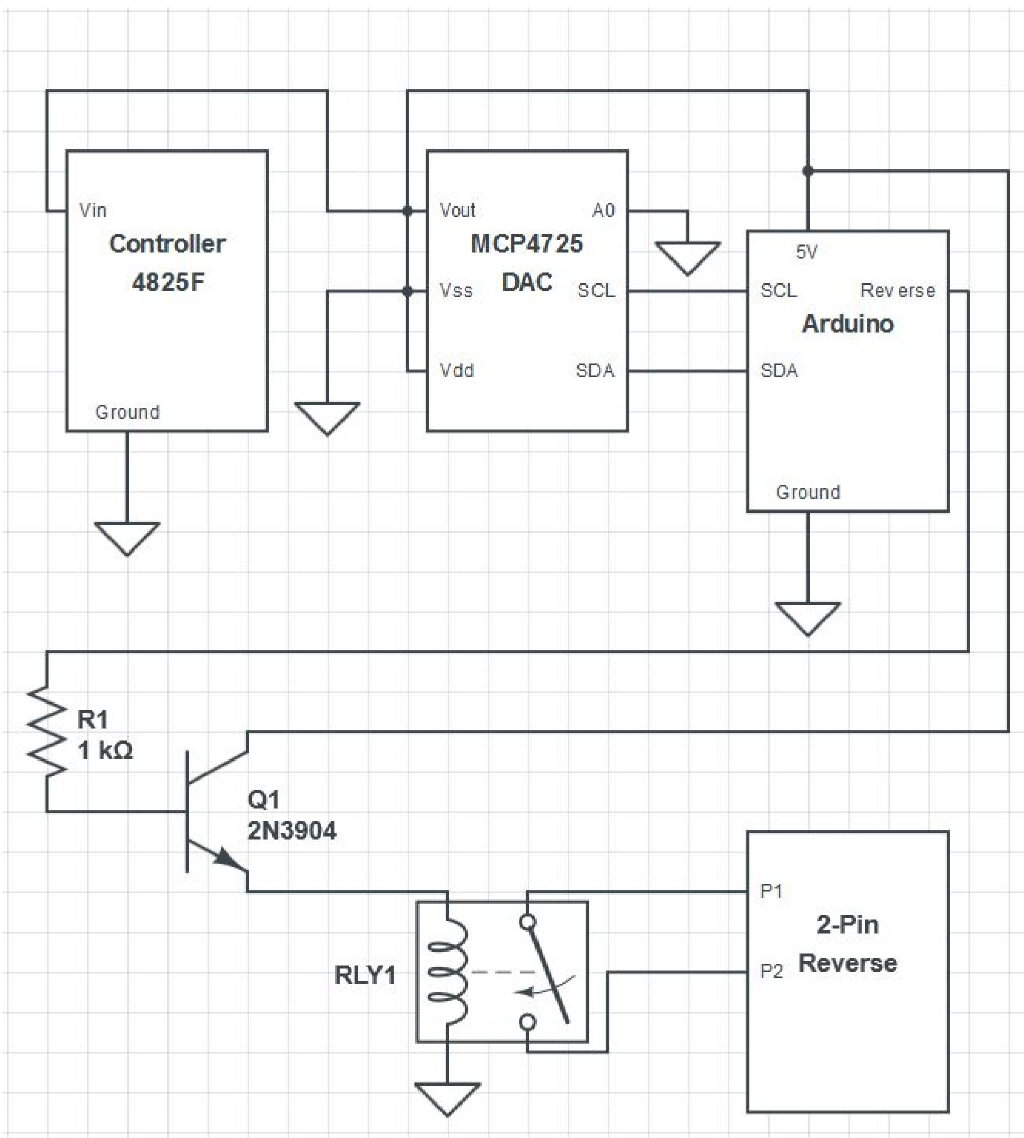


Intermediate Propulsion

Acknowledgement

First and foremost, thanks are given to the intermediate scale bogie team for stepping in to set up the propulsion requirements and design the motor mount. Thank you David De Ocampo for contacting Danny Ornellas to come help the team. Thank you Danny Ornellas for spending a lot of time troubleshooting the motor and controller and writing a basic code and wiring diagram for the team. Major thanks are given to Augustine Soucy and Scott Garfield for writing and troubleshooting the final propulsion code as well as integrating and re-writing steering code. Without all of their help, the bogie would not be moving at all. Thank you to Alex Valenzuela for providing extensive knowledge on hub motors.

Propulsion Circuit Diagram



Maker Faire Code

```
//Library Inclusions
#include <Wire.h>
#include <Adafruit_MCP4725.h>   //You must download this library in order for this code to
work at all

Adafruit_MCP4725 dac;

//Motor Speeds
#define Drive_OFF 0              // drive motor at 0 rpm
#define Drive_LOW 1200           // drive motor at 1200 rpm
#define Drive_MED 1600           // drive motor at 1600 rpm
#define Drive_HIGH 2000          // drive motor at 2000 rpm
#define Drive_MAX 3100           // drive motor at 3100 rpm

//Arduino Pins
#define dirPin                8  // stepper motor 1 direction input connected to pin 8
#define pulsePin              9  // stepper motor 1 pulse input connected to pin 9
#define dirPin2               10  // stepper motor 2 direction input connected to pin 10
#define pulsePin2             11  // stepper motor 2 pulse input connected to pin 11
#define driveDirectionPin     12  //
#define hallPin 18              // the number of the hall effect sensor pin
#define ledPin 13               // the number of the LED pin
#define switchPin 19            // the number of the switch pin

//Program Constants
#define delayTime             50  // delay time 50 ms for steps
#define stepsPerRevolution   7200  // number of steps to make full revolution
#define NUM_STEPS            900  // number of steps to make desired rotation
#define PULSE_DELAY_MS       600  // delay 0.6 microseconds (600 nanoseconds)

//Program Variables
int hallState = 0;              // variable for reading the hall sensor status
int switchState = 0;            // variable for reading the switch status
int i = 0;                      // initialize i to 0
volatile int hallCount = 2;       // initialize hallCount to 2
unsigned long time_last_read = 0;
int hall_effect_interval = 15000;
int current_state = 0;

//Set-Up Function Block
void setup()
{
  //Dac Begin
  dac.begin(0x60);
```

```
  //Hall Sensor Interrupt
  attachInterrupt(digitalPinToInterrupt(hallPin), hallCountUp, RISING);

  //Configure Pin I/Os
  pinMode(driveDirectionPin, OUTPUT);
  pinMode(switchPin, INPUT_PULLUP);    // initialize the switch pin as an input with the
internal pull-up resistor enabled
  pinMode(ledPin, OUTPUT);             // initialize the LED pin as an output
  pinMode(switchPin, INPUT);           // initialize the switch pin as an input
  pinMode(hallPin, INPUT);             // initialize the hall effect sensor pin as an input
  pinMode(dirPin, OUTPUT);             // initialize stepper motor 1 direction pin as an output
  pinMode(pulsePin, OUTPUT);           // initialize stepper motor 1 pulse pin as an output
  pinMode(dirPin2, OUTPUT);            // initialize stepper motor 2 direction pin as an output
  pinMode(pulsePin2, OUTPUT);          // initialize stepper motor 2 pulse pin as an output

  //Set Pin Default Values
  digitalWrite(driveDirectionPin, LOW);
  digitalWrite(dirPin, LOW);       // Initialize dir pin 1 to low
  digitalWrite(pulsePin, LOW);     // Initialize step pin 1 to low
  digitalWrite(dirPin2, LOW);      // Initialize dir pin 2 to low
  digitalWrite(pulsePin2, LOW);    // Initialize step pin 2 to low
  Serial.begin(9600);
  delay(1000);

  initializeRightZero();


  delay(100);
  time_last_read = millis();
}

void loop()
{
  i = 0;
  Serial.print(current_state); Serial.print('\t'); Serial.print(hallCount); Serial.print('\t');
Serial.print(hallCount % 2); Serial.print('\t'); Serial.println(millis() - time_last_read);
  if(current_state != hallCount)
  {
    switch(hallCount % 2)
    {
      case 0:
      Stop();
      setForward();
      steerRight();
      Go();
      current_state = hallCount;
```

```
      Serial.println("forwardd");
      break;

      case 1:
      Stop();
      setReverse();
      steerLeft();
      Go();
      current_state = hallCount;
      Serial.println("reversee");
    }
  }

  else
  {

  }

}

void initializeRightZero()
{
switchState = digitalRead(switchPin);   // read the switch pin
if (switchState == LOW)
    {
       while (i == 0) {
        digitalWrite(dirPin, HIGH);             // set direction pin 1 low
        digitalWrite(dirPin2, LOW);             // set direction pin 2 high
           digitalWrite(pulsePin, LOW);        // set pulse pin 1 low
           delayMicroseconds(PULSE_DELAY_MS);  // delay 0.6 ms
           digitalWrite(pulsePin, HIGH);       // set pulse pin 1 high
           delayMicroseconds(PULSE_DELAY_MS);  // delay 0.6 ms
           digitalWrite(pulsePin2, HIGH);      // set pulse pin 2 high
           delayMicroseconds(PULSE_DELAY_MS);  // delay 0.6 ms
           digitalWrite(pulsePin2, LOW);       // set pulse pin 2 low
           delayMicroseconds(PULSE_DELAY_MS);  // delay 0.6 ms
        switchState = digitalRead(switchPin);   // read the switch pin
        if (switchState == HIGH)
          {
            i = 1;
          }
        }
    }
   digitalWrite(pulsePin, HIGH);   // set pulse pin 1 high
   digitalWrite(pulsePin2, HIGH);  // set pulse pin 2 high
   Serial.println("zero");
```

```
    Serial.println(i);
}

void Go()
{
  dac.setVoltage(Drive_LOW, false);
  //delay(2000);
  dac.setVoltage(Drive_MED, false);
  //delay(100);
}

void setForward()
{
  digitalWrite(driveDirectionPin, LOW);
  //delay(500);
}

void setReverse()
{
  digitalWrite(driveDirectionPin, HIGH);
  //delay(500);
}

void Stop()
{
  dac.setVoltage(Drive_LOW, false);
  //delay(1000);
  dac.setVoltage(Drive_OFF, false);
  //delay(500);
}

void steerLeft()
{
       digitalWrite(dirPin, LOW);
       digitalWrite(dirPin2, HIGH);
          for (int i = 0; i < NUM_STEPS ; i++) {
              digitalWrite(pulsePin, LOW);
              digitalWrite(pulsePin2, LOW);
              delayMicroseconds(PULSE_DELAY_MS);

              digitalWrite(pulsePin, HIGH);
              digitalWrite(pulsePin2, HIGH);
              delayMicroseconds(PULSE_DELAY_MS);

              }
          delay(1000);
```

```
}

void steerRight()
{
switchState = digitalRead(switchPin);   // read the switch pin
if (switchState == LOW)
   {
      digitalWrite(dirPin, HIGH);
      digitalWrite(dirPin2, LOW);
         for (int i = 0; i < NUM_STEPS ; i++) {
             digitalWrite(pulsePin, LOW);
             digitalWrite(pulsePin2, LOW);
             delayMicroseconds(PULSE_DELAY_MS);

             digitalWrite(pulsePin, HIGH);
             digitalWrite(pulsePin2, HIGH);
             delayMicroseconds(PULSE_DELAY_MS);
        if (switchState == HIGH)
          {
            i = 1;
          }
        }
   }
   digitalWrite(pulsePin, HIGH);   // set pulse pin 1 high
   digitalWrite(pulsePin2, HIGH);  // set pulse pin 2 high
   Serial.println("zero");
   Serial.println(i);
         delay(1000);
}
void hallCountUp()
{
 if(millis() - time_last_read > hall_effect_interval)
 {
   hallCount++;
   time_last_read = millis();
 }

 else
 {

 }

}
```

Intermediate Steering and braking

Bill of Materials

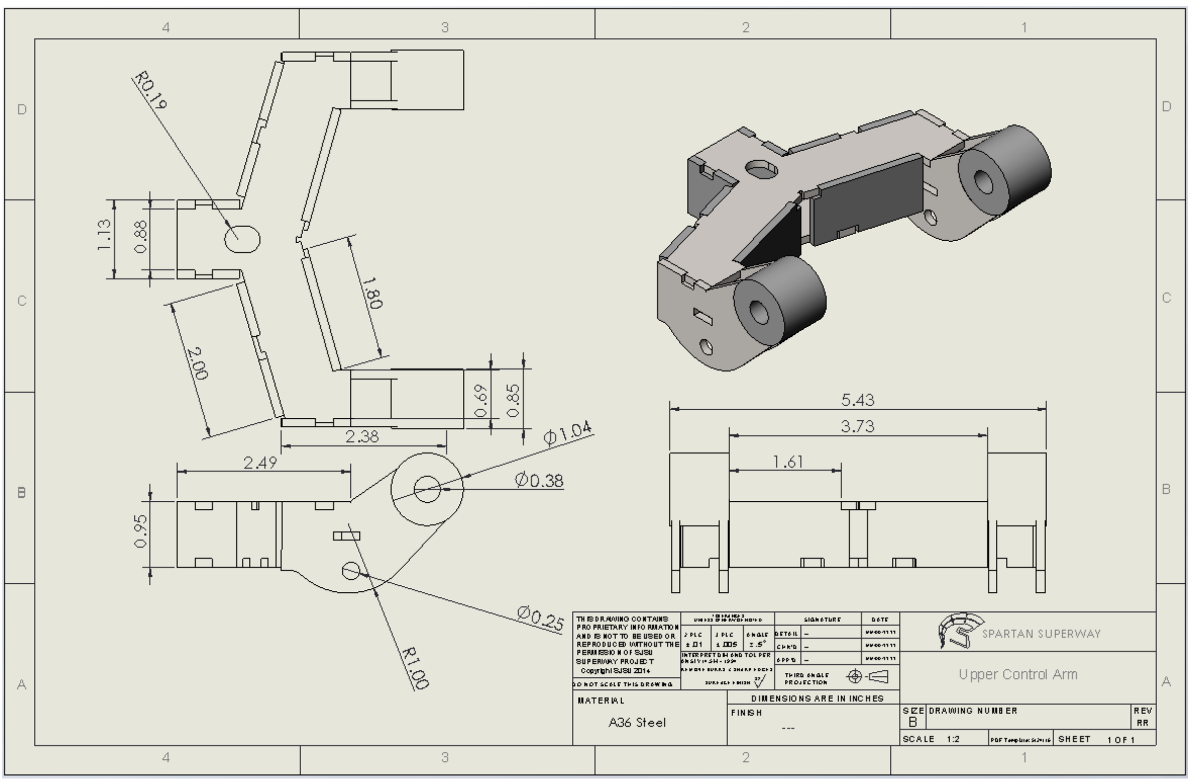
Table 1: Steering Bill of Materials

Component	Vendor	Unit Cost	Quantity	Total Cost
PK Series 2-Phase Stepper Motor with 36:1 Gear Reduction	Oriental Motors	$268.00	2	$536.00
CW230 Microstepping Motor Driver 24 - 36 VDC 0.9 - 3.0A	Circuit Specialists	$39.50	2	$79.00
One-Piece Clamp-On Rigid Shaft Coupling [dia. (A) = 1/2", dia (B) = 3/8"]	McMaster-Carr	$40.54	2	$81.08
2-1/2" diameter Nylon Wheels	McMaster-Carr	$2.71	12	$32.52
48" x 24" x 11GA A36 Steel Plate	Sims Metal Management	$27.00	1	$27.00
5 ft long 1/2" x 1" x 16GA A36 Steel Rectangular Tube	Sims Metal Management	$4.23	1	$4.23
4 ft long 1" x 1" x 16GA A36 Steel Square Tube	Sims Metal Management	$11.70	1	$11.70
Bolts, Nuts, Washers	Fastenal	N/A	N/A	$50.00
3/8" Threaded Rod	Home Depot	$5.82	1	$5.82
3/8" Tie Rods	Home Depot	$2.97	4	$11.88
Arduino Mega 2560	N/A	DONATED	1	DONATED
24V Power Supply	N/A	DONATED	1	DONATED
Waterjet Cutting	Techshop	N/A	N/A	$600.00
		GRAND TOTAL: $1439.23		

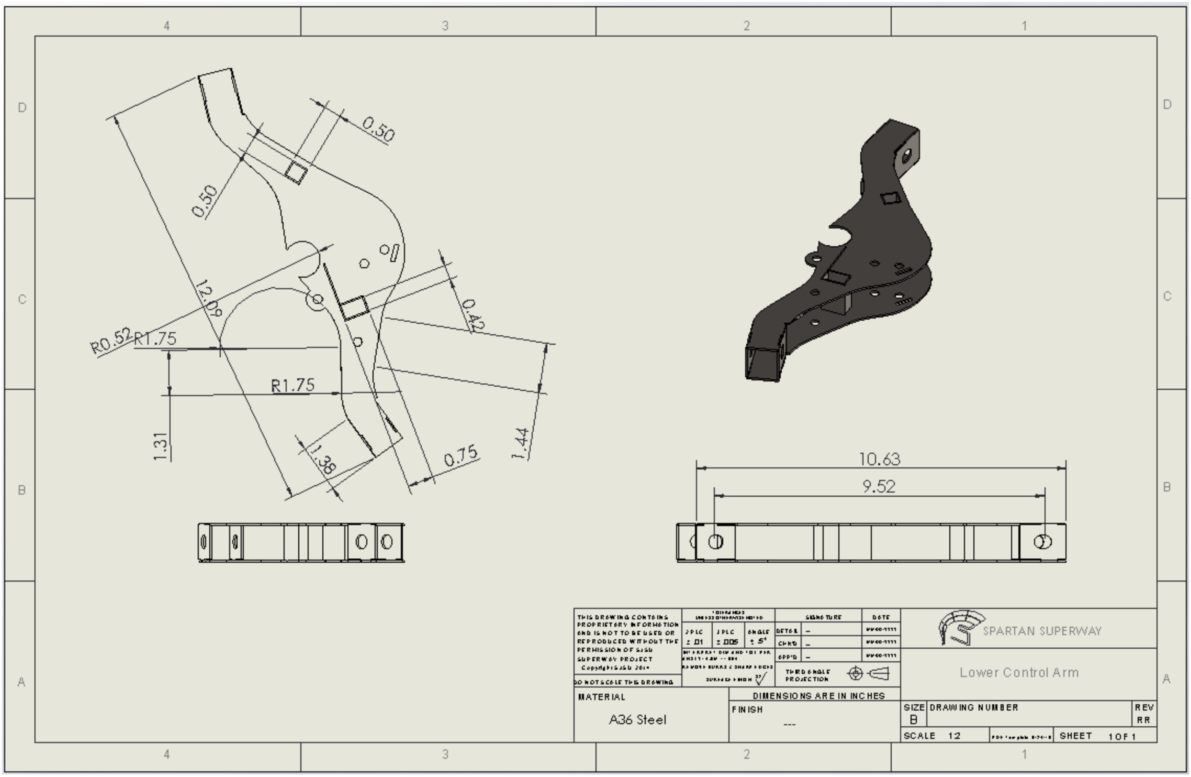
Table 2: Braking Bill of Materials

Bill of Materials for Braking							
Part	**Material**	**Size**	**Vendor / Manufacturer**	**Quantity**	**Purchased**	**Unit Cost**	**Total Cost**
Disc Brakes	aluminum	4.7" Diameter	electricscooterparts.com	1	yes	$53.44	$53.44
Ultrasonic sensor	N/A	N/A	Fry's Electronic	1	yes	$5	$5.00
Controller	N/A	N/A	Ardurino	1	yes	$15	$15.00
mini breadboard	N/A	N/A	Fry's Electronic	1	yes	$5	$5.00
small push-pull solnoid			amazon	1	yes	$26.35	$26.35
worm gear			amazon	1	yes	$73.32	$73.32
Brake Cable	steel	60-65" long	ebay.com / bike shop	1	yes	$5	$5
Zip ties	N/A	7"	ebay.com	100	yes	$5.07	$5.07
hand brake			pick-pull		yes	$20	$20
						Total	$208.18

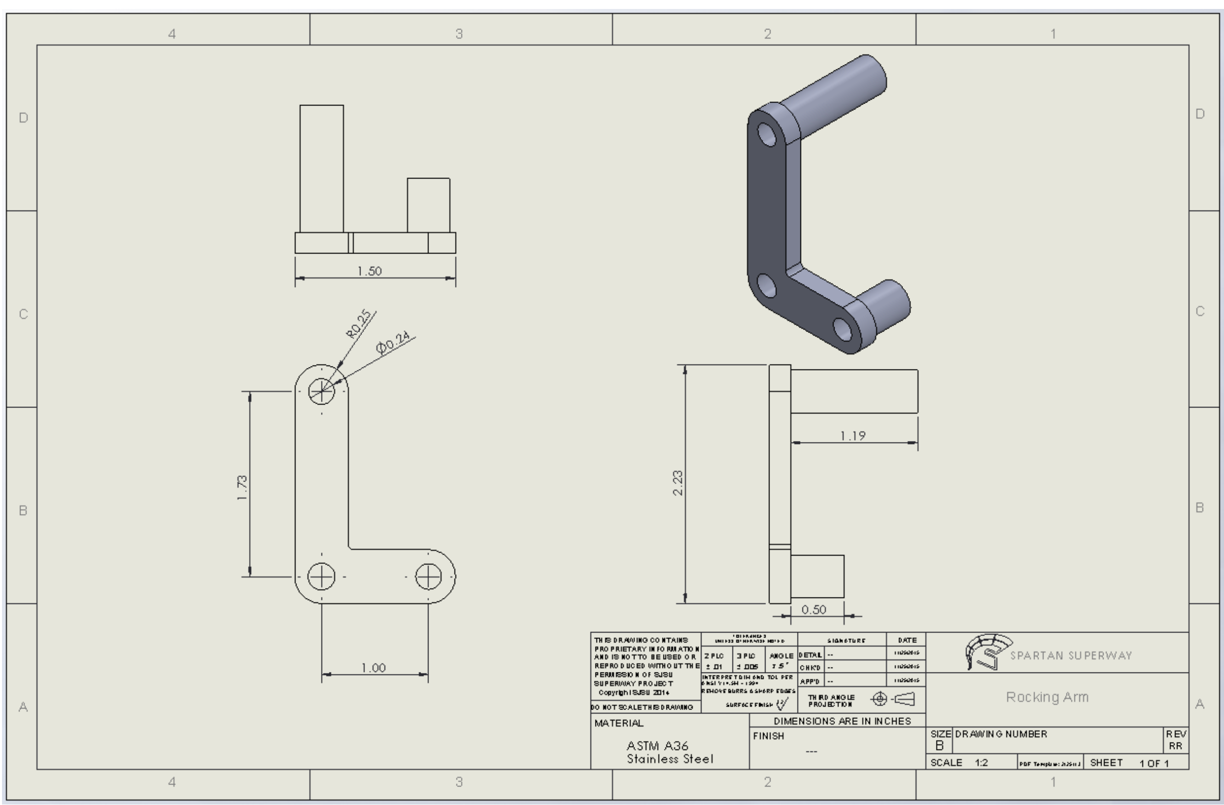
Steering Mechanism Part Drawings



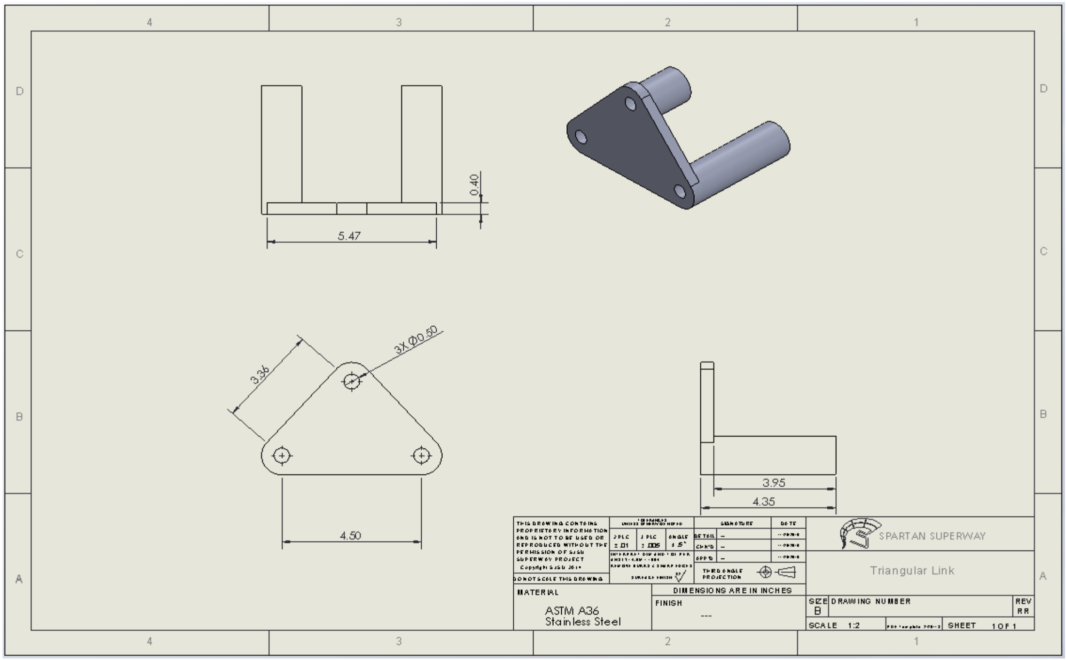
Drawing of Upper Control Arm



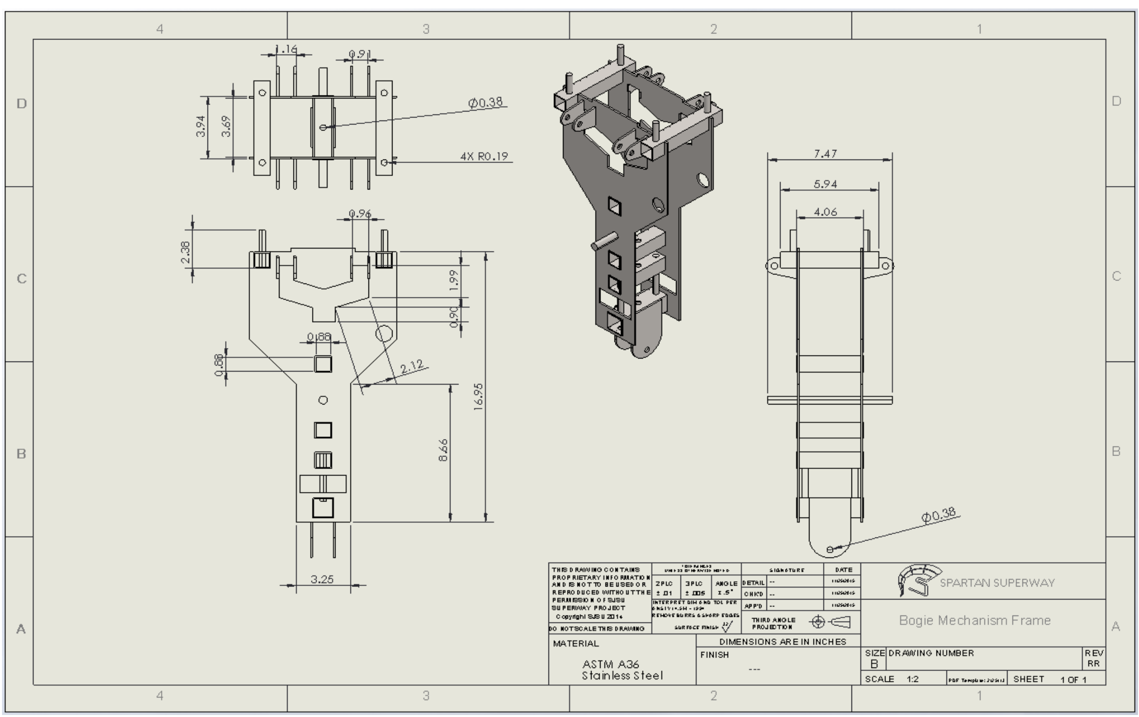
Drawing of Lower Control Arm



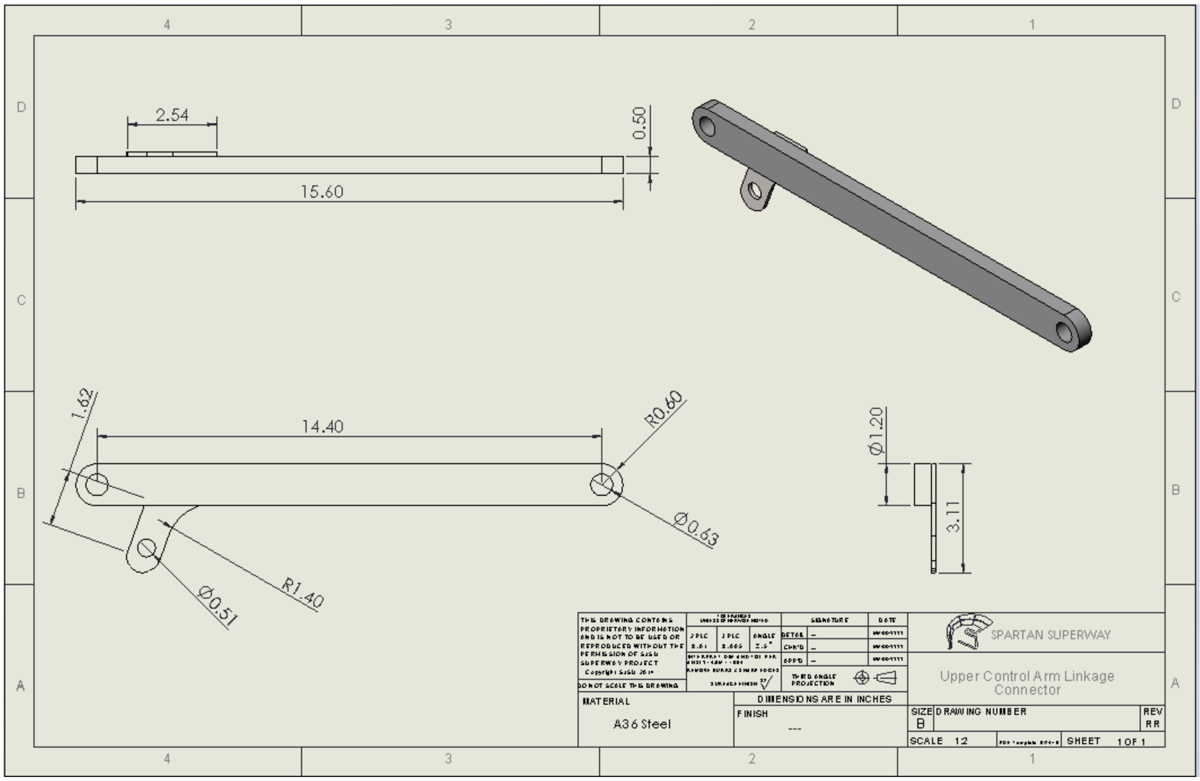
Drawing of L-bracket/Rocking Arm



Drawing of Triangular Link

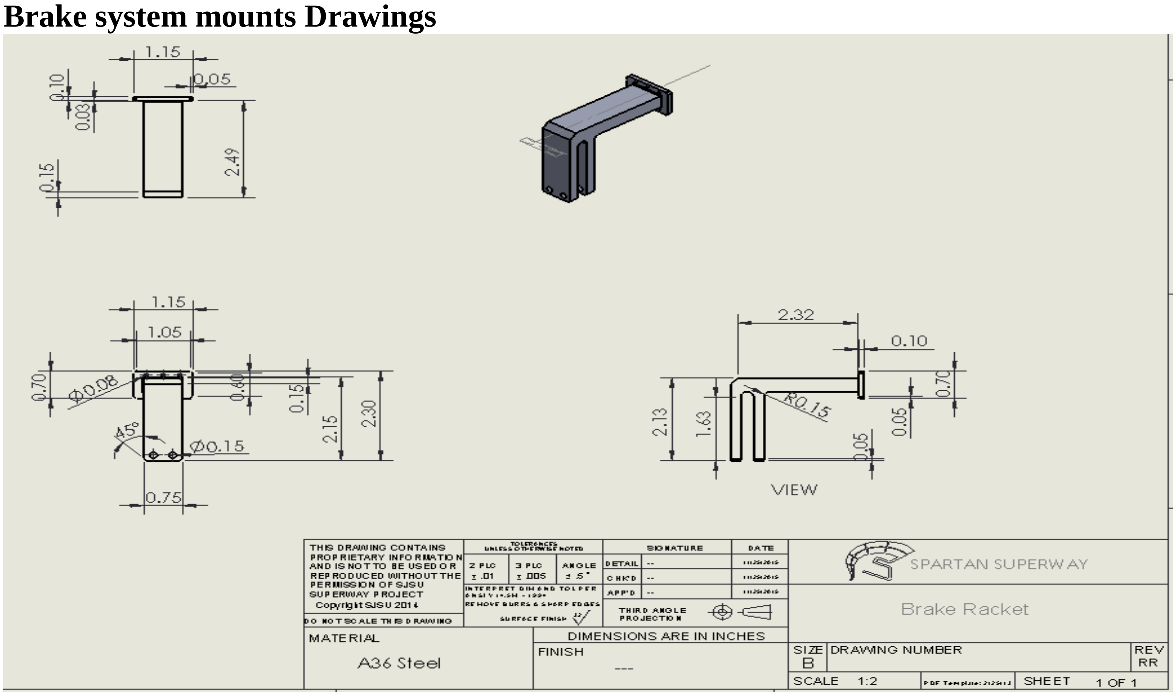


Drawing of Bogie Frame

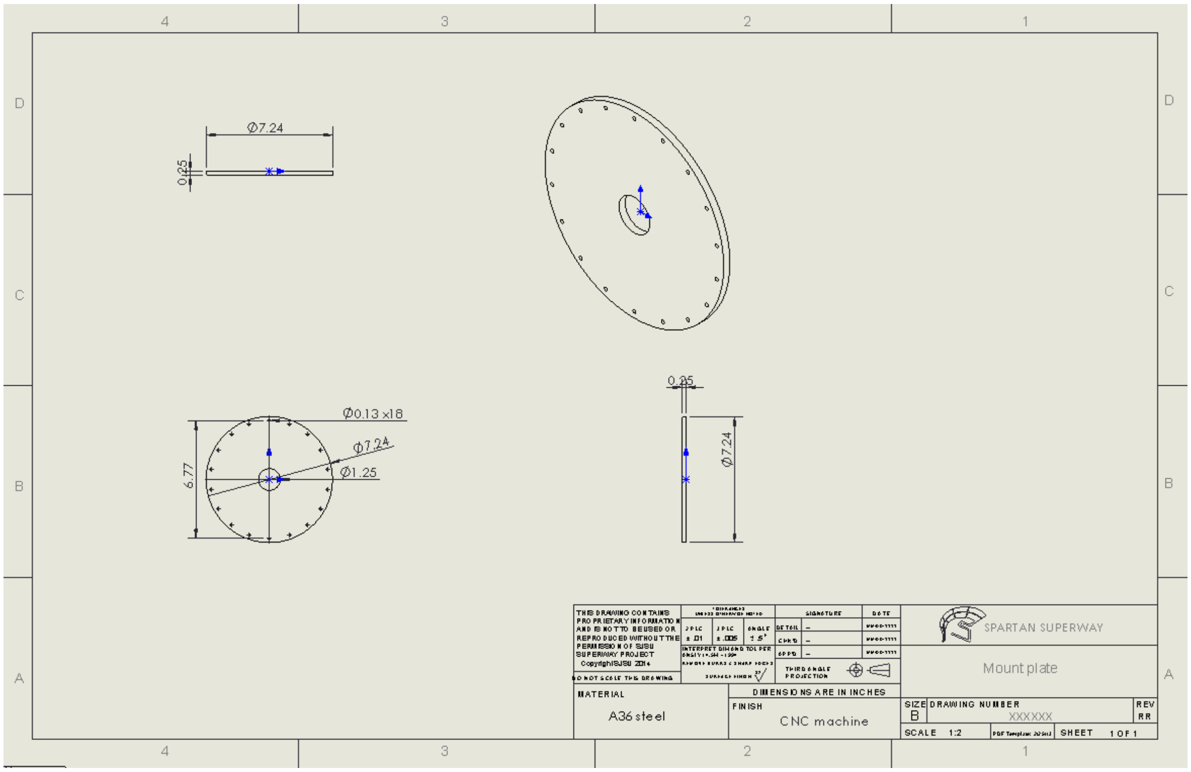


Drawing upper control arm linkage connector

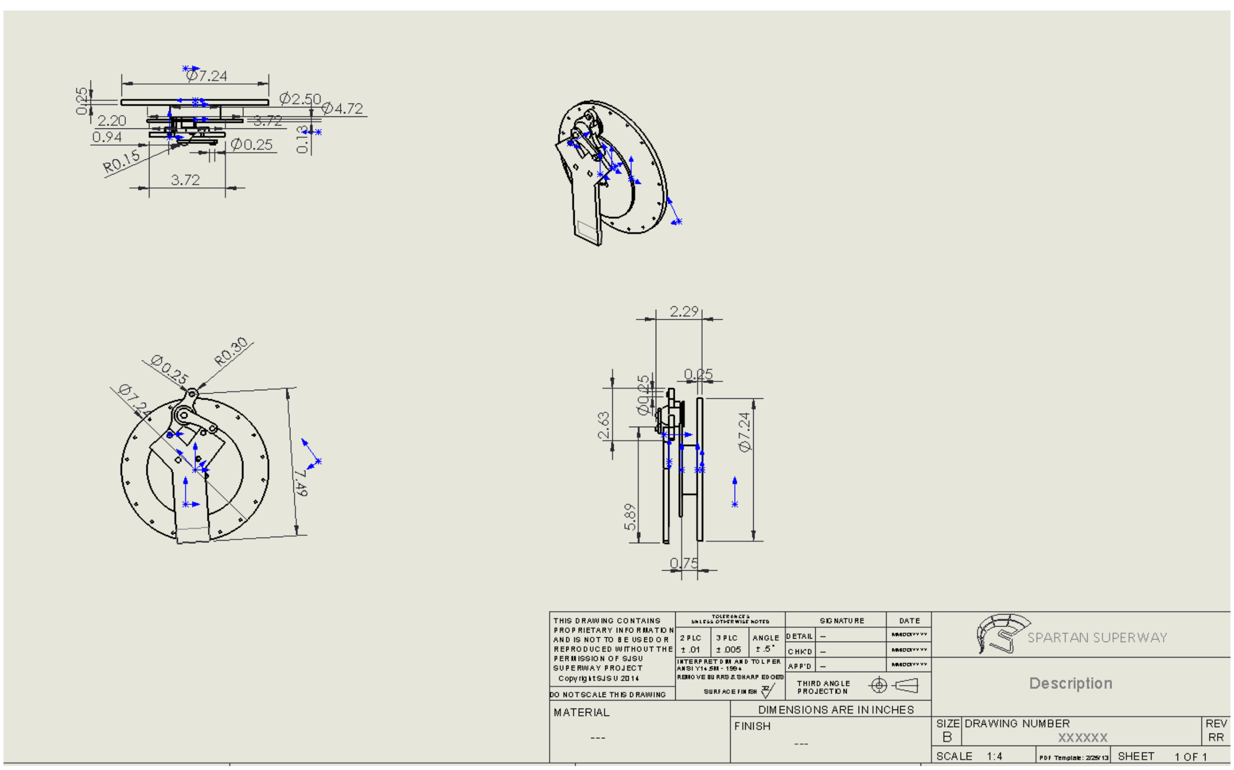
Brake system mounts Drawings



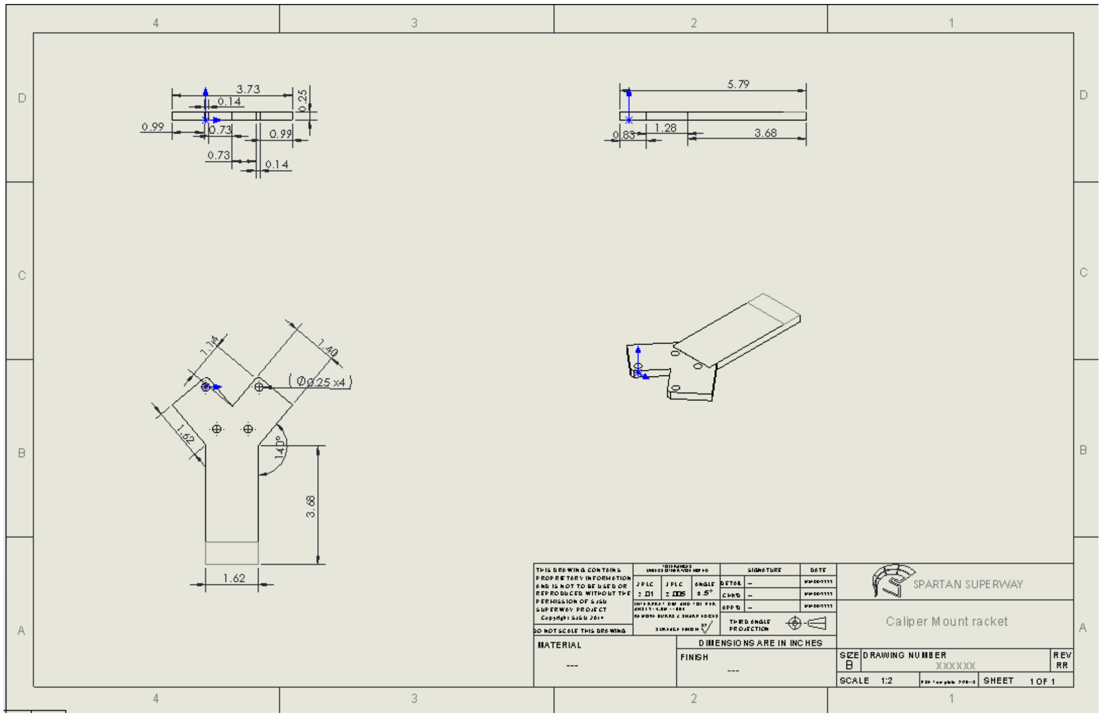
Supporting racket



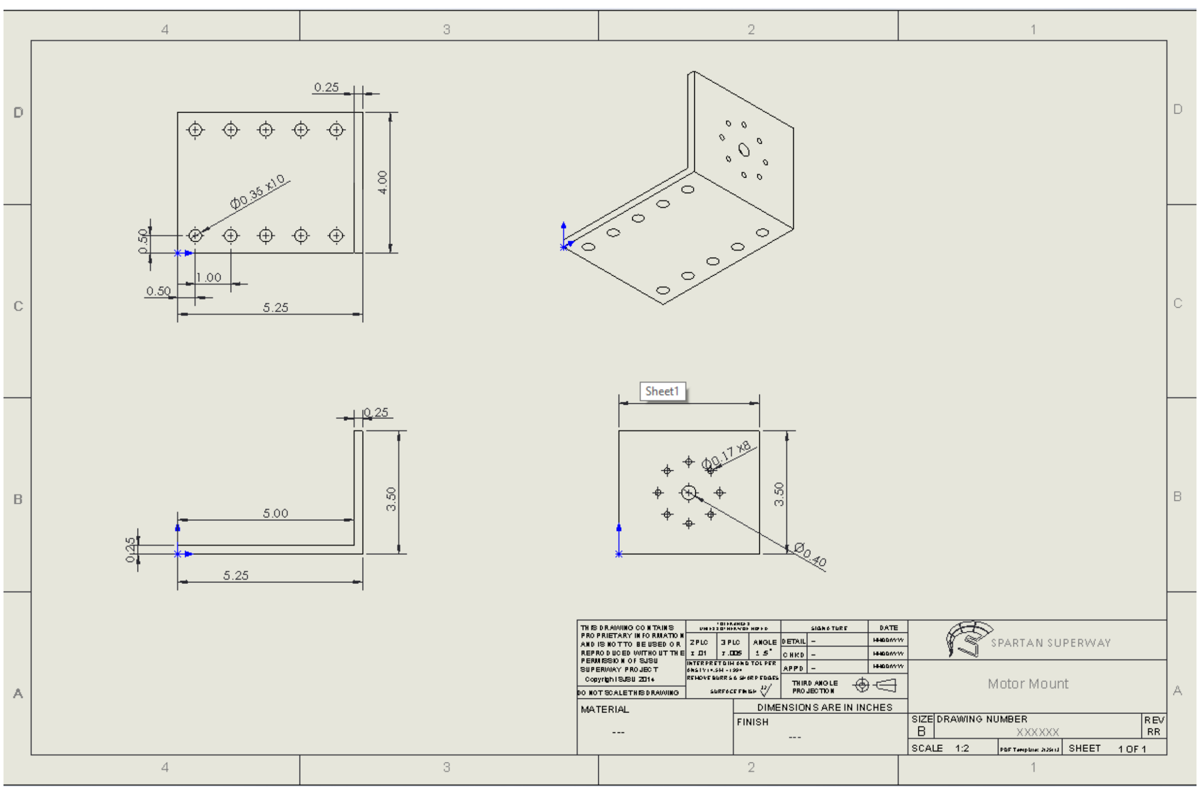
Mounting Plate



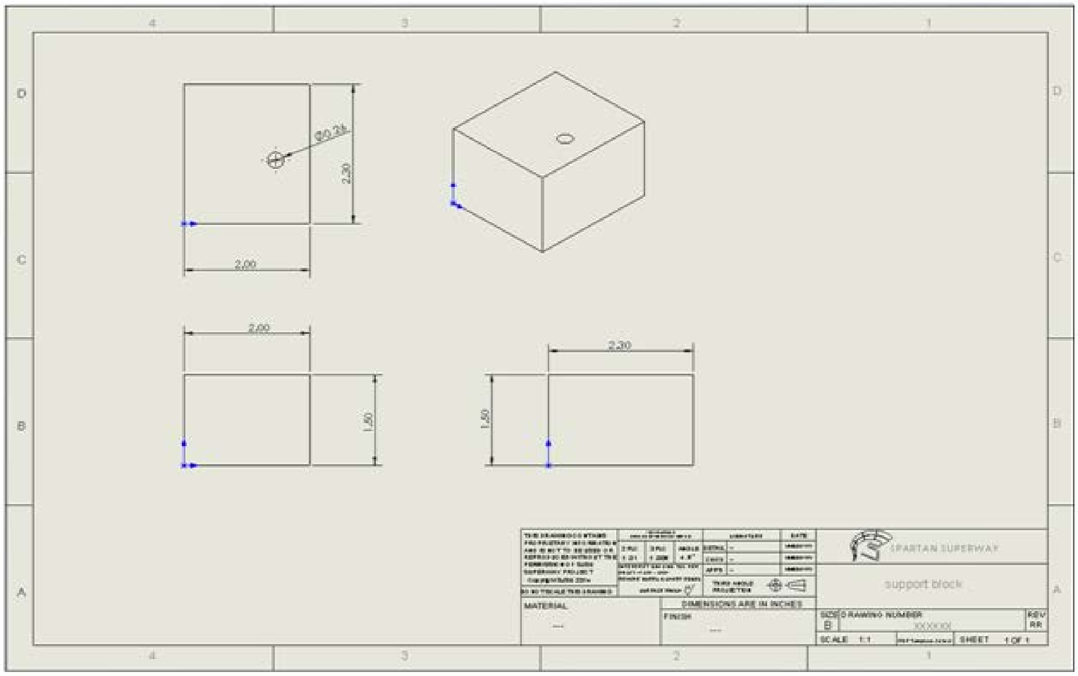
Mounting assembly for brake system on hub-motor



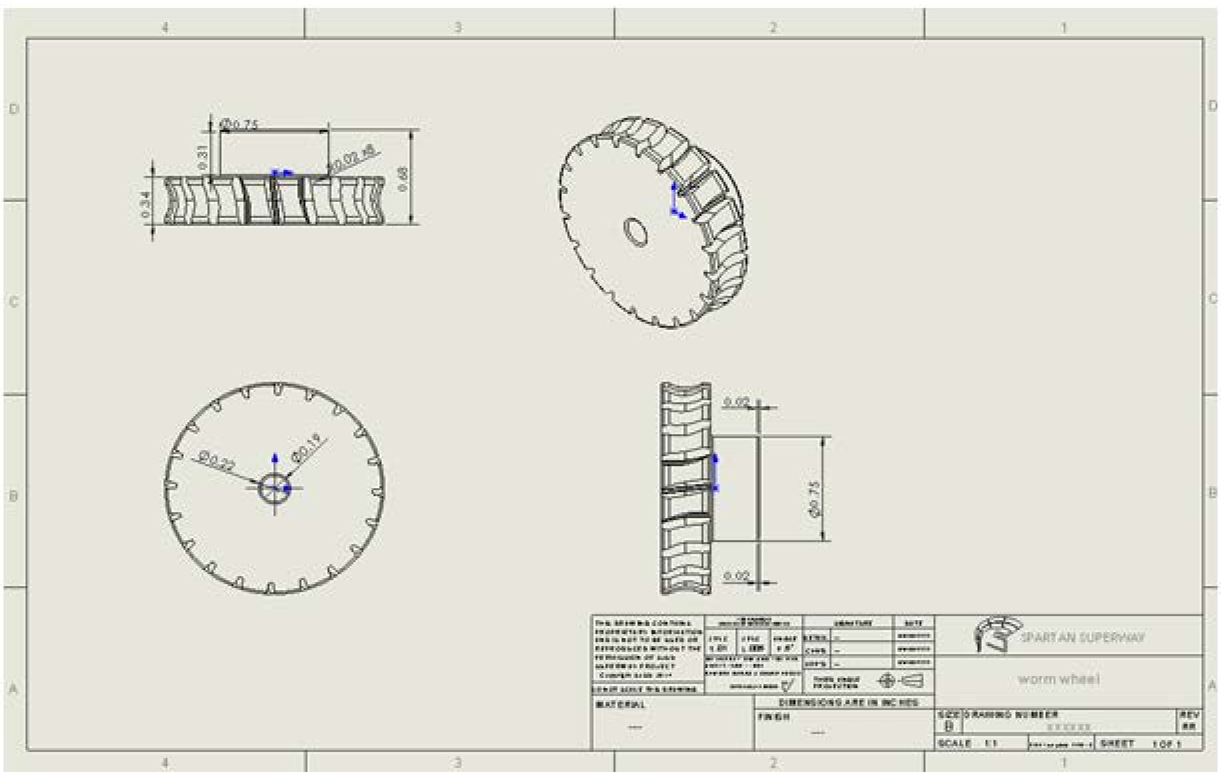
Mounting bracket for caliper



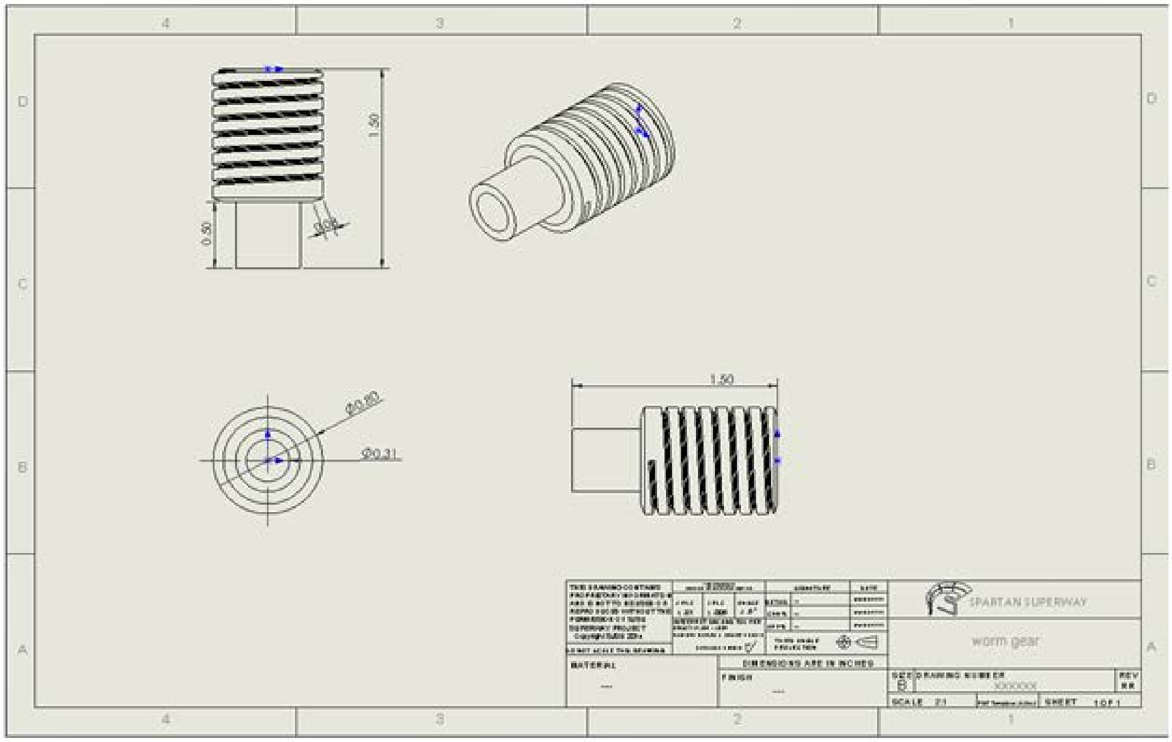
Mounting plate for motor



Support Block



Worm Wheel

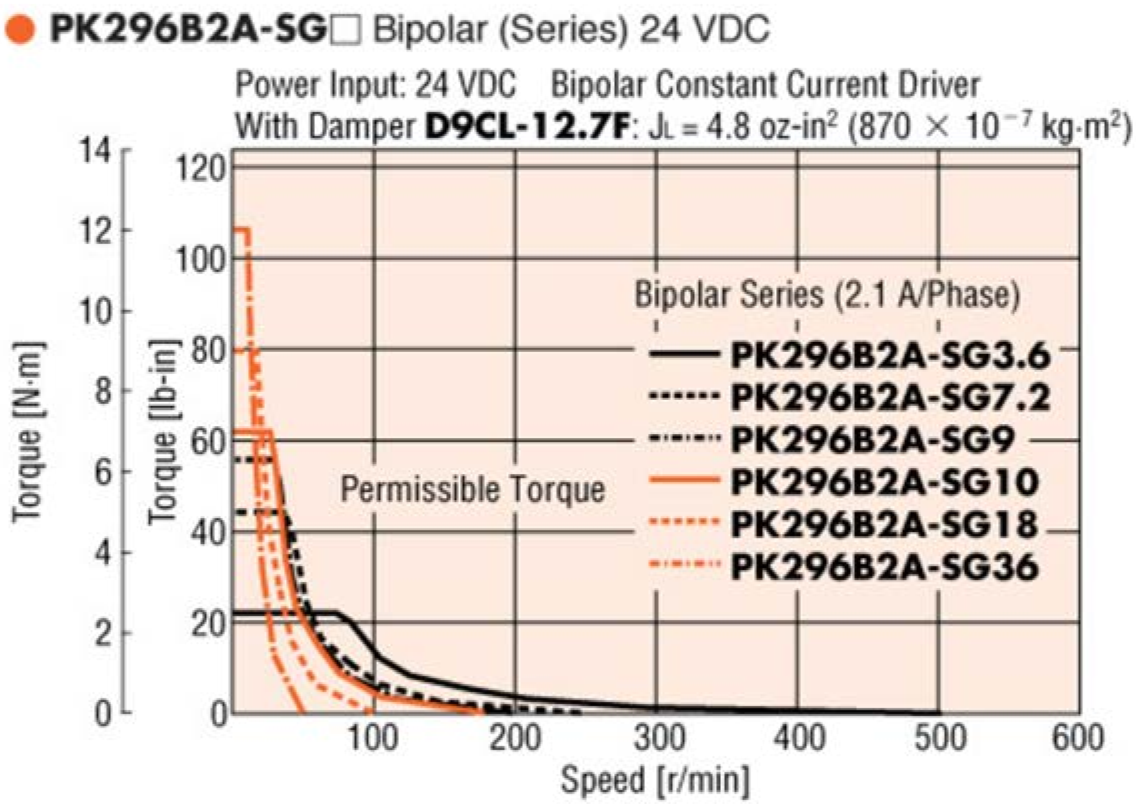


Worm gear

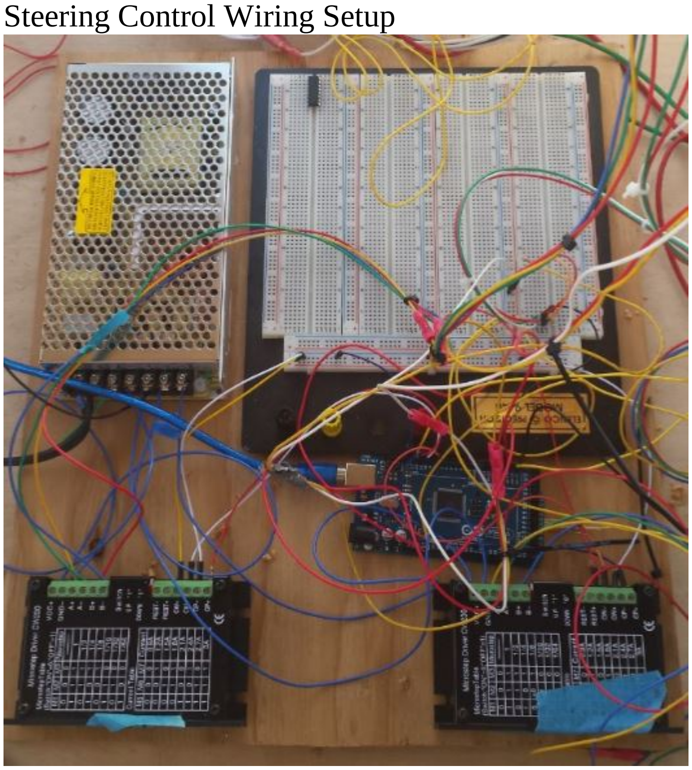
Gantt Chart for Steering and Braking

Project Name	Start Date	End Date	Time	%	Team	All Color
Design Implementation	23-Jan	25-May	123	100	All	
Update Design	23-Jan	27-Feb	35	100	All	
Look for components and parts	27-Feb	12-Mar	14	100	All	
Speak to manufacturers	5-Mar	12-Mar	7	100	All	
Purchase materials, begin assembly	12-Mar	19-Mar	7	100	All	
Continue assembly	19-Mar	23-Apr	35	100	All	
Finish building initial assembly	23-Apr	23-Apr	0	100	All	
Testing and troubleshooting	23-Apr	30-Apr	7	100	All	
Make necessary changes and finalize model	30-Apr	7-May	7	100	All	
Maker Faire preparation	22-Apr	22-May	30	100	All	

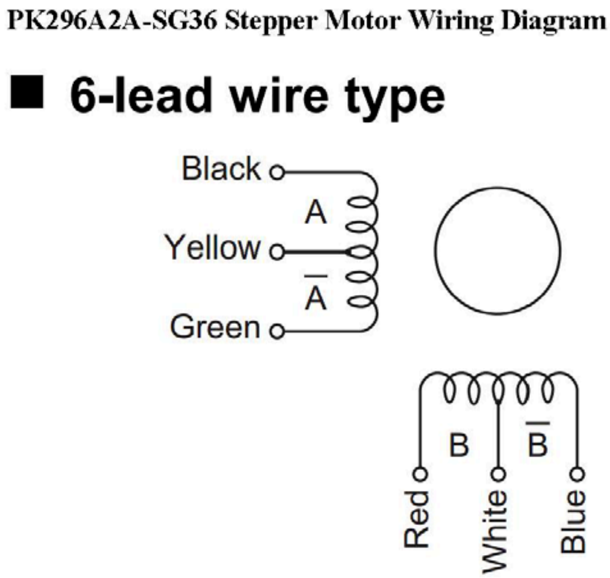
Steering Mechanism Specifications, Datasheets, and Setup



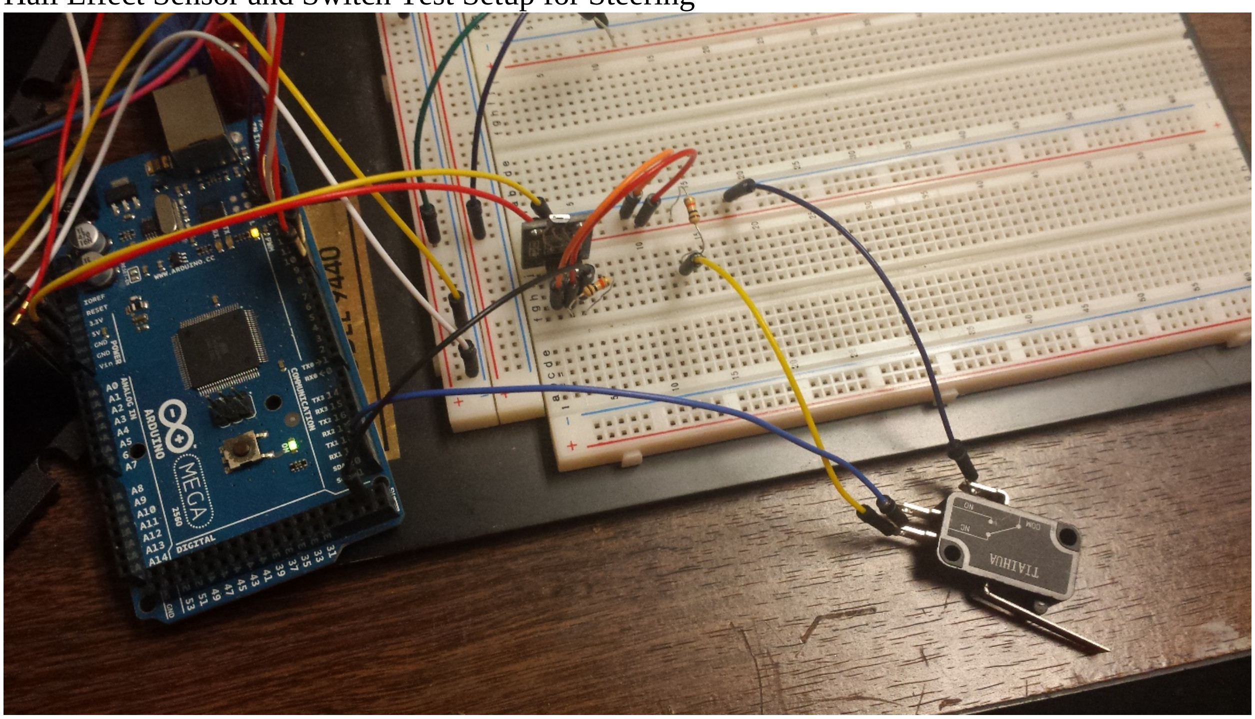
Steering Control Wiring Setup



Stepper Motor Wiring Diagram



Hall Effect Sensor and Switch Test Setup for Steering



Item Number PK296A2A-SG36, Stepper Motor

Web Price $268.00

Stepper Motor

Incorporating the SH gears with high permissible torque delivers high resolution, high torque and smooth low-speed rotation.

RoHS

· LEAD TIME · SPECIFICATIONS

LEAD TIME

Available to Ship [1]	05/31/2016

1 Quoted Ship Date for orders placed before 12:00 pm PST. Quantities may affect Shipping Date.

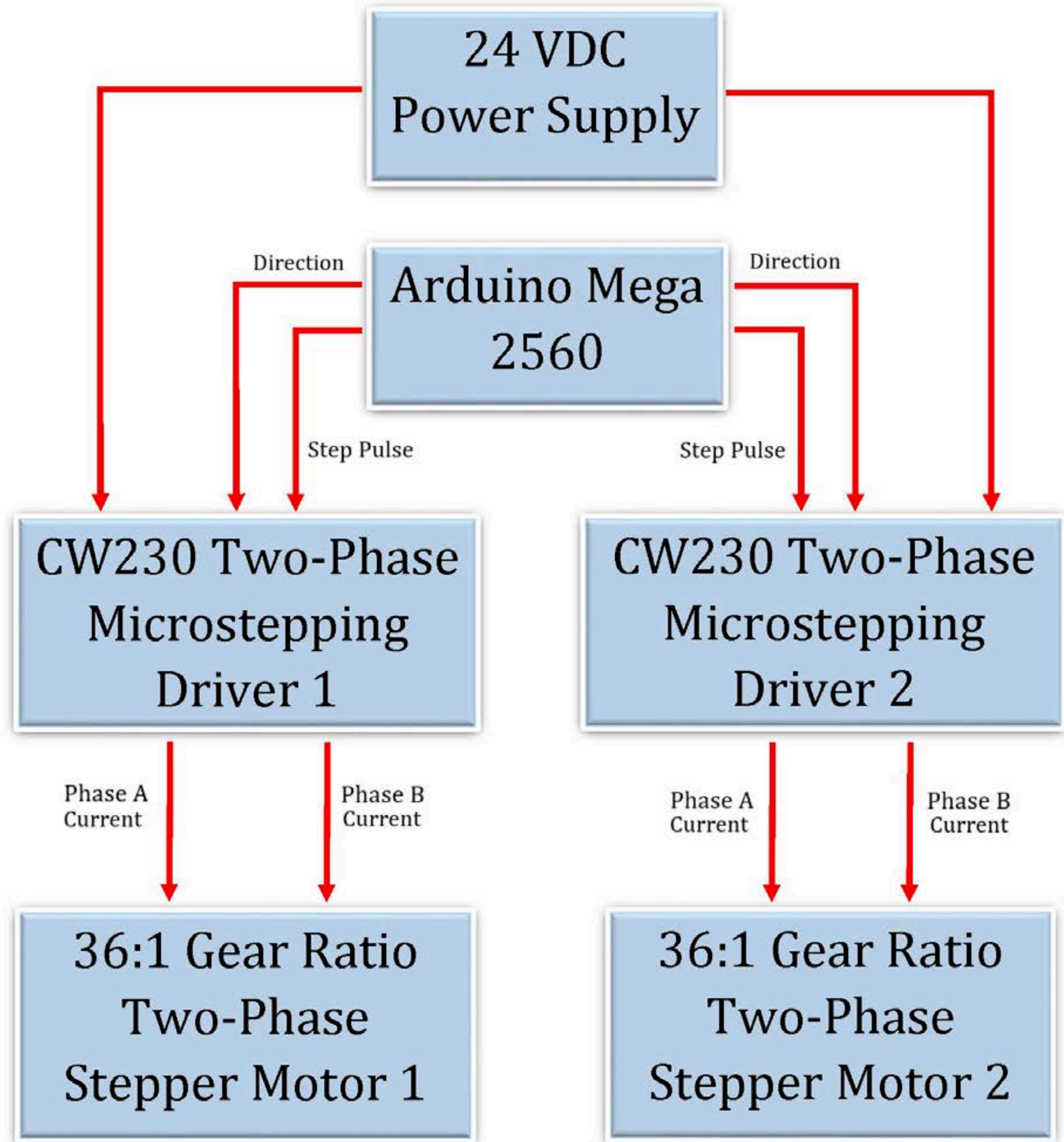
SPECIFICATIONS

Motor Type	2-Phase
Frame Size	3.54 in
Motor Length	4.96 in.
Speed-Torque Characteristics	 Speed - Torque Characteristics
Holding Torque	1696 oz-in
Shaft/Gear Type	Spur Gear
Gear Ratio (X:1)	36 :1
Shaft	Single

Type	Geared
Encoder	Not Equipped
Basic Step Angle	1.8°
Output Step Angle	0.05 °
Electromagnetic Brake	Not Equipped
Motor Connection Type	Flying Leads
Connection Type	Bipolar (Series) Unipolar
Current per Phase (A/phase)	2.1 [Bipolar (Series)] 3 [Unipolar]
Lead Wires	6
Voltage (VDC)	2 [Bipolar (Series)] 1.4 [Unipolar]
Resistance (Ω/phase)	0.96 [Bipolar (Series)] 0.48 [Unipolar]
Inductance (mH/phase)	6 [Bipolar (Series)] 1.5 [Unipolar]
Rotor Inertia	7.7 oz-in²
RoHS Compliant	Yes
Insulation Resistance	100 M Ω or more when 500 VDC megger is applied between the windings and the case under normal ambient temperature and humidity.
Dielectric Strength	Sufficient to withstand 1.0 kVAC at 50 Hz or 60 Hz applied between the windings and the case for 1 minute under normal ambient temperature and humidity.
Temperature Rise	Temperature rise of the windings is 176°F (80°C) or less measured by the change resistance method. (at rated voltage, at standstill, 2 phases energized)
Insulation Class	Class B [266°F (130°C)]
Ambient Temperature Range	14 ~ 122°F (-10 ~ 50°C) (non-freezing)
Ambient Humidity	85% or less (non-condensing)
Shaft Runout	0.05 mm (0.002 in.) T.I.R.
Concentricity	0.075 mm (0.003 in.) T.I.R.
Perpendicularity	0.075 mm (0.003 in.) T.I.R.
Radial Play	0.025 mm (0.001 in.) maximum of 5 N (1.12 lb.)

Axial Play	0.075 mm (0.003 in.) maximum of 10 N (2.2 lb.)
Radial Load	0 in. from Shaft End = 49 lb 0.2 in. from Shaft End = 56 lb 0.59 in. from Shaft End = 78 lb 0.79 in. from Shaft End = 90 lb 0.39 in. from Shaft End = 67 lb
Axial Load	22 lb

Stepper Motor Block Diagram



CW230 2-Phase Mircostepping Motor Driver

Characteristics:

1.DC power input type:24V~36V

2.Output current:0.9~3A

3.Mircostepping: 1(1.8°)、1/2、1/4、1/8、1/16、1/32、1/64

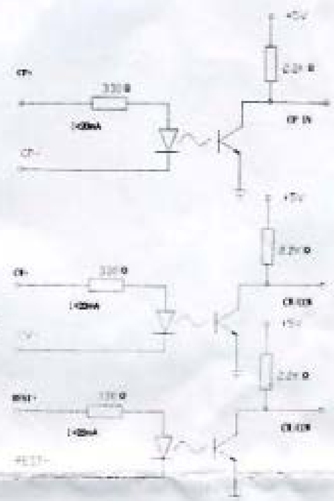
4.Protect form : Overheated protect, lock automatic half current ,error connect protect

5.Dimensions: 115mm×72mm×32mm

6.Weight: <300g.

7.Working environment: Temperature-15~40℃ Humidity<90%.

I/O Ports:



1、VCC+: DC power positive pole
Note:Must guard against exceeding 40V, so as not to damage the module

2、GND: DC power cathode

3、A+、A-: Stepping motor one winding

4、B+、B-: Stepping motor other winding

5、CP+、CP-: Stepping pulse input+5V (Rising edge effective, rising edge duration >10μS)

6、CW+、CW-: Stepping motor direction input, voltage level touched off, high towards, low reverse

7、REST+、REST-: motor free

The interface see the right picture

. NOTE:

1, When ambient temperature is high or working current over 2A, fix the module on big metal shell , or use axle flows fan dispels the heat, to make the module run reliably for a long time.

2, Half current automatically: if control machine not send out signal in half second, driver enter half current state of automatically for electricity saving, the phase current of the winding of the electric

3, The fault phase is protected : When the double-phase electrical machinery is connected with driver , users are apt to connect the phase by mistake, thus would damage the driver seriously. The protecting circuit is within this driver, when users connect by mistake, the driver will not be damaged, but the electrical machinery runs abnormally, shake , and output is small.Please check whether the wiring of electrical machinery is a mistake

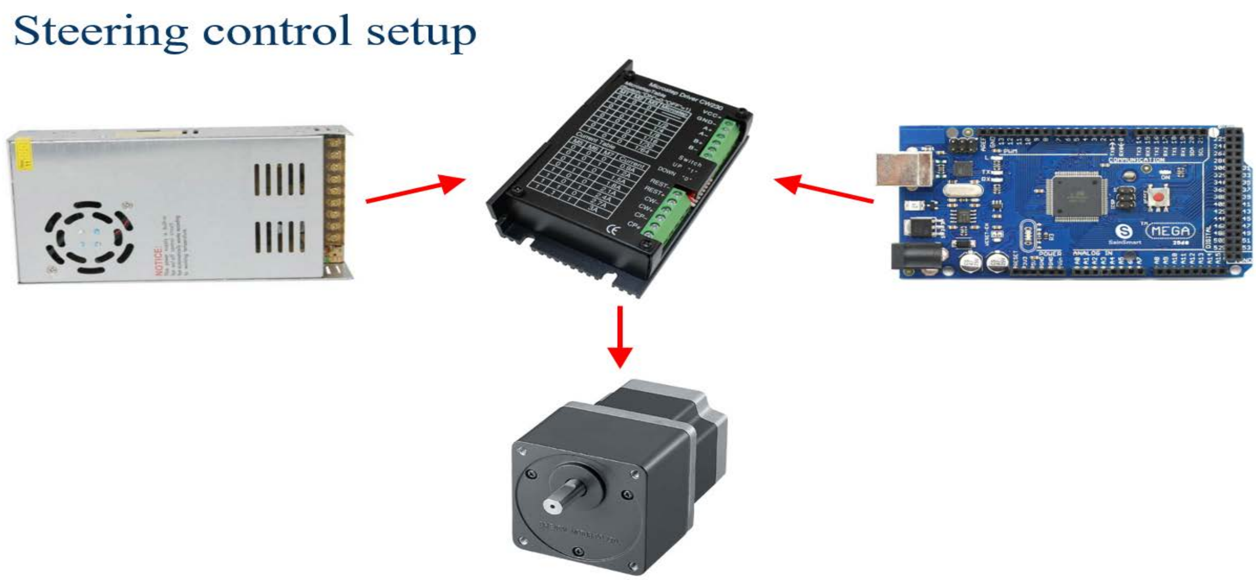
Switch Choice: ("ON=0, OFF=1")

1、Microstepping choice

M1	1	0	1	0	1	0	1	0
M2	1	1	0	0	1	1	0	0
M3	1	1	1	1	0	0	0	0
Micro	1	1/2	1/4	1/8	1/16	1/32	1/64	___

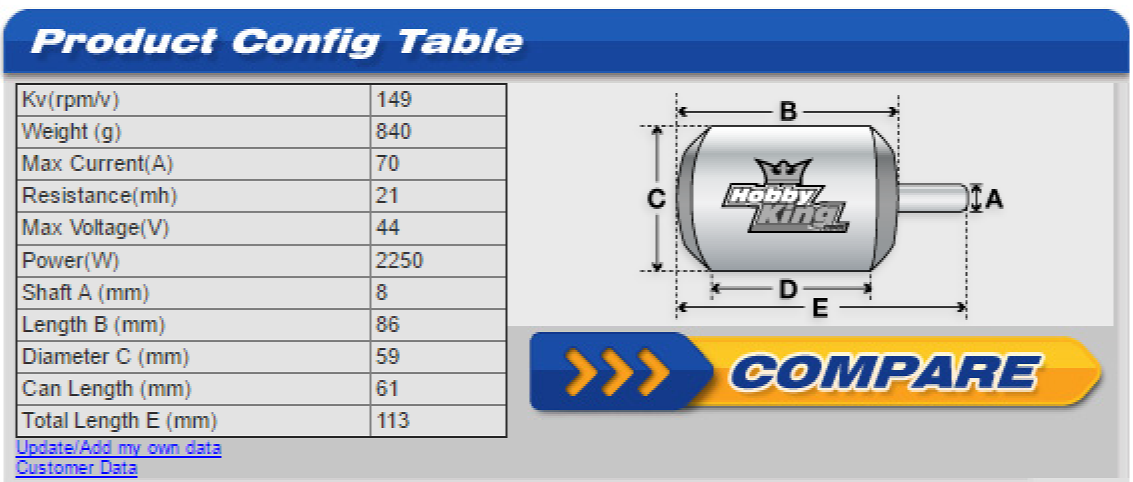
2、Current choice:

M5	0	0	0	0	1	1	1	1
M6	0	0	1	1	0	0	1	1
M7	0	1	0	1	0	1	0	1
Current (A)	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3



Braking Specifications

DC motor specs:



Product Config Table

Kv(rpm/v)	149
Weight (g)	840
Max Current(A)	70
Resistance(mh)	21
Max Voltage(V)	44
Power(W)	2250
Shaft A (mm)	8
Length B (mm)	86
Diameter C (mm)	59
Can Length (mm)	61
Total Length E (mm)	113

Update/Add my own data
Customer Data

Speed= 6556 RPM, after 20 gear reduction > 327.8 RPM

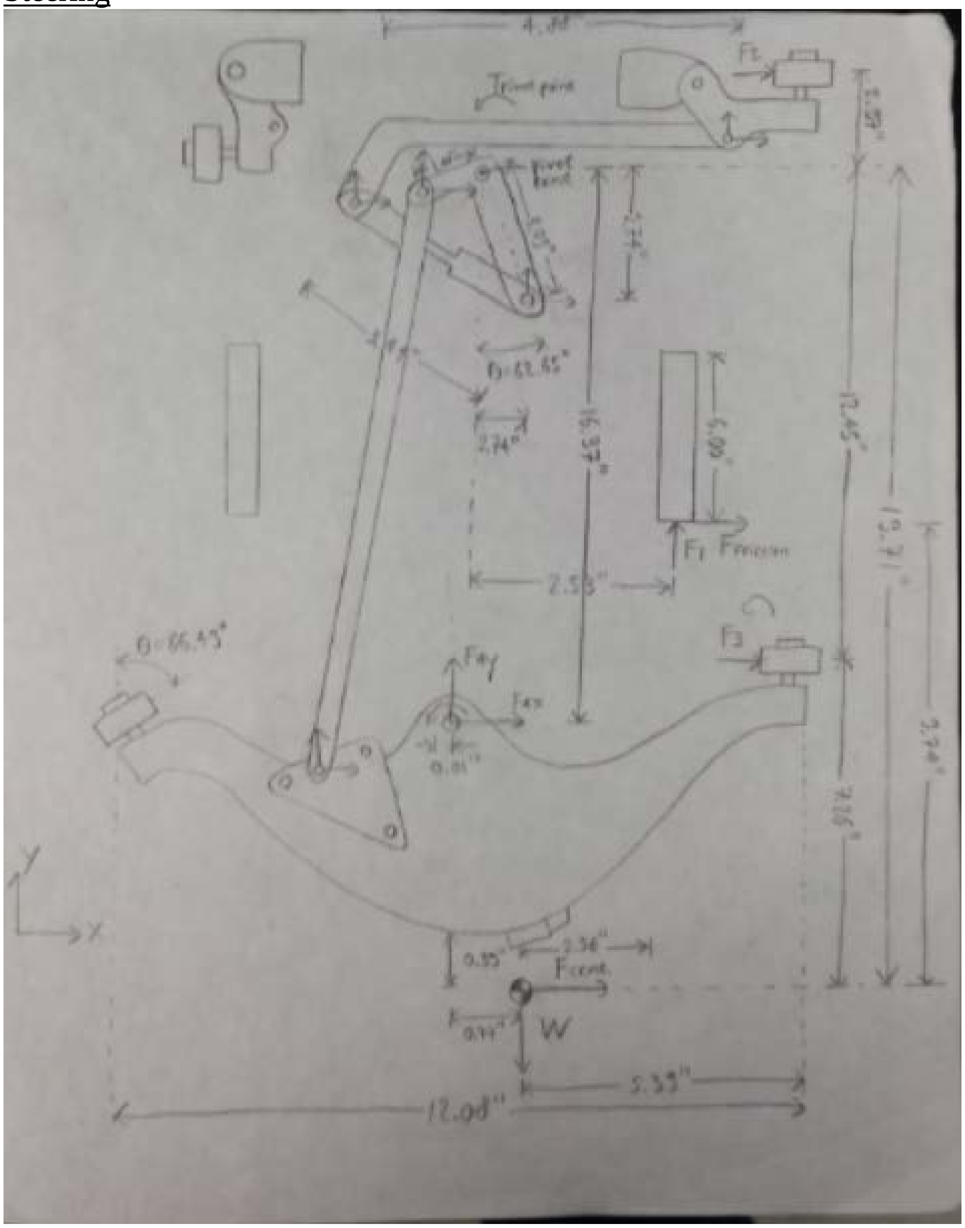
Max torque= 463.78 oz-in, after 20 gear reduction > 9275.60 oz-in

ESC specs

Specs:
Cont Current: **100A**
Burst Current: **120A**
UBEC Mode: **3A/5v out**
Voltage Range: **5.6v ~ 26v**
Weight: **80g**
Size: **80x31x17mm**

Calculations and Analysis

Steering



For brake:

Assumptions:

friction is negligible

V_o= 0.5 mph= 0.22352 m/s

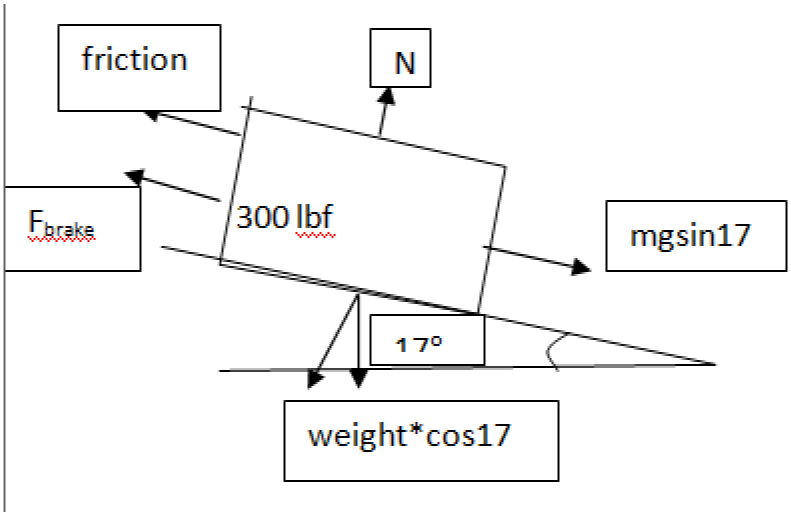
V_f= 2 mph = 0.894 m/s

decline 17 degree slope

weight is roughly 300 lbf= 1334.47 N

s=braking distance = 17 feet= 5.1816 m

Brake rotor diameter=4.7 in=0.11938 m



$$\sum F_x = ma$$

F_{brake}- mgsin17+$F_{friction}$ = ma (equation 1)

F_{brake} =(1334.47/9.81)(0.0639)+(1334.47*sin17)

$\mathbf{F_{brake}}$= 398.8537 N

V_f^2- V_0^2= 2as (equation 2)

0.844^2-0.22352^2= 2(-a)(5.1816)

deceleration: a=-0.0639 m/s^2

Braking duration:

V_f= V_0+a*t (equation 3)

0.844= 0.22352 + (0.0639)t

time= t = 10.49 sec

power = F*s /time (equation 4)

power= 398.8537 (5.1816) /10.49 = 197.016 watts or 0.264 Horse power

F_{brake}= 398.8537 N= 89.666 lbf

Torque = force* rotor radius*coefficient of friction (equation 5)

Torque= 89.666*(4.7/2)*0.3= 63.2145 lb-in= 1011.432 oz-in

Steering and Propulsion Code

```
//Library Inclusions
#include <Wire.h>
#include <Adafruit_MCP4725.h>   //You must download this library in order for this code to work at all

Adafruit_MCP4725 dac;

//Motor Speeds
#define Drive_OFF 0                // drive motor at 0 rpm
#define Drive_LOW 1200             // drive motor at 1200 rpm
#define Drive_MED 1600             // drive motor at 1600 rpm
#define Drive_HIGH 2000            // drive motor at 2000 rpm
#define Drive_MAX 3100             // drive motor at 3100 rpm

//Arduino Pins
#define dirPin                   8  // stepper motor 1 direction input connected to pin 8
#define pulsePin                 9  // stepper motor 1 pulse input connected to pin 9
#define dirPin2                 10  // stepper motor 2 direction input connected to pin 10
#define pulsePin2               11  // stepper motor 2 pulse input connected to pin 11
#define driveDirectionPin       12  //
#define hallPin 18                  // the number of the hall effect sensor pin
#define ledPin 13                   // the number of the LED pin
#define switchPin 19                // the number of the switch pin

//Program Constants
#define delayTime               50  // delay time 50 ms for steps
#define stepsPerRevolution    7200  // number of steps to make full revolution
#define NUM_STEPS              900  // number of steps to make desired rotation
#define PULSE_DELAY_MS         600  // delay 0.6 microseconds (600 nanoseconds)

//Program Variables
int hallState = 0;                  // variable for reading the hall sensor status
int switchState = 0;                // variable for reading the switch status
int i = 0;                          // initialize i to 0
volatile int hallCount = 2;         // initialize hallCount to 2
unsigned long time_last_read = 0;
int hall_effect_interval = 2000;
int current_state = 0;

//Set-Up Function Block
void setup()
{
  //Dac Begin
  dac.begin(0x60);
```

```
  //Hall Sensor Interrupt
  attachInterrupt(digitalPinToInterrupt(hallPin), hallCountUp, RISING);

  //Configure Pin I/Os
  pinMode(driveDirectionPin, OUTPUT);
  pinMode(switchPin, INPUT_PULLUP);    // initialize the switch pin as an input with the internal pull-up resistor enabled
  pinMode(ledPin, OUTPUT);             // initialize the LED pin as an output
  pinMode(switchPin, INPUT);           // initialize the switch pin as an input
  pinMode(hallPin, INPUT);             // initialize the hall effect sensor pin as an input
  pinMode(dirPin, OUTPUT);             // initialize stepper motor 1 direction pin as an output
  pinMode(pulsePin, OUTPUT);           // initialize stepper motor 1 pulse pin as an output
  pinMode(dirPin2, OUTPUT);            // initialize stepper motor 2 direction pin as an output
  pinMode(pulsePin2, OUTPUT);          // initialize stepper motor 2 pulse pin as an output

  //Set Pin Default Values
  digitalWrite(driveDirectionPin, LOW);
  digitalWrite(dirPin, LOW);       // Initialize dir pin 1 to low
  digitalWrite(pulsePin, LOW);     // Initialize step pin 1 to low
  digitalWrite(dirPin2, LOW);      // Initialize dir pin 2 to low
  digitalWrite(pulsePin2, LOW);    // Initialize step pin 2 to low
  Serial.begin(9600);
  delay(1000);

  initializeRightZero();


  delay(100);
  time_last_read = millis();
}

void loop()
{
  i = 0;
  Serial.print(current_state);
  Serial.print('\t');
  Serial.print(hallCount);
  Serial.print('\t');
  Serial.print(hallCount % 2);
  Serial.print('\t');
  Serial.println(millis() - time_last_read);
if(current_state != hallCount)
  {
    switch(hallCount % 2)
    {
```

```
      case 0:
      Stop();
      setForward();
      steerRight();
      Go();
      current_state = hallCount;
      Serial.println("forwardd");
      break;

      case 1:
      Stop();
      setReverse();
      steerLeft();
      Go();
      current_state = hallCount;
      Serial.println("reversee");
    }
  }

  else
  {

  }

}

void initializeRightZero()
{
    switchState = digitalRead(switchPin);   // read the switch pin
if (switchState == LOW)
    {
       while(i == 0) {
         digitalWrite(dirPin, HIGH);              // set direction pin 1 low
         digitalWrite(dirPin2, LOW);              // set direction pin 2 high
             digitalWrite(pulsePin, LOW);         // set pulse pin 1 low
             delayMicroseconds(PULSE_DELAY_MS);   // delay 0.6 ms
             digitalWrite(pulsePin, HIGH);        // set pulse pin 1 high
             delayMicroseconds(PULSE_DELAY_MS);   // delay 0.6 ms
             digitalWrite(pulsePin2, HIGH);       // set pulse pin 2 high
             delayMicroseconds(PULSE_DELAY_MS);   // delay 0.6 ms
             digitalWrite(pulsePin2, LOW);        // set pulse pin 2 low
             delayMicroseconds(PULSE_DELAY_MS);   // delay 0.6 ms

            switchState = digitalRead(switchPin);   // read the switch pin
```

```
            //Serial.println("low");
            if (switchState == HIGH)
            {
               i = 1;
               //Serial.println("high");
            }
         }
    }
    digitalWrite(pulsePin, HIGH);   // set pulse pin 1 high
    digitalWrite(pulsePin2, HIGH);  // set pulse pin 2 high
    Serial.println("zero");
    Serial.println(i);
}

void Go()
{
  dac.setVoltage(Drive_LOW, false);
  delay(1000);
  dac.setVoltage(Drive_MAX, false);
  delay(100);
}

void setForward()
{
  digitalWrite(driveDirectionPin, LOW);
  delay(100);
}

void setReverse()
{
  digitalWrite(driveDirectionPin, HIGH);
  delay(100);
}

void Stop()
{
  dac.setVoltage(Drive_LOW, false);
  delay(1000);
  dac.setVoltage(Drive_OFF, false);
  delay(100);
}
```

```
void hallCountUp()
{
  if(millis() - time_last_read > hall_effect_interval)
  {
    hallCount++;
    time_last_read = millis();
  }

  else
  {

  }

}
```

Brake testing code with Wii nun chuck interface brushless motor

```
#include "Wire.h"
// Library for Wii Nunchuck
#include <Servo.h> // Library for controlin Servo or ESC
#include "WiiChuck.h"
WiiChuck chuck = WiiChuck();
Servo myservo;
const int dirPin = 7; //Direction state, this pin connect to the base of
boolean dir = 0; //State of the motor

int speed_valy; // Speed value y
int speed_valx; // Speed value x

int speed_val_cur_y = 1200; // Current speed value y
int speed_val_cur_x = 1200; // Current speed value x

int y = 0; // Jaystick value for upward
int x = 0; // Joystick value for downward

int time = 1; // Delay timer
void setup() {
  Serial.begin(115200);
  chuck.begin();
  chuck.update();
  myservo.attach(9); // ESC attached to 9 pin of Arduino
}
void loop() {
  // If you hold down Z button of Nunchuck you accelerate faster
  if ((chuck.buttonZ)||(chuck.buttonC)) {
    if (chuck.buttonZ) {
      Serial.print(" Z ");
      time = 1;
    }
    // If you hold down C button of Nunchuck you accelerate slower
    if (chuck.buttonC) {
      Serial.print(" C ");
      time = 1;
    }
  }
  else time = 1;
  delay(time);
  chuck.update();
  y = chuck.readJoyY(); //Pass the value from WiiChuck.h for upward
  x = chuck.readJoyX(); //Pass the value from WiiChuck.h for downward
```

```
if (y > x) //Check if y is being pressed
{
state(); //Call the state() function to switch up the direction

// Maps the joystick value to the speed value (max speed 2000) max posible
Serial.println();
speed_valy = map(y, 0, 123, 1200, 2000);
// This is what hapens in case we loose a Blue tooth conecction
if (y > 122) {
  speed_valy = 1200; // 60 means - no speed , motor stoped
  speed_val_cur_y = 1200; // 60 means - no speed , motor stoped
}
// This is whats hapens then we again have BT signal, it just restarts eve
if (y == 123) setup();
if (y <= 0) {
  speed_val_cur_y = 1200;
  speed_valy = 2000;
}
if (speed_val_cur_y < speed_valy) speed_val_cur_y = speed_val_cur_y + 1;
else speed_val_cur_y = speed_valy;
myservo.writeMicroseconds(speed_val_cur_y); // Here we control ESC
}

else if (x > y)// If x is being pressed
{
state(); //Call the state() function to switch up the direction

// Maps the joystick value to the speed value (max speed 2000) max posible
Serial.println();
speed_valx = map(x, 0, 123, 1200, 2000);
// This is what hapens in case we loose a Blue tooth conecction
if (x > 122) {
  speed_valx = 1200; // 60 means - no speed , motor stoped
  speed_val_cur_x = 1200; // 60 means - no speed , motor stoped
}
// This is whats hapens then we again have BT signal, it just restarts eve
if (x == 123) setup();
if (x <= 0) {
  speed_val_cur_x = 1200;
  speed_valx = 2000;
}
if (speed_val_cur_x < speed_valx) speed_val_cur_x = speed_val_cur_x + 1;
else speed_val_cur_x = speed_valx;
myservo.writeMicroseconds(speed_val_cur_x); // Here we control ESC
```

```
  //----- Printing to screen to see results ---------
  Serial.print("JoyY = "); //print out the speed, the buttons
  Serial.print(y);
  Serial.print(" ");
  Serial.print("Speed = ");
  Serial.print(speed_val_cur_y);

  Serial.print("JoyX = "); //print out the speed, the buttons
  Serial.print(x);
  Serial.print(" ");
  Serial.print("Speed = ");
  Serial.print(speed_val_cur_x);
}

//Function that check the direction of the motor
void state() {
switch(dir)
{
case 0:

digitalWrite(dirPin,HIGH);
dir=1;
break;

case 1:

digitalWrite(dirPin,LOW);
dir=0;
break;
}
}
```

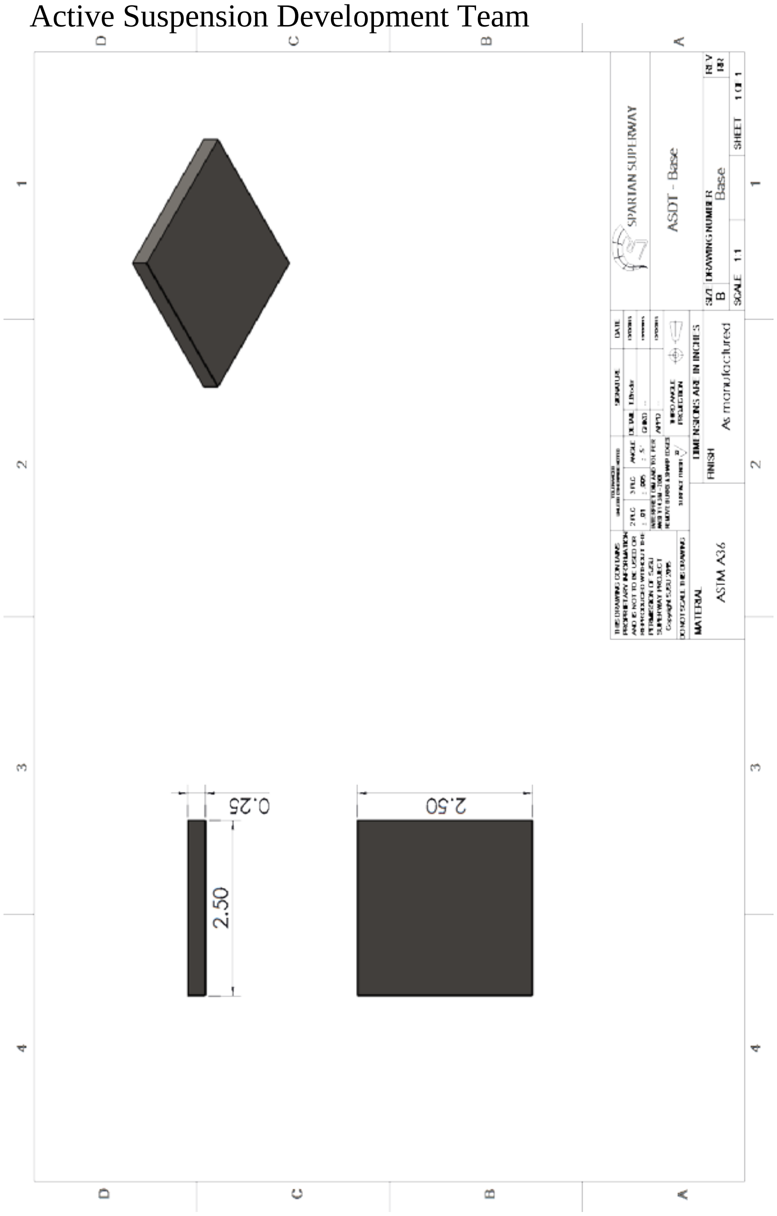
Ultrasonic testing code with servo

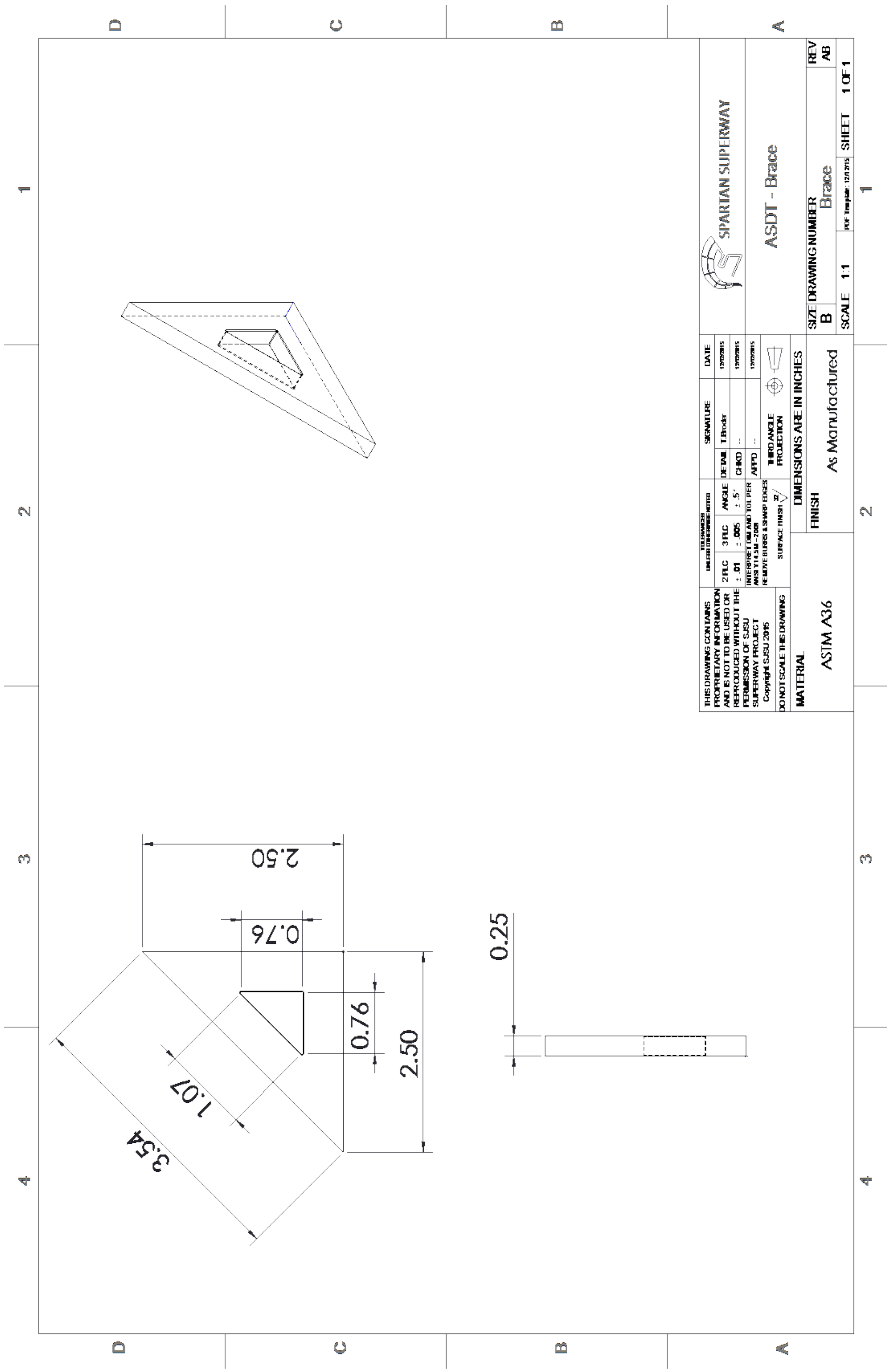
```
#include <Servo.h>
const int trigPin = 9;
const int echoPin = 10;
Servo myservo;
int pos = 0;
// defines variables
long duration;
long distance;
void setup() {
pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
pinMode(echoPin, INPUT); // Sets the echoPin as an Input
Serial.begin(9600); // Starts the serial communication
myservo.attach (8);

}
void loop() {

// Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
// Reads the echoPin, returns the sound wave travel time in microseconds
duration = pulseIn(echoPin, HIGH);
// Calculating the distance
distance= duration*0.034/2;
// Prints the distance on the Serial Monitor
Serial.print("Distance: ");
Serial.println(distance);



int am = 7;
if (am < distance){

  for(pos = 0; pos < 180; pos += 1)  // goes from 0 degrees to 180 degrees
{                                   // in steps of 1 degree
  myservo.write(pos);               // tell servo to go to position in variable 'pos'
     delay(15);                     // waits 15ms for the servo to reach the position
}
}
```

```
else {
for(pos = 180; pos>=1; pos-=1)      // goes from 180 degrees to 0 degrees
{
  myservo.write(pos);               // tell servo to go to position in variable 'pos'
      delay(15);                     // waits 15ms for the servo to reach the position
}
}
  }
```

Intermediate Active Suspension

Active Suspension Development Team





SPARTAN SUPERWAY
ASDT - Brace
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2 PLC ± .01
3 PLC ± .005
ANGLE ± .5°
INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009
REMOVE BURRS & SHARP EDGES
SURFACE FINISH
SIGNATURE
DATE
DETAIL T.Brodr
CHKD --
APPD --
THIRD ANGLE PROJECTION
DIMENSIONS ARE IN INCHES
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ASTM A36
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As Manufactured
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DRAWING NUMBER
Brace
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0.76
0.76
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3.54
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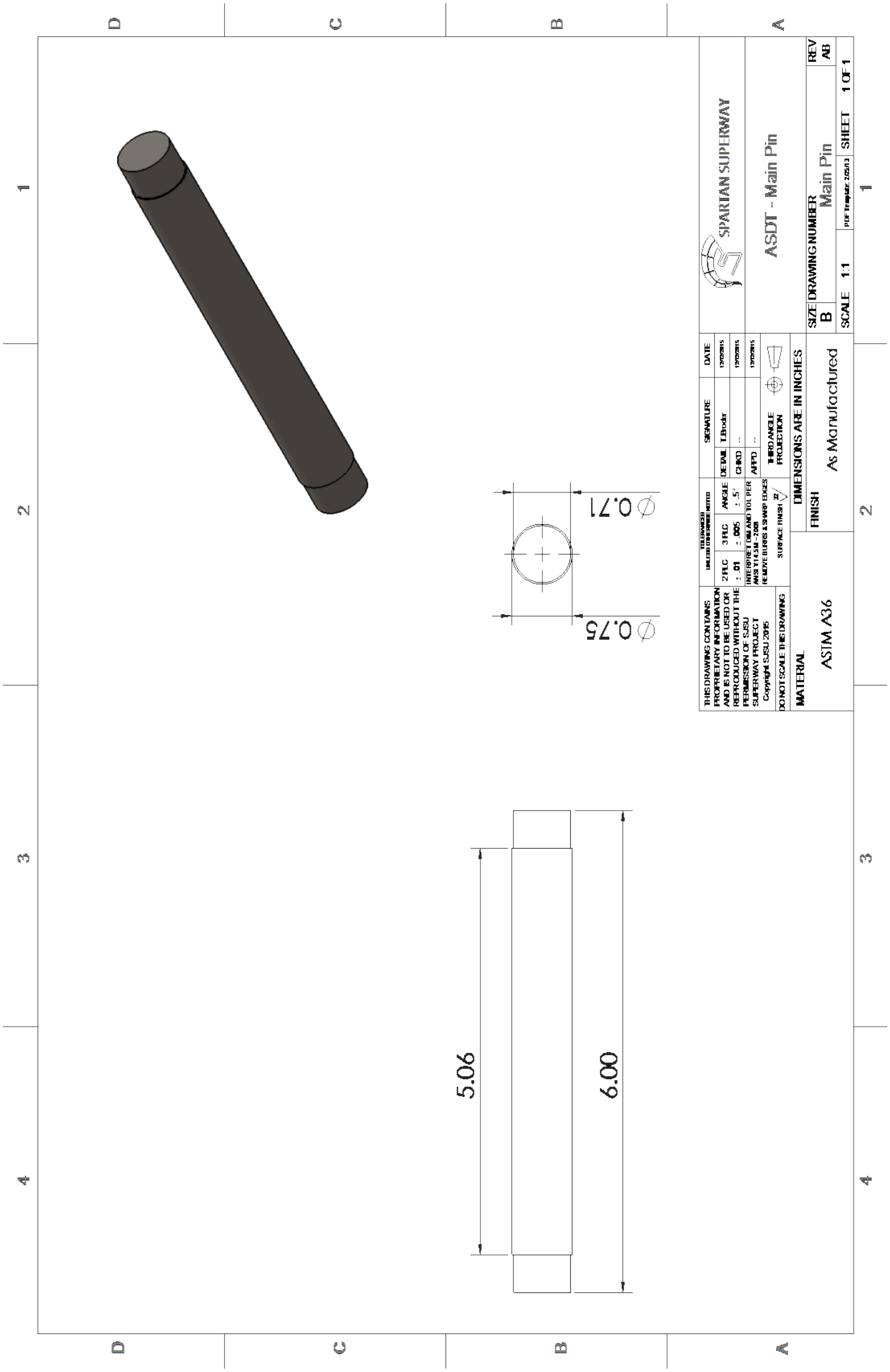

SPARTAN SUPERWAY
ASDT - Main Pin
Ø0.75
Ø0.71
5.06
6.00
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DIMENSIONS ARE IN INCHES
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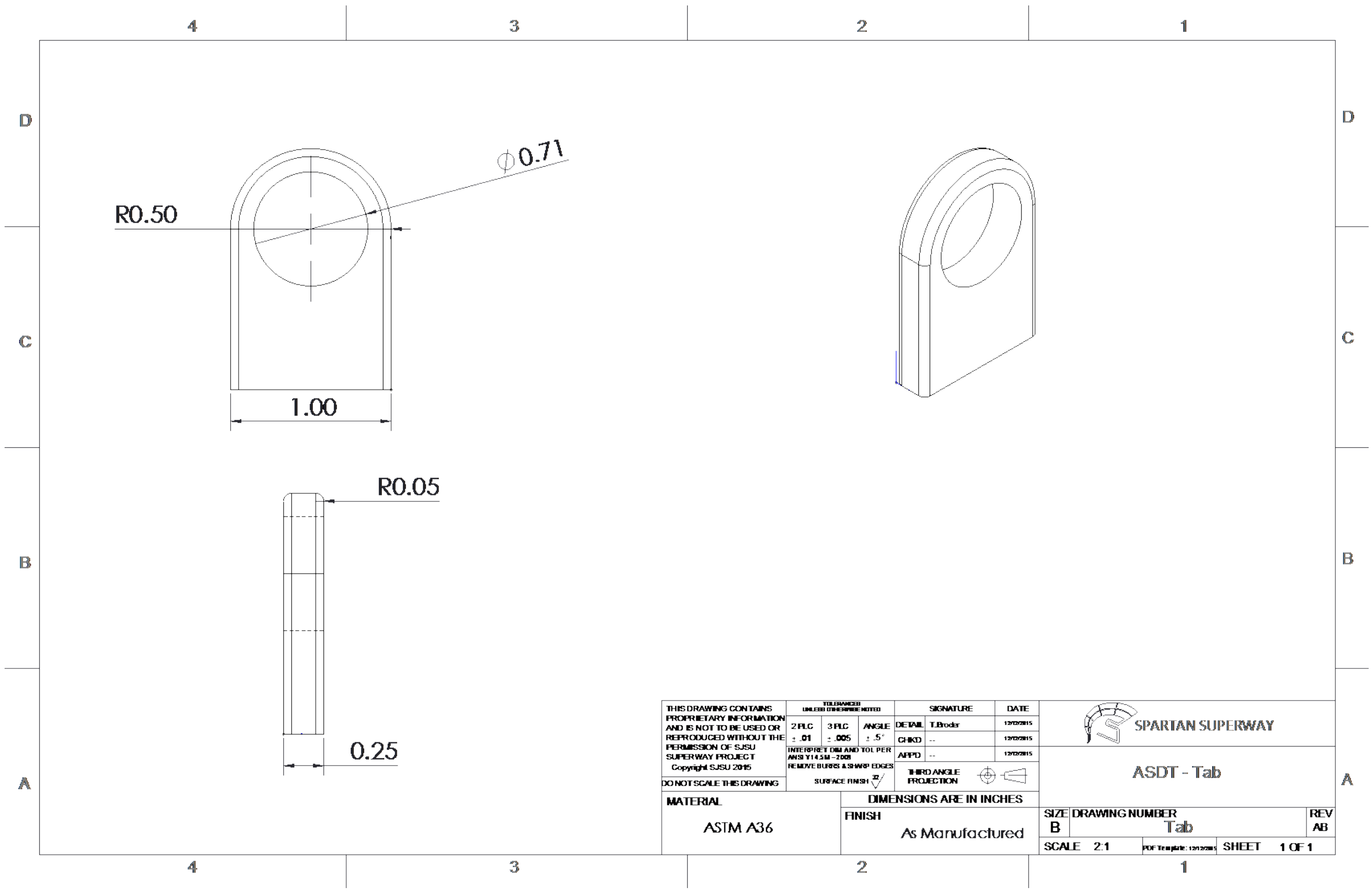
SHEET 1 OF 1


R0.50
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3 PLC ± .005
ANGLE ± .5°
INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009
REMOVE BURRS & SHARP EDGES
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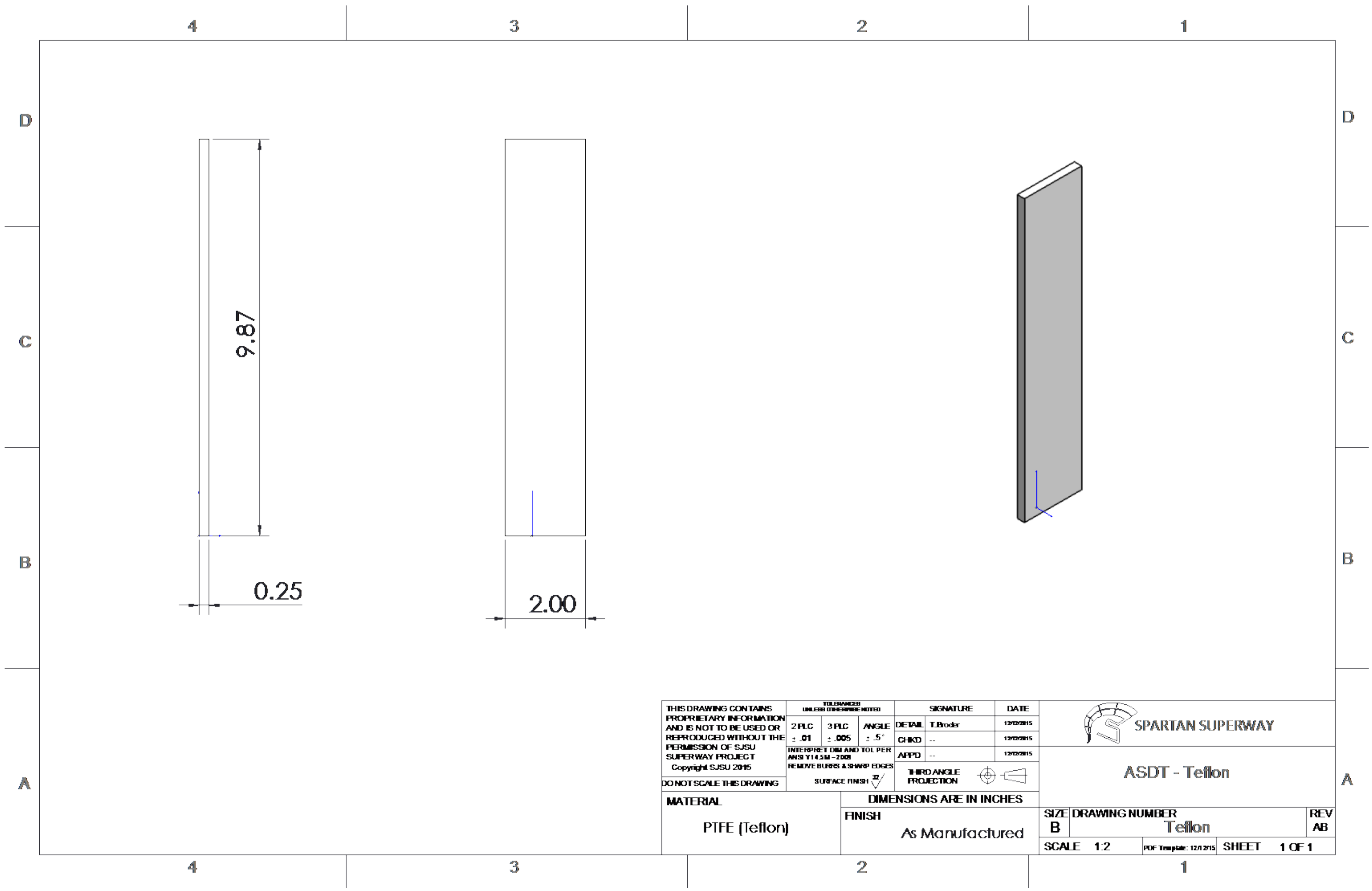
CHKD --
APPD --
THIRD ANGLE PROJECTION
SPARTAN SUPERWAY
ASDT - Tab
MATERIAL
ASTM A36
DIMENSIONS ARE IN INCHES
FINISH
As Manufactured
SIZE B
DRAWING NUMBER Tab
REV AB
SCALE 2:1
SHEET 1 OF 1



9.87
0.25
2.00
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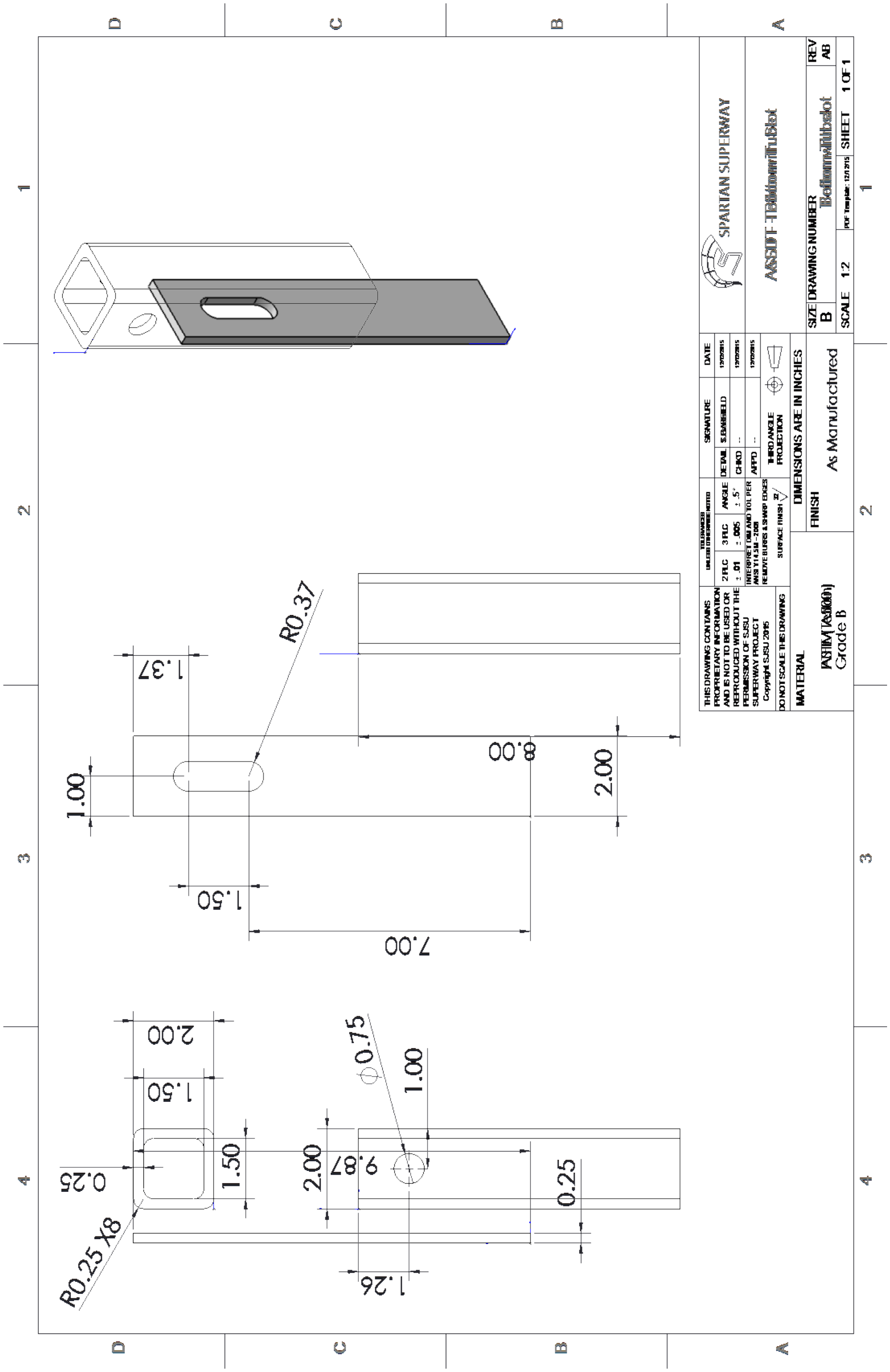
2 PLC ±.01
3 PLC ±.005
ANGLE ±.5°
INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009
REMOVE BURRS & SHARP EDGES
SURFACE FINISH
SIGNATURE
DATE
DETAIL T.Broder
CHKD --
APPD --
THIRD ANGLE PROJECTION
SPARTAN SUPERWAY
ASDT - Teflon
MATERIAL
PTFE (Teflon)
DIMENSIONS ARE IN INCHES
FINISH
As Manufactured
SIZE B
DRAWING NUMBER Teflon
REV AB
SCALE 1:2
SHEET 1 OF 1



SPARTAN SUPERWAY
R0.25 X8
0.25
1.50
2.00
1.50
2.00
9.87
ϕ0.75
1.00
0.25
1.26
1.00
1.37
R0.37
8.00
2.00
1.50
7.00
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MATERIAL
Grade B
FINISH
As Manufactured
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
SIGNATURE
DATE
DETAIL
CHKD
APPD
SIZE
B
DRAWING NUMBER
SCALE 1:2
SHEET 1 OF 1
REV
AB

```
/* Active Suspension Development Team
* Actuator code to keep cabin level
* Author: Scott Garfield (Team Lead); scott.garfield@sjsu.edu
* Date Last Revised: May 24, 2016
*/
// include the needed libraries:

#include <SPI.h>
#include <Wire.h>
#include <LSM6.h>
#include <PID_v1.h>

//Analog Inputs
#define POS_FRONT   8
#define POS_MIDDLE  9
#define POS_REAR    10
#define HALL_TOP    12
#define HALL_MIDDLE 13
#define HALL_BOTTOM 14

//actuator params
float OUT_MIN_FRONT = 13.8;
float OUT_MAX_FRONT = 21.71;
float OUT_MIN_REAR = 13.89;
float OUT_MAX_REAR = 21.70;
float IN_MIN = 9.9;
float IN_MAX = 13.78;
float target_front;
float target_rear;
float length_front;
float length_middle;
float length_rear;

//angle params
double theta = 0;
double filter_theta = 0;
double w0 = 0;
#define array_size 30
float divider = array_size + 0.00;
float ax [array_size];
float ay [array_size];
float az [array_size];
float gx [array_size];
float sumax;
float sumay;
float sumaz;
float sumgx;
```

```
float accel_x;
float accel_y;
float accel_z;
float gyro_x;
float offset_accel_x = 0.00;
float offset_accel_y = 0.00;
float offset_accel_z = 0.00;
float offset_gyro_x = 0.00;
float accel_scale = 16384.00;
float gyro_scale = 133.74;
float last_read;
float dt;
float pitch;
#define HPF 0.980
#define LPF (1.00-HPF)
#define delay_time 1
const float pi = 3.14;


// L9958 slave select pins for SPI
#define SS_M4 14
#define SS_M3 13
#define SS_M2 12
#define SS_M1 11
// L9958 DIRection pins
#define DIR_M1 2
#define DIR_M2 3
#define DIR_M3 4
#define DIR_M4 7
// L9958 PWM pins
#define PWM_M1 9
#define PWM_M2 10    // Timer1
#define PWM_M3 5
#define PWM_M4 6     // Timer0


// L9958 Enable for all 4 motors
#define ENABLE_MOTORS 8

int pwm1, pwm2, pwm3, pwm4;
boolean dir1, dir2, dir3, dir4;

//gyro stuff
LSM6 imu;
char report[80];
char info[80];
```

```
//Define Variables we'll be connecting to for PID
double Setpoint, Input, Output;
double Setpoint1, Input1, Output1;
int tilt_speed_new = 0;
int tilt_speed_old = 0;
int act_direction_new;
int act_direction_old;
//Specify the links and initial tuning parameters and direction
for PID
int tuner = 100;
PID myPID(&Input, &Output, &Setpoint, tuner, 0, 0, DIRECT);
int tuner1 = 20;
PID myPID1(&Input1, &Output1, &Setpoint1, tuner1, .75, 1.5,
REVERSE);
/*
 ' L9958 Config Register
 ' Bit
 '0 - RES
 '1 - DR - reset
 '2 - CL_1 - curr limit
 '3 - CL_2 - curr_limit
 '4 - RES
 '5 - RES
 '6 - RES
 '7 - RES
 '8 - VSR - voltage slew rate (1 enables slew limit, 0 disables)
 '9 - ISR - current slew rate (1 enables slew limit, 0 disables)
 '10 - ISR_DIS - current slew disable
 '11 - OL_ON - open load enable
 '12 - RES
 '13 - RES
 '14 - 0 - always zero
 '15 - 0 - always zero
 */  // set to max current limit and disable ISR slew limiting
 unsigned int configWord = 0b0000010000001100;

 //incase of failure: configWord = 0b0000010000001110;

void setup() {

 pinMode(22, OUTPUT);
 digitalWrite(22, LOW);


 // put your setup code here, to run once:
 pinMode(SS_M1, OUTPUT); digitalWrite(SS_M1, HIGH);  // HIGH =
not selected
```

```
 pinMode(SS_M2, OUTPUT); digitalWrite(SS_M2, HIGH);
 pinMode(SS_M3, OUTPUT); digitalWrite(SS_M3, HIGH);
 pinMode(SS_M4, OUTPUT); digitalWrite(SS_M4, HIGH);

 // L9958 DIRection pins
 pinMode(DIR_M1, OUTPUT);
 pinMode(DIR_M2, OUTPUT);
 pinMode(DIR_M3, OUTPUT);
 pinMode(DIR_M4, OUTPUT);

 // L9958 PWM pins
 pinMode(PWM_M1, OUTPUT);  digitalWrite(PWM_M1, LOW);
 pinMode(PWM_M2, OUTPUT);  digitalWrite(PWM_M2, LOW);    //
Timer1
 pinMode(PWM_M3, OUTPUT);  digitalWrite(PWM_M3, LOW);
 pinMode(PWM_M4, OUTPUT);  digitalWrite(PWM_M4, LOW);    //
Timer0

 // L9958 Enable for all 4 motors
 pinMode(ENABLE_MOTORS, OUTPUT);
digitalWrite(ENABLE_MOTORS, HIGH);  // HIGH = disabled

/******* Set up L9958 chips *********/


 SPI.begin();
 SPI.setBitOrder(LSBFIRST);
 SPI.setDataMode(SPI_MODE1);  // clock pol = low, phase = high

 // Motor 1
 digitalWrite(SS_M1, LOW);
 //SPI.transfer(configWord);
 SPI.transfer(lowByte(configWord));
 SPI.transfer(highByte(configWord));
 digitalWrite(SS_M1, HIGH);
 // Motor 2
 digitalWrite(SS_M2, LOW);
 SPI.transfer(lowByte(configWord));
 SPI.transfer(highByte(configWord));
 digitalWrite(SS_M2, HIGH);
 // Motor 3
 digitalWrite(SS_M3, LOW);
 SPI.transfer(lowByte(configWord));
 SPI.transfer(highByte(configWord));
 digitalWrite(SS_M3, HIGH);
 // Motor 4
 digitalWrite(SS_M4, LOW);
```

```
  SPI.transfer(lowByte(configWord));
  SPI.transfer(highByte(configWord));
  digitalWrite(SS_M4, HIGH);

  //Set initial actuator settings to pull at 0 speed for safety
  dir1 = 0; dir2 = 0; dir3 = 0; dir4 = 0; // Set direction
  pwm1 = 0; pwm2 = 0; pwm3 = 0; pwm4 = 0; // Set speed (0-255)

  digitalWrite(ENABLE_MOTORS, LOW);// LOW = enabled

  Serial.begin(9600);
  Wire.begin();

  if (!imu.init())
  {
    Serial.println("Failed to detect and initialize IMU!");
    while (1);
  }
  imu.enableDefault();

  //initialize the variables we're linked to
  Input = 0;
  Setpoint = 0.00;
  myPID.SetOutputLimits(-200,200);

  //turn the PID on
  myPID.SetMode(AUTOMATIC);

  //initialize the variables we're linked to
  Input1 = 0;
  Setpoint1 = 0.00;
  myPID1.SetOutputLimits(-200,200);

  //turn the PID on
  myPID.SetMode(AUTOMATIC);
  //turn the PID on
  myPID1.SetMode(AUTOMATIC);

  //set angle
  initAngle();
  set_offset();

} // End setup

void loop() {
```

```
 //get actuator positions
 getActsPos();
 //get IMU info
 get_info();
 //calculate angle based on accells
 pitch = (double)((atan2(accel_z,accel_y)*180/3.14) + 90)*-1;
 //calculate angle based on gyro
 theta = theta + gyro_x * dt/1000.000;
 //combine both calculations to compensate for errors
 filter_theta =HPF*(filter_theta + gyro_x*dt/1000) +
LPF*(pitch);

 //debug and status information
 //Serial.println("p");
 Serial.print(pitch);
 Serial.print("  ");
 //Serial.println("ft");
 Serial.print(theta);
 Serial.print("  ");
 Serial.print(filter_theta);
 Serial.print("  ");

  //send current angle to PID controller
  Input = filter_theta;
  //calculate output based on angle
  myPID.Compute();
  //set actuator speeds
  tilt_speed_new = Output;
  //tilt actuators
  tilt();
  //Serial.println("Tilt Speed");
  Serial.println(tilt_speed_new);


}//end void loop

void tilt() //this fucntion tilts the cabin
{
 //PID values determines titl direction and speed
 if(tilt_speed_new > 0)
 {
   act_direction_new = 0;
   dir1 = 0, dir2 = 1;
 }

 else
 {
```

```
   act_direction_new = 1;
   dir1 = 1, dir2 = 0;
 }

 pwm1 = abs(tilt_speed_new);
 pwm2 = abs(tilt_speed_new);

 if(tilt_speed_new != tilt_speed_old || act_direction_new !=
act_direction_old) //status check to avoid uneccessary commands
 {
   digitalWrite(DIR_M1, dir1);
   analogWrite(PWM_M1, pwm1);
   digitalWrite(DIR_M2, dir2);
   analogWrite(PWM_M2, pwm2);// write to pins

   tilt_speed_old = tilt_speed_new;
   act_direction_old = act_direction_new;
 }
 else
 {

 }

}

void set_offset() //zeros the sensors to eliminate error from
mounting sensors
{
 delay(200);
 get_info();

 offset_accel_x = accel_x;
 offset_accel_y = accel_y;
 offset_accel_z = accel_z - 1;
 offset_gyro_x = gyro_x;
 Serial.println("Now Offset");

 Serial.println(offset_accel_x);
 Serial.println(offset_accel_y);
 Serial.println(offset_accel_z);
 Serial.println(offset_gyro_x);

}

void reset_variables() //resets critical angle variables for
when values drift after long runtime
{
```

```
 filter_theta = 0;
 theta=0;
 w0=0;
 Serial.println("Variables Reset");
 delay(500);
}

void get_info() //gets sensor information and takes a 30 sample
average to act as a filter
{
 last_read = millis();

 for ( int i = 0; i < array_size; i++)
 {
   imu.read();
   ax[i] = imu.a.x / accel_scale;
   ay[i] = imu.a.y / accel_scale;
   az[i] = imu.a.z / accel_scale;
   gx[i] = imu.g.x / gyro_scale;

   delay(delay_time);
 }



 for ( int i = 0; i < array_size; i++)
 {
   sumax = sumax + ax[i];
   sumay = sumay + ay[i];
   sumaz = sumaz + az[i];
   sumgx = sumgx + gx[i];
 }
 /*Serial.println(sumax);
 Serial.println(sumay);
 Serial.println(sumaz);
 Serial.println(sumgx);*/

 accel_x = (sumax / divider) - offset_accel_x;
 accel_y = (sumay / divider) - offset_accel_y;
 accel_z = (sumaz / divider);
 gyro_x = (sumgx / divider) - offset_gyro_x;

 sumax = 0;
 sumay = 0;
 sumaz = 0;
 sumgx = 0;
```

```
 dt = millis() - last_read;

 /*Serial.print("x ");
 Serial.println(accel_x);
 Serial.print("y ");
 Serial.println(accel_y);
 Serial.print("z ");
 Serial.println(accel_z);
 Serial.print("gx ");
 Serial.println(gyro_x);
 Serial.println("");*/


}

void getActsPos() //calucates actuator lengths
{
 //get actuator positions
 length_front = ((float) (analogRead(POS_FRONT)/602.00)) *
(OUT_MAX_FRONT - OUT_MIN_FRONT) + OUT_MIN_FRONT;
 length_middle = ((float) ((analogRead(POS_MIDDLE))/870.00)) *
(IN_MAX - IN_MIN) + IN_MIN;
 length_rear = ((float) (analogRead(POS_REAR)/611.00)) *
(OUT_MAX_REAR - OUT_MIN_REAR) + OUT_MIN_REAR;
}

void initAngle()  //intializes the system to be perpendicular
with the rail. takes the assumption that it is initialized on
level track
{
 getActsPos();
 Input1 = 90.00 - ((180.00 / pi) *
acos(((sq(sqrt(sq(length_middle) + sq(2.00))) + sq(12.00) -
sq(length_front)) / (2.00 * sqrt(sq(length_middle) + sq(2.00)) *
12.00))) + ((180.00 / pi) * asin((2.00)/(sqrt(sq(length_middle)
+ sq(2.00))))));
 while(Input1 >= 0.5 || Input1 <= -0.5)
 {
   myPID1.Compute();
   tilt_speed_new = Output1;
   tilt();
   getActsPos();
   Input1 = 90.00 - ((180.00 / pi) *
acos(((sq(sqrt(sq(length_middle) + sq(2.00))) + sq(12.00) -
sq(length_front)) / (2.00 * sqrt(sq(length_middle) + sq(2.00)) *
12.00))) + ((180.00 / pi) * asin((2.00)/(sqrt(sq(length_middle)
+ sq(2.00))))));
```

```
    Serial.println(Input1);
  }
  tilt_speed_new = 0;
  tilt();
}
```

Intermediate Cabin

Acknowledgement:

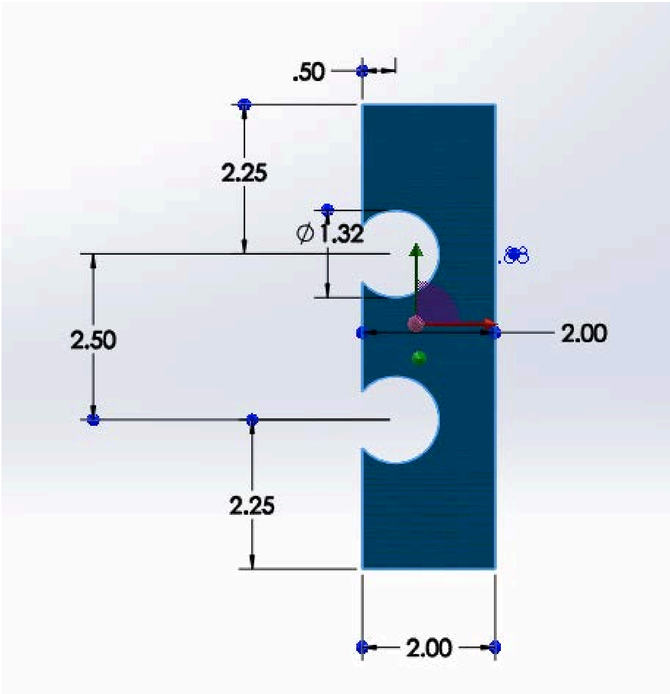
Thank you Scott Rechenmacher for the use of your tools and guidance so we did not chop fingers off. And everyone else in the class who offered advice and help with the cabins.

Gantt Charts for Spring Semester 2016

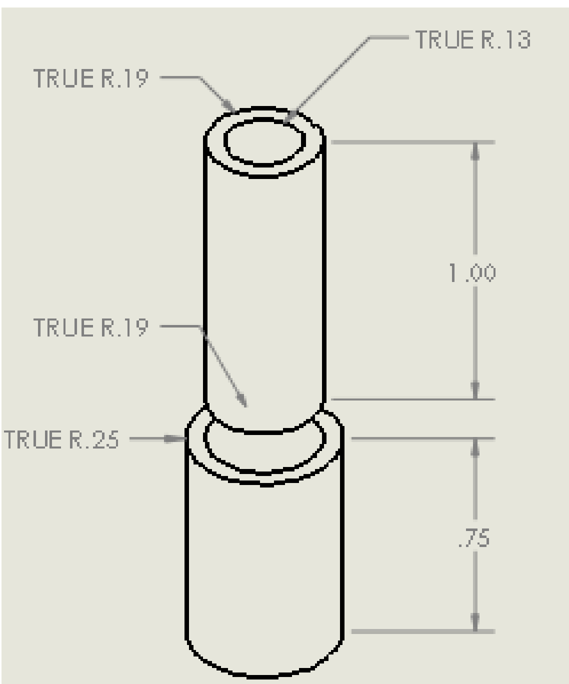
Project Name	Start Date	End Date	Time	%	Team
Material Finialization	18-Dec	1-May	18-May	100	All
Wooden Materials	18-Dec	18-Apr	35	100	All
Interior Materials	30-Mar	22-Apr	35	100	All
Miscellaneous Pieces	18-Dec	29-Apr	35	100	All
1/4 Scale model					All
Cardboard model	3-Feb	16-Mar	30	100	All
Cutting parts	3-Feb	16-Mar	30	100	All
Assembly	3-Feb	9-Mar	30	100	All
Modifications	3-Feb	16-Mar	30	100	All
Wooden Shell	3-Feb	22-Apr	60	100	All
Tracing Design onto Plywood Pieces	3-Feb	11-Apr	21	100	All
Cutting Plywood Pieces	3-Feb	11-Apr	50	100	All
Prep for Asssembly	29-Feb	11-Apr	7	100	All
Interior	1-Mar	6-May	99	100	All
Create interior pieces	1-Mar	6-May	14	100	All
Manufacture Pieces	13-Apr	6-May	60	100	All
Clean-Up Parts	15-Apr	6-May	14	100	All
Assembly	1-Mar	13-May	19	100	All
Wood pieces	1-Mar	13-May	50	100	All
Assemble Shells	1-Mar	13-May	50	100	All
Reinforce Shell #2	1-Mar	13-May	50	100	All
Paint Shells	28-Mar	13-May	50	100	All
Assemble Interior Pieces	4-Apr	13-May	12	100	All

Project Name	Start Date	End Date	Time	%	Team
Track Model					All
Wooden Shell	18-Apr	13-May	29	100	All
Tracing Design onto Plywood Pieces	18-Apr	13-May	30	100	All
Cutting Plywood Pieces	18-Apr	13-May	30	100	All
Prep for Asssembly	18-Apr	13-May	30	100	All
Assembly	18-Apr	13-May	30	100	All
Prepare All Pieces for Assembly	18-Apr	13-May	30	100	All
Assemble Shells	18-Apr	13-May	30	100	All
Reinforce Shell #2	18-Apr	13-May	30	100	All
Paint Shells	18-Apr	13-May	30	100	All
Test Completed Product on Rail System	18-Apr	13-May	30	100	All
Presentation 4	2-Mar	9-Mar	7	100	All
Presentation 5	10-Mar	13-Apr	14	100	All
Student Conference	14-Apr	13-May	14	100	All

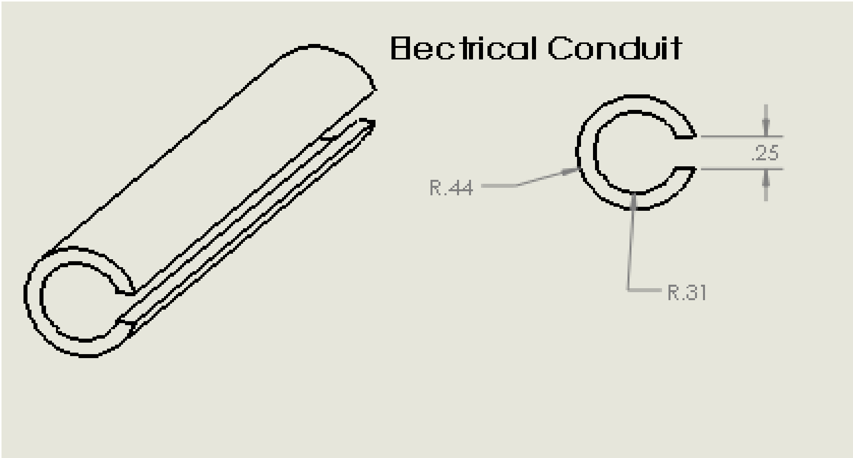
Intermediate Wayside Power



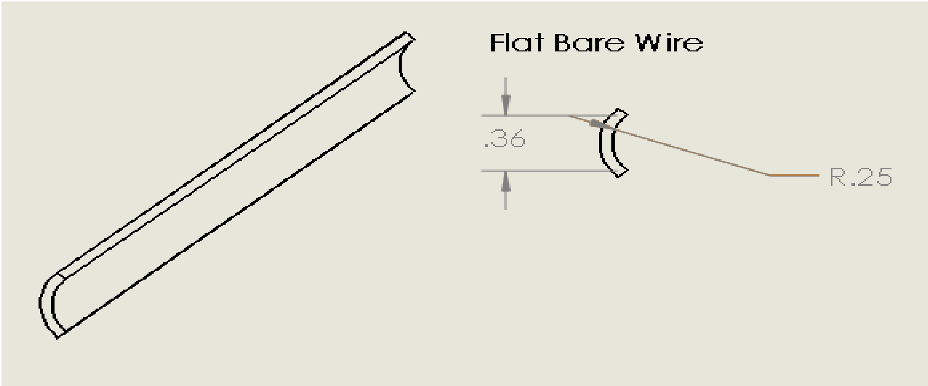
The final design on the bracket



The collector shoe assembly



The Electrical Conduit that housed the current and return rails



The bare copper wire that was used as the wayside rails

<u>Torsion</u>

Experiment Data for Angle of Twist

41.69" Circular Pipe Calibration Specimen		
Torque	Angle of Twist	Calculated Angle
750	0	0
1500	0.2	0.26
2250	0.4	0.52
3000	0.7	0.79
3750	1	1.05
4500	1.3	1.31
5250	1.6	1.57
6000	1.9	1.83
6750	2.2	2.09
7500	2.5	2.35
8250	2.8	2.61

53.69" Circular Pipe Calibration Specimen		
Torque	Angle of Twist	Calculated Angle
750	0	0
1500	0.3	0.33
2250	0.6	0.67
3000	1	1.01
3750	1.3	1.34
4500	1.6	1.68
5250	1.9	2.02
6000	2.2	2.35
6750	2.5	2.69
7500	2.9	3.02
8250	3.4	3.36

70" Circular Pipe Intermediate Specimen		
Torque	Angle of Twist	Calculated Angle
750	0	0
1500	0.4	0.44
2250	0.8	0.88
3000	1.3	1.31
3750	1.7	1.75
4500	2.2	2.19
5250	2.7	2.63
6000	3.1	3.07
6750	3.4	3.51
7500	3.9	3.95
8250	4.4	4.39

63" Square Intermediate Specimen		
Torque	Angle of Twist	Calculated Angle
750	0	0
1500	0.3	0.3
2250	0.8	0.6
3000	1.2	1
3750	1.5	1.3
4500	1.8	1.6
5250	2.1	1.9
6000	2.5	2.2
6750	2.8	2.5
7500	3.1	2.8
8250	3.4	3.2
9000	3.7	3.5
9750	4	3.8
10500	4.2	4.1
11250	4.6	4.4
12000	4.9	4.7
12750	5.3	5

Experiment Data for Strain

70" Circular Pipe Intermediate Specimen				
Torque	Microstrain			
	[Measured]	[Calculated]	[ANSYS]	Error
0	0	0	0	0.0%
750	194	110	111	74.8%
1500	331	219	221	49.8%
2250	466	329	332	40.4%
3000	598	439	442	35.3%
3750	737	549	553	33.3%
4500	872	658	663	31.5%
5250	999	768	774	29.1%
6000	1144	878	885	29.3%
6750	1274	998	995	28.0%
7500	1408	1097	1106	27.3%
8250	1541	1207	1216	26.7%
9000	1684			
9750	1853			
10500	1960			

63" Square Pipe Intermediate Specimen			
Torque	Microstrain		
	[Measured]	[ANSYS]	Error
0	0	0	0.0%
750	160	90	77.8%
1500	253	181	39.8%
2250	348	271	28.4%
3000	442	361	22.4%
3750	539	452	19.2%
4500	634	542	17.0%
5250	727	632	15.0%
6000	824	723	14.0%
6750	926	813	13.9%
7500	1016	903	12.5%
8250	1133	994	14.0%
9000	1227		
9750	1344		

Appendix B: Small Scale

Small Scale Controls

Arduino Code

```
#include <TimerOne.h>
#include <ServoTimer2.h>

// Define vehicle id number
#define vehicle_number  2

// Pin Definitions
#define barcode_sensor_1    2   // Interrupt Pin
#define barcode_sensor_2    3   // Interrupt Pin
#define motor_enco_1a      A2  // Interrupt pin using custom interrupt setup
#define motor_enco_1b      A3  //  (Motor 2 encoder on pins A4, A5 - not used)
#define motor1_dir         A0  //
#define motor2_dir         A1  //
#define motor1             9   // PWM pin
#define motor2             10  // PWM pin
#define servo_pin          11  // PWM Pin
#define trigger            12  //
#define echo               13  //


//System Wide Global Variables
int state = 0;  // 0 = Offline, 1 = Online/Idle, 2 = Online/Active
unsigned int track_location = 0;
unsigned int instruction[25][2];
int instruction_step = 0;

// Control System Variables
int sense_rpm = 0, pwm_out = 0, rpm_err;
int acc_err, enc_count, set_rpm;
const float v_Kp = 0.01, v_Ki = 0.1;
boolean STOP = true;

boolean enc_prestate;
boolean servo_switch;

int head_distance = 60;
int last_hDistance;
const int dist_limit = 3;
const int dist_thresh = 16;


// Speed Controller Variables
```

```
unsigned long last_time;
long period = 1000 / 20;
int control_rpm;


// Communication Variables
String input_string = "";        // String to hold incoming data
boolean string_complete = false;  // Flag for checking if string is complete
boolean string_enable = false;    // Flag for stream in

byte *_track    = new byte[2];  // Temporary char arrays for
byte *_distance = new byte[2];  // parsing chars into 16 bit
byte *_speed    = new byte[2];  // data types
byte *_m_count  = new byte[2];


//Barcode Scanner Variables
const int max_bit_count = 16;
unsigned int thresh_min = 3;
unsigned int thresh_max = 200;

unsigned int bit_count1, bit_count2;
unsigned long last_tick1, last_tick2;
unsigned int times1[max_bit_count];
unsigned int times2[max_bit_count];


//Hardware Interrupts
void barcode(); //Barcode change interrupt
void encoder(); //Encoder rising interrupt
ServoTimer2 servo;

void setup() {
  // Disable interrupts
  noInterrupts();

  // Set fast pwm pins
  PCICR |= 0x01;  PCMSK1 |= 0x08;

  // Timer Counter Control Register for Timer0
  //  Set clock mode for timer one
  //TCCR0A = 0xa1;  TCCR0B = 0x01;

  // Set clock speed
  //  - A: First timer limit
  //  - B: PWM Duty cycle
  //    Used for motor speed pwm control
  //OCR0A = 0;      OCR0B = 0;      // overflow 1, 0% duty cycle
```

```
// Component Pinmodes
pinMode(barcode_sensor_1, INPUT);  // Left Barcode Scanner
pinMode(barcode_sensor_2, INPUT);  // Right Barcode Scanner
pinMode(servo_pin, OUTPUT);        // Servo control
pinMode(motor_enco_1a, INPUT);     // Encoder interrupt
pinMode(motor_enco_1b, INPUT);     // Encoder interrupt
pinMode(motor1, OUTPUT);           // motor 1 pwm
pinMode(motor2, OUTPUT);           // motor 2 pwm
pinMode(motor1_dir, OUTPUT);       // motor 1 direction
pinMode(motor2_dir, OUTPUT);       // motor 2 direction
pinMode(trigger, OUTPUT);          // Ultrasonic trigger
pinMode(echo, INPUT);              // Ultrasonic echo

digitalWrite(motor1_dir, HIGH);    // Set initial motor1 direction
digitalWrite(motor2_dir, LOW);     // Set initial motor2 diection
digitalWrite(motor_enco_1a, LOW);  // Set interrupt condition
digitalWrite(motor_enco_1b, LOW);  //   or disable pullup resistor

servo.attach(servo_pin);


// Set TimerOne to signal at 20Hz frequency (20 times/sec)
Timer1.initialize(1000000 / 1000);


// Hardware Interrupts
attachInterrupt(digitalPinToInterrupt(barcode_sensor_1), barcode1, CHANGE);
attachInterrupt(digitalPinToInterrupt(barcode_sensor_2), barcode2, CHANGE);

// Set up External Interrupts on Analog pins
PCMSK1 |= 0b00111100;
PCICR  |= 0b00000010;

// Serial Communication
Serial.begin(9600);


// Set Initial Variables
Sta
te = 1;
enc_count = 0;
set_rpm = 0;

// Start timer1 PWM for Motors
Timer1.pwm(motor1, 0);
Timer1.pwm(motor2, 0);
```

```
  // Send online signal
  byte checksum = 0x00;

  checksum = 0x00 + (byte)vehicle_number + 0x30 + (byte)state;

  Serial.print((char)0x81);           //Message Start
  Serial.print((char)0x00);           //  0 Receiver
  Serial.print((char)vehicle_number);  //  1 Sender
  Serial.print((char)0x30);           //  2 Type
  Serial.print((char)state);          //  3 Status
  Serial.print((char)(0 - checksum));  //  4 Checksum
  Serial.println((char)0x7E);          //Message End


  // Reenable interrupts
  interrupts();
}

void loop() {
  // Switching Signal
  if(track_location == instruction[instruction_step][0] && state == 2) {
    servo_switch = (boolean)instruction[instruction_step][1];
    instruction_step++;

    if(instruction[instruction_step][0] == 0xFF){
      state = 1;    sendState();   // Change state of vehicle
      if(digitalRead(instruction[instruction_step][1]+2) == 1)
        set_rpm = 0;    STOP = true;    // Stop vehicle
    }
  }

  // Run speed controller
  if (millis() - last_time >= period)
    controlsUpdate();
}

void controlsUpdate(){
  // Collision Avoidance
  head_distance = ultrasonic(); //Update distance ahead of vehicle

  if (head_distance > dist_thresh)
    control_rpm = set_rpm;
  else if (head_distance <= dist_thresh && head_distance >= dist_limit)
    control_rpm = set_rpm * (head_distance * head_distance) / (dist_thresh * dist_thresh);
  else if (head_distance < dist_limit){
    control_rpm = 0;
    rpm_err = 0; acc_err = 0;
```

```
  }


  // PI Speed Controller
  //count1 *= 5.27; //20(20hz) * 60(min) / 3(pole) / 75.81 ~94ticks/cycle or 1880/sec 4.133rev/s at
wheels at max pwm
  sense_rpm = (float)( enc_count / 6 ) * ( 1000.0 / (millis() - last_time));

  rpm_err = control_rpm - sense_rpm;
  acc_err += rpm_err;
  pwm_out = (v_Kp * rpm_err) + (v_Ki * acc_err);


  // PWM range limiter
  if (pwm_out >= 255)     { pwm_out = 255;    }
  else if (pwm_out <= 0)  { pwm_out = 0;      }

  // Update Motor power outputs
  if (STOP) {
    rpm_err = 0; acc_err = 0;
    Timer1.setPwmDuty(motor1, 0);
    Timer1.setPwmDuty(motor2, 0);
  }
  else if ( pwm_out > 4 && pwm_out <= 200) {
    Timer1.setPwmDuty(motor1,  pwm_out    * 4);
    Timer1.setPwmDuty(motor2, (pwm_out - 4) * 4);
  }
  else {
    Timer1.setPwmDuty(motor1, pwm_out * 4);
    Timer1.setPwmDuty(motor2, pwm_out * 4);
  }

  // Servo control using clock signal
  if (servo_switch)
    servo.write(900);
  else
    servo.write(2100);

  //Serial.println((String)"cRPM: " + control_rpm + " sRPM: " + sense_rpm + " PWM_out: " + pwm_out +
" eRPM: " + rpm_err + " eAcc: " + acc_err + " hDist " + head_distance);

  enc_count = 0;
  last_time = millis();
}

void serialEvent() {
  byte checksum = 0x00;
```

```
  while (Serial.available())
  {
    // Get new byte:
    char char_in = (char)Serial.read();

    // End message
    if (char_in == (char)0x7E && string_enable == true) {
      string_complete = true;
      string_enable = false;

      // Calculate checksum
      if (checksum == 0)
        processData();
      else
        Serial.println("message not received");
    }

    // Record incomming message
    if (string_enable == true) {
      input_string += char_in;
      checksum += (byte)char_in;
    }

    // Start Message
    if (char_in == (char)0x81 && string_enable == false) {
      string_enable = true;
      input_string = "";
    }
  }
}

// Serial output function
void sendMessage(String message) {
  byte checksum = 0x00;

  // Write out message start character
  Serial.print((char)0x81);

  // Write message
  for (int ltr = 0; ltr < message.length(); ltr++) {
    Serial.print((char)message[ltr]);
    checksum += message[ltr];
  }

  // Write out checksum and message end character
  Serial.print((char)0 - checksum);
  Serial.println((char)0x7E);
}
```

```
void processData() {
  char *temp = new char[2];

  if ((int)input_string[0] == vehicle_number || input_string[0] == 0xF0) {
    if (input_string[2] == (char)0x1F) {     //Set all
      temp[0] = input_string[4];
      temp[1] = input_string[3];
      memcpy(&track_location, temp, sizeof(int));
      temp[0] = input_string[8];
      temp[1] = input_string[7];
      memcpy(&set_rpm, temp, sizeof(int));


    } else if (input_string[2] == (char)0x05) { // Send Current State
      sendState();

    } else if (input_string[2] == (char)0x01) { // Go
      temp[0] = input_string[4];
      temp[1] = input_string[5];
      memcpy(&set_rpm, temp, sizeof(int));
      STOP = false;

    } else if (input_string[2] == (char)0x02) { // Emergency Stop
      set_rpm = 0;
      STOP = true;

    } else if (input_string[2] == (char)0x07) { // Switch Servo
      servo_switch = !servo_switch;

    } else if (input_string[2] == (char)0x10) { // Receive Instructions
      int message_pos = 4;
      int instruct_step = 0;

      while (message_pos < input_string.length()-1) {
        instruction[instruct_step][0] = (input_string[message_pos]<<8 & 0xFF) |
(input_string[message_pos+1] & 0xFF);
        instruction[instruct_step][1] = input_string[message_pos + 2];

        message_pos += 3;
        instruct_step++;
      }

      instruction[instruct_step][0] = 0xFF;

      instruction_step = 0;
      state = 2;
```

```
      for (int i = 0; i < instruct_step; i++)
        Serial.println((String)"Track: " + instruction[i][0] + " Side: " + instruction[i][1]);
    }
  }
}

void sendState() {
  byte checksum = 0x00;
  memcpy(_track, &track_location, sizeof(int));
  memcpy(_speed, &sense_rpm, sizeof(int));

  checksum = 0x00 + (byte)vehicle_number + 0x05 + (byte)state + (byte)_track[1] + (byte)_track[0] +
(byte)_speed[1] + (byte)_speed[0];

  Serial.print((char)0x81);            //Message Start
  Serial.print((char)0x00);            //  0 Receiver
  Serial.print((char)vehicle_number);  //  1 Sender
  Serial.print((char)0x05);            //  2 Type
  Serial.print((char)state);           //  3 Status
  Serial.print((char)_track[1]);       //  4 Track
  Serial.print((char)_track[0]);       //  5
  Serial.print((char)_speed[1]);       //  6 State
  Serial.print((char)_speed[0]);       //  7
  Serial.print((char)(0 - checksum));  //  8 Checksum
  Serial.println((char)0x7E);          //Message End
}

void calculateBarcode(unsigned int times[]) {
  int time_short = times[0], time_long = times[0];
  int u_time = 0;
  track_location = 0;

  // Find the minima and maxima in recorded number range
  for (int idx = 1; idx < max_bit_count; idx++) {
    if (times[idx] < time_short && times[idx] != 0)
      time_short = times[idx];

    if (times[idx] > time_long)
      time_long = times[idx];
  }

  // Calculate the time of a short bar
  u_time = (time_short + time_long) / 3;

  // Convert recoreded times into an integer
  // by using bit math.
  for (int idx = 0; idx < max_bit_count; idx++) {
    if (times[idx] > u_time * 1.3){
```

```
            track_location |= (1 << idx);
        }else{
            track_location |= (0 << idx);
        }
    }

    // Clear variables
    memset(times, 0, sizeof(int) * max_bit_count);
    bit_count1 = 0;
    bit_count2 = 0;

    // Send current state information
    sendState();
}

void barcode1() {
    unsigned long current_time = millis();
    unsigned long d_time = current_time - last_tick1;

    if(bit_count1 < max_bit_count && d_time > thresh_min){
        if (digitalRead(barcode_sensor_1) == 1)
            times1[bit_count1] = d_time;
        else
            times1[bit_count1] = (1.9 * d_time);

        last_tick1 = current_time;
        bit_count1++;
    }

    if(d_time > thresh_max)
        bit_count1 = 0;

    if(bit_count1 == max_bit_count)
        calculateBarcode(times1);
}

void barcode2() {
    unsigned long current_time = millis();
    unsigned long d_time = current_time - last_tick2;

    if(bit_count2 < max_bit_count && d_time > thresh_min){
        if (digitalRead(barcode_sensor_2) == 1)
            times2[bit_count2] = d_time;
        else
            times2[bit_count2] = (1.9 * d_time);

        last_tick2 = current_time;
        bit_count2++;
```

```
  }

  if(d_time > thresh_max)
    bit_count2 = 0;

  if(bit_count2 == max_bit_count)
    calculateBarcode(times2);
}

ISR(PCINT1_vect) {
  if (digitalRead(motor_enco_1a) == HIGH && enc_prestate)
    if (digitalRead(motor_enco_1b) == HIGH)
      Serial.println("enco++");
    else
      enc_count--;

  if (digitalRead(motor_enco_1a) == LOW)
    enc_prestate = true;
  else
    enc_prestate = false;
}

int ultrasonic() {
  digitalWrite(trigger, LOW);
  delayMicroseconds(2);
  digitalWrite(trigger, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigger, LOW);

  int duration = pulseIn(echo, HIGH, 3000);

  if(duration > 0)
    return float(duration / 58.2);
  else
    return 30;
}
```

Processing Code

Controls

```
import processing.serial.*;
import processing.net.*;
import pathfinder.*;
import mqtt.*;

MQTTClient mqtt_client;
Client server_socket;
Serial xbee_comm;
```

```
Car[] vehicle;

// Create button for vehicles, stations, and controls
//   Button button_name = new Button(x_position, y_position, width, height, shape(sides), "Label",
font_size, color(0,0,0));
   Button[] vehicle_button = new Button[10];
   Button[] station_button = new Button[8];

// Contorl Buttons
   Button up    = new Button(1218, 370, 30, 30, 3);
   Button down  = new Button(1218, 535, 30, -30, 3);
   Button go    = new Button(1056, 560, 150, 50, 4, "Go", 35, color(50, 180, 50));
   Button stop  = new Button(1256, 560, 150, 50, 4, "Stop", 35, color(180, 50, 50));
   Button servo = new Button(1056, 620, 150, 50, 4, "Switch", 35, color(50, 180, 200));
   Button state = new Button(1256, 620, 150, 50, 4, "Status", 35, color(200, 200, 50));
   Button all = new Button(1365, 290, 36, 36, 1, "A", 24, color(235, 0, 0));


// Controls variables
   int v_focus = 0;
   int set_speed = 0;
   PImage logo;
   int _mouseX, _mouseY;


// Control panel positioing variable
   int control_x = 1020;

   boolean debug_mode = false;
   boolean mqtt_server = false;
   String mqttTopic = new String();


// Pathfinding Library setup
   Graph[] gs = new Graph[4];
   PImage[] graphImage = new PImage[4];
   int start[] = new int[4];
   int end[] = new int[4];
   float nodeSize[] = new float[4];

   GraphNode[] gNodes, rNodes;
   GraphEdge[] gEdges, exploredEdges;

   // Pathfinder algorithm
   IGraphSearch pathFinder;

   // Used to indicate the start and end nodes as selected by the user.
   GraphNode startNode, endNode;
```

```
  boolean selectMode = false;
  long time;
  int graphNo = 0;
  int algorithm;
  int overAlgorithm, overOption, overGraph;
  int offX = 10, offY = 10;
  PrintWriter output;

void setup()
{
  // Initialize window for User Interface
  size(1440, 840);
  background(230);
  surface.setTitle("1/12 Scale Control");

  // Print available serial ports
  printArray(Serial.list());

  // Try to connect to serial port, if unavailable throw error
  try {
    xbee_comm = new Serial(this, Serial.list()[0], 9600);
    xbee_comm.bufferUntil('\n');
  }
  catch (IndexOutOfBoundsException e) {
    System.err.println("IndexOutOfBoundsException: " + e.getMessage());
  }

  // Connect to server
  if (mqtt_server == true) {
    mqttTopic = "vehicleInfoData2";
    mqtt_client = new MQTTClient(this);
    mqtt_client.connect("mqtt://192.168.1.140:1883", "Control");
    mqtt_client.subscribe(mqttTopic);
  }

  // Initialize array for 10 vehicles
  vehicle = new Car[10];

  // Draw initial control panel
  drawinf();

  // Add button for vehicle selection & initialize vehicles
  for (int veh = 0; veh < vehicle.length; veh++)
  {
    vehicle_button[veh] = new Button(veh*(width / 16)+35, 65, 70, 70, 1, str(veh+1), 35, color(0x03,
0xA9, 0xF4));
    vehicle[veh] = new Car();
    vehicle[veh].dest = -1;
```

```
  }

  // Add button for station
  int row = 0, col = 0;
  for (int sta = 0; sta < 8; sta++) {
    col = sta;
    if (sta >= 4) {
      row = 1;
      col = sta-4;
    }
    station_button[sta] = new Button((col*(width / 16))+1065, row*(width/16)+65, 70, 70, 1, str(sta+1),
35, color(0xEF, 0x6C, 0x00));
  }

  smooth();
  ellipseMode(CENTER);

  graphNo = 3;
  nodeSize[graphNo] = 12.0f;
  graphImage[graphNo] = loadImage("Track.JPG");
  gs[graphNo] = new Graph();
  makeGraphFromFile(gs[graphNo], "Superway_track.txt");;
  gs[graphNo].compact();

  gNodes =  gs[graphNo].getNodeArray();
  gEdges = gs[graphNo].getAllEdgeArray();
  // Create a path finder object based on the algorithm
  pathFinder = makePathFinder(gs[graphNo], algorithm);
  usePathFinder(pathFinder);
}

// Draw user interface and button
void drawinf()
{
  // Draw controls box
  stroke(0);
  strokeWeight(3);
  fill(255);
  rect(control_x, 260, width - control_x, height);

  // Draw labels for vehicle and station selection
  textSize(72);
  fill(255, 255, 255, 120);
  text("Vehicles", 50, 70);
  text("Stations", control_x+50, 70);

  // Draw components for control panel
  textSize(52);
```

```
    fill(0, 0, 0, 120);
    text("Controls", control_x+100, 330);
    fill(0, 0, 0, 30);
    rect(control_x+60, 412, 300, 80, 20);
    line(control_x, 0, control_x, height);
    line(0, 150, control_x, 150);

    // Draw Superway logo
    logo = loadImage("super_logo.png");
    image (logo, 1070, 720);
    line(control_x, 700, width, 700);

    try {
      text(vehicle[v_focus].speed, 1040, 160);
    }
    catch(NullPointerException npe) {
      println("Error: No vehicles active.");
    }
}

// Looping block
void draw ()
{
    // Update vehicle and station button in real time
    for (int veh = 0; veh < 10; veh++) {
      if     ((veh == vehicle[v_focus].dest && veh >= 10) || (veh == v_focus))
        vehicle_button[veh].in_focus = true;
      else if ((veh != vehicle[v_focus].dest && veh >= 10) || (veh != v_focus))
        vehicle_button[veh].in_focus = false;

      vehicle_button[veh].update();
    }

    for (int sta = 0; sta < 8; sta++) {
      station_button[sta].update();
    }

    // Update control button in real time
    up.update();
    down.update();
    stop.update();
    go.update();
    servo.update();
    state.update();
    all.update();
    image(graphImage[3], 200, 200);
    drawNodes();
    drawEdges(gEdges, color(192, 192, 192, 128), 1.0f, true);
```

```
   drawRoute(rNodes, color(200, 0, 0), 5.0f);

   // Update Set speed window
   fill(220);
   stroke(0);
   rect(control_x + 60, 410, 300, 85, 20);
   textSize(72);
   fill(180);
   text(set_speed, control_x + 145, 480);
}

void mousePressed()
{
   _mouseX = mouseX;
   _mouseY = mouseY;

   // Vehicle/Station button Select
   for (int veh = 0; veh < 10; veh++) {
      vehicle_button[veh].select();

      if (vehicle_button[veh].click)
         v_focus = veh;
   }

   for (int sta = 0; sta < 8; sta++) {
      station_button[sta].select();

      if (station_button[sta].click) {
         vehicle[v_focus].dest = sta;
         goToStation(v_focus+1, sta);
         pathfind();
      }
   }

   //Check for control button clicks
   up.select();
   down.select();
   stop.select();
   go.select();
   servo.select();
   state.select();
   all.select();


   // Vehicle control commands
   if (go.click) {
      // See goCommand function under communication
      goCommand(v_focus+1);
```

```
  } else if (stop.click) {
    String output ;
    output = "" + (char)(v_focus+1) + (char)0x00 + (char)0x02;
    sendMessage(xbee_comm, output);
  } else if (servo.click) {
    String output ;
    output = "" + (char)(v_focus+1) + (char)0x00 + (char)0x07;
    sendMessage(xbee_comm, output);
  } else if (state.click) {
    requestState(v_focus+1);
  } else if (up.click) {
    set_speed += 15;
    if (set_speed > 255)
      set_speed = 255;
  } else if (down.click) {
    set_speed -= 15;
    if (set_speed < 0)
      set_speed = 0;
  }

  _mouseX = -1;
  _mouseY = -1;
}
```

Communication

```
// Serial input interrupt
void serialEvent(Serial xbee_comm)
{
  byte[] xbee_in = new byte[25];
  boolean string_enable = false;
  byte checksum = 0x00;
  int msg_pos = 0;

  while(xbee_comm.available() > 0){
    // Get new byte:
    byte char_in = (byte)xbee_comm.read();

    // End message
    if (char_in == (byte)0x7E && string_enable == true) {
      string_enable = false;
      xbee_comm.clear();

      // Check for errors
      if(checksum == 0)
        process_data(xbee_in);
      else
        requestState((int)xbee_in[1]);
```

```
        }

        // Record incomming message
        if (string_enable == true){
            xbee_in[msg_pos] = char_in;
            checksum += char_in;
            msg_pos++;
        }

        // Start Message
        if (char_in == (byte)0x81 && string_enable == false)
            string_enable = true;

        if (debug_mode == true)
            System.out.print(char(char_in));
    }

    if (debug_mode == true)
    System.out.println();
}

// Serial output function
void sendMessage(Serial port, String message){
    byte checksum = 0x00;

    // Write out message start character
    port.write(0x81);

    // Write message
    for(int ltr = 0; ltr < message.length(); ltr++){
        port.write(message.charAt(ltr));
        checksum += message.charAt(ltr);
    }

    // Write out checksum and message end character
    port.write(0-checksum);
    port.write(0x7E);
}

void process_data(byte[] input){
    if(input[2] == 0x30){
        vehicle_button[input[1]-1].online = true;
        System.out.println("Vehicle " + (int)input[1] + " connected.");
    }
    else if(input[2] == 0x05){
        vehicle[(int)input[1]-1].status = (int)input[3];
        vehicle[(int)input[1]-1].speed = (input[6]<<8) | (input[7] & 0xFF);
        vehicle[(int)input[1]-1].on_track = (input[4]<<8) | (input[5] & 0xFF);
```

```
    String message_out = "Vehicle " + (int)input[1] + " State: " + (int)input[3] + " Speed: " +
vehicle[(int)input[1]-1].speed + " TrackID: " + vehicle[(int)input[1]-1].on_track;

    System.out.println(message_out);

    if(mqtt_server == true)
      mqttMessageOut((String)"" + (int)input[1] + " " + (int)input[3] + " " + vehicle[(int)input[1]-
1].on_track + " " + vehicle[(int)input[1]-1].speed);
  }
}

void requestState(int vehicle){
  String output ;
  output = "" + (char)(vehicle) + (char)0x00 + (char)0x05 + (char)0x00;
  sendMessage(xbee_comm, output);
}

void goToStation(int vehicle, int station){
  String instructions_out;

  instructions_out = "" + (char)(vehicle) + (char)0x00 + (char)0x10 + (char)0x00 + (char)0x00 + (char)0x65
+ (char)1 + (char)0x00 + (char)0x64 + (char)0 + (char)0x00 + (char)0x13 + (char)1 + (char)0x00 +
(char)0x76 + (char)0 + (char)0x00 + (char)0x19 + (char)1;

  sendMessage(xbee_comm, instructions_out);

  goCommand(vehicle);
}

void goCommand(int vehicle){
    char speed[] = new char[2];
      speed[0] = (char)set_speed;
      speed[1] = (char)(set_speed >> 8);

    String output ;
      output = "" + (char)(vehicle) + (char)0x00 + (char)0x01 + (char)0x00 + (char)speed[0] +
(char)speed[1];
      sendMessage(xbee_comm, output);
}
```

Car Code

```
public class Car
{
  int status = 0;   // 0 = Not connected, 1 = Connected/Idle, 2 = Active
  int dest = -1;    // Station number
  int on_track, state, speed;
```

```
    double distance;


    public Car()
    {
      on_track    = 0;    distance    = 0;
      state       = 0;    speed       = 0;
    }
}
```

Pathing Code

```
void pathfind() {

    //startNode = gs[graphNo].getNodeAt(255, 460, 0, 16.0f);
    start[graphNo] = vehicle[v_focus].on_track;

    switch(vehicle[v_focus].dest) {
    case 0:
      // startNode = gs[graphNo].getNodeAt(255, 460, 0, 16.0f);
      endNode = gs[graphNo].getNode(110);
      end[graphNo] = endNode.id();
      usePathFinder(pathFinder);
      break;

    case 1:
      //startNode = gs[graphNo].getNodeAt(255, 460, 0, 16.0f);
      endNode = gs[graphNo].getNode(108);
      end[graphNo] = endNode.id();
      usePathFinder(pathFinder);
      break;

    case 2:
      //startNode = gs[graphNo].getNodeAt(255, 460, 0, 16.0f);
      endNode = gs[graphNo].getNode(201);
      end[graphNo] = endNode.id();
      usePathFinder(pathFinder);
      break;

    case 3:
      //startNode = gs[graphNo].getNodeAt(255, 460, 0, 16.0f);
      endNode = gs[graphNo].getNode(101);
      end[graphNo] = endNode.id();
      usePathFinder(pathFinder);
      break;
    }

    println("Starting Node Position");
```

```
    println(start[graphNo]);
    println("List of Route Notes");

    int routenode [] = new int[rNodes.length];

    for (int i=0; i<rNodes.length; i++) {
      routenode[i] = rNodes[i].id();

      println(rNodes[i].id() + " " + gNodes[i].id());
      //routenode[graphNo]= rNodes[i].id();
    }

    println("Ending Location");
    println(end[3]);
  }

  void drawNodes() {
    pushStyle();
    noStroke();
    fill(0);
    for (GraphNode node : gNodes)
      ellipse(node.xf(), node.yf(), nodeSize[graphNo], nodeSize[graphNo]);
    popStyle();
    fill(255, 0, 0, 100);
    for (GraphNode node2 : rNodes)
      ellipse(node2.xf(), node2.yf(), nodeSize[graphNo], nodeSize[graphNo]);
  }

  void usePathFinder(IGraphSearch pf) {
    time = System.nanoTime();
    pf.search(start[graphNo], end[graphNo], true);
    time = System.nanoTime() - time;
    rNodes = pf.getRoute();
    exploredEdges = pf.getExaminedEdges();
  }

  IGraphSearch makePathFinder(Graph graph, int pathFinder) {
    IGraphSearch pf = null;
    float f = (graphNo == 2) ? 2.0f : 1.0f;
    switch(pathFinder) {
    case 0:
      pf = new GraphSearch_DFS(gs[graphNo]);
      break;
    case 1:
      pf = new GraphSearch_BFS(gs[graphNo]);
      break;
    case 2:
      pf = new GraphSearch_Dijkstra(gs[graphNo]);
```

```
      break;
   case 3:
      pf = new GraphSearch_Astar(gs[graphNo], new AshCrowFlight(f));
      break;
   case 4:
      pf = new GraphSearch_Astar(gs[graphNo], new AshManhattan(f));
      break;
   }
   return pf;
}

void makeGraphFromFile(Graph g, String fname) {
   String lines[];
   lines = loadStrings(fname);
   int mode = 0;
   int count = 0;
   while (count < lines.length) {
      lines[count].trim();

      if (!lines[count].startsWith("#") && lines[count].length() > 1) {
         switch(mode) {
            case 0:
               if (lines[count].equalsIgnoreCase("<nodes>"))
                  mode = 1;
               else if (lines[count].equalsIgnoreCase("<edges>"))
                  mode = 2;
               break;
            case 1:
               if (lines[count].equalsIgnoreCase("</nodes>"))
                  mode = 0;
               else
                  makeNode(lines[count], g);
               break;
            case 2:
               if (lines[count].equalsIgnoreCase("</edges>"))
                  mode = 0;
               else
                  makeEdge(lines[count], g);
               break;
         } // end switch
      } // end if
      count++;
   } // end while
}

void makeNode(String s, Graph g) {
   int nodeID;
```

```
    float x, y, z = 0;
    String part[] = split(s, " ");

    if (part.length >= 3) {
      nodeID = Integer.parseInt(part[0]);
      x = Float.parseFloat(part[1]);
      y = Float.parseFloat(part[2]);

      if (part.length >=4)
        z = Float.parseFloat(part[3]);

      g.addNode(new GraphNode(nodeID, x, y, z));
    }
  }


  void makeEdge(String s, Graph g) {
    int fromID, toID, side;
    float costOut = 0, costBack = 0;
    String part[] = split(s, " ");

    if (part.length >= 4) {
      fromID = Integer.parseInt(part[0]);
      toID = Integer.parseInt(part[1]);

      try {
        costOut = Float.parseFloat(part[2]);
      } catch(Exception excp) {
        System.out.println("Exception: " + excp.getMessage());
        costOut = -1;
      }

      side = Integer.parseInt(part[3]);

      // If either cost is less than 0,
      // then that edge will not be created
      if (costOut >= 0)
        g.addEdge(fromID, toID, costOut, side);
      if (costBack >= 0)
        g.addEdge(toID, fromID, costBack, side);
    }
  }

  void drawEdges(GraphEdge[] edges, int lineCol, float sWeight, boolean arrow) {
    if (edges != null) {
      pushStyle();
      noFill();
      stroke(lineCol);
```

```
    strokeWeight(sWeight);
    for (GraphEdge ge : edges) {
      if (arrow)
        drawArrow(ge.from(), ge.to(), nodeSize[graphNo] / 2.0f, 6);
      else {
        line(ge.from().xf(), ge.from().yf(), ge.to().xf(), ge.to().yf());
      }
    }
    popStyle();
  }
}

void drawArrow(GraphNode fromNode, GraphNode toNode, float nodeRad, float arrowSize) {
  float fx, fy, tx, ty;
  float ax, ay, sx, sy, ex, ey;
  float awidthx, awidthy;

  fx = fromNode.xf();
  fy = fromNode.yf();
  tx = toNode.xf();
  ty = toNode.yf();

  float deltaX = tx - fx;
  float deltaY = (ty - fy);
  float d = sqrt(deltaX * deltaX + deltaY * deltaY);

  sx = fx + (nodeRad * deltaX / d);
  sy = fy + (nodeRad * deltaY / d);
  ex = tx - (nodeRad * deltaX / d);
  ey = ty - (nodeRad * deltaY / d);
  ax = tx - (nodeRad + arrowSize) * deltaX / d;
  ay = ty - (nodeRad + arrowSize) * deltaY / d;

  awidthx = - (ey - ay);
  awidthy = ex - ax;

  noFill();
  strokeWeight(4.0f);
  stroke(160, 128);
  line(sx, sy, ax, ay);

  noStroke();
  fill(48, 128);
  beginShape(TRIANGLES);
  vertex(ex, ey);
  vertex(ax - awidthx, ay - awidthy);
  vertex(ax + awidthx, ay + awidthy);
  endShape();
```

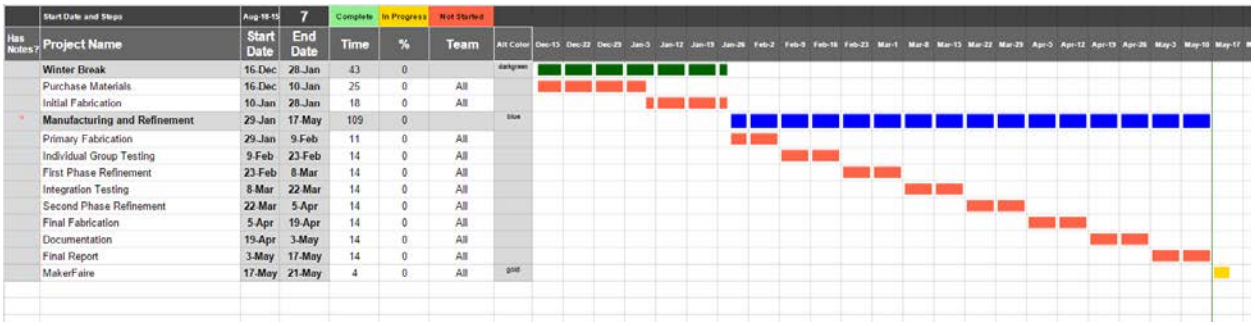
```
}

void drawRoute(GraphNode[] r, int lineCol, float sWeight) {
  if (r.length >= 2) {
    pushStyle();
    stroke(lineCol);
    strokeWeight(sWeight);
    noFill();
    for (int i = 1; i < r.length; i++)
      line(r[i-1].xf(), r[i-1].yf(), r[i].xf(), r[i].yf());
    // Route start node
    strokeWeight(2.0f);
    stroke(0, 0, 160);
    fill(0, 0, 255);
    ellipse(r[0].xf(), r[0].yf(), nodeSize[graphNo], nodeSize[graphNo]);
    // Route end node
    stroke(160, 0, 0);
    fill(255, 0, 0);
    ellipse(r[r.length-1].xf(), r[r.length-1].yf(), nodeSize[graphNo], nodeSize[graphNo]);
    popStyle();
  }
}
```

Appendix C: Solar

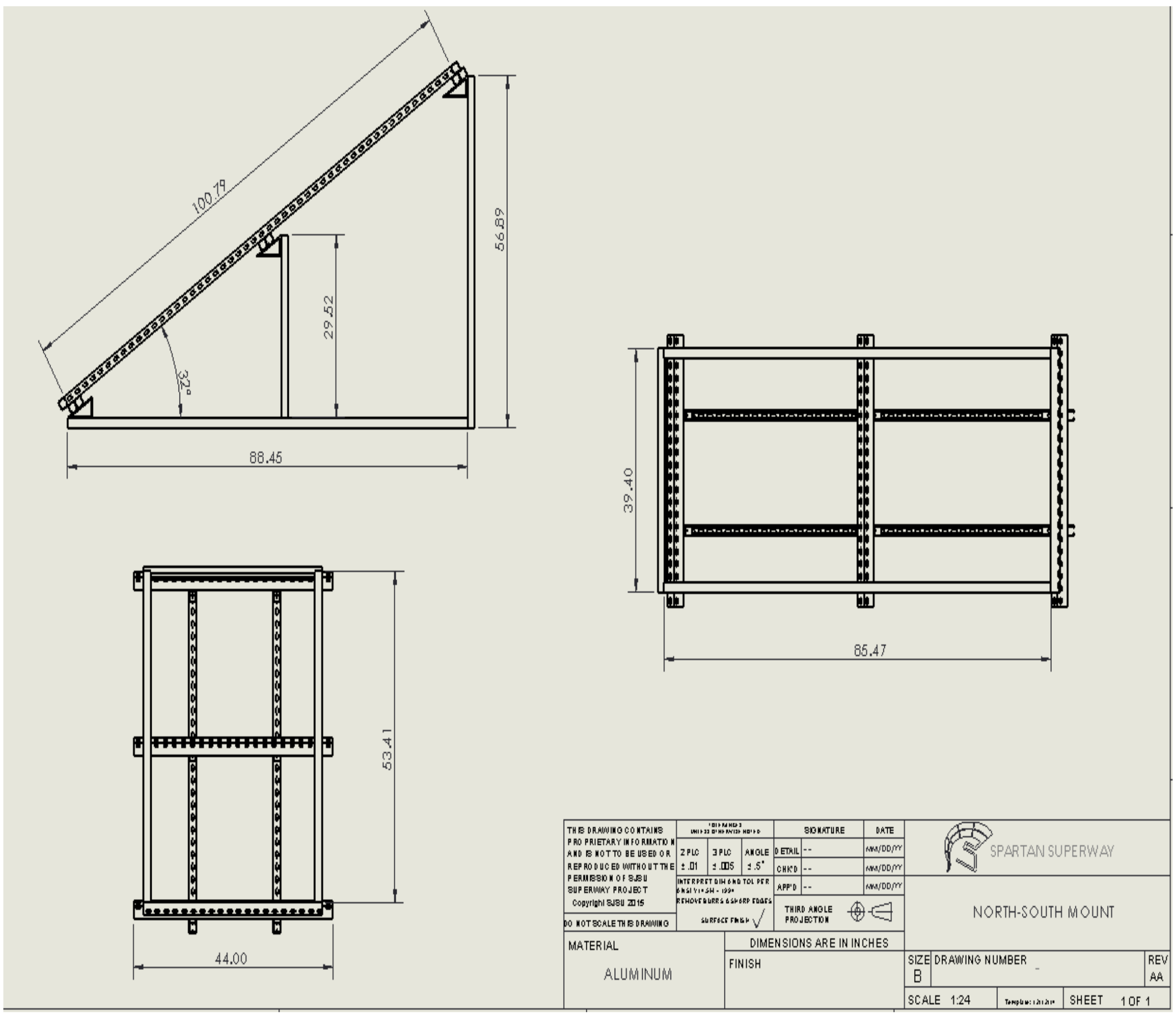
Intermediate Solar Power

Intermediate Solar Team Gantt Chart for Spring 2016 Semester

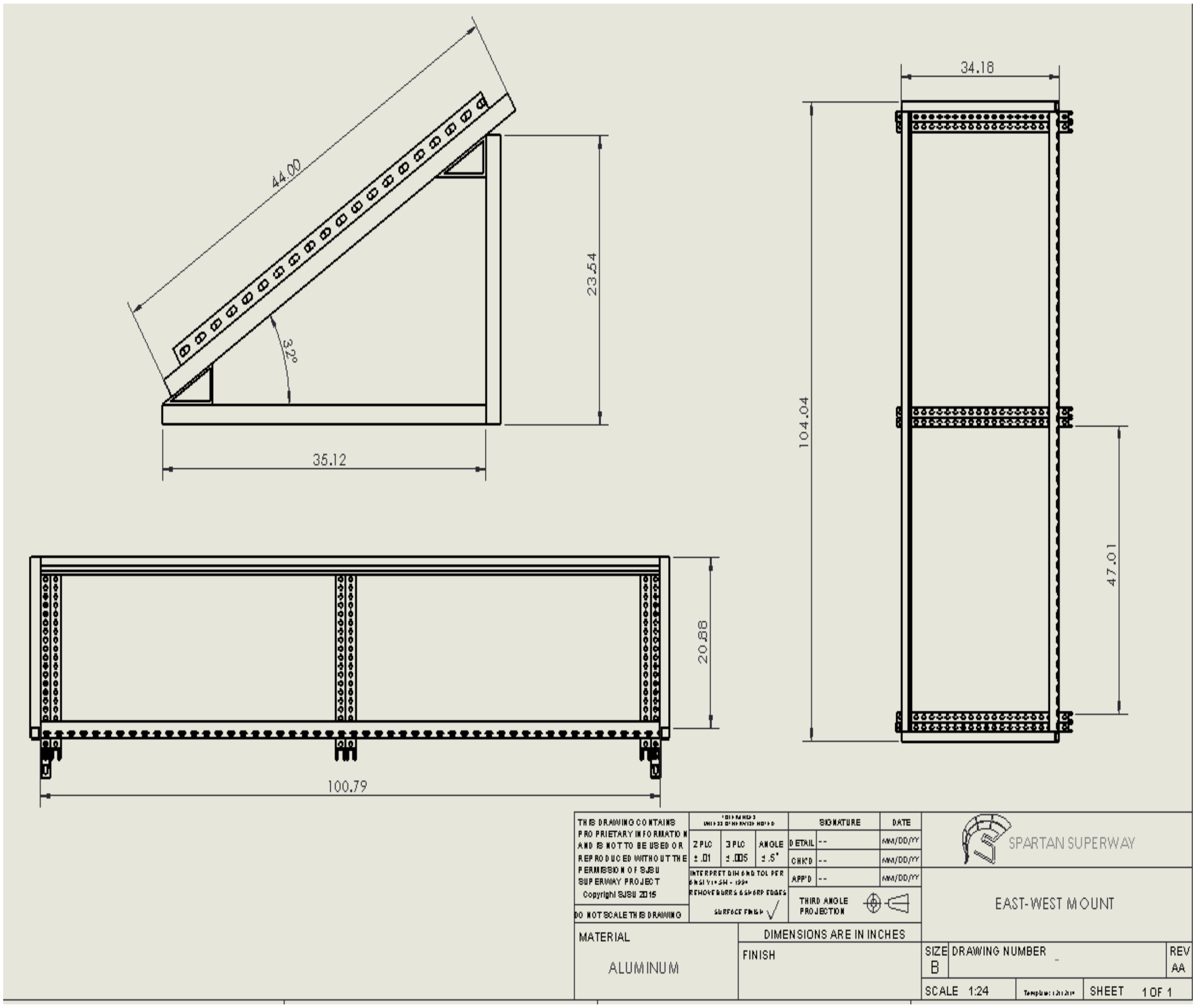


Has Notes?	Project Name	Start Date	End Date	Time	%	Team	Alt Color
	Winter Break	16-Dec	28-Jan	43	0		darkgreen
	Purchase Materials	16-Dec	10-Jan	25	0	All	
	Initial Fabrication	10-Jan	28-Jan	18	0	All	
*	Manufacturing and Refinement	29-Jan	17-May	109	0		blue
	Primary Fabrication	29-Jan	9-Feb	11	0	All	
	Individual Group Testing	9-Feb	23-Feb	14	0	All	
	First Phase Refinement	23-Feb	8-Mar	14	0	All	
	Integration Testing	8-Mar	22-Mar	14	0	All	
	Second Phase Refinement	22-Mar	5-Apr	14	0	All	
	Final Fabrication	5-Apr	19-Apr	14	0	All	
	Documentation	19-Apr	3-May	14	0	All	
	Final Report	3-May	17-May	14	0	All	
	MakerFaire	17-May	21-May	4	0	All	gold

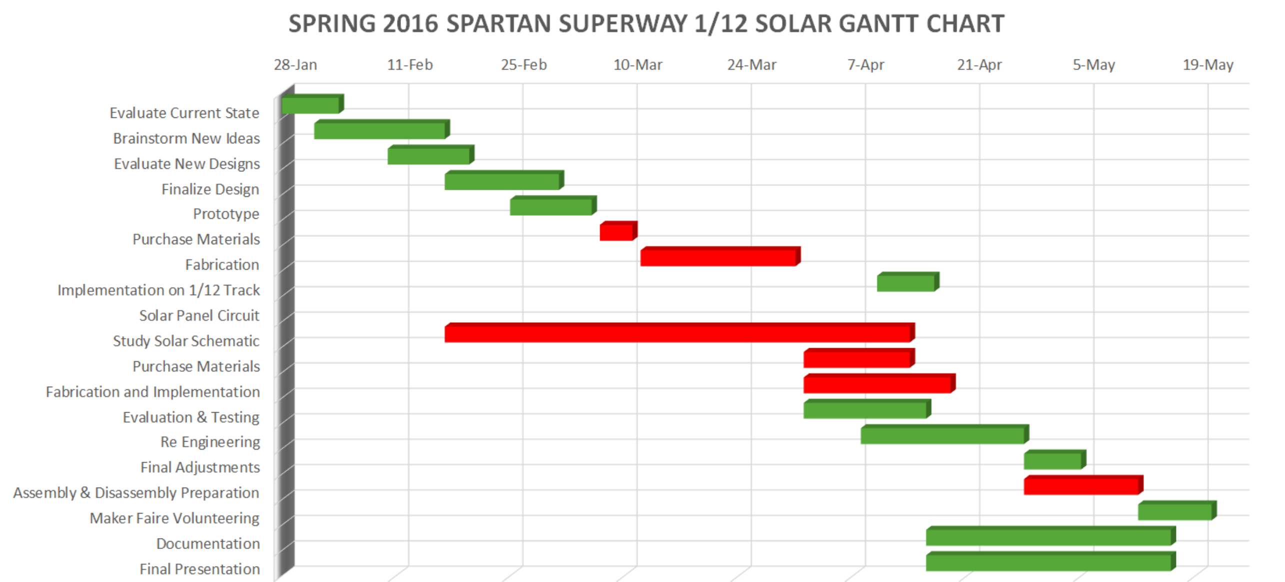
North-South Mount Drawing



East-West Mount Drawing



<u>Small Scale Solar Power</u>



	Final Presentation	Documentation	Maker Faire Volunteering	Assembly & Disassembly Preparation	Final Adjustments	Re Engineering	Evaluation & Testing	Fabrication and Implementation	Purchase Materials	Study Solar Schematic	Solar Panel Circuit	Implementation on 1/12 Track	Fabrication	Purchase Materials	Prototype	Finalize Design	Evaluate New Designs	Brainstorm New Ideas	Evaluate Current State
START DATE	16-Apr	16-Apr	12-May	28-Apr	28-Apr	8-Apr	1-Apr	1-Apr	1-Apr	17-Feb		10-Apr	12-Mar	7-Mar	25-Feb	17-Feb	10-Feb	1-Feb	28-Jan
DAYS TO COMPLETE	30	30	9	14	7	20	15	18	13	57		7	19	4	10	14	10	16	7

2015-16 Spring Spartan Superway Gantt Chart

SPRING 2016 SUPERWAY 1/12 SOLAR GANTT CHART						
OBJECTIVES	START DATE	DUE DATE	DAYS TO COMPLETE	% COMPLETE	DONE	OBJECTIVE LEAD
Redesign						
Evaluate Current State	28-Jan	4-Feb	7	100%	●	ALL
Brainstorm New Ideas	1-Feb	17-Feb	16	100%	●	ALL
Evaluate New Designs	10-Feb	20-Feb	10	100%	●	ALL
Finalize Design	17-Feb	2-Mar	14	100%	●	ALLAN
Manufacturing						
Prototype	25-Feb	6-Mar	10	100%	●	BRIAN
Purchase Materials	7-Mar	11-Mar	4	100%	●	IVAN
Fabrication	12-Mar	31-Mar	19	100%	●	BRIAN
Implementation on 1/12 Track	10-Apr	17-Apr	7	100%	●	ALL
Solar Panel Circuit						
Study Solar Schematic	17-Feb	14-Apr	57	100%	●	IVAN
Purchase Materials	1-Apr	14-Apr	13	100%	●	IVAN
Fabrication and Implementation	1-Apr	19-Apr	18	100%	●	ALL
Design Evaluation						
Evaluation & Testing	1-Apr	16-Apr	15	100%	●	ALLAN
Re Engineering	8-Apr	28-Apr	20	100%	●	ALL
Maker Faire Preparation						
Final Adjustments	28-Apr	5-May	7	100%	●	ALL
Assembly & Disassembly Preparation	28-Apr	12-May	14	100%	●	ALL
Maker Faire Volunteering	12-May	21-May	9	100%	●	ALL
Final Report & Presentation						
Documentation	16-Apr	16-May	30	100%	●	ALL
Final Presentation	16-Apr	16-May	30	100%	●	ALL

Spring 2016 Spartan Superway 1/12 Solar Gantt Chart.

No	Material	Description	Qty.	Price $	In-house Material	Supplier	Total Price $ *
1	SP1 Panel	11.5" x 60" x 0.7" Solar Panel	3.00	N/A	✘	SoloPower	$0.00
2	Buck Converter	DROK DC 12V 24V NC Step Down Voltage Regulator	1.00	$16.58		Amazon	$16.58
3	Buck Converter	DROK LM2596 DC Buck Voltage Regulator	1.00	$12.79		Amazon	$12.79
4	Diodes	Uxcell Diodes 5A 40V 20 Pcs	1.00	$6.01		Amazon	$6.01
5	MC4 Tool	Renogy MC4 Assembly Tool	1.00	$6.99		Amazon	$6.99
6	Crimping Tool	Signstek MC4 Cable Crimping Tool	1.00	$29.19		Amazon	$29.19
7	Digital Multimeter	Bayite DC Voltage Amperage Power Energy Meter	2.00	$16.98		Amazon	$33.96
8	Battery Charger	iMAX B6AC Battery Charger	1.00	$63.99		Amazon	$63.99
9	MC4 Connector	MC4 Splitter Cable	1.00	$7.19		Amazon	$7.19
10	Electrical Wire	THHN 12 AWG Stranded Copper Red Wire	1.00	$10.67		Home Depot	$11.63
11	Electrical Wire	THHN 12 AWG Stranded Copper Black Wire	1.00	$19.17		Home Depot	$20.85
12	2 x 4 Stud	22"x 2" x 4" Wooden Stud	N/A	N/A	✘	N/A	$0.00
13	Wooden Board	White 36" x 9" x 3/4" Board	N/A	N/A	✘	N/A	$0.00
14	Aluminum Sheet	40" x 40" x 0.125" Aluminum Sheet	N/A	N/A	✘	N/A	$0.00
15	Aluminum Sheet	25" x 20" x 0.1" Aluminum Sheet	N/A	N/A	✘	N/A	$0.00
16	Plain Square Tube	36" x 1-1/4" x 1/16" Steel Tube	N/A	N/A	✘	N/A	$0.00
17	Steel Plate	20" x 20" x 1/16" Steel	N/A	N/A	✘	N/A	$0.00
18	Slotted Angle Bar	1-1/2" x 72" Steel	N/A	N/A	✘	N/A	$0.00
19	Acetone	QT Acetone	1.00	$7.49		Lowe's	$8.16
20	Semi-Gloss Paint	15-oz Black Semi-Gloss Paint	2.00	$5.28		Lowe's	$11.51
21	Plastic Drop	0.7mil 9-12 Plastic Drop	1.00	$1.98		Lowe's	$2.16
22	Hex Bolt	0.5" x 0.25" Hex Bolt	20.00	N/A	✘	N/A	$0.00
23	Hex Nut	0.25" Hex Nut	20.00	N/A	✘	N/A	$0.00
24	Washer	0.25" Washer	20.00	N/A	✘	N/A	$0.00
25	Hex Bolt	3/8" x 1-1/2" Hex Bolt	8.00	N/A	✘	N/A	$0.00
26	Hex Nut	3/8" Hex Nut	8.00	N/A	✘	N/A	$0.00
27	Brad Nail	1.5" Brad Nail 50 Pcs	1.00	$3.99	✘	Orchard Supply	$4.34
28	Spray Paint	White Spray Paint	1.00	$6.00		Orchard Supply	$6.00
29	White Paint	White Flat Paint	2.00	$3.57		Orchard Supply	$7.14
30	2 x 4 Stud	8"x 2" x 4" Wooden Stud	2.00	$6.14		Home Depot	$13.51
31	2 x 6 Stud	8"x 2" x 6" Wooden Stud	1.00	$4.83		Home Depot	$5.31
32	Hex Bolt	0.1" x 0.125" Hex Bolt	12.00	$0.22		Home Depot	$2.90
33	Hex Nut	0.125" Hex Nut	12.00	$0.20		Home Depot	$2.64
34							
35							
36							
		Grand Total					$272.86
		Projected Total					$350.00
		Total Saved					$77.14

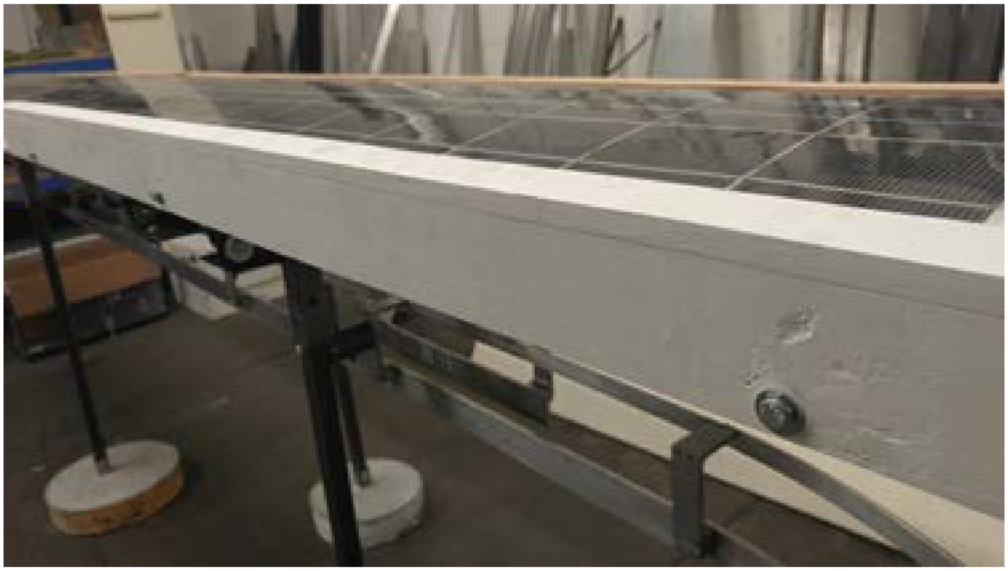
2015-2016 Spartan Superway 1/12 Solar Cost Analysis.

Fixed 1st bottom slot		Fixed 2nd bottom Slot		Fixed 3rd bottom Slot		Fixed 4th bottom Slot		Fixed 5th bottom Slot	
Top Bar Slots	Angle(deg)	Top Bar Sl	Angle(deg)	Top Bar Slot	Angle(deg)	Top Bar Slots	Angle(deg)	Top Bar Sl	Angle(deg)
1	35.44	1	37.01	1	37.48	1	36.35	1	32.4
2	37.01	2	40.05	2	42.19	2	43.19	2	42.49
3	37.48	3	42.19	3	46.07	3	49.11	3	51.07
4	36.35	4	43.19	4	49.11	4	54.33	4	58.9
5	32.4	5	42.49	5	51.07	5	58.9	5	66.44
		6	38.64	6	51.33	6	62.74	6	74.05
		7	26.41	7	48.21	7	65.4	7	82.36
				8	34.81	8		8	92.9

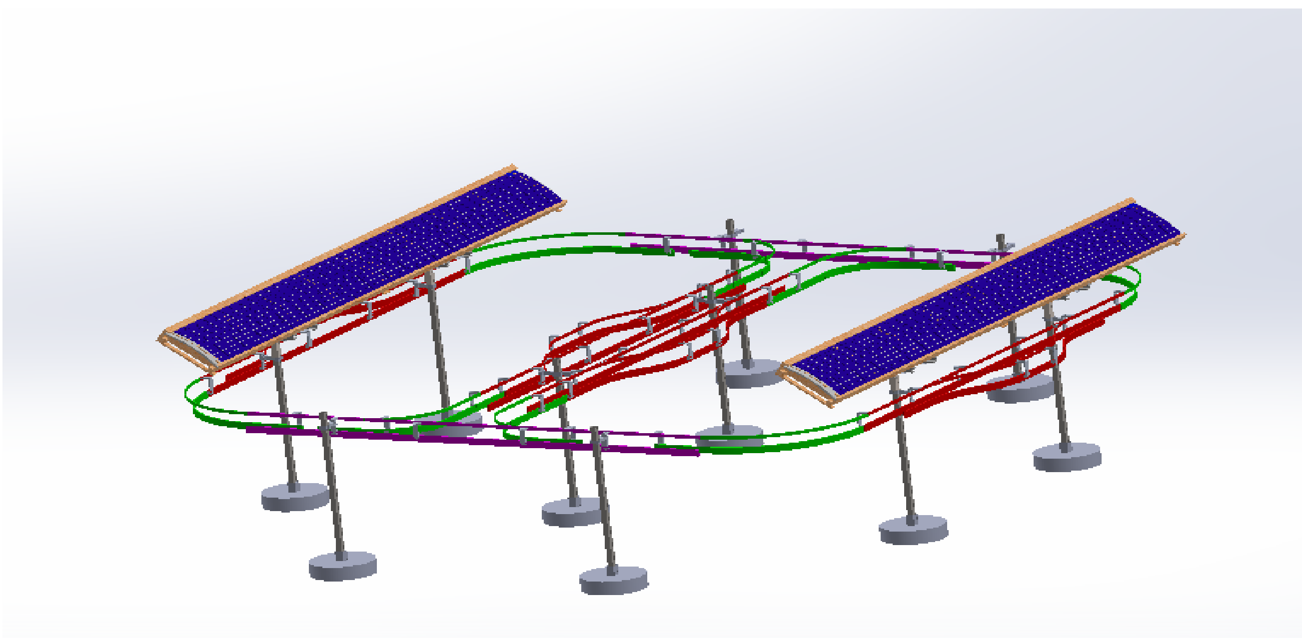
Estimated angles found by pinning the shortest bar in the three-bar system.

The stationary slits allow the solar panel to be held at a slight angle

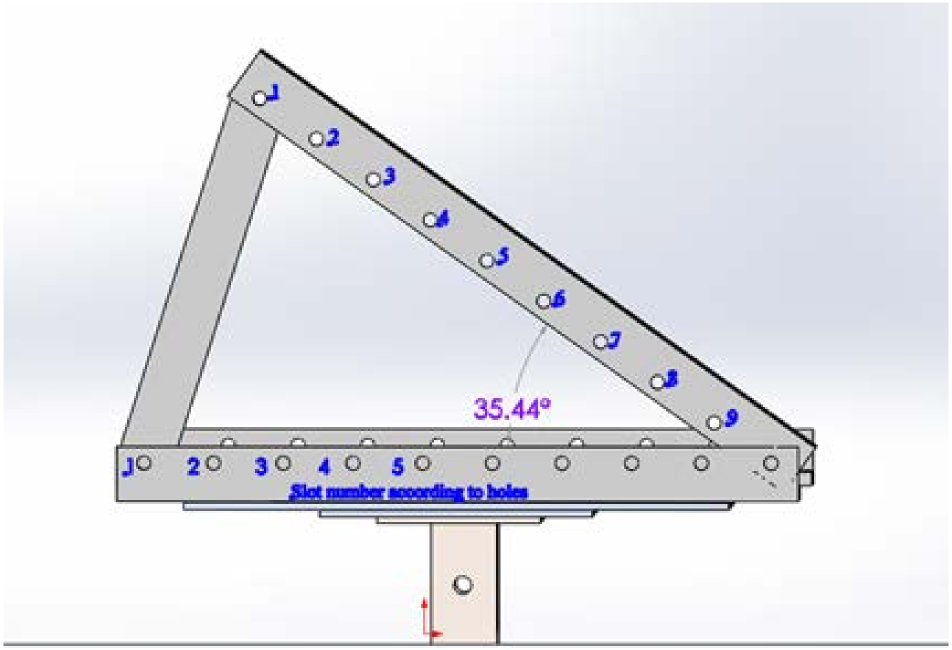
Implementation of solar panels to the stationary slits



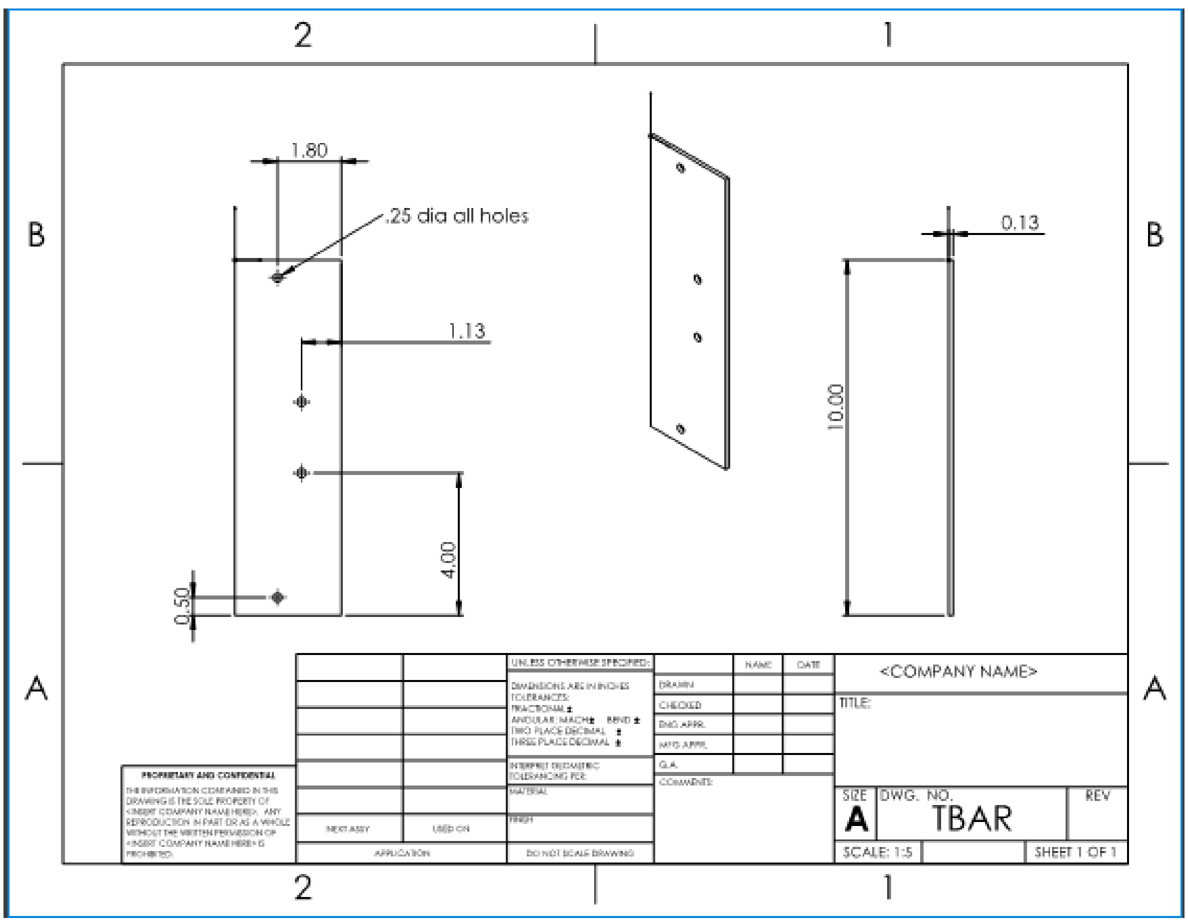
Implementation of the detachable rail on the frame



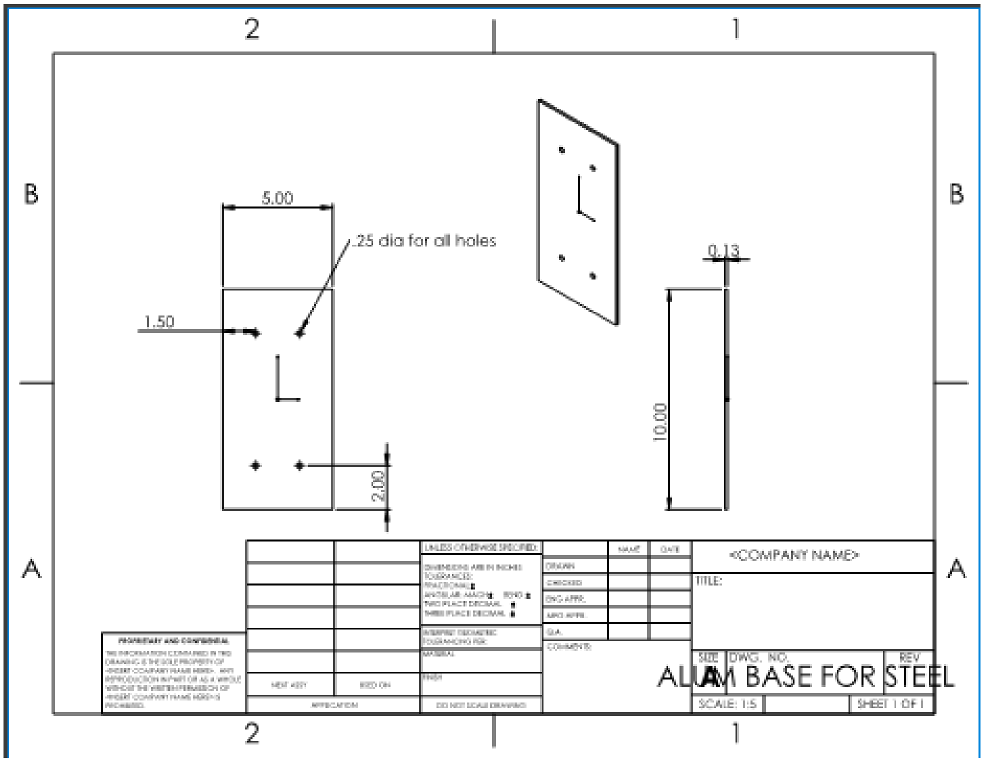
Final Assembly with the two-loop track



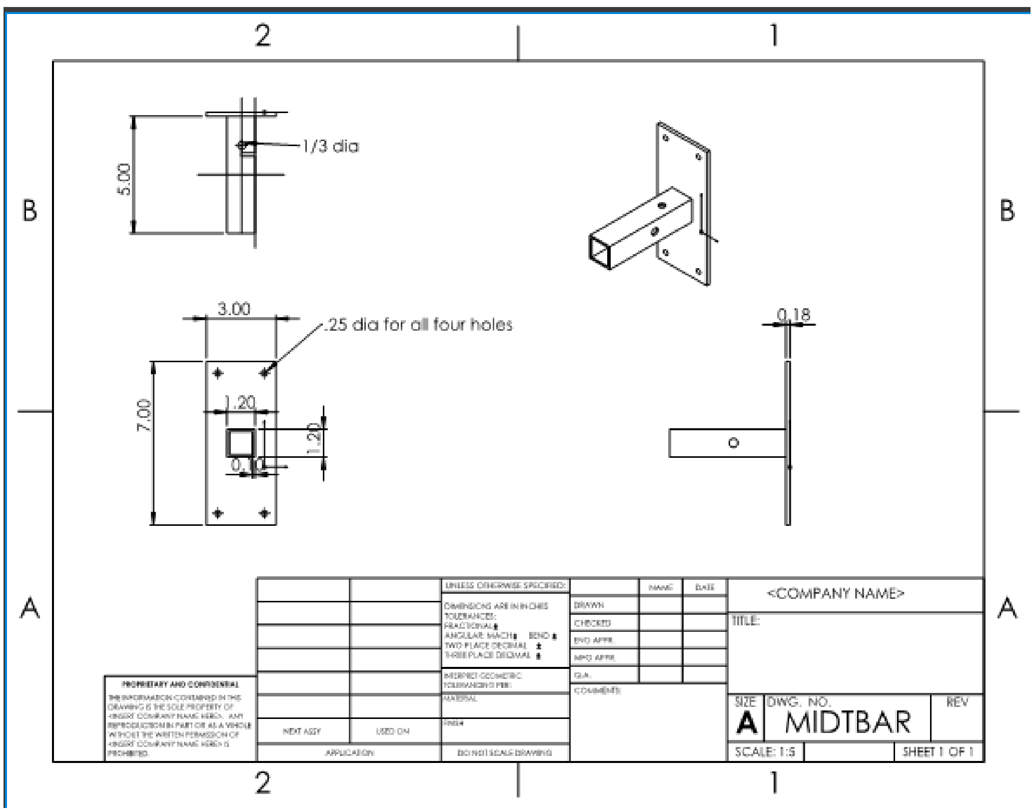
Labeled slots of the three bar system



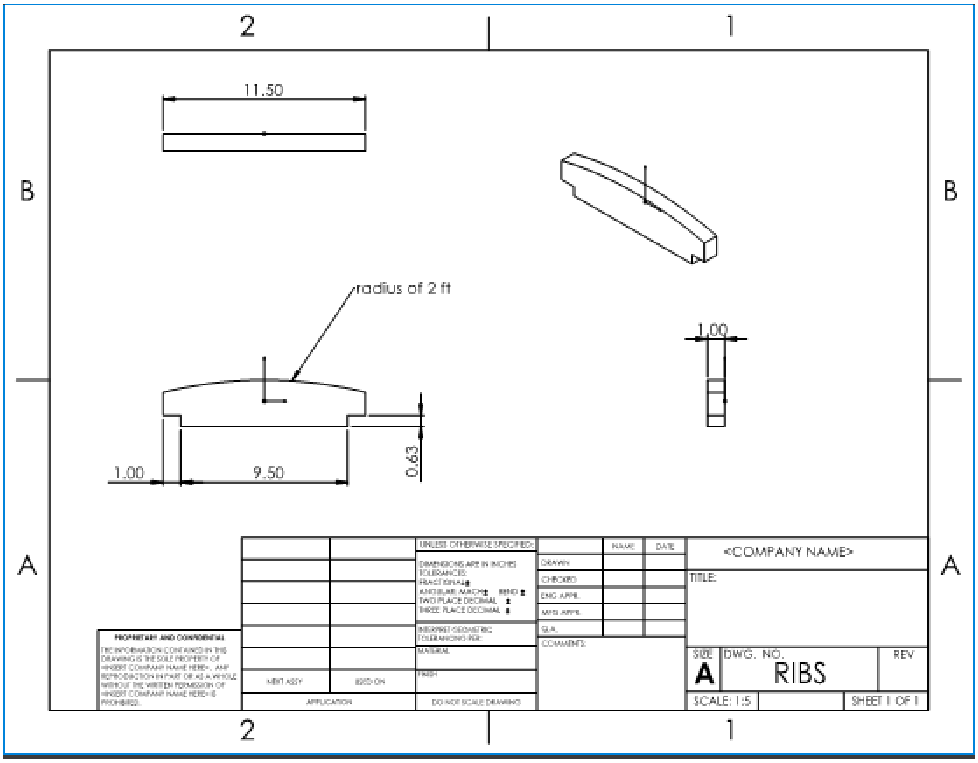
Detail drawing of 3x10 aluminum plate



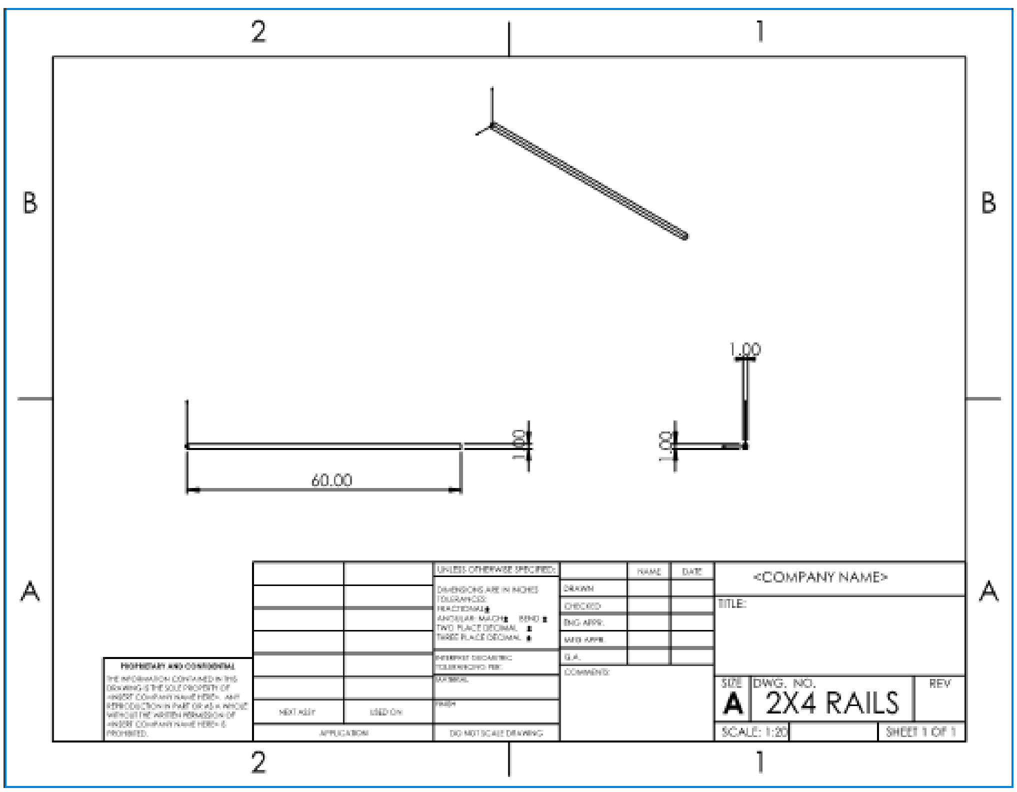
Detail drawing of 5x10 aluminum plate



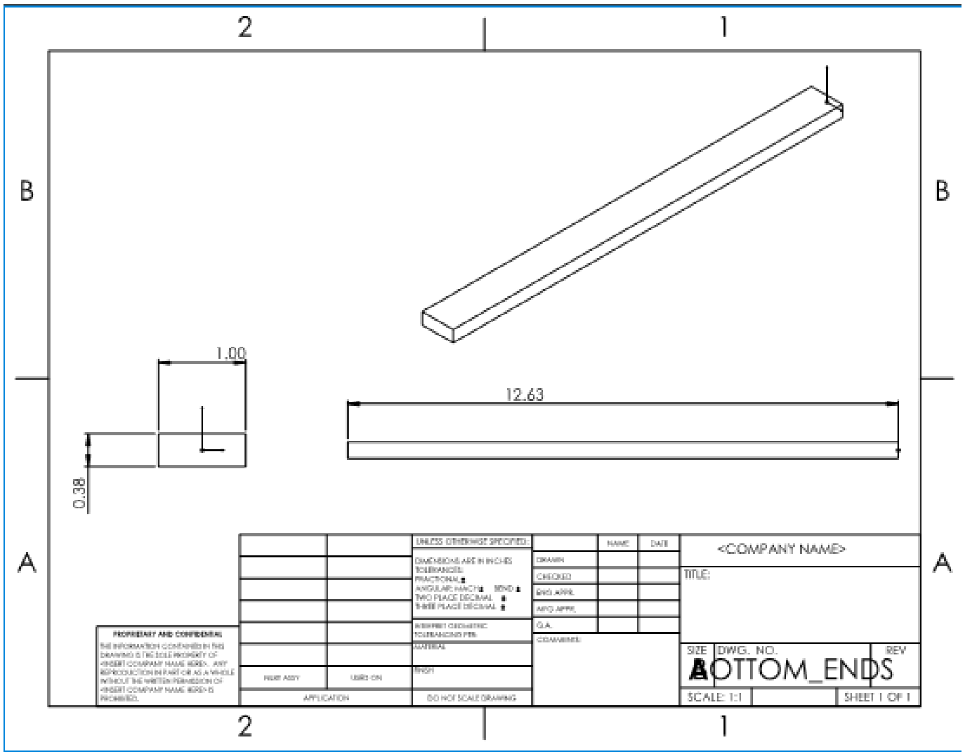
Detail drawing of the MIG welded rectangular tubing with the steel plate



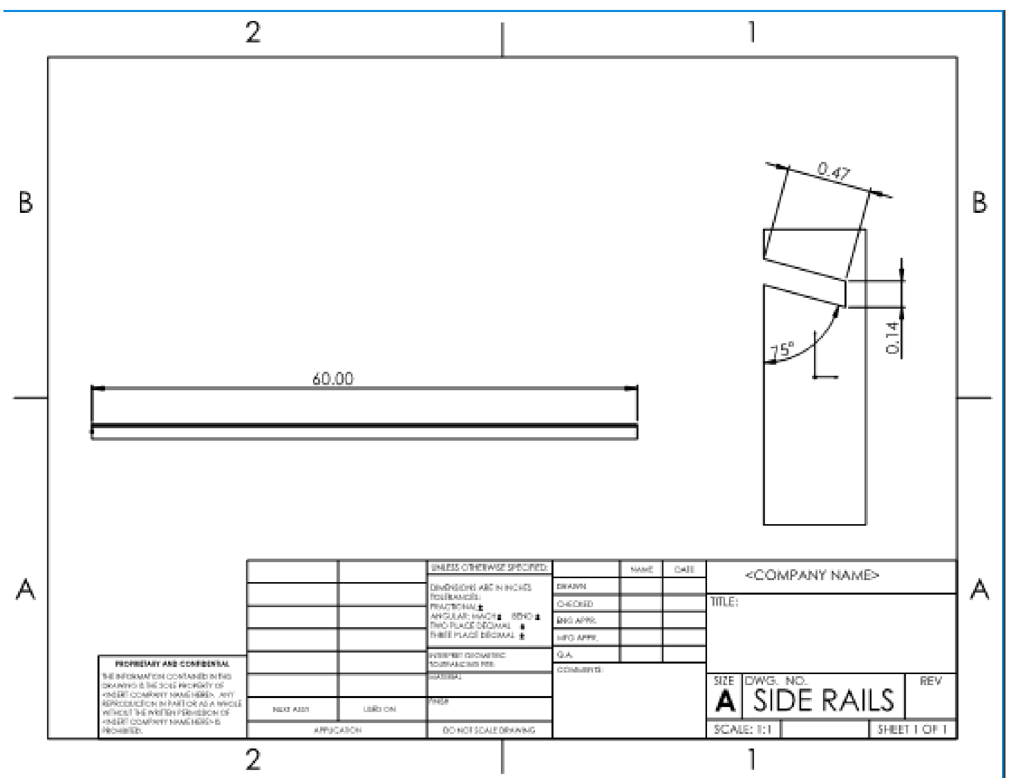
Detailed drawing of rib design in inches.



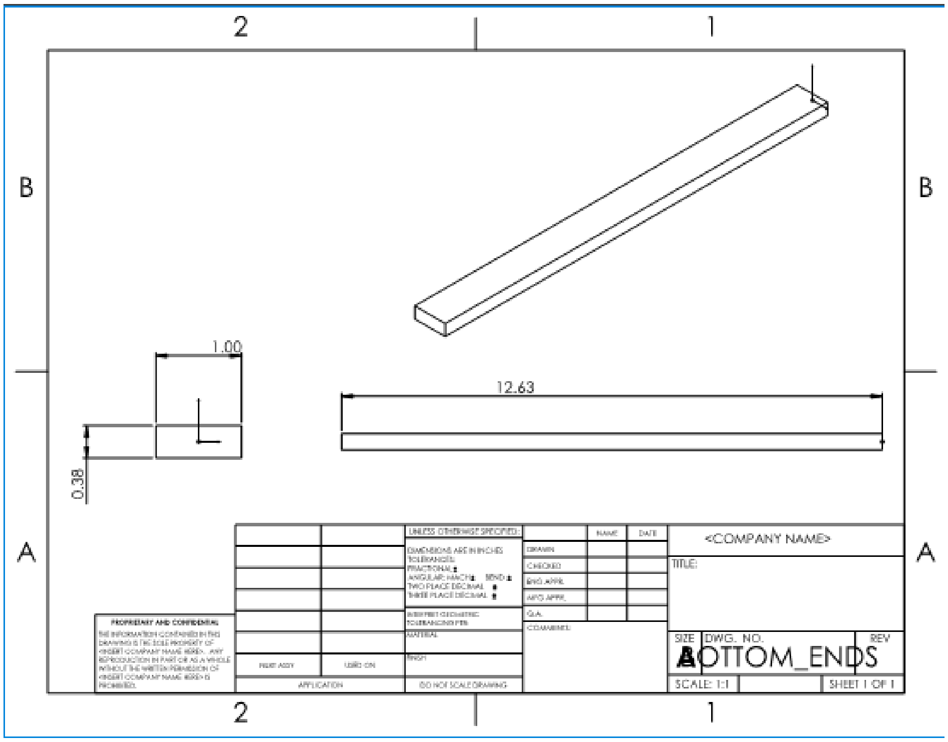
Detailed drawing of bottom rail in inches.



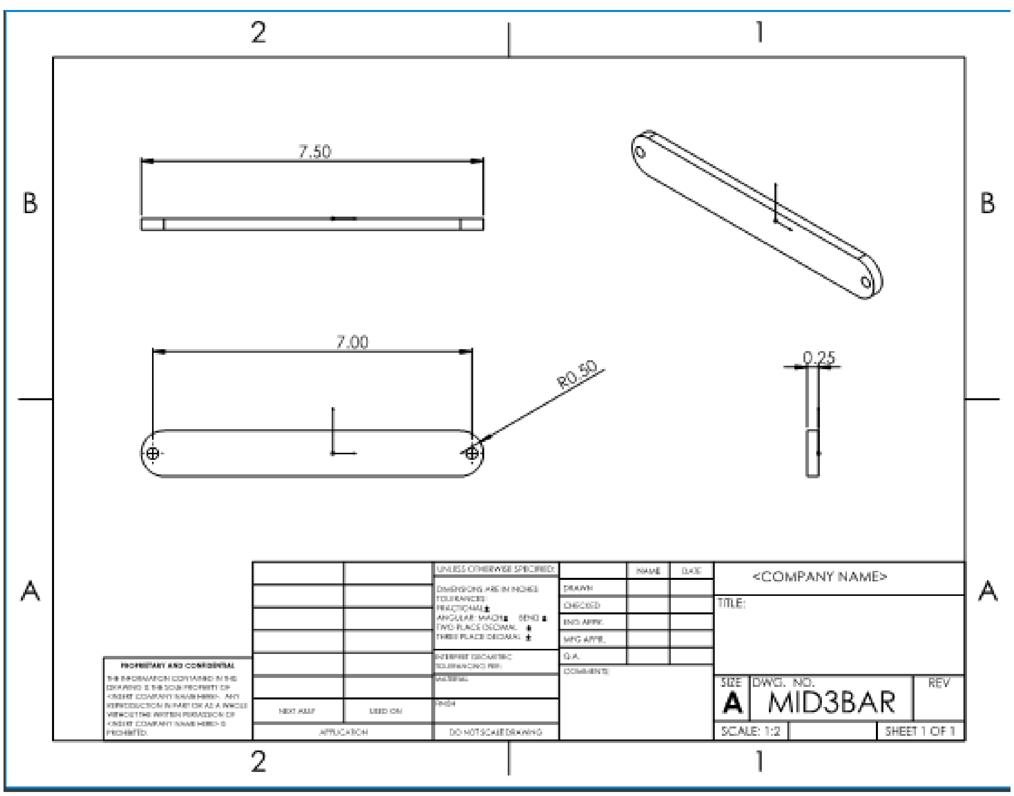
Bottom ends of the frame



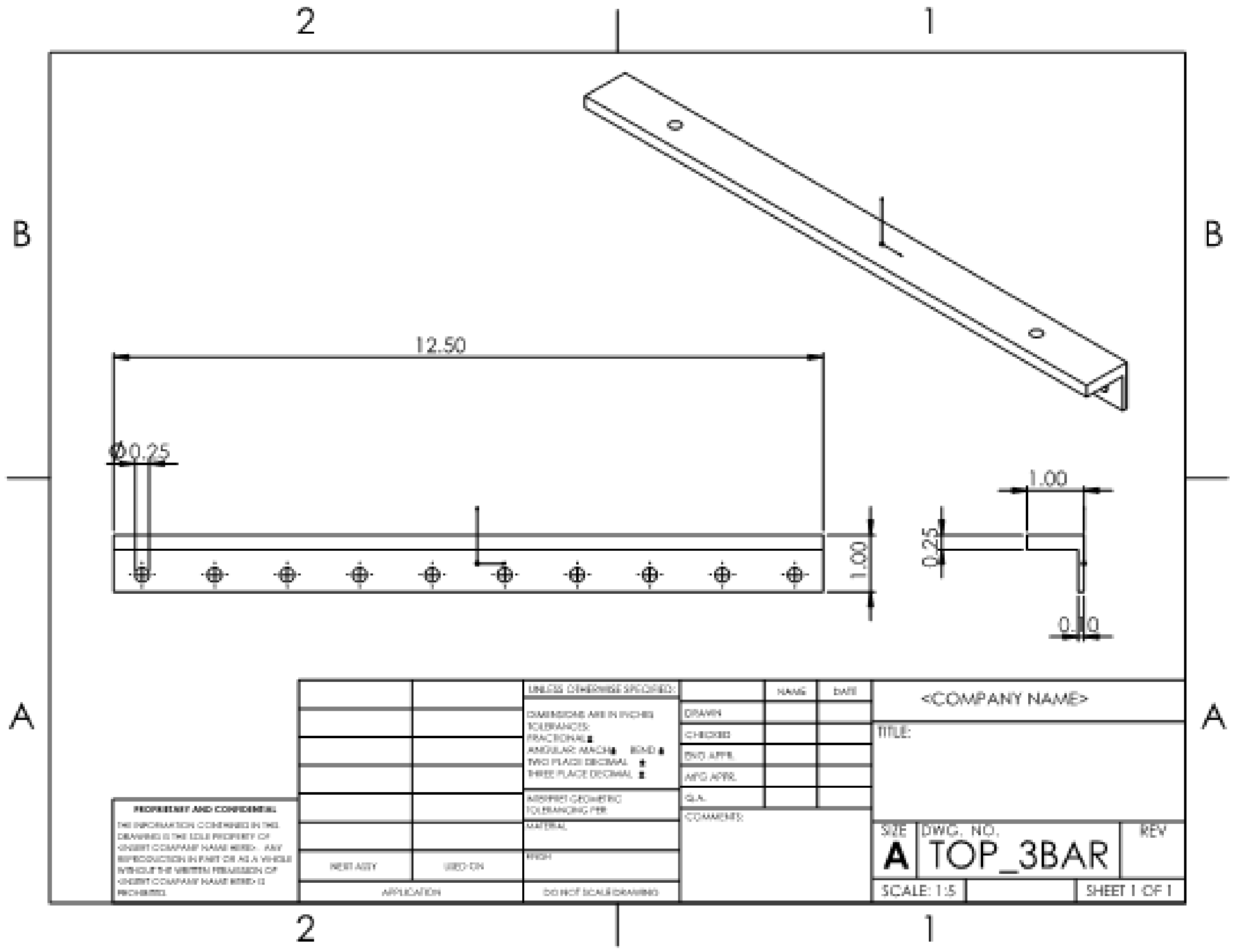
Detailed drawing of the slit made for 60 inch rails.



Detailed drawing of the bottom ends of the frame



Detail drawing of the shortest bar in the mounting assembly



Detail drawing of the top and bottom in the mounting assembly