SPARTAN
SUPERWAY

A Solar Powered Automated Public Transportation System

San Jose State University
Mechanical Engineering Department
ME 195A Final Report
December 15, 2015

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SPARTAN
SUPERWAY

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SPARTAN SUPERWAY

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. Through the first three years of the project the team developed a One-Twelfth Scale Model that supported working software and a control system for a single car, as well as a Full Scale length of track that 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 One-Quarter Scale Model will be the focus of this year's Spartan Superway Team. The One-Quarter 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.

Executive Summary

Small Scale

The current twelfth scale track displays limited capabilities and rough transitions. It is limited to left-handed stations and runs one car at a time. Although the summer team designed an additional path for the bogie to travel, which was called a ‘shortcut’, it was not a reasonable implementation. The track was designed in multiple, small segments, which created rough transition points for the bogie. Our solution is to expand the track to display its network capability, consequently, the track will have multiple loops and more stations to allow for more vehicles. There will be both, left-handed and right-handed stations to show adaptability. To mitigate the rough transitions, the track will be built with longer segments and brazed in many locations, adding to the track’s rigidity.

This semester, we decided to modify the bases for the steel supports, making the construction more simple and lightweight. We also completed the final track and support designs, discussed fabrication methods, recorded current inventory and created a bill of materials. Within the coming semester, we plan to obtain materials and begin fabrication of half of the track. Upon completion of two loops, the track will be available for other sub teams to implement their designs. Wayside power and small scale solar will be able to implement their designs. Also, the bogie and controls team will be able to test their designs.

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.

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.

Intermediate Scale

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 not a misconception, but rather is a harsh reality. The scenarios such as motor and power failure, earthquake and falling objects on the guideway are highly possible. Even a mechanically well-designed bogie cannot undergo these fatal scenarios, unless the design is equipped with proper fail/safe mechanisms. In an event of mechanical failure, fail-safe mechanisms respond to either nullify or minimize the impact of the failure, so that there are no human casualties and a mere property damage.

In this section, objectives of the fail-safe team will be explained, followed by the design requirements and the specifications of the fail/safe designs. Also, the research that the team did during the initial phase will be presented. Next, the design concepts will be explained, along with the detailed CAD drawings. Most importantly, FEA analysis on the designs of the fail-safe mechanisms will be explained. The implication of the fail-safe mechanisms and its importance to the overall Spartan Superway's system will be addressed. Lastly, the accomplishments of the fail-safe team throughout the semester will be addressed along with the plans for the Spring 2016 semester.

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 4-6 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.

The goals of the project are refining the steering mechanism, adding a braking system, and redesigning the guideway. 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. Furthermore, the guideway was redesigned by having the track leading to the station run down a 17° slope and creating loop sections to demonstrate the performance of the whole bogie and podcar. 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. An braking system consisting of bicycle disc brakes was chosen to be implemented due to low cost and reliability. The guideway consists of several critical sections which are the part that runs down a 17° slope to the station to pick up passengers and several loop sections to allow for a continuous running guideway.

Finite Element Analysis was performed on the critical parts of the steering mechanism, braking system, and guideway 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 machined using a bandsaw, mill, lathe, and welding machines. The guideway parts will be extruded, cut, welded, and undergo bending.

The Spartan Superway personal rapid transit system has been in development for the past 3-4 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 limit vibrations to the cabin, and to be able to keep the cabin level to traverse 17 degree slopes. The suspension system was an integral part that had been missing from the Superway system.

The following sections are from the Fall 2015 team 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 semester.

The primary goal for the torsion test sub-team 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. This will be done prior to the analysis and torsion testing of the full guideway section in order to verify the ANSYS modelling and the experimental methodologies used in the torsion test. The following section outlines how these initial tests will be performed. Future plans for the torsion test sub-team will also be discussed.

Solar

The Solar Interface Electrical sub-team is composed of three senior electrical engineering students. This semester, our team has developed a scalable, modular electrical interface for the SMSSV. This interface is designed to take power produced by solar cells, as well as power taken from the city power grid, and supply it to a conductor rail providing power to the system's electric vehicles.

The overall system design will apply to both the 1:12 scale and 1:4 scale models. However, there are several key differences between the two scale model circuits. For the 1:12 scale circuit, the grid power will be supplied via a separate DC power supply. 100% of the power produced by the 1:12 scale solar cells will be used to power the 1:12 scale bogies, and any extra energy produced will not be stored. The major components of the 1:12 scale circuit are solar cells, linear regulators, high-current diodes and a 12 volt DC power supply.

The 1:4 scale circuit will be designed to supply any access power generated via the solar cells back to the power grid. This circuit will utilize solar cells, a DC-DC converter circuit and source switching circuitry similar to the 1:12 scale circuit. In addition, the 1:4 scale circuit will include rectifier and inverter components that will allow the system to both draw power directly from the power grid and also supply any excess power back to the grid. Unfortunately, at the time of writing this report, the exact power requirements for the 1:4 scale model have not been determined. As such, our team was not able to develop specific design details or a bill of materials for the 1:4 scale solar interface circuit at the time of writing this report.

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 a modular mounting system to be used in the Power Supply System. 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 purpose of the 1/12 scale track was to show individuals how the Spartan Superway works. Currently, the 1/12 scale track operates with batteries on-board the bogie and does not fully capture one of the important issues the Spartan Superway is trying to solve. Each bogie has their own battery pack and needs to be recharged every so often. In order to show one of the most important aspects of this project, solar panels are needed to be installed where it can be visually displayed. To stay true to the whole design of the Spartan Superway, the solar panels also need to be fully functional, which can be achieved with the help from the EE team. A mounting assembly is needed to attach a number of solar panels onto the existing steel posts. The solar panels also need to be orientated 32 degrees true south, in order to achieve the best results for a passive solar panel system. Previous solar panel solutions involved a tracking system in order to achieve the best possible angle at any given time. Due to the large nature of the Spartan Superway, a complex tracking system with many moving parts will require more maintenance. In order to keep the system simple and cost effective, a passive solar panel system can achieve the desired energy requirement as well as provide ease of installation.

Acknowledgements

Table of Content

Abstract... 3
Executive Summary 4
Acknowledgements.. 9
Table of Content 10
List of Figures 11
List of Tables 15
Chapter 1: Introduction..16
Chapter 2: Small Scale 17
Chapter 3: Intermediate Scale..47
Chapter 4: Solar..109
References 135
Appendix A: Small Scale 138
Appendix B: Intermediate Scale 143
Appendix C: Solar 170

List of Figures

Figure 2-1:Summer 2015 track concept design. 18
Figure 2-2: Fall 2015 newly improved track concept design 18
Figure 2-3: Summer team support concept design...19
Figure 2-4: Steel plate base concept design. :..20
Figure 2-5: Simple support concept design 20
Figure 2-6: Final track design assembly. 22
Figure 2-7: Brazed pieces are joined together by guide connectors. 22
Figure 2-8: Top rail station ends does not seamlessly connect with the top rail straight end. 23
Figure 2-9: Curved top rail ends will be joined together with the straight top rail ends using bolts. 23
Figure 2-10:Summer Team Ultrasonic sensor design...27
Figure 2-11:The top portion of the vehicle shown is the current bogie design for the vehicle. Changes to the bogie design are minimal and only serve to reduce weight, remove sharp edges and corners, allow room for wire management, and integrate the new design for the new design for the turning mechanism...28
Figure 2-12:The figure above displays the current cabin design and placement of the ultrasonic sensor..28
Figure 2-13: Comparison between delta (top) and width (bottom) bar codes...........................29
Figure 2-14:Here are the images taken from the initial barcode scanning tests, on the left we have the hand drawn barcodes, on the right we have the make shift optical encoder for scanning the barcodes and at the center we have two test runs showing the results. 30
Figure 2-15: Final Ultrasonic Sensor Placement Design 30
Figure 2-16: Design for Collision Detection Code...31
Figure 2-17: Conceptual Design of the Small Scale Cabin. The cabin will be a 3D printed shell that will look more similar to the cabin model drawn in figure 2-15. 32
Figure 2-18: The cabin will be 3D printed as two half shells to allow easy assembly and allow easy access when mounting circuit components. 33
Figure 2-19: Slot cars use a forth rail system with current and return rail (Slot cars: How it works, 2015). 36
Figure 2-20: 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)...38
Figure 2-21: A chart showing the relative cost of materials with respect to its conductivity ("Resitivity-Cost"). 39
Figure 2-22: A 1/12th scale third rail concept using a roller for a collector shoe. 40
Figure 2-23: A 1/12th scale third rail concept using a slider for a collector shoe. 40
Figure 2-24: A 1/12th scale forth rail concept, using a H/O scale model train track. 41
Figure 2-25:The fourth rail system final design..41
Figure 2-26: The collector shoe assembly..42
Figure 2-27: The flat ¼ inch 10 AWG wires that will be used for the current and return rails. 42
Figure 2-28: The 1/12 scale, forth rail final design. 43
Figure 2-29: The insulated housing will be bent into shape using a wooden frame (Doherty, 2015). 44
Figure 2-30: Gantt Chart for Spring 2016 46

Figure 2-31: Tasks for Spring 2016. 46
Figure 3-1: Safety Chain Dog used for Roller Coaster (Theme Park Review, 2010). 48
Figure 3-2: Upstop wheel from a rollercoaster (Theme Park Studio, 2013). 49
Figure 3-3: View of bogie with all final fail-safe mechanisms visible 50
Figure 3-4: Modified design of the upstop wheel. This modified design has the upstop wheel attached above the steering mechanism. 50
Figure 3-5: Past bogie design derailing due to the lack of catches. 51
Figure 3-6: View of top half of bogie with inside catch highlighted in blue. 51
Figure 3-7: Upper hook made of ⅜ A36 steel plate stress analysis. 52
Figure 3-8: Inside Catch under 700lb load. 53
Figure 3-9: Top catch made of ¼ A36 Steel under 700lb load. 53
Figure 3-10: Bottom Catch made of ¼ A36 Steel under 700lb load. 54
Figure 3-11: The cabin used on West Virginia University's PRT system (writeopinions.com) 57
Figure 3-12: : ULTra system found at Heathrow Airport (londonist.com) 57
Figure 3-13: Similar form of bike storage on a public bus (cycle-works.com) 58
Figure 3-14: Concept sketch of the cabin's exterior shell 59
Figure 3-15: Early sketches of the interior design. 59
Figure 3-16: Wheelchair cabin space visualization 60
Figure 3-17: Powered wheelchair cabin placement 60
Figure 3-18: Wheelchair anchor hook locations. 61
Figure 3-19: Wheelchair restraint locations 61
Figure 3-20: Final design of the cabin's exterior shell 62
Figure 3-21: : Pressure contours on cabin design 63
Figure 3-22: Airflow model of cabin flow simulation 64
Figure 3-23: Examples of how a wheelchair/bike will sit 65
Figure 3-24: Bike hooks that will securely store bikes in a vertical position 65
Figure 3-25: Upper steering mechanism control arm 70
Figure 3-26: CAD model of bogie with modified steering mechanism 71
Figure 3-27: Triangular link 71
Figure 3-28: L-bracket 72
Figure 3-29: Control Bar 72
Figure 3-30: Brake Racket 73
Figure 3-31: Top View of Guideway 73
Figure 3-32: L-bracket Von Mises stress 74
Figure 3-33: L-bracket deformation 75
Figure 3-34: Triangular link Von mises stress 76
Figure 3-35: Brake Bracket Von mises stress 76
Figure 3-36: Sloped section deflection analysis. 77
Figure 3-37: Three axes of motion 81
Figure 3-38: Torque and Angular Momentum of a Ridgid Body 81
Figure 3-39 Damped spring mass system with vertical motion 82
Figure 3-40 Different damping system scenarios 83
Figure 3-41 The position of the cabin and station platform must be level in order to ensure passenger safety and convenience 83

Figure 3-42 An example of utilizing a modular design approach where parts are built around certain specifications, ensuring compatibility even after small changes are made.....................84
Figure 3-43: Morgan Town Public Rail Road Transit System 85
Figure 3-44: Wuppertal Suspension Railway...86
Figure 3-45: Chiba Suspension Railway 86
Figure 3-46: Suspension System of a Typical Suspended Railway Transit System...................87
Figure 3-47: JPods...87
Figure 3-48: Swift...87
Figure 3-49: MISTER pod design...88
Figure 3-50: MISTER at a decline of 45 degrees..88
Figure 3-51: Cantilever Design Suspension 89
Figure 3-52: Utilization of Air Bag and Magnetic Dampers 90
Figure 3-53: Utilizing Actuators and Coil Overs...90
Figure 3-54: Actuators and coil over to keep the cabin level..91
Figure 3-55: This figure represents the distribution of the von Mises stresses in the Bottom Tube assembly..92
Figure 3-56: This figure shows the distribution of von Mises stresses in the Top Tube assembly. 93
Figure 3-57: This figure shows the distribution of von Mises stresses in the Top Connection Plate. 94
Figure 3-58: This figure shows the relationship between the transmissibility ratio of the suspension and the excitation frequency...95
Figure 3-59: Outer square tubing assembly Figure 3-60: Inner square tubing assembly..96
Figure 3-61: Top connection plate..96
Figure 3-62: Full assembly...97
Figure 3-63: Circular Closed Cross Section: This piece is used for calibrating the torsion test machine: 100
Figure 3-64. Simple Square Closed Hollow Cross Section for first torsion test........................101
Figure 3-65. Full-scale Track Design by Bengt Gustafson: Spartan Superway will use this design as a basis, with some minor changes 101
Figure 3-66. Jake's initial design of five foot full scale guideway. This is an initial design, which needs adjusting, that will be used for the torsion testing. The side plates and end bars are shown here. 102
Figure 3-67. Design comparison of full scale models. Mr. Gustafson's design invokes a potential flaw in Mr. Parkhurst's design 102
Figure 4-1:DC Power Regulator LTspice Model. This circuit is for the 1:12 scale electrical interface circuit. It utilizes three LT3083 linear voltage regulators in parallel to generate a total maximum current of 3 Amps DC. 110
Figure 4-2:Overall System Block Diagram. This system takes power generated from the solar cells and uses a DC-DC converter circuit to condition the power before it is sent to the conductor rail. It also uses the city power grid as both an additional power source and power storage system...111

Figure 4-3:Project Gantt chart as of December 4th, 2015. The design of the 1:4 scale circuit was not completed this semester due to lack of power specifications. The 1:4 scale circuit will be designed during the spring semester, once the power requirements for the 1:4 scale model ..113
Figure 4-4: Monocrystalline silicon solar panel (Image retrieved from: http://www.borgenergy.com/monocrystalline-solar-panel/) 115
Figure 4-5: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)..116
Figure 4-6: : Miasole Flex 02 thin film solar cell (Image retrieved from: http://miasole.com/products/) 116
Figure 4-7: Initial planar mounting design. This is the design chosen that was later improved.117
Figure 4-8: Initial concave mounting design. This design was least appealing to us compared to the other two. 118
Figure 4-9: Initial convex mounting design. This will be looked into next semester to see if it can be improved to succeed the planar design. 118
Figure 4-10: East to West track mounting design. Made from strut channel, it is light-weight and easy to fabricate...119
Figure 4-11: North to South track mount design. 119
Figure 4-12: Mount system on full scale model. 120
Figure 4-13: A screenshot of our calculator with showing our power and track requirements. .121
Figure 4-14: Calculations of cost, efficiency, etc of solar panel 122
Figure 4-15: Initial Mount Design for Solar Panels. The design on the left allows for a more stable base. Both designs have ¼ inch aluminum rails that will be secured by screws. The rails will be where the solar panels will be attached. 124
Figure 4-16: Location of the base of the mounting assembly where hex bolts and nuts will be used to secure the mounting assembly onto the steel posts..124
Figure 4-17: Final design of mounting assembly. Full assembly consists of four individual pieces each out of 3/16 inch aluminum flat bar. Individual pieces will be welded together. 125
Figure 4-18: Final design of solar panel frame mount. Aluminum frame consists of ¼ inch aluminum square bars welded together. 1/16 inch aluminum sheet metal will be used to secure the solar panel to a flat base. The sheet metal will be spot welded onto the frame before inserting the solar panel. 126
Figure 4-19: Underneath the solar panel aluminum frame. Four holes will be threaded with two holes on either side of the frame. 127
Figure 4-0-20: Fully assembled solar panel mount. On the left, a back view shows two mounting assemblies attached to the steel post, while the front view is on the right. 127
Figure 4-21: Stress analysis done on previous design with a maximum strain of 0.16.............128
Figure 4-22: Stress analysis of final design with a maximum strain of 0.046. 129
Figure 4-23: Location of where sheet metal will be folded. 129
Figure 4-24: Locations of TIG welding...130
Figure 4-25: Two hex bolts and nuts are to be fastened onto the mount for easy removal. 130
Figure 4-26: Eight machine screws will be used on the red location. 131
Figure 4-27: Complete 12 panel solar system implemented on 1/12 scale model. 133

List of Tables

Table 2-1: Bill of Material for the small-scale wayside rail system 37
Table 3-1: Parameters for Torsional Analysis of the Circular Hollow Section 104
Table 3-2. Results of Analysis of the Circular Hollow Cross Section 104
Table 3-3. Parameters for torsional analysis of the square hollow cross section 105
Table 3-4. Results of analysis of the square hollow cross section 106
Table 4-1 List of Systems and Corresponding Major Components. The table contains all the components for the 1:12 scale circuit. At the time of writing this report, the power requirements and system components for the 1:4 scale circuit design have not been determined................111
Table 4-2: Estimated Cost for 1:12 Scale Solar Interface. This cost estimate includes all the components needed for the current 1:12 scale circuit design, as well as an AC/DC power supply that will be used to simulate city grid power for the 1:12 scale model......................................112
Table 4-3:Project Deliverable Dates, Descriptions and Estimated Cost. This table only contains deliverables for the 1:12 scale model circuit. The 1:4 scale circuit deliverables will be determined and produced during the spring semester..114
Table 4-4: Solar panel technical specifications including current, voltage, and power. Bogie measurements provided by 1/12 scale team. 132

Chapter 1: 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 2: Small Scale

Small Scale Track Team

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.

Design Concepts

Track Design Concepts

The summer 2015 track team had spent much of their time designing a new track with the help of Swedish Professor, Bengt Gustafsson. Their design expanded the current track and added an extra loop with two stations in the middle of the track as shown in Figure 2-1. This track will able to accommodate for multiple vehicles running at the same time and allow for two directions of travel at the middle section of the track. The vehicles on the track will only be able to run in one circular direction, either clockwise or counterclockwise, on the two loop. When working with this track design concept from the summer team, we ran into some problems with how the guide connectors were drawn as they were offset from one another and not symmetrical. Also, the guide connectors which holds the individual track sections together were not implemented in the drawings, so there would be more guide connectors needed in the drawing.

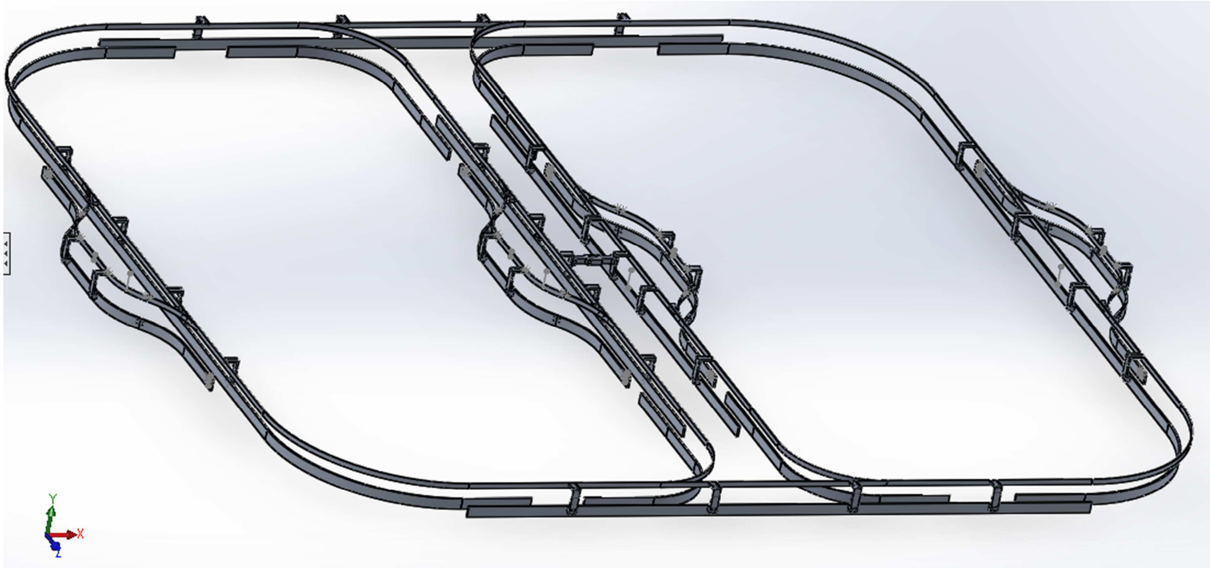


Figure 2-1:Summer 2015 track concept design.

Another track design concept was generated by our Fall 2015 track team. We used the Summer 2015 design and improved on it. Our new track design as shown in Figure 2-2 will have two additional loops added right next to the summer team's track design. Having four loops will show the proof of concept for the modularization of the track design. The track may be expanded by attaching additional two loops on any side of the original two loop design and that is what makes the design modular. The four loop track will have more space for a number of vehicles to run on the track and will be able to accommodate more space needed for the Small Scale Solar Team to implement their solar panels on the supports as well as for the Wayside team to attach their wayside pick-up on the track supports. An improvement can be seen in the placements of the supports and the materials used. Fabrication processes will also be done differently as opposed to the current process used for the existing track at SSDC.

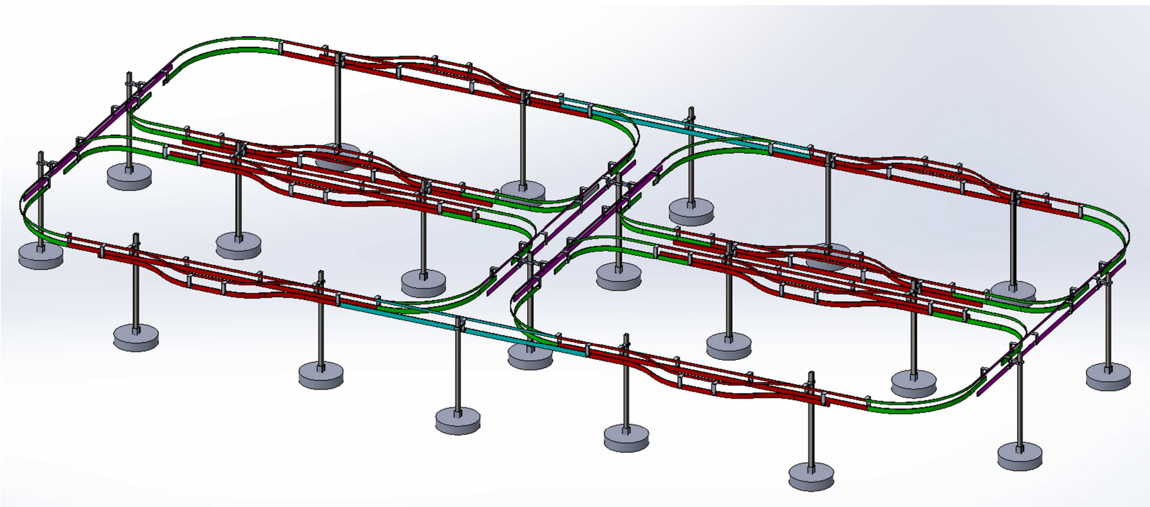


Figure 2-2: Fall 2015 newly improved track concept design

Support Design Concepts

The summer 2015 track team also had a new design for the track supports to replace the aluminum rod supports we currently have at SSDC. Their design includes a square steel tube to enable it to be more robust compared to the aluminum rods that could be easily bent by the weight of the track or by external forces. The square tube is then fixated to a cement base by using a steel plate that is bolted down by four aluminum angle brackets to each side of the square tube as shown in Figure 2-3. It is similar to the design of the current support at SSDC. The cement base has been lowered to 4 inches in height to reduce the weight of the cement. New double sided square clamps have been designed by this team to clamp onto both sides of the track which can be implemented on the middle section of the double loop track.

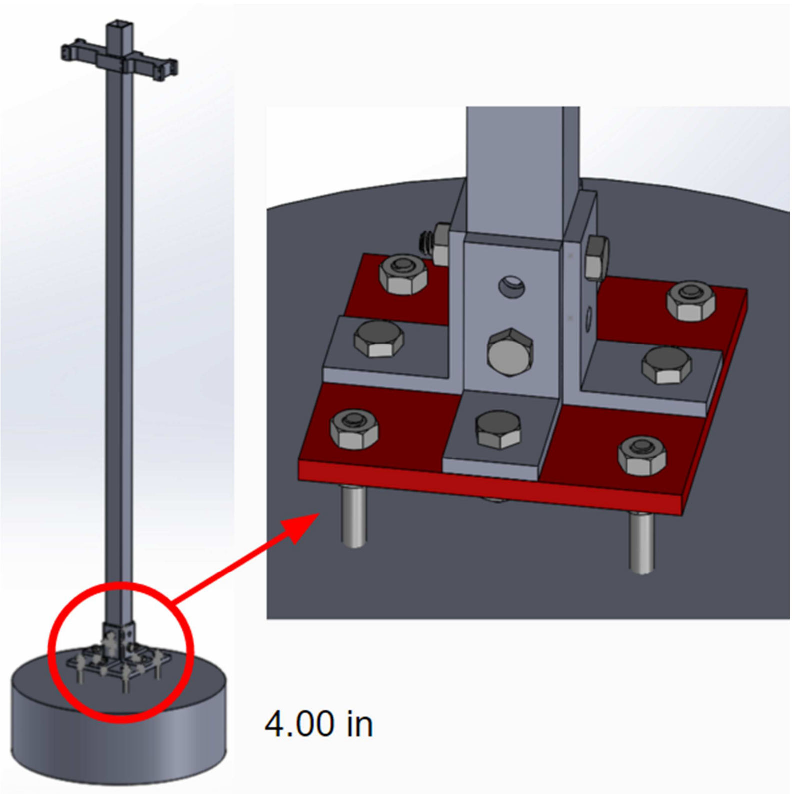


Figure 2-3: Summer team support concept design

Our team designed with a new support which stray away from using the cement base. We wanted to replace the cement base with a steel plate base to reduce the weight of the base drastically of about 20-30 pounds as shown in Figure 2-4. The design will use the same four aluminum angle brackets that will join the steel plate to the steel square tube. It will be roughly 8x8 inches with ¼ inch thickness. The design was made to improve the aesthetic look of the base and to eliminate the chances of tripping over the large cement base when passing by.

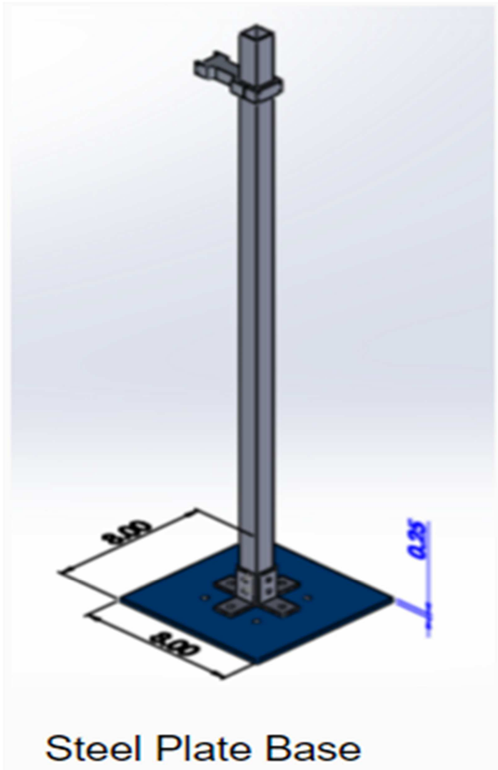


Figure 2-4: Steel plate base concept design. :

Our next concept design uses the cement base. The main drive for this design is to keep the fixture between the base and the support post to be as simple as possible. This means reducing the size of it even further down to 3 inches, in hopes of cutting down the weight even more for easier transport to the events. Also, the support base joining unit (the four angle brackets, steel plate, nuts, and bolts) will be replaced by a single square steel tube of a size slightly larger than the square tube post. It will be 5 inches in height and the square post will slip inside the inner hole of the square tube as shown in Figure 2-5.

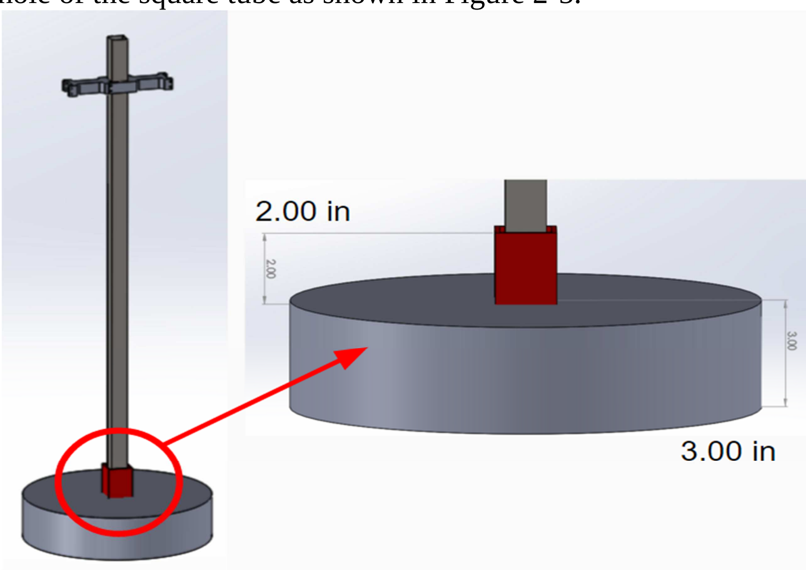


Figure 2-5: Simple support concept design

Analysis and Concept Selections

For the track design concepts, our final design was made by progressive improvements of the summer team's track design. When going through their drawings on Solidworks, we faced many problems with regards to how the parts were joined together and built. There were missing guide connectors that needed to be placed to hold the track pieces together. Also, there were some alignment issues with the guide connectors that we were able to redraw and constrain. However, though the process of fixing and investigating their drawings in every detail, we were able to improve and add new parts to the drawings, Our final track design now has the current station parts that were manufactured by Vanderbend. The station is slightly larger than as drawn so adjustments were made to the drawings. We also fixed the positions of the guide connectors with the idea of brazing sections of the track together for easier transport as well as assembly and disassembly. The locations of the supports were repositioned evenly to areas around the track. They will be able to hold distributed loading and will account for slight vibrations when multiple are running on it at the same time with the help of the final support design.

Our final support design was accounted for using cost analysis, ease of fabrication, material usage, and transportability. We decided to use the track design in Figure 2-5 since the plate base concept design was heavy on the costs and the materials for the cement base were fairly inexpensive. We also liked the idea of removing the excessive base plate and the four angled brackets since it will reduce the fabrication process by a few steps and reduce the cost even more. It will also help with the assembly and disassembly processes since the support post will only have to be inserted into the larger square tube as opposed to bolting them together using an angle bracket and a steel plate in the previous designs. There will be a small clearance in between the post and the square tube which will allow the post to not be statically be in place. It will act as a shock absorber to reduce the stress that will be transferred to the brittle cement. This design will lower the overall height of the track by 5 inches, but we will able to extend the post a few inches by welding the extra inches as needed. Also, the weight of the cement will be reduced by 10 pounds since we are reduced the cement height to 3 inches.

Fabrication Methods

The current track is held together with many tiny screws and sometimes these screws get loose over time which leads to faulty vehicle traveling. The screws also pose trouble when disassembling and re-assembling the track when we take it out of the SSDC to other events. In order to combat this problem, we plan on brazing parts of the track which will get rid of some of the screws. We will however, screw to bigger sections of the track so we can still transport the track in sections. The planned sections of the track are shown below in Figure 2-6.

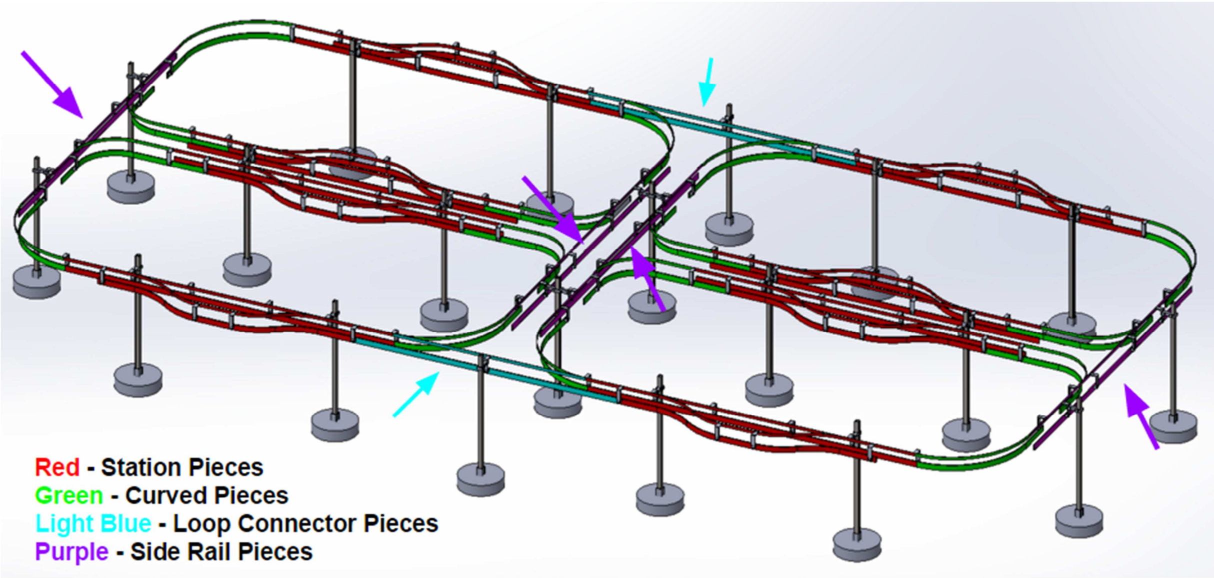


Figure 2-6: Final track design assembly.

The figure above shows the track color coordinated with the brazed sections. Each color represents a section of the track. Every component within that section will be brazed and each section will be screwed together as seen in the Figure 2-7.

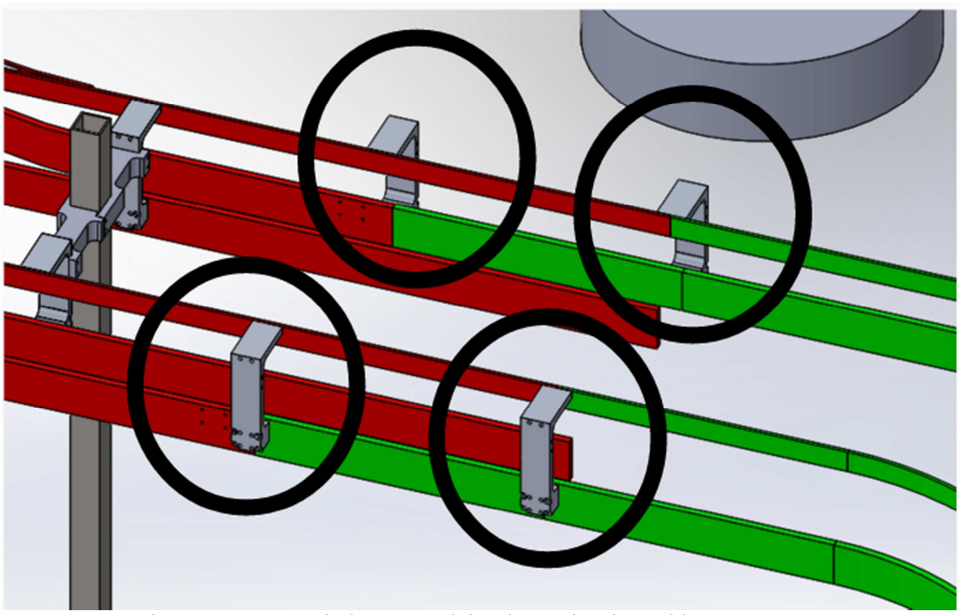


Figure 2-7: Brazed pieces are joined together by guide connectors.

When we were making the model for the track, we realized that some of the station tracks don't seamlessly transition into the main track as seen in Figure 2-8.

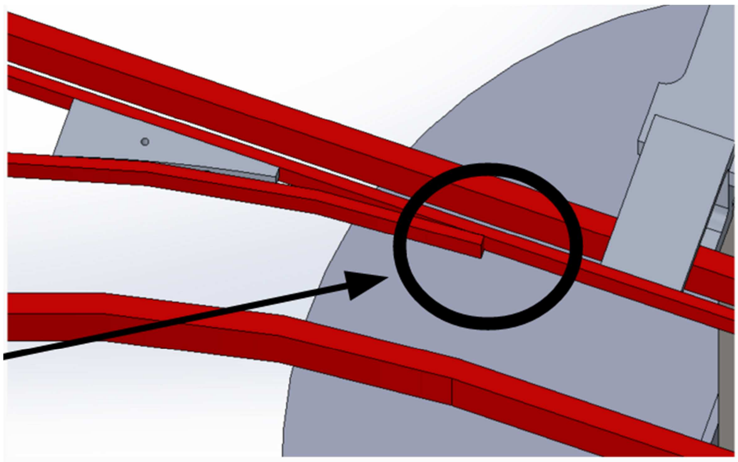


Figure 2-8: Top rail station ends does not seamlessly connect with the top rail straight end.

In order to fix this issue, we will cut off some of the excess material of the station rail and then grind the rail to make the transition smooth. If there happens to be a little gap between the two rails, we will fill it in with some brazing material and then grind it smooth.

Brazing will be the main method of fabricating the top and bottom rails as well as some of the guide connectors together. Brazing is a combination of soldering and welding which involves a heat torch and brazing rod. The brazing rod we will be using is made of aluminum but it also comes in different materials. In order to braze, we heat the part up and drag the brazing rod at the joint and the brazing rod will melt into the joint and will join the pieces together.

Another issue we found was joining the green curve section to the purple straight section. To fix this issue, we decided to drill a small hole into the purple section that goes into the green curve and use a small fastener to join them together so it can look like the Figure 2-9 below. We will then grind any protrusions that would interfere the movement of the vehicles.

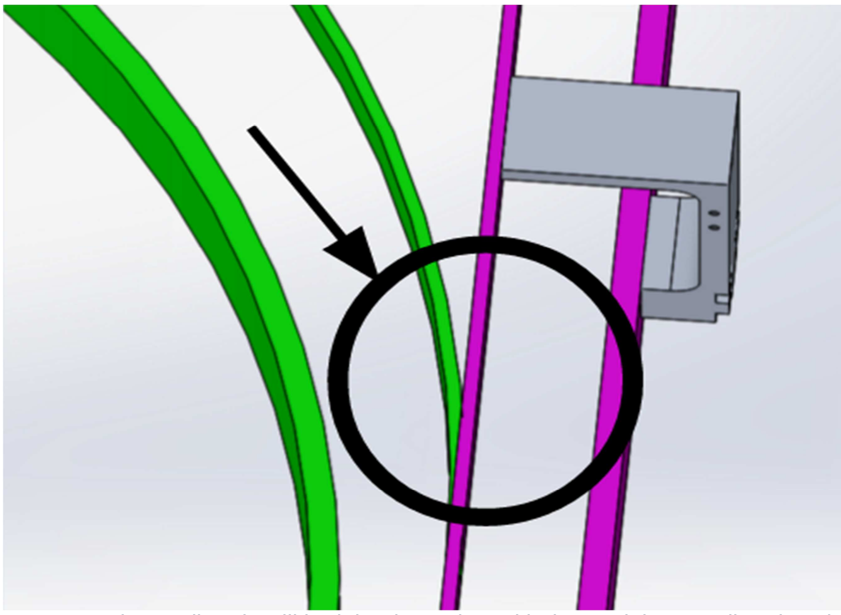


Figure 2-9: Curved top rail ends will be joined together with the straight top rail ends using bolts.

In order to make the structural supports, we will use concrete and steel tubing. To make the supports, we will make circular molds made out of cardboard with a release agent on the inside perimeter. We will place a section of square tubing in the center of the circle and then mix and pour the concrete around the tube. The finished track supports should look like the ones shown in Figure 2-5. The tube that we will be putting will be slightly bigger than the tube that will be attached to the support legs on the track so they will slight right in.

Outcomes

Figure 2-2 shows that we have designed a whole new track that can accommodate multiple vehicles. We have a fabrication plan which shows how we will be going about to making the track. We also designed new track supports which will minimize the costs. Since we have our fabrication all planned out , we are ready to start building the track. All we need to do is buy the aluminum for the track, learn how to braze, and start building the track. The sooner we can get the materials, the sooner we can start.

Discussion

Our major accomplishments from this semester includes having completed a track and support design to be fabricated next semester. During the process of creating the new track design, we have done a lot of research regarding the history of the project as well as what needs to be done. The summer track team has done a great job at providing us with the necessary materials and information to build upon and improve on. We also kept our connections with previous manufacturers for our project such as Vanderbend. Overall, our track subteam managed to research and develop a new track design that is compatible with the Solar and Wayside team's design to implement the solar panels and wayside pick-up.

Our plans for the winter break and next semester, Spring 2016, is outlined in the Gantt chart listed in the appendix. Each week we continue on finding out new information about the summer team design and the inventory we currently have in the SSDC. We will keep on doing some research on where the guide connectors, square clamp, double square clamp, and curve connector were manufactured. Communication with the small scale solar and wayside team will be held regularly to make sure their parts are compatible with the track. We will practice brazing on scrap parts we have in SSDC sometime during the winter break so that we will be prepared to start brazing the actual parts once the Spring semester starts. Research regarding how to build the cement base will be done and we will also practice different methods to create a robust cement base. We will also need to order as much parts we need from the Bill of Materials listed on the appendix for next semester during the winter break. This will prepare us for next semester where we can focus on brazing, making the cement base, and putting the track together. At the start of the Spring semester, we will build the two loop first, then if time and money permits, continue to build the four loop as planned.

Small Scale Controls and Bogie Teams

Objectives

The objective of the small scale model is to simulate the vision that is the Spartan Superway project. Its purpose is to bring the project a little closer to reality through a physical representation of the system. To do this we will be building a more complex track that consist of multiple loops, not just one. In terms of vehicles we aim to build up to ten and have them all running at any given moment. To manage all those vehicles we will need a control center that can take care of everything from pathfinding and vehicle management. All of this would not be complete without the most important element of them all, the human element. We plan to change this by connecting the control center to the internet where it will act as a server that can get user input as to where they are and where they would like to go.

In terms of sub-team specific objectives the bogie team will redesign the servo steering linkages, the current design relies on thin wire which is not rigid enough for its application. They will also be tasked with creating a scale model of the cabin that will act as a chassis to mount the electronics and act as a visual representation of the actual vehicles. The controls team’s objective this semester is to design a control center that will controls all the vehicles from one central location. Their objectives will also include developing a barcode location system, integrating a collision avoidance system, and write a path generation algorithm so the vehicles can find its way from location to destination.

The objectives for the vehicle sub team is to finalize the vehicle's design. Also, the team create SolidWorks part and drawing files of finalized component designs of bogie and cabin. After that, the final design of the cabin model shell will be 3D-printed. And for the bogie, the finalized design will be sent to David Moal for fabrication.

Design Requirements and Specifications

The bogie team’s objective this year will be to redesign the servo to steering arm linkages to be more reliable. They are currently held together by piano wire, and they tend to slip out of their joints which results in vehicle failure. The solution we are going to use are hobby grade ball linkages that are used in remote controlled vehicles. The ball linkages will be more rigid and provide a better connection between the servo arms and the steering arms. The other objective is to also design a printable cabin that will act as the chassis that will holds all the electronics on the vehicle and act as a visual model of the large scale cabin. The scale model must be sturdy, aesthetically pleasing, and easy to take apart and put back together.

The objectives for the controls team this year is to design a new control center, integrate a better collision avoidance system, and develop a more robust location system for the small scale model. The control center will be the heart of the Superway model, it will be in charge or path finding, sending and receiving information from the vehicles and it will need to be able to receive data from the internet as user input. The control center will essentially be a dedicated computer that is in charge of handling all the task for the entire system to run. One of the biggest requirements we will have for the control center is its ability to gather user input like a server. This will be how people can interact with the system, they will have to be able to tell the control center their location and then where they would like to go. With multiple vehicles running at the same time we will also need a sophisticated collision avoidance system that will be able maintain the vehicle's speed, not come to a full stop when there is something in front of it. Finally a new location system will need to be developed for the track, it will use some technology much like last year’s design however instead of magnets it will use barcodes. The idea of barcodes is that they are easy to print out, and they have a higher information density to cost ratio than the single bit magnets.

All components must be lightweight and cost efficient. The turning mechanism has to be redesigned to maximize the reliability of turning actuation. Also, components such as motor, servo, Arduino and ultrasonic sensor must have a designated area for mounting. Moreover, wires must be well managed to minimize errors when rewiring components. For the cabin, it has to be large enough to house all circuit components safely and securely. The cabin design must look similar to the full scale model to ensure that Spartan Superway Project is properly represented to potential sponsors and audiences.

Design Concepts

Barcode Location System

One important component to our project is to have an effective location system. We need a more robust location system since our track is no longer going to be a single dimensional loop. For this reason we would need a tracking system that would give us more information. The cost of Hall Effect sensors and magnets are far greater than an optical encoder and printed barcodes, not only that, a single magnet can only provide us with a single bit of information whereas a barcode can be unlimited in length. For our design we plan to use foil tape, or something similar that has high light reflectivity to signal the start and end of the barcode reading, then the barcodes can be printed using a width code protocol. Alternating black and white will signal the next bit, and the duration of the code would provide the bit value, where short would equal 0 and long would equal 1. Since we will have several sections of track we will be using a barcode that is 10 to 16 bits long to allow for sufficient numbering. Shorter configurations in barcodes will be used for signaling when the vehicle should engage its steering mechanism and position on within the station.

Central Control

One of the big tasks we need to overcome this semester for the controls team is to develop the brains of the entire system. The vehicles can have any sensors and feedback system to tell it what to do situationally, however we need a something that gives them a specific task. For this we need a control center that processes all the vehicles position, and pathfinding in real time all while taking in user inputs such as vehicle requests and their desired destination to travel to. For this task we want to use a computer that stores all the information about the track and have an algorithm to decide how to go from location to destination. The control center will also need be able to access the internet to acquire user input. This is going to be the greatest challenge for this upcoming semester along with developing the algorithm that will be used to calculate the best path for the vehicle to travel.

Collision Control System

For the collision detection system, the team from the past summer proposed the following design.

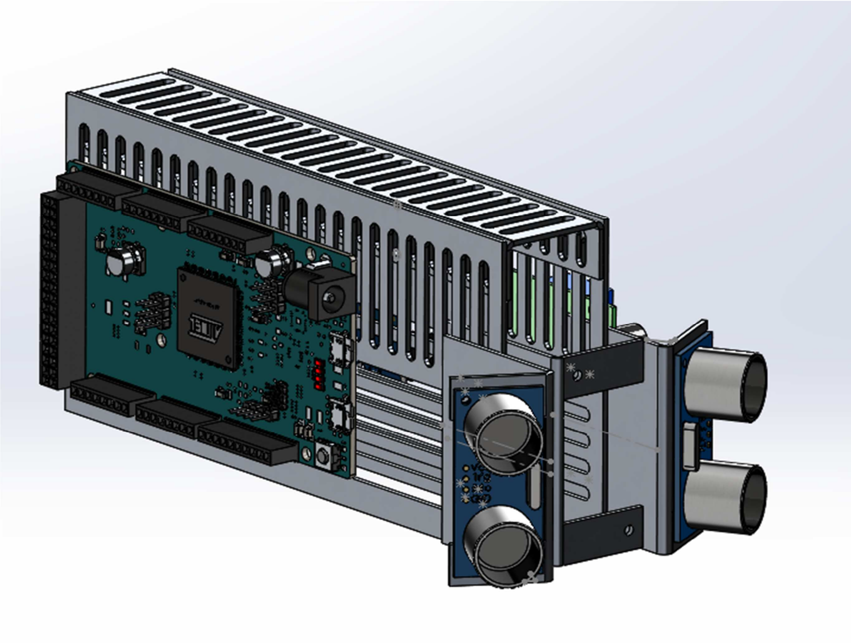


Figure 2-10:Summer Team Ultrasonic sensor design.

After looking at their design, we decided to brainstorm other types of sensors that could be implemented in the collision detection system. We looked into the idea of using infrared laser sensors that would utilize a laser triangulation system. While it would have been more accurate in the sense that there would be less interference we ultimately decided that it would be more cost effective to use ultrasonic sensors. Further, we noted that it was unnecessary for the vehicles to have two ultrasonic sensors oriented at an angle outward from the vehicle's front. Because the vehicles would be traveling in a straight line a majority of the time we decided that one ultrasonic sensor placed at the front of the vehicle would suffice.

Vehicle

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.

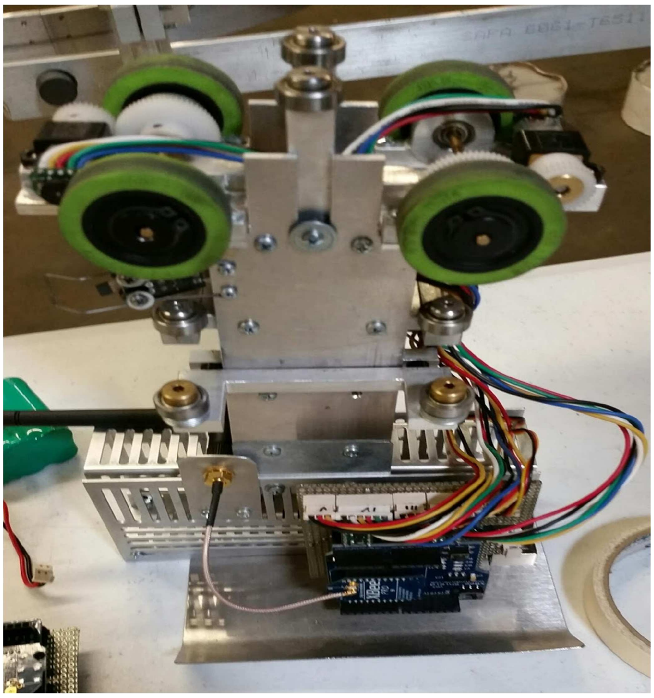


Figure 2-11:The top portion of the vehicle shown is the current bogie design for the vehicle. Changes to the bogie design are minimal and only serve to reduce weight, remove sharp edges and corners, allow room for wire management, and integrate the new design for the new design for the turning mechanism

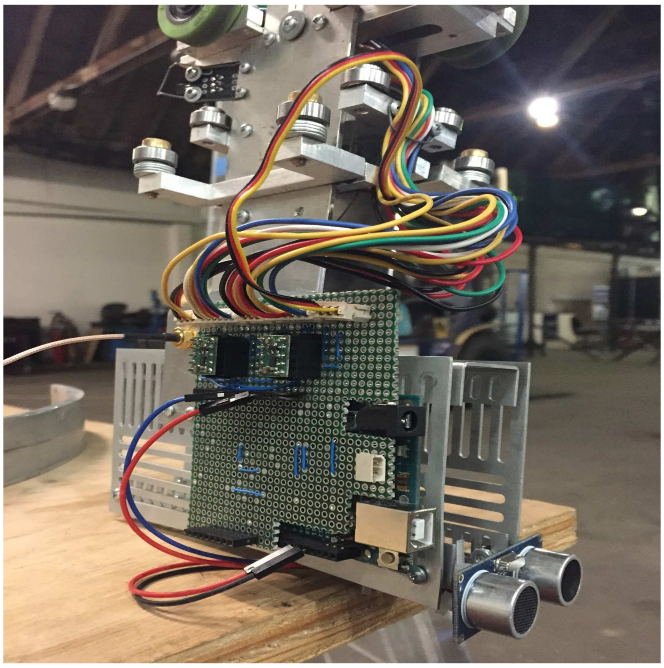


Figure 2-12:The figure above displays the current cabin design and placement of the ultrasonic sensor

Analysis and Concept Selections

Barcode Scanner

The barcode scanner method was considered because it would be a cheaper alternative to buying and using magnets and Hall Effect sensors. The Hall Effect sensors cost as much as an optical encoder, however the cost of magnets and extra manufacturing steps would make them harder to work with. For our plan of having barcodes that can express 10 to 16 bits of information would require the same number of magnets for each section of track. We can print as many barcodes out as we need however the extra steps in precisely placing those magnets would give us more trouble than they are worth.

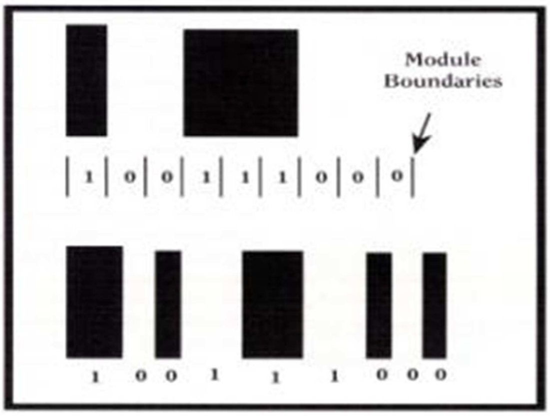


Figure 2-13: Comparison between delta (top) and width (bottom) bar codes.

We have also already gone ahead with developing our barcode scanning method with some basic components. Since we did not already have an optical encoder we used an LED with a shroud around it and a photoresistor that read the changes in light intensity. The barcodes initially used were simply sharpied on a stripe of paper. These tests were initially unsuccessful however we found a different way to differentiate bits of information rather than having it based on a unit length. Using a width code the scanner can more easily differentiate one bit from the last and by changing the length of that bit we can express that as a one or zero.

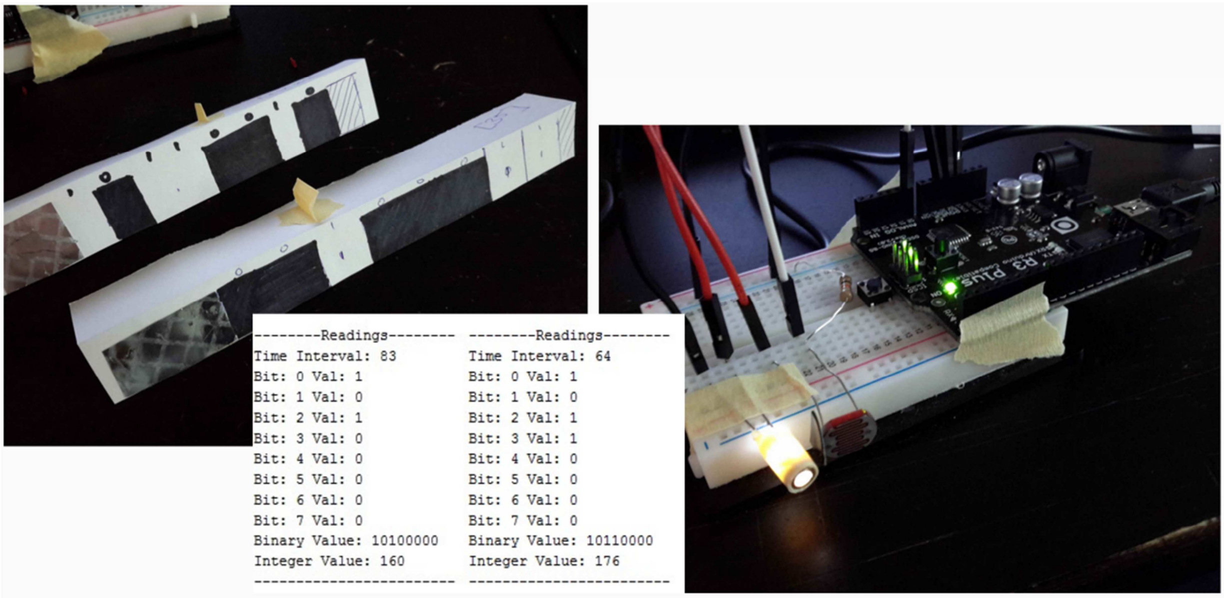


Figure 2-14:Here are the images taken from the initial barcode scanning tests, on the left we have the hand drawn barcodes, on the right we have the make shift optical encoder for scanning the barcodes and at the center we have two test runs showing the results.

Collision Control System

Below you can see the team's final design for the ultrasonic sensor as it would be encased by the 3D printed shell.

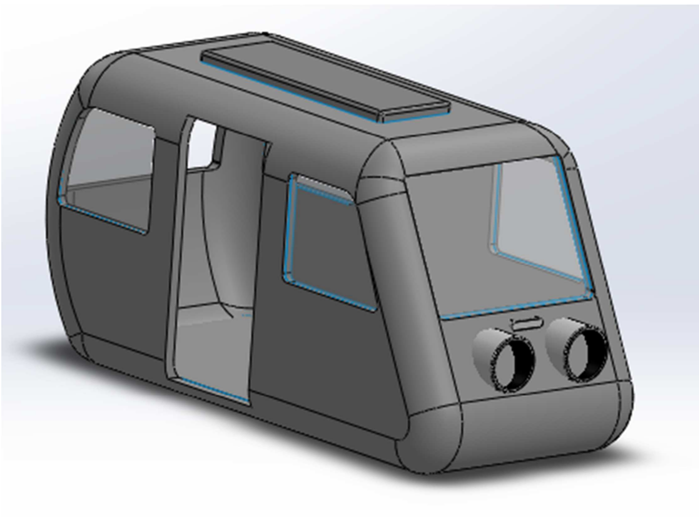


Figure 2-15: Final Ultrasonic Sensor Placement Design

For the ultrasonic sensor, we decided to use the HC-SR04 Ultrasonic sensor module that would be easily interfaced with the Arduino. This provided a cost efficient solution because there was already an inventory of these sensors in the Spartan Student Design Center.

Vehicle

Based on the current design of the bogie and cabin fabricated by the Spartan Superway summer 2015 team, the current vehicles team has made changes to design choices that have been considered as a design flaw or a unfinished design. One design flaw that was noticed was the choice of using piano wire connect to the servo in order to actuate the turning mechanism of the vehicle. The new design for the turning mechanism will replace the piano wire with ball links in order to provide a solid connection between the servo and the turning components. This will increase the reliability of the turning mechanism substantially because the ball links will be more solid and have less play compared to the piano wire connection. The current design for the cabin was also analyzed and as a result the current vehicle team has determined that the cabin design is unfinished. Currently the cabin consists of several components that serve solely as a support for the Arduino and other circuit components. The new design for the cabin looks very similar to the proposed large scale design created by the large scale cabin sub team. The new design will better articulate to potential sponsors the concept of the Spartan Superway project therefore, increasing the chances of appealing new sponsors into investing in the project.

<u>Fabrication Methods</u>

Collision Control System

For fabrication, the collision detection system would ultimately rely on the printing of the vehicle shells. Once fabricated, the sensor would be easily placed inside and interfaced with the Arduino. Most of the “fabrication” for this sub system was primarily programming the logic of the controller itself. Below is a general screenshot of the code we wrote for the collision and

```
void setup() {
  Serial.begin(9600);

  attachInterrupt(0, encoder, RISING);

  Timer1.initialize(tspd);
  Timer1.attachInterrupt(tIntspdErrupt);

  sKp = 0.3;
  sKi = 0.1;
  sKd = 0.05;

  cKp = 0.2;
  cKi = 0.0;
  cKd = 0.1;

  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(m1, OUTPUT); //motor pwm
  pinMode(m2, OUTPUT); //motor pwm
  pinMode(dir, OUTPUT); //motor direction
  digitalWrite(dir, HIGH);
}
```

```
void loop()
{
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = (duration / 2) / 29.1;

  void tIntspdErrupt() {
    //Set speed control
    speedController();

    //Set collision control
    collisionControl();

    if (power > 500)
      power = 500;
    else if (power < 0)
      power = 0;

    analogWrite(5, power);
    analogWrite(6, power);

    ENC_last = ENC_count;
    angVelo = (float)ticks * 5.27;
  }
```

```
void speedController()
{
  spdErr = setVelo - angVelo;
  ticks = ENC_count - ENC_last;

  spdIntg = spdIntg + spdErr;

  spdProp = spdErr * sKp;
  spdIntg = spdIntg * sKi;
  spdDeri = (float)ticks * sKd;

  power = (spdProp + spdIntg + spdDeri);
}

void collisionControl()
{
  if(distance < distThresh)
  {
    power = 0;
  }
  else if (distance < 60)
  {
    colErr = distance - distThresh;
    dDistance = distance - lastDistance;

    colIntg = colIntg + colErr;
```

Figure 2-0-16: Design for Collision Detection Code

We would have a timer initialized with interrupts attached. When the interrupt occurs, the function would be called that checks the distance between the vehicle and any object in front of it. If there were nothing in front of the object the motor would written with a pwm for full speed. The next function in the code would detect whether or not an object was within 60cm. If it were within that range it would adjust the speed accordingly. Finally, if the vehicle became within 10cm of the object in front the program would stop the motor completely in order to prevent a collision.

Small Scale Cabin

The final design for the vehicles have been drawn using Solidworks. The drawings for the components of the bogie have been created as pdf files and will be sent to David Moal in Oakland for fabrication when the final designs are confirmed and correctly incorporate all needs including the needs of other groups such as the wayside pickup sub team. The finalized cabin model will be 3D printed in-house using the 3D printer provided in the Spartan Student Design Center (SSDC). The ball links for the new turning mechanism design will be bought as it would be more cost effective to buy pre made components rather than spending time to design and fabricate an existing component.

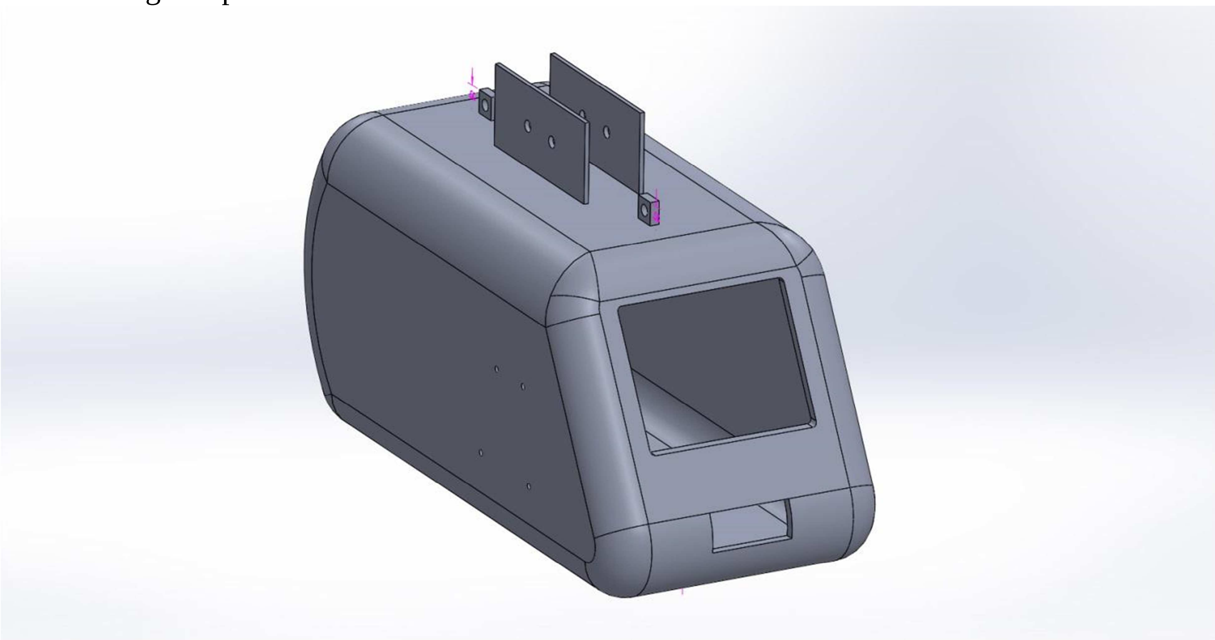


Figure 2-17: Conceptual Design of the Small Scale Cabin. The cabin will be a 3D printed shell that will look more similar to the cabin model drawn in figure 2-15.

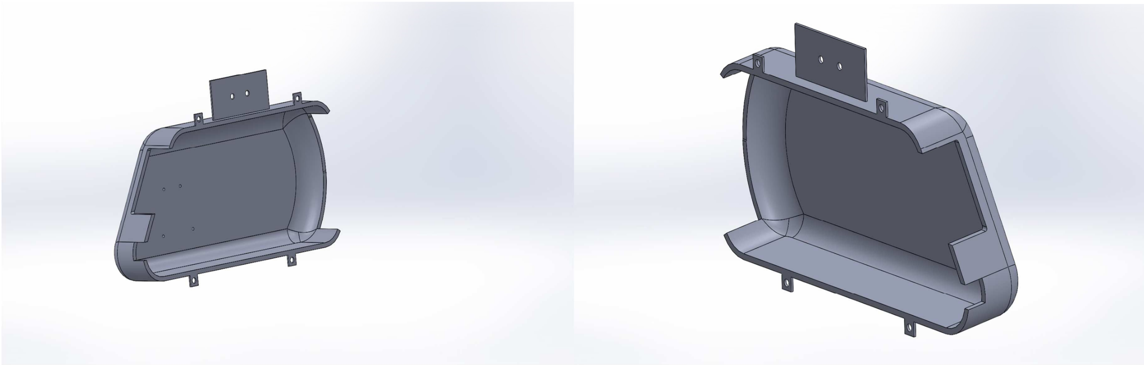


Figure 2-18: The cabin will be 3D printed as two half shells to allow easy assembly and allow easy access when mounting circuit components.

<u>Outcomes</u>

Barcode Scanner

The barcode scanner as of now with the make-shift optical encoder and hand drawn barcodes does not work reliably, however that does not mean it does not work. Since we will be purchasing actual sensors and printing out barcodes with more precision it will perform with a higher level of accuracy. Also when implement the width code format it should make it easier to read the barcodes leading to better readings. For the sake of reading the barcodes part of the track may need to be painted black. The paint will help with preventing the vehicle from picking up false readings which may affect the performance of the vehicle.

Collision Control system

For collision detection, the code successfully performed according to our goals and met all objectives. In the reference section is a YouTube link to the demonstration. While the demonstration is short it is evident that the trailing vehicle is traveling at a much faster speed and then detects the vehicle in front traveling at a constant speed. As the trailing vehicle approaches it slows down and finally when the lead vehicle stops, the trailing vehicle stops as well maintaining its distance.

Vehicle

As an outcome of the modifications to the vehicle design, the bogie design is now finalized and ready to be sent to David Moal for fabrication. Ball links have been added to the bill of materials and will be ordered and ready for implementation when production begins next semester. Lastly the cabin model has been created but not finalized.

<u>Discussion</u>

Control Center and Pathfinding

As of now the control center has not gone through any further development, which it needs. We have put that off until we have a system that we can test on. In the upcoming semester we will need to find a dedicated computer or find a way to have our program online that can easily be acquired and ran with minimal effort by anyone who is trying to run the program. We will also be talking to the master students also working on this project to integrate the user app input that we would like to have for the model. As for the pathfinding algorithm we will either leave that up to the master students of research it over winter break. Since our track is becoming more complex, counting how many magnets you have passed will not cut it as a location system. Some possible issues that may arise may be that we are developing the system faster than the current technology can keep up with so we may need to upgrade the Arduinos to Megas in the future.

Barcode Scanner

The barcode system is semi-proven to work, further development needs to be made on it before it is ready to be implemented to the track. The barcodes will have to be at least 10 bits long, to account for future expansion, and having a decent numbering system where tracks beginning with a certain numerical value represents a certain type of track such as straights, turns, and forks. The next step we have to take is to test the width code format this may prove to be more reliable than the delta code we tested previously. Also with an actual optical encoder the results may be more accurate since they will use infrared and will be less susceptible to visible light. This will also need further testing to see how it performs under sunlight, if there is a disturbance in readings we will have to design a shroud that goes around the sensor to limit external light sources.

Collision system

For future evaluation of the collision system, the vehicles will be tested further to ensure proper functionality next semester. Upon observation, any problems that may occur will be investigated and fixed as soon as possible. Also, the collision system code will be revamped in order to smooth out the reaction when detecting vehicles in the line of path to reduce vibrations that may occur.

Vehicle

The cabin model will be prototyped beginning next semester in order to ensure correct sizing needed for the purposes of the small scale track team. Once the prototype stage is complete, further modifications will be made as needed until a design can be finalized for the 3D printed cabin. Upon completion of the design, 10 sets of cabin shells will be 3D printed and will be implemented on the 10 sets of bogies to create a total of 10 sets of vehicles.

<u>Conclusion</u>

This year we decided to focus on further developing the scale model rather than to scrape the old design and come up with a new track and bogie. With that in mind we mainly had to refine the old system and develop and integrate the new systems we had in mind for the project. The track team is focused on creating a more realistic track set up and fixing the kinks to allow for a smoother ride, while the controls and bogie team is focused developing and implementing new system that will help bring the Spartan Superway closer to reality. So far we have created a speed controller and a collision avoidance system that will prevent the vehicles from hitting each other. We have also tested a location system using barcodes should be a lot more reliable when we acquire the proper components for it. When the next semester comes we will have to redesign the control center and work on a path finding algorithm that will help the vehicles get to where they need to go. Now we have made a list of all the components that we need, and set a goal for the next semester to reach. Ten vehicles and a working model.

Wayside Power

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 progressed, there has been no team that worked on integrating power from solar panel into a wayside pickup system that would power the vehicles. As mentioned previously, the Spartan Superway models have been battery powered. This year's team is focusing on research and design of a wayside pickup system. Research was done on third rail, how trains and subways works, fourth rail pickup, conductive materials, how to charge a battery, and materials that can be used for fabrication for the wayside rail system for the 1/12th 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 a simple design that will be easy to assemble, 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 ten vehicles on the small-scale model. 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 rail of the wayside rails, which will then supply power to the batteries for each vehicle. 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 and green energy, which is the overall goal of Spartan Superway. The solar panels will provide the energy that will make the Spartan Superway ATN sustainable.

Design Requirements and Specifications

The goal of the wayside power team was to give ten bogies power via a wayside power system. The design for the 1/12th scale wayside rail will adopt the forth rail system much like a slot car's power pickup seen in Figure 2-19. This system uses two rails to provide current and return the current.

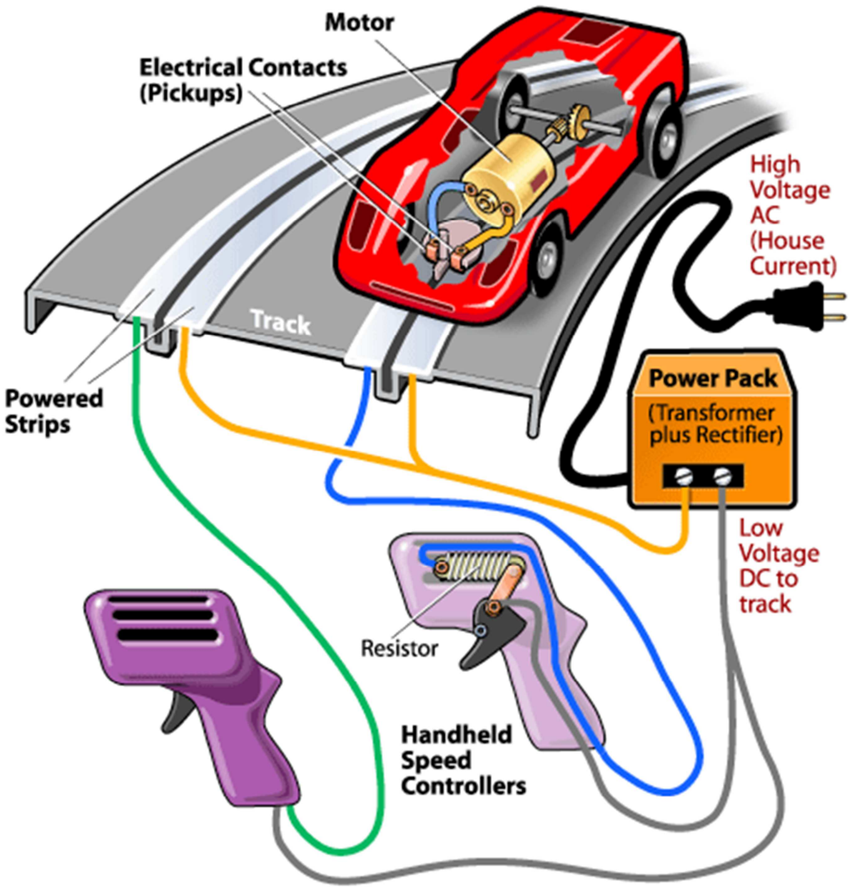


Figure 2-19: Slot cars use a forth rail system with current and return rail (Slot cars: How it works, 2015).

Since the 1/12th scale track will be shown at Maker Faire, there must be some sort of insulated housing protecting onlookers from hazardous shock. Insulated housing for the current rail and the return rail will make it safe for children and adults to examine the model at Maker Faire. The insulated housing must also have mounting brackets every three feet at the minimum to provide proper stability. A ¼ inch slit will be cut into the housing for the collector shoe to slide along in. The housing must also be able to handle the heat that will develop in the current and return rails when the system is running which will be no more than 60°C. The wayside rail must be able to come apart in six foot sections allowing the wayside rails to be taken apart easily and reassembled elsewhere. The current rail and return rail will be seated inside of the insulated housing. A glue that can handle the constant 60°C from the rails will be needed. The current and return rails will need to handle a minimum constant current of 20 Amps and get no hotter than 60 °C. The rails must also be flexible so that they can follow the contours of the track. A collector shoe will be attached to the boogie. The collector shoe must not interfere with any other the other components on or that will be added to the bogie. This shoe will slide along the current and return rails, providing the power for the whole bogie assembly. With the system powered the final requirements will be to make sure that the collector shoe will not lose contact with the current and return rails. To prevent this problem, the collector shoe will be spring loaded in some way.

The ¼ scale wayside rail will need to meet similar requirements as the 1/12th scale model. Therefore, the forth rail system used on the 1/12 scale model can be scaled up roughly three times to get an approximation for this design. The ¼ scale will require much more current, making it a more hazardous endeavor. This means that safety will be a top priority. The insulated housing on the ¼ scale will be rated to handle high temperatures from the rails inside. The rails themselves will be rated to handle high Amperage and get not hotter than 60 °C. The rails need to be bent or be flexible to fit the contours of the track.

The amount of material that will be required for construction of the system on the small-scale model can be found in Table 2-1 along with the total estimated cost of the system.

Table 2-1: Bill of Material for the small-scale wayside rail system

DETAILED BILL OF MATERIAL (BoM)

No	MATERIAL	QTY	PRICE $	MANUFACTURER	SUPPLIER	TOTAL COST $
1	1/2" X 10 FT PVC SCHEDULE 40 CONDUIT PIPE	35	$ 1.59	JM EAGLE	THE HOME DEPOT	$ 55.65
2	FAST DRY 10.1 OZ. WHITE ACRYLIC LATEX PLUS SILICONE CAULK	4	$ 2.88	DAP	THE HOME DEPOT	$ 11.52
3	60:25 CAULK GUN	1	$ 2.77	HDX	THE HOME DEPOT	$ 2.77
4	FLAT BARE COPPER BRAID WIRE 1/4" DIAMETER 25' LENGTH	14	$ 19.67	SMALL PARTS	AMAZON	$ 275.38
5	ABS 3D PRINTING FILAMENT 1KG	2	$ 19.89	USA Filaments	AMAZON	$ 39.78
6	6-32 X 1/4" MACHINE SCREWS 3PACK	10	$ 0.45	CROWN BOLTS	THE HOME DEPOT	$ 4.50
7	6-32 STAINLESS STEEL HEX NUTS 30 PACK	1	$ 6.98	THE HILLMAN GROUP	THE HOME DEPOT	$ 6.98
					TOTAL COST	$ 389.60
					TAXES/SHIPPING (~10%/5%)	$ 58.44
					GRAND TOTAL	$ 448.04

State-of-the-Art/Literature Review

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 2-20: 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, super capacitors, 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.

A critical goal in the development of the 1/12 scale model is to keep it as true as possible to the full-scale implementation of the Superway. This is so that visitors easily make the connection between the various scale models during presentations at Maker Faire and other events. To be successful in the implementation of wayside power on the 1/12 scale model means having the power to run 10 bogies on the track in a manner that is safe for bystanders during presentations. OSHA determines 50mA to 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).

Conducting materials was researched in order to select the material for the wayside rail and the shoe collector. An electrical conductor is a substance where electrical charge carriers, electrons can easily move from atom to atom with an applied voltage. 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 2-21. Copper will be chosen for the wayside rails and collector brush.

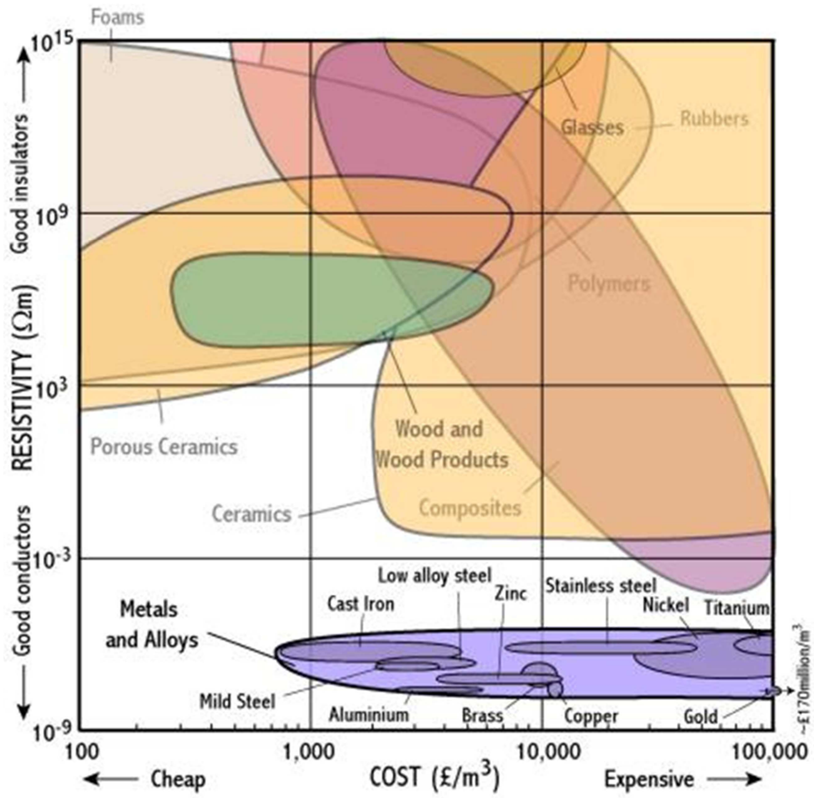


Figure 2-21: A chart showing the relative cost of materials with respect to its conductivity ("Resitivity-Cost").

<u>Design Concepts</u>

A third rail system was the first design that was developed for the 1/12 scale wayside power, seen in Figure 2-22. In this design the switching rail has an insulated strip underneath it. Directly underneath that there is a copper strip, which would be used as the current rail. The bogie itself has a collector shoe attached to it. In this design, the collector shoe uses a copper wheel that rolls along the current rail. Other third rail collector shoe design were created, seen in Figure 2-23, but the third rail system could not be used because it requires the support rail to be used as the return rail which brought problems and lead to the design's demise.

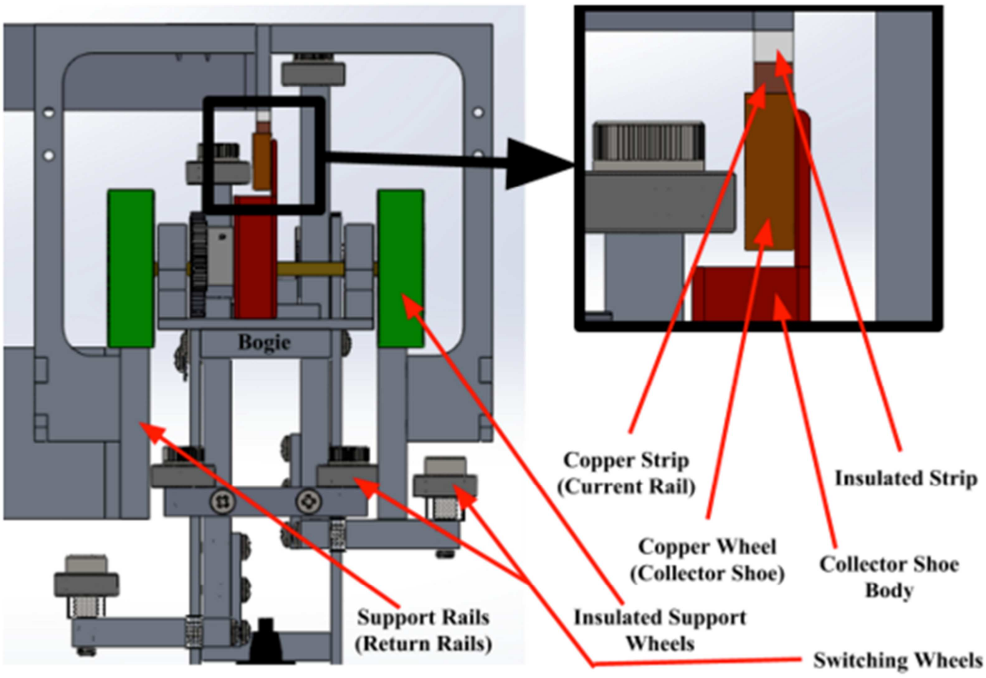


Figure 2-22: A 1/12th scale third rail concept using a roller for a collector shoe.

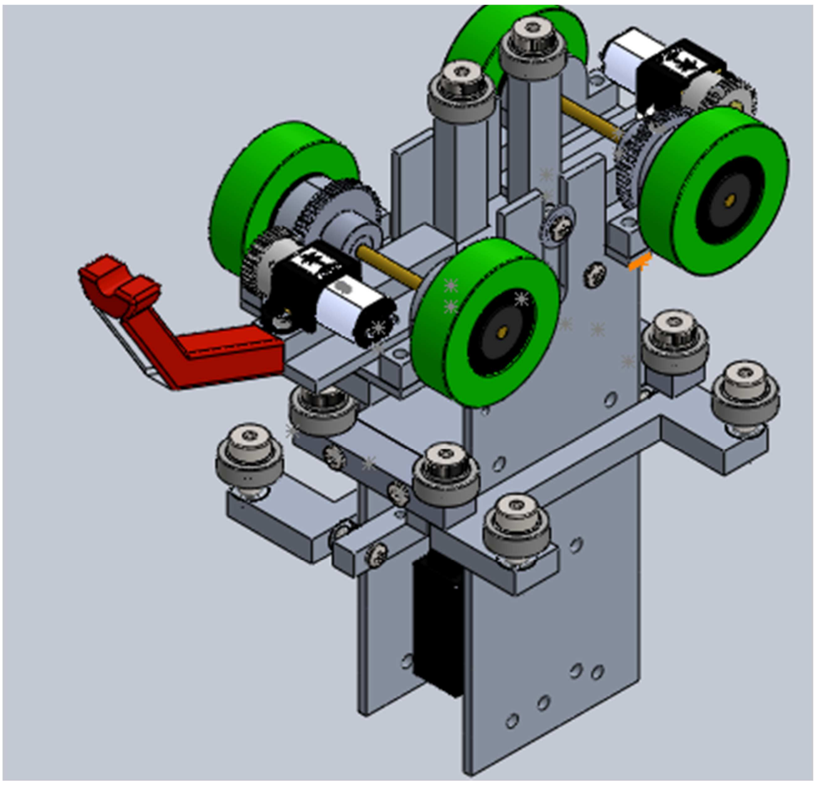


Figure 2-23: A 1/12th scale third rail concept using a slider for a collector shoe.

The forth rail system has perks to offer, it is a safer and more reliable system because the current does not have to travel through the entire supporting structure. Instead, the return current has its own dedicated wire, which can be insulated, preventing hazardous shock. The first fourth rail concept can be seen in Figure 2-24.

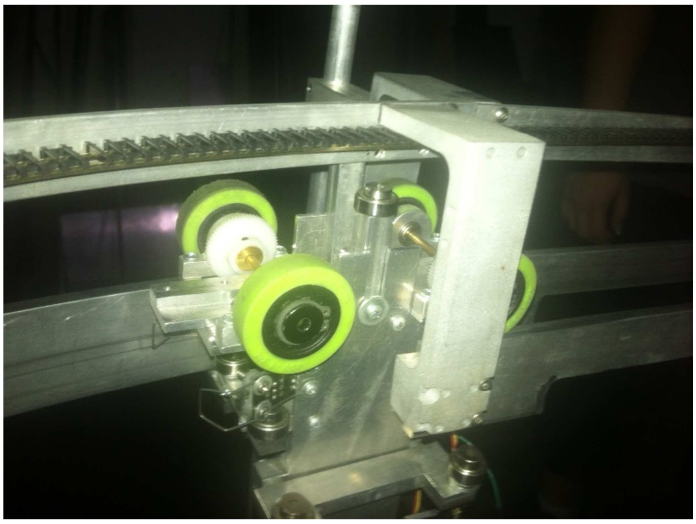


Figure 2-24: A 1/12th scale forth rail concept, using a H/O scale model train track.

This design uses a H/O scale model train track as its current and return rails. The track is flexible so it can make the turns on track. The problem with the H/O track was that it would get in the way of the switching wheels. To get out of the way of the switching mechanisms, it was decided that the wayside rail should be located below the support rails. This would give the current and new mechanisms on the bogie ample room to operate. The design created is seen in Figure 2-25.

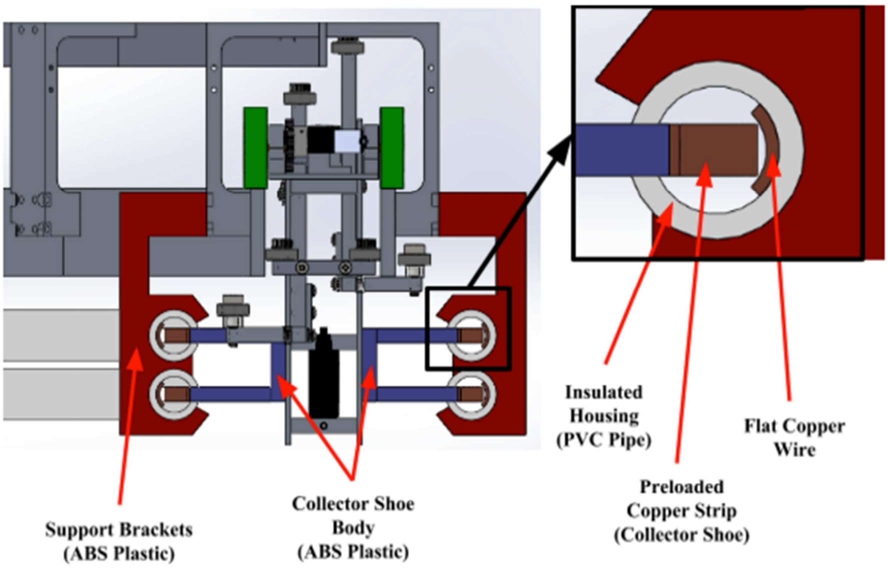


Figure 2-25:The fourth rail system final design

The concept chosen as the final design was the forth rail system with the perpendicular collector shoes on either side. The collectors on both sides allow the bogie to get power when on the main track and when at a station. The collectors will be 3D printed and made from ABS plastic. They will have holes going down the stems that allow wires to come through where they can be soldered to the copper shoe (seen in Figure 2-26).

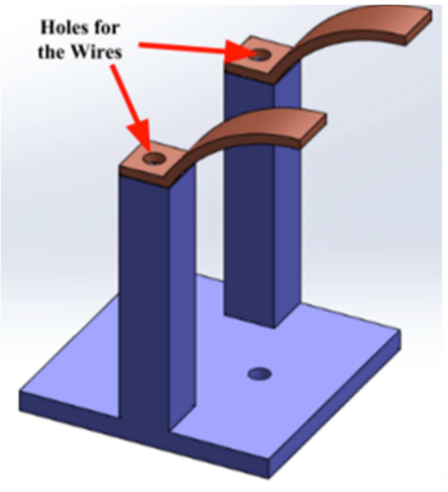


Figure 2-26: The collector shoe assembly

The PVC insulated housing keeps the rails out of reach, so that electrical shock is not a problem. The material used can be purchased at Home Depot; it is schedule 40 PVC electrical conduit. The wire that will be used for the return rails will be ¼ inch flat 10 AWG bare wire, that is flexible seen in Figure 2-27.

Figure 2-27: The flat ¼ inch 10 AWG wires that will be used for the current and return rails.

This wire can handle 30 Amps of current constantly and stay at a temperature of 60°C. The wire can handle a maximum current of 53 Amps. The support brackets will be 3D printed using ABS plastic.

Analysis/Concept Selection

Most Electric Transport Systems, whether they are automated or not, use a third rail system. But, those systems have metal wheels on their bogies, which are constantly in contact with the support rails. This allows their wayside power systems to use the support rails as their return rail and only require one extra rail (or third rail) to get their power. The 1/12 scale model uses rubber wheels to support the boogie, this gives the bogie more grip on the Aluminum track. It was quickly realized that this system would not work as a third rail system. This is because the rubber wheels insulate the bogie from the track, disallowing any current to flow between them. The switch wheels were then considered to ground the bogie, but testing showed that they do not stay in constant contact with the support structure. This restricts the wayside power to be a fourth rail system. The forth rail design chosen is seen from a different angle in Figure 2-28.

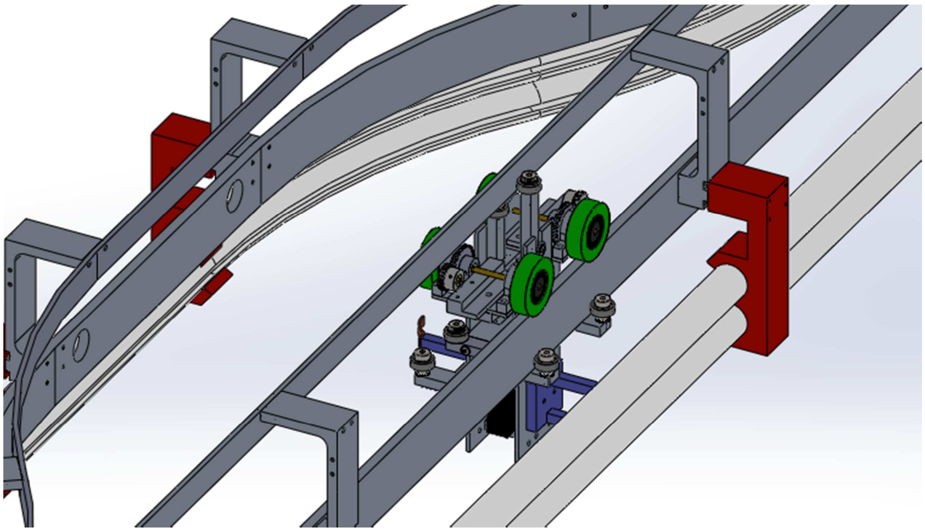


Figure 2-28: The 1/12 scale, forth rail final design.

Fabrication Methods

Fabrication of the 1/12 scale wayside power system will involve 3D printing of the support brackets and collector shoes, bending and cutting of the insulated housing, and adhesion of the flat copper wire. The 3D printing was originally planned to be done in house at the SSDC but new information about the consistency of prints on the Superway 3D printer has led to the search for outside vendors who can create the quality and quantity of prints that the project requires in a cost effective manner. 3D printing was chosen for these parts due to the properties of electrical insulation that polymers provide, along with the flexibility in geometry and cost effectiveness for relatively low production counts when compared to traditional methods such as injection molding.

The insulated housing will be bent using an inner/outer radius mold constructed from plywood as seen in Figure 2-29. This method will be used to achieve a consistent radius while providing the additional benefit of holding the pieces in the correct shape during the cooling process. The pipes will be heated internally by filling them with hot sand and externally using a heat gun. Once they become malleable they will be forced into the shape of the mold and allowed to cool before removing the sand.

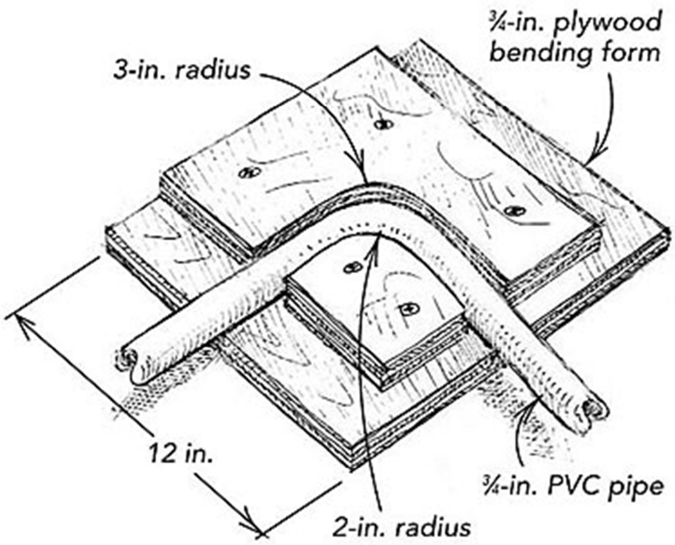


Figure 2-29: The insulated housing will be bent into shape using a wooden frame (Doherty, 2015).

After bending, the insulated housing will be cut open to allow for the collector shoe to enter. Several methods will be tested on a scrap piece of PVC to determine the quickest and cleanest way to achieve the desired results. These include the use of Dremel bits, cutting wheels, and other high-speed cutting devices. Finally, the flat copper wire will be fixed to the inside of the insulated housing using silicone caulk. This was determined as the best solution for a robust, semi-permanent adhesion. The flat copper wire introduces one of the most significant costs to building the wayside system and so a more forgiving adhesion is desirable so that the wire may be repurposed if necessary.

Outcomes

Throughout the semester, the wayside team had developed several approaches to solve the problem presented on the models. First the team had decided to integrate a third rail system configuration, however this design was discarded for several reasons. As mentioned previously in third rail systems the support rails are used for return currents. This caused an issue due to the fact that the structure for the small-scale model does not contain a ground. The wayside group had conducted an experiment using a power supply and a motor to see if the structure of the model would ground the returning current. This experiment resulted in the motor being run at every point of the small-scale model. This was expected since there are not insulators or any sort of ground connection between the support rail and the structure of the smalls scale model. This raised a safety concern because if a person comes in contact with any part of the model when bogies are being run then they can get shocked since they will be the person would be the path for the return current.

Furthermore, the wayside team had moved towards a different configuration of fourth rail systems. As mentioned earlier, this system configuration has a separate rail for the return current. One challenge the team faced while designing a fourth rail system was the lack of space on the small-scale model design. There were many obstacles that came in way of possible setups. Finally, the team had developed a final design of two PVC conduit pipes on which one would contain the running power rail and the other would be for the returning current. These rails will be insulated from the structure and limits the possibility of human interaction.

At this point the research and the design that the wayside team has developed implies that it is possible to power bogies using a wayside power track. This would make the current and future models be presented in a more efficient way without having the need of replacing batteries. Moreover, the model will be able imply how renewable resources such as solar energy can be used into transporting people around places and help reduce demand for electricity which release carbon emissions.

Discussion

In conclusion, this semester the wayside power team was successfully able to develop a design that would allow solar energy to be transmitted into running the Spartan Superway bogies. After researching and evaluating different possible configurations for a wayside rail system, the team has decided to go with a fourth rail configuration. This configuration will be more safe and efficient because there will be an additional track through which the return current will return. This would eliminate issues of having the current return through the structure, which would be experienced in third rail configurations. The team designed a forth rail system which consists of a conduit containing conductive material through which power will be transmitted to the bogies battery pack using a collector shoe with conducting material.

The wayside power team will be focusing on the next phase of the project starting late December The focus will be on fabricating, assembling and testing the designed system to develop a final working Spartan Superway model utilizing solar energy to run bogies. The work that needs to be done next semester is shown in the Figure 2-30 and Figure 2-31. The group is planning on assembling the wayside track and will begin testing in portions of track using electric motor and electricity. Once it is confirmed that the wayside track will be able to power the bogies battery, the team will then integrate solar energy into powering the track. To accomplish the goals of the project it is very important that there is strong communication between the Small Scale Track Design, Controls group and Small Scale Solar Team. Finally, once it has been verified that wayside power is able to power up bogies on the small-scale model the team will then integrate the same concept on large-scale models. However, the constraints to that would be that there would be much more power needed to run bogies. Overall, the wayside group will bring Spartan Superway a step close to being a new sustainable mode of transportation.

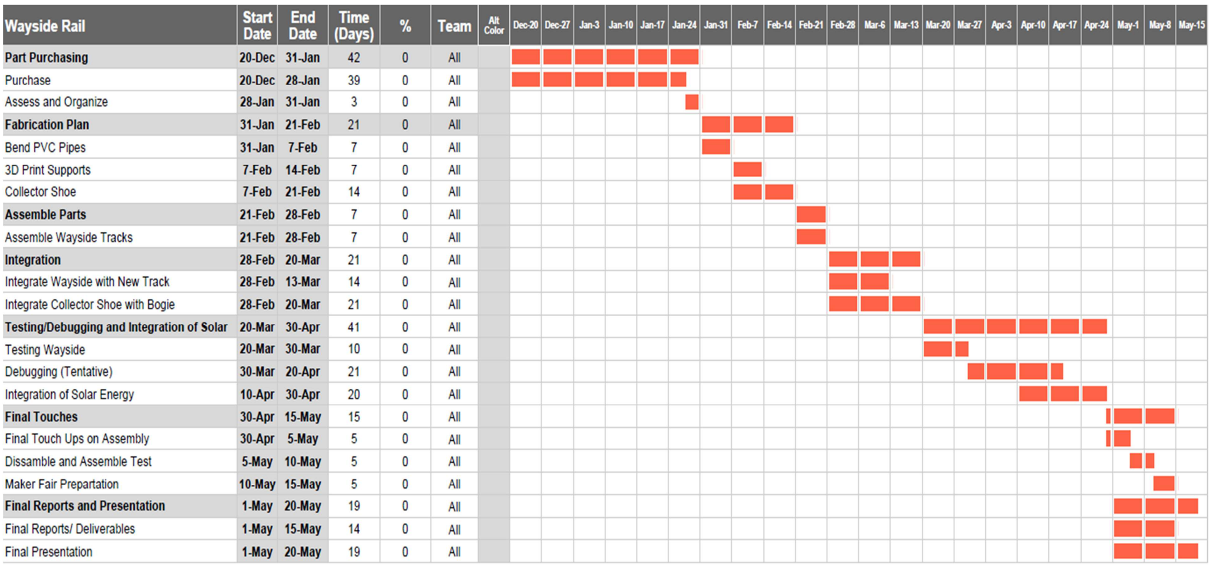


Figure 2-30: Gantt Chart for Spring 2016

Wayside Rail	Start Date	End Date	Time (Days)
Part Purchasing	20-Dec	31-Jan	42
Purchase	20-Dec	28-Jan	39
Assess and Organize	28-Jan	31-Jan	3
Fabrication Plan	31-Jan	21-Feb	21
Bend PVC Pipes	31-Jan	7-Feb	7
3D Print Supports	7-Feb	14-Feb	7
Collector Shoe	7-Feb	21-Feb	14
Assemble Parts	21-Feb	28-Feb	7
Assemble Wayside Tracks	21-Feb	28-Feb	7
Integration	28-Feb	20-Mar	21
Integrate Wayside with New Track	28-Feb	13-Mar	14
Integrate Collector Shoe with Bogie	28-Feb	20-Mar	21
Testing/Debugging and Integration of Solar	20-Mar	30-Apr	41
Testing Wayside	20-Mar	30-Mar	10
Debugging (Tentative)	30-Mar	20-Apr	21
Integration of Solar Energy	10-Apr	30-Apr	20
Final Touches	30-Apr	15-May	15
Final Touch Ups on Assembly	30-Apr	5-May	5
Dissamble and Assemble Test	5-May	10-May	5
Maker Fair Prepartation	10-May	15-May	5
Final Reports and Presentation	1-May	20-May	19
Final Reports/ Deliverables	1-May	15-May	14
Final Presentation	1-May	20-May	19

Figure 2-31: Tasks for Spring 2016.

<u>Chapter 3: Intermediate Scale</u>

Fail-Safe Mechanism

Objectives

The current bogie design has been created to traverse a track with no elevation change. Additionally, it has no fail-safe mechanisms. The objective of the fail-safe team is to re-design the bogie to be able to traverse these elevation changes as well as create fail-safe mechanisms to keep the bogie from derailing. All of these designs will be done based on the full scale design. However, this team will be building the fail-safe mechanisms on an intermediate scale; therefore the designs will be tested and analyzed for the intermediate scale. Finally, as per Professor Furman's input, the designs created will not rely on power and/or sensors as this leaves room for the possibility of failure due to an issue with either or. The specific objectives the team will be tackling are as follows:

- Re-design bogie to be able to traverse up and down a guideway sloped at ±17° (30% grade)
- Design fail-safe mechanisms that keep bogie from falling off the guideway despite failure of switching or main support wheels

Design Requirements and Specifications

It will fulfill the design requirements listed below:

- Bogie must have multiple fail-safe systems 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 750lbs(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 4

State-of-the-Art/Literature Review

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 in Figure 3-1 (Pescovitz).

Figure 3-1: 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 **Error! Reference source not found.**.

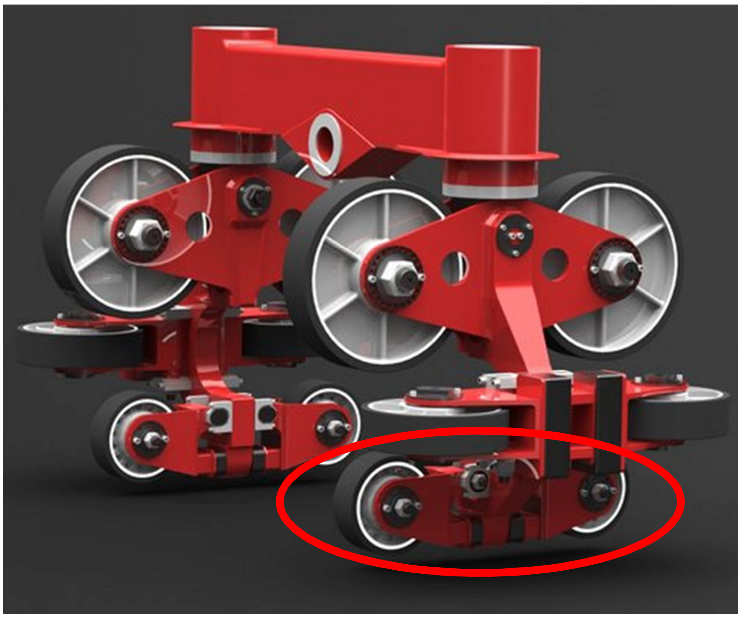


Figure 3-2: Upstop wheel from a rollercoaster (Theme Park Studio, 2013).

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.

Design Concepts

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 wheel 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 3-3.

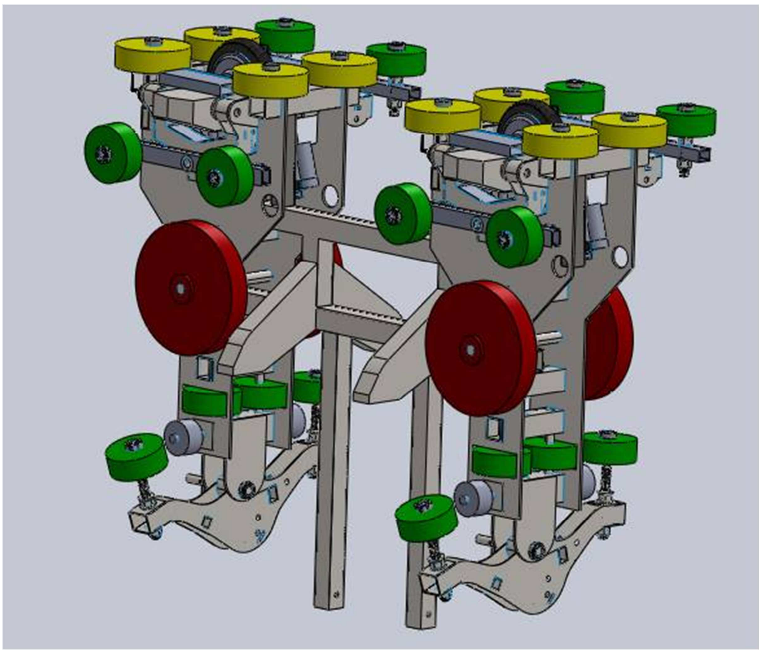


Figure 3-3: View of bogie with all final fail-safe mechanisms visible

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 3-4.

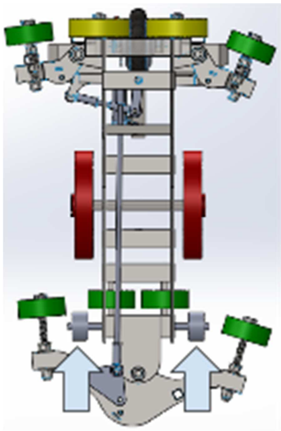


Figure 3-4: Modified design of the upstop wheel. This modified design has the upstop wheel attached above the steering mechanism.

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 top and bottom catches were also designed to help the prevent the bogie from falling off the guideway. When the bogie is about to derail by falling to the 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 3-5**.**

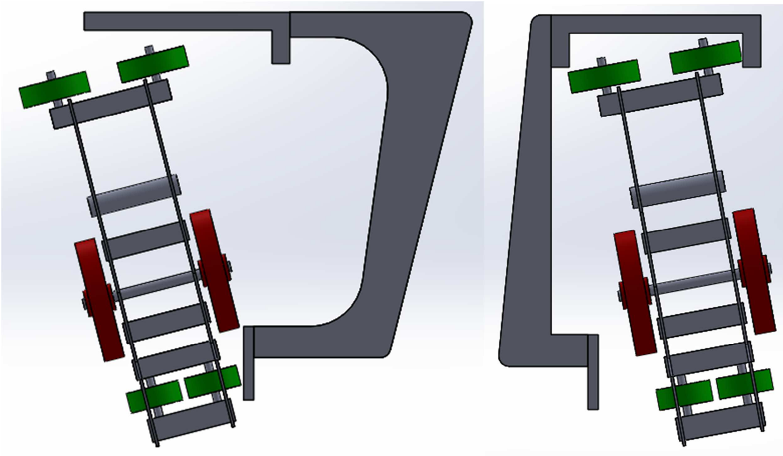


Figure 3-5: Past bogie design derailing due to the lack of catches.

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 will be 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 cannot be too far or the catches' stress analysis will need to be redone to ensure that it can withstand the impact load,

The top of the bogie was improved as well. The fail-safe team implemented a inside catch between the two wheels located at the top, as shown in Figure 3-6**.**

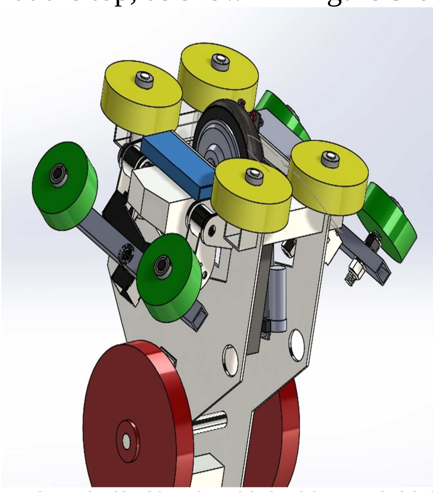


Figure 3-6: View of top half of bogie with inside catch highlighted in blue.

The two inside catches act as a fail-safe mechanism that would trigger if one of the yellow wheels broke causing the bogie to tip. The inside catches would prevent the bogie from tipping by catching against the inside of the top rail of the guideway.

<u>Analysis and Concept Selections</u>

Once the final design was approved by the team and Professor Furman, the different fail-safe mechanisms were tested in SolidWorks. For this, we performed finite element analysis on every part simulating fully loaded condition of 700lb using A36 steel as the material. The load was chosen to be 700lbs as that is the current estimated maximum weight of the bogie, cabin and suspension systems. The results of the first simulations performed, shown in Figure 3-7, suggested that the stresses were very low since the material selected was too thick for the application.

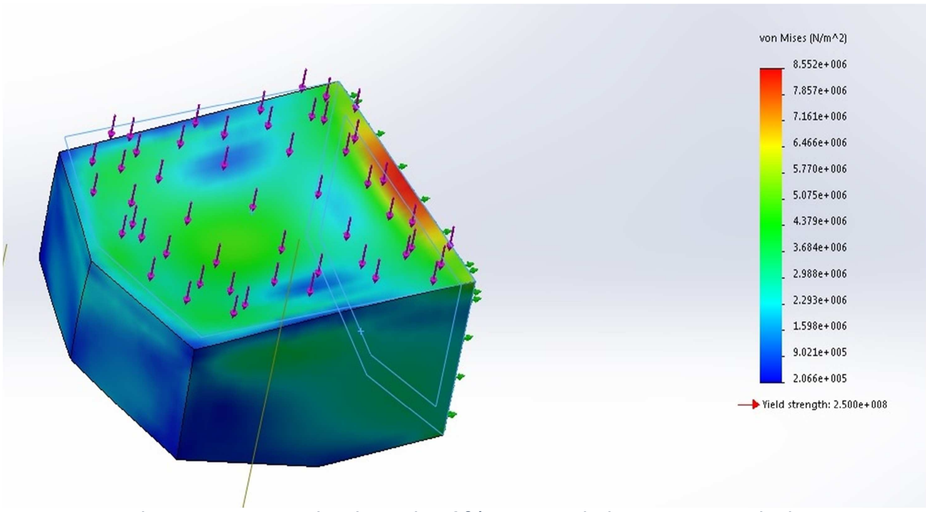


Figure 3-7: Upper hook made of ⅜ A36 steel plate stress analysis.

From here, we proceeded to reduce the thickness of the material from ⅜ inch to ¼ inch and performed all the tests again. Using the stress analysis software available in Solidworks, it showed that the upper inside catch, shown in Figure 3-8, produced a safety factor of 32.2. The upper catch, as shown in Figure 3-9, produced a safety factor of 12.8.

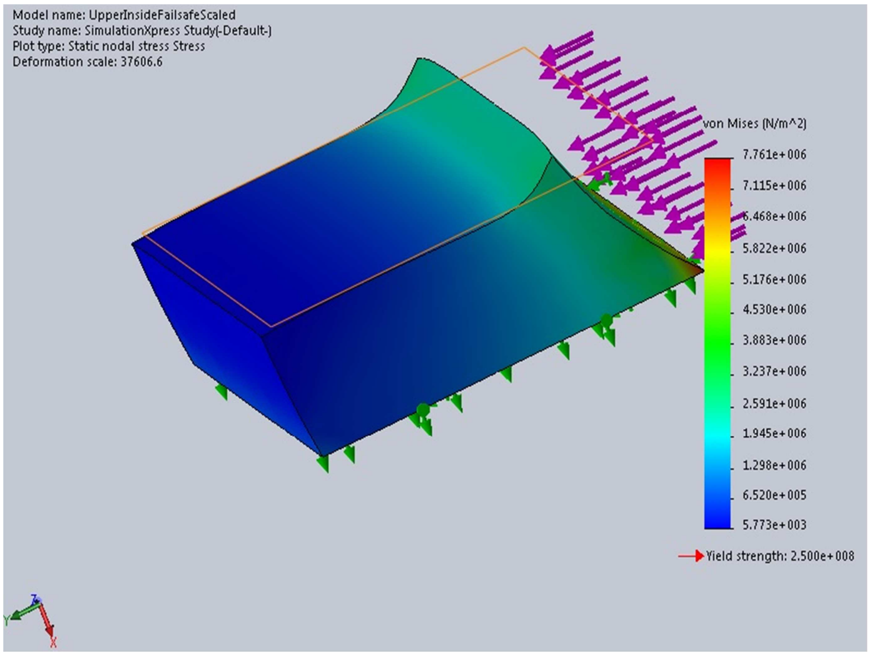


Figure 3-8: Inside Catch under 700lb load.

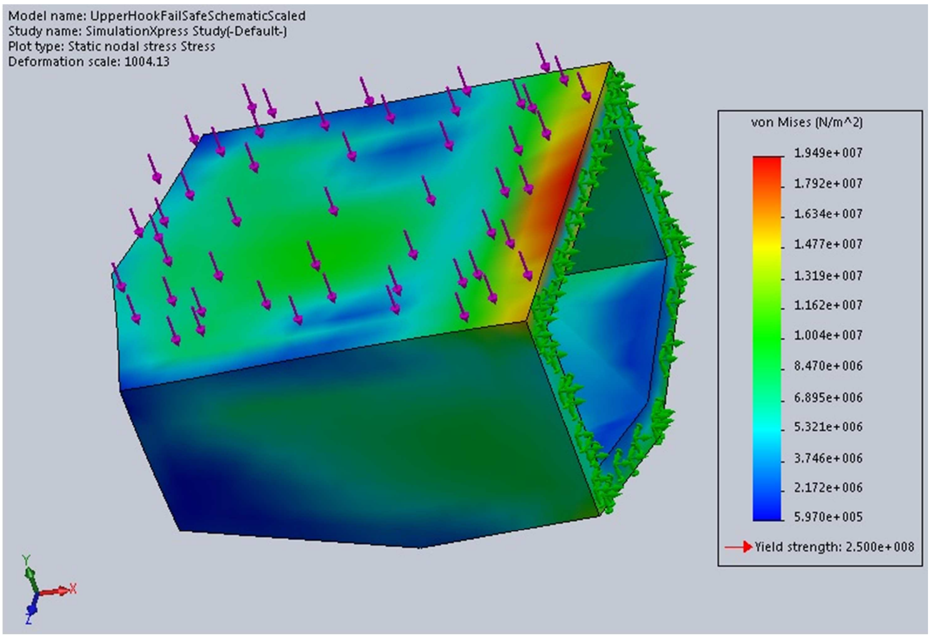


Figure 3-9: Top catch made of ¼ A36 Steel under 700lb load.

Lastly the bottom catch, shown in Figure 3-10, produced a safety factor of 5.26. Through finite element analysis, it shows that the design and material selected for the fail-safe mechanisms greatly surpass the original safety factor requirements.

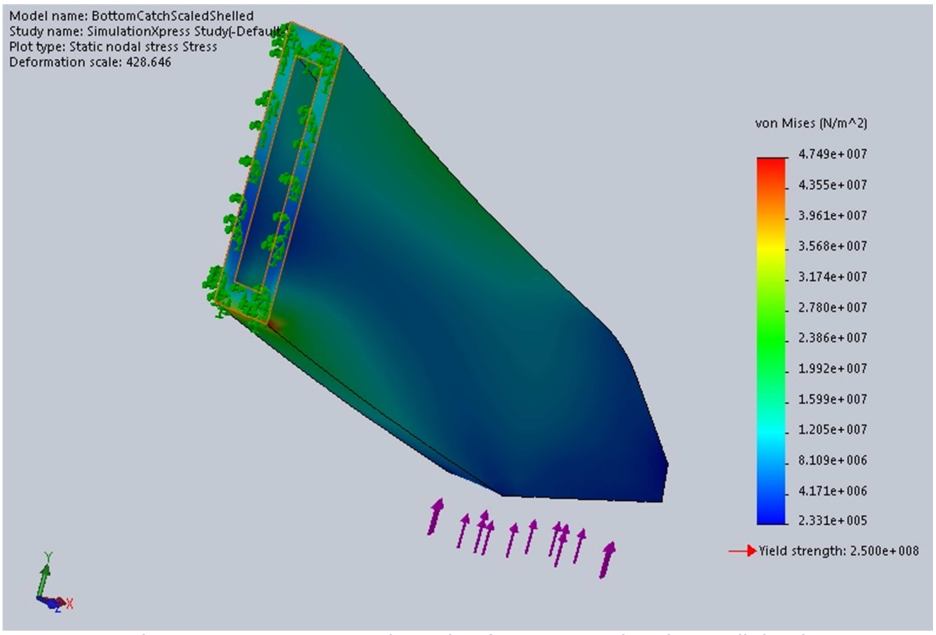


Figure 3-10: Bottom Catch made of ¼ A36 Steel under 700lb load.

Fabrication Methods

In order to simplify manufacturing of the fail-safe mechanisms, the decision was made to purchase stock materials and fabricate them into catches instead of ordering custom made parts. This would make the process of fabrication easier, more effective, and cost efficient. The stock parts to be purchased are ¼ inch A36 steel plates, which will be used and cut to specifications through waterjet cutting. Waterjet cutting was chosen because of access to the machine and it provides even and consistent cuts causing less error and waste of materials. After the pieces for the catches are cut, they will be TIG/MIG welded together to form their respective catches. TIG welding will provide clean welds that do not produce residual splatter, however it is more time consuming. MIG welding is also an option because pieces can be welded together quickly, but it produces splatter and the welds are not as clean. Nonetheless either of these welding techniques will provide strong structural integrity for the fail-safe system, The welding method will be determined once access to either is established. Lastly the fail-safe mechanisms will be attached to the bogie via TIG/MIG welding.

Outcomes

As stated earlier in the report, the bogie was created without any mechanical fail-safes. 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. Future teams may 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.

Discussion

The fail-safe team has four major accomplishments for this semester: the bottom catch, top catch, inside catch, and upstop wheel. All of these designs help satisfy the objectives, design requirements and specifications. Based on the testing done, they should work successfully.

At this point, the team has selected the materials by taking outside condition into consideration in order to resist wear and corrosion. Also, the materials were selected with respect to the dimensions and identical threaded size. The team selected McMaster and Metal Depot to obtain parts for the fail-safe mechanism. All the parts are on stock, so there is not any hassle of customization and delay. The team has a fabrication plan for all three of the catches and the upstop wheel will be assembled from that components (wheels, nuts, washers, shaft, and shaft collar) of McMaster. The next goal for the team is to purchase all the required materials and look to the prospect of fabrication.

The team spent the majority of the semester researching on the fail-safe mechanisms. Since the team has finalized four major fail-safe mechanisms, the team will take the initiative and proceed towards the fabrication process. Prior to the beginning of spring semester, the team will be finalizing the design along with other intermediate scale sub-teams. Once this is done, the budget will be re-analyzed and based on the overall project budget, parts for the project will be ordered. As parts come in, the team will work with other members from the intermediate scale to potentially begin the fabrication process. The fabrication process may be lengthy because it is important that the parts are manufactured correctly. As stated earlier, the top and bottom catches are designed to clear the guideway; however if the guideway is warped, or the catches are placed incorrectly, then there can be an issue with clearance. It will be very important for the fabrication process to be done correctly the first time.

Cabin

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. Also, we want to design a station that will allow the cabin to dock safely and securely.

Once the team has a final design of the cabin, we will be fabricating two quarter scale wooden models that will display our design. One of the models will be completely hollowed to allow the suspension team to add weights in the cabin. This model will be connected to the actual quarter scale system that will be fully functional. The other 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. Depending on time, we will also fabricate a station to show how it will function with the cabin.

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.

The station design is focused on the interaction between the cabin and station. When the cabin pulls into a station the floor must be level between the two. The station also must have a securing mechanism that will be able to hold onto the cabin and prevent any unnecessary movement during loading and unloading.

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 3-11, 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 3-11: 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 3-12: : 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 3-13 of a bus using a bus rack. Having bike storage on the PRT system will keep up with the demand of bike usage.

Figure 3-13: Similar form of bike storage on a public bus (cycle-works.com)

<u>Design Concepts</u>

Exterior of Cabin

For the exterior shell of the cabin, we want to incorporate 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 3-14 shows a 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. 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.

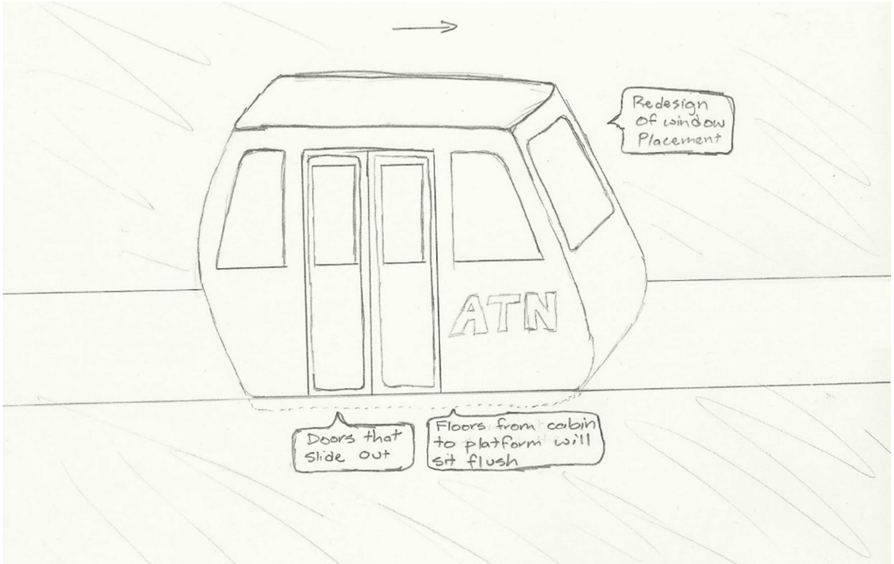


Figure 3-14: Concept sketch of the cabin's exterior shell

Interior of Cabin

The interior of the 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 3-15 shows early sketches on how the interior will look when a bike is stored with a seat in a folded position.

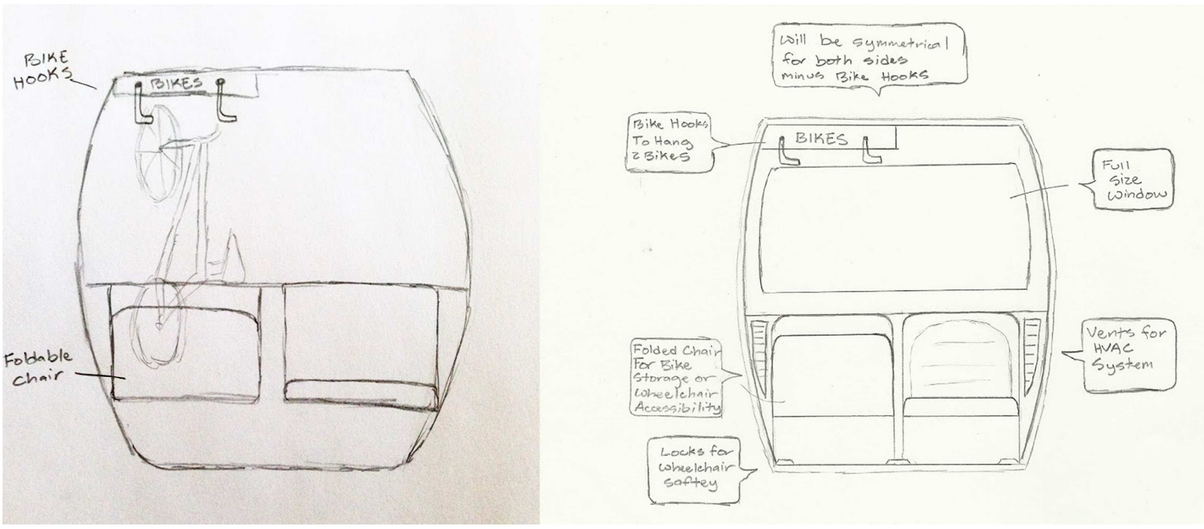


Figure 3-15: Early sketches of the interior design

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 3-16. 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 3-17. The vehicles 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.

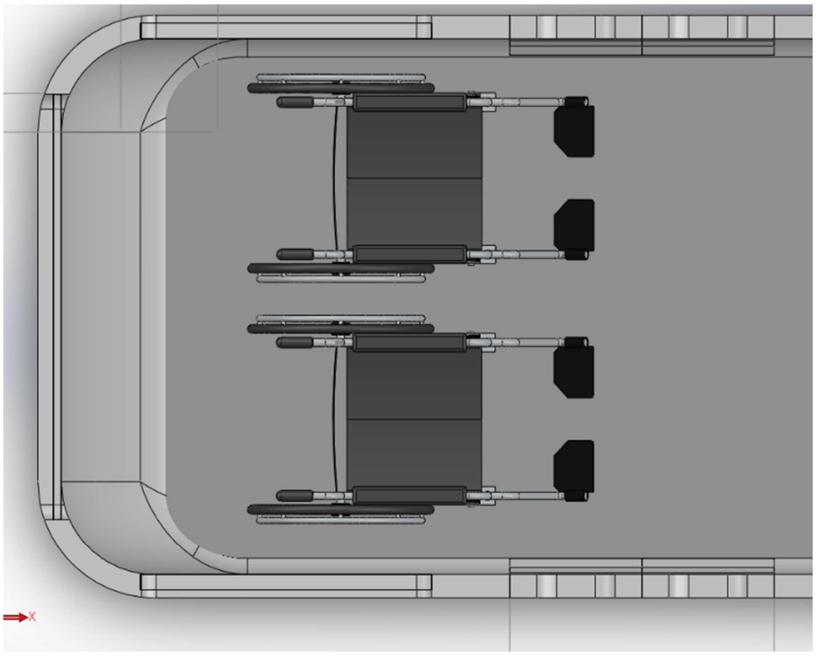


Figure 3-16: Wheelchair cabin space visualization

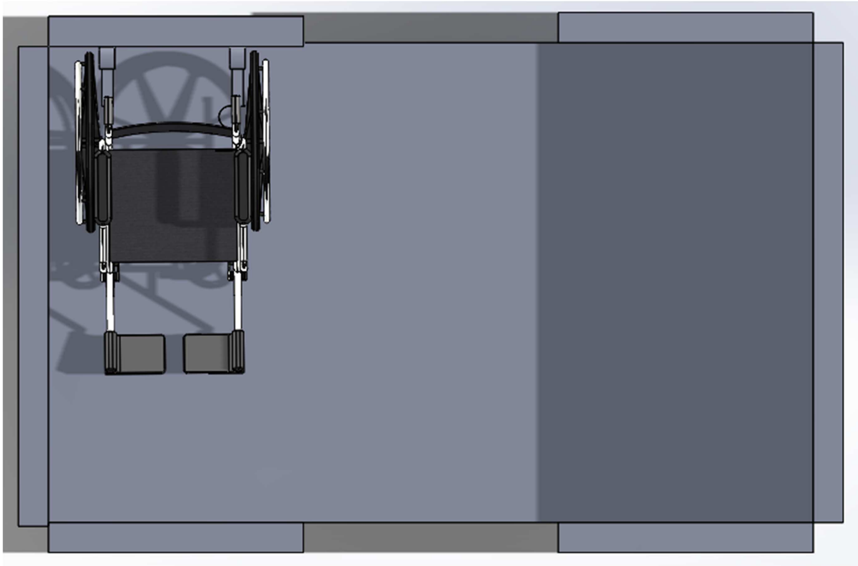


Figure 3-17: Powered wheelchair cabin placement

Safety

Preliminary designs for safety features of the cabin focused on wheelchairs and their securement to the cabin. As shown in Figure 3-18, the wheelchair is anchored to the floor by hooks attached to the front and back wheels.

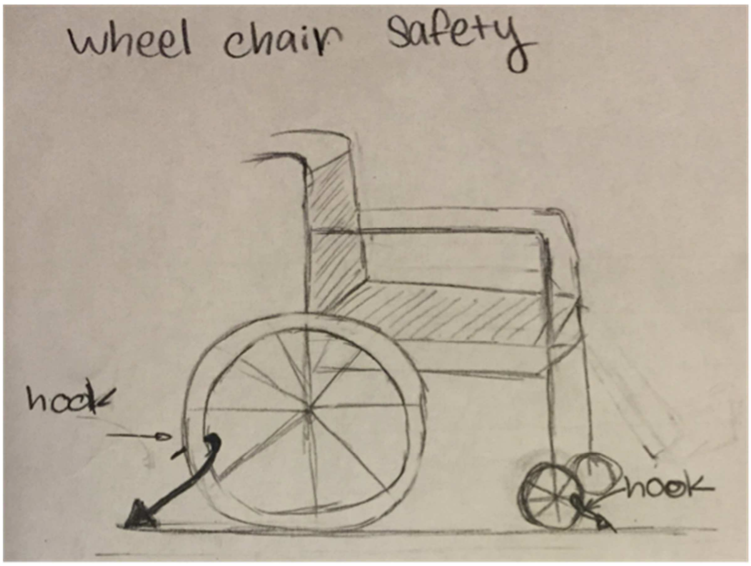


Figure 3-18: Wheelchair anchor hook locations

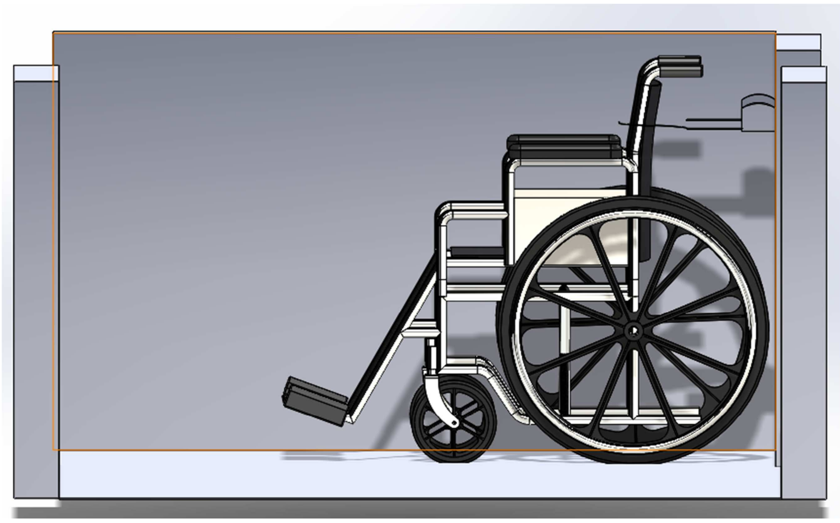


Figure 3-19: Wheelchair restraint locations

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 3-19, 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. Cabin to station gap must also not exceed four inches. It prevents tripping from those entering and exiting the cabin during usage. Also the floor of the cabin and station will be the same elevation so no ramps need to be implemented. Then wheelchairs of any type can enter and existing can do this with ease, and provides less work for the user.

Cabin Station

The cabin station concepts are still under consideration. The concept decisions will be moved forward if there is time during the second semester. Fabrication is the main focus.

Analysis and Concept Selections

Exterior Design

With some changes and improvements to our earlier sketched, we rendered our final cabin design shown in Figure 3-20. 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.

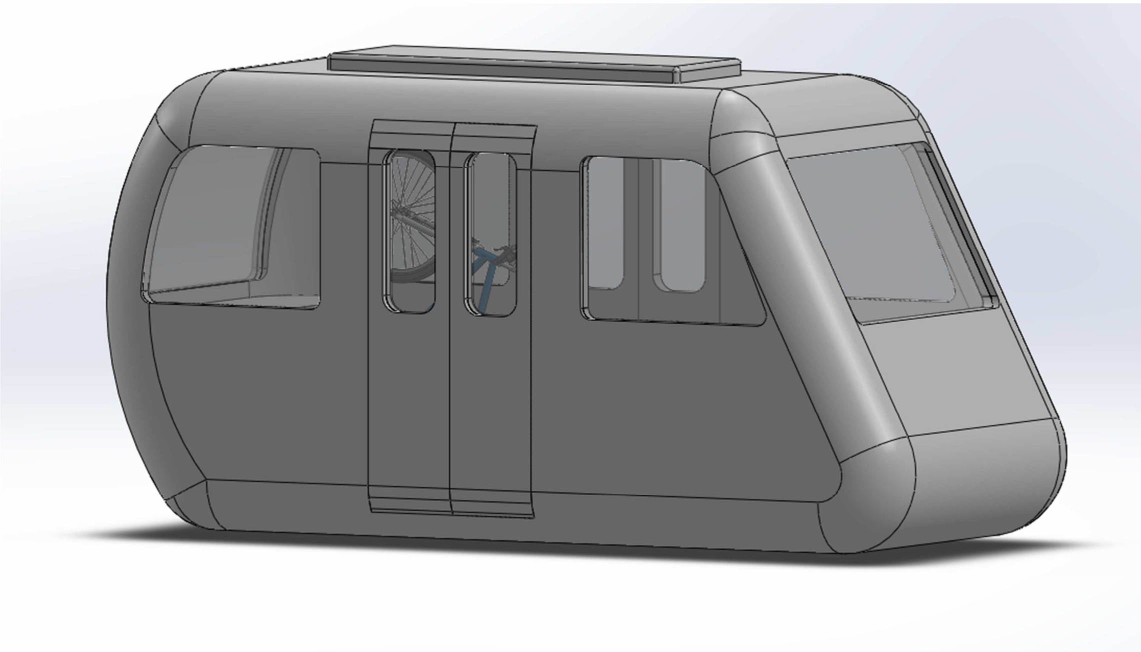


Figure 3-20: Final design of the cabin’s exterior shell

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.

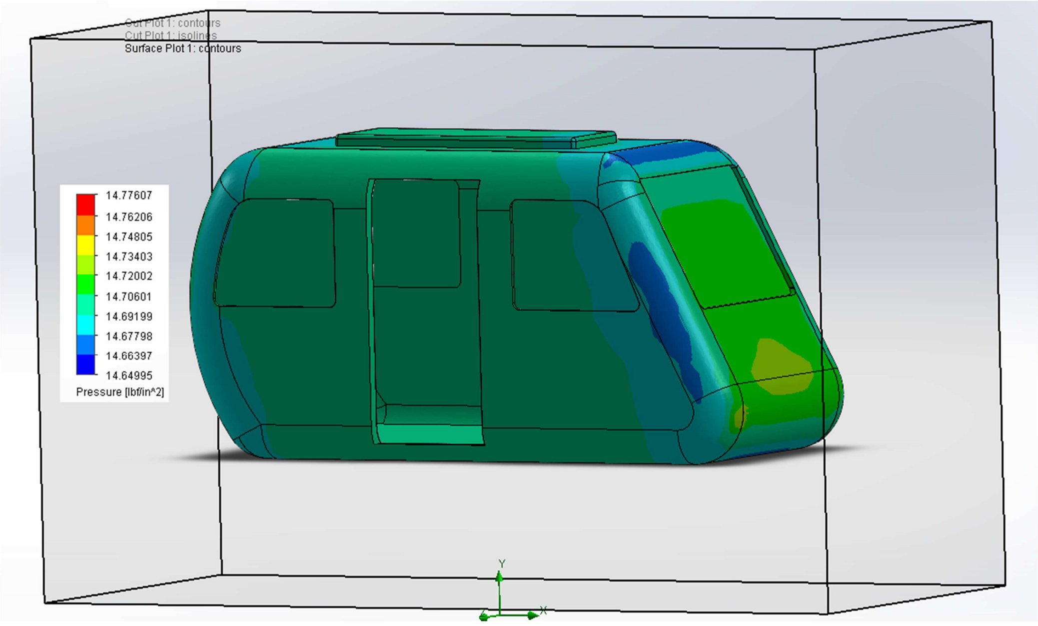


Figure 3-21: : Pressure contours on cabin design

The first iteration of the simulation shows simple pressure contours on the model. In Figure 3-21 the air flows from right to left and hits the cabin full in the front. It can be seen that the average drag force experienced by the cabin is about 14.7 psi. The point of highest force (rounded yellow 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. Figure 3-22 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.

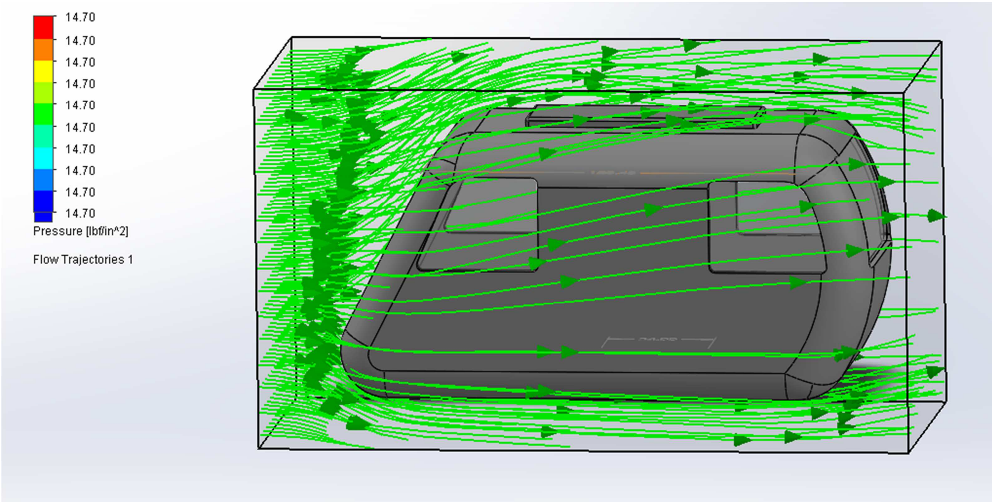


Figure 3-22: Airflow model of cabin flow simulation

The Solidworks flow simulation can also run equations based on the data found during calculation. Using Equation 1 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 1.023. This value is successfully between our goal values of 0.8-1.8.

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

Interior Design

The interior design will have foldable chairs to allow space for wheelchairs and bikes. Figure 3-23 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.

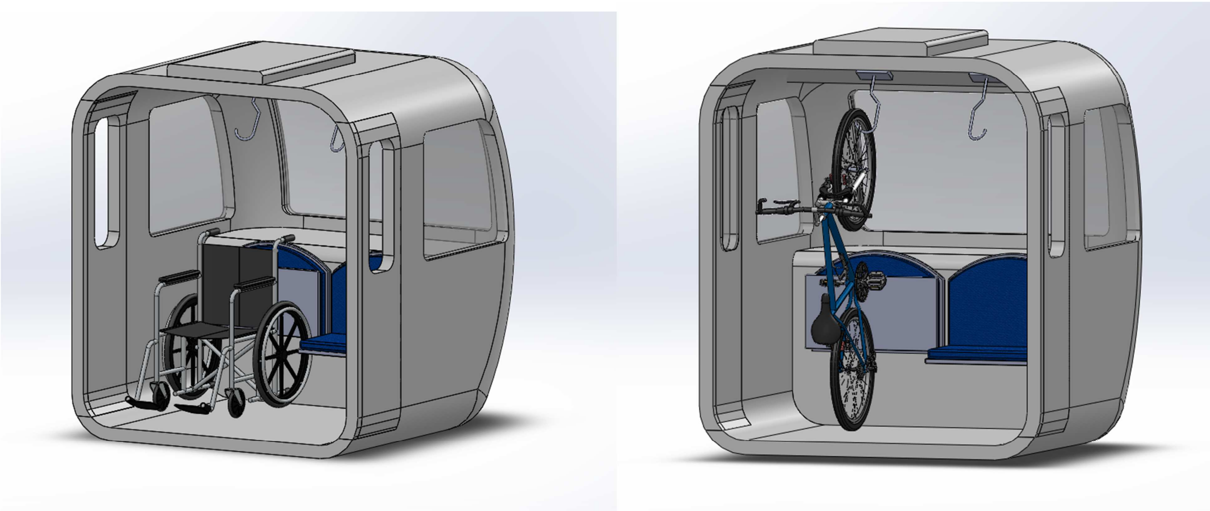


Figure 3-23: Examples of how a wheelchair/bike will sit

To allow storage of a bike in a vertical position, the roof will have a hook mechanism, shown in Figure 3-24, 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 4 bike hooks in the interior design, 2 on each side.

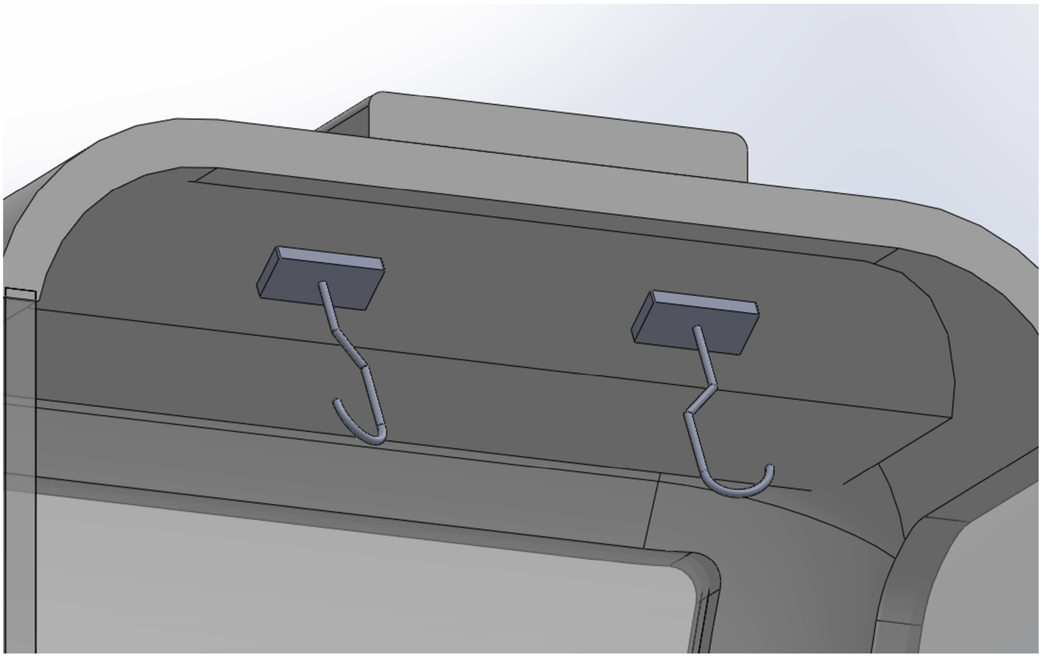


Figure 3-24: Bike hooks that will securely store bikes in a vertical position

<u>Fabrication Methods</u>

Fabrication for the quarter scale cabin models will be wood based. Plywood will be used for the outer shell to give it the strength and weight needed for the quarter scale model. The wood will be cut to the desired specifications and holes will be cut for windows. The rounded portions will be completed using a mix of bendable plywood and expansion foam. Expansion foam will fill up the empty spaces as well as allow for more detailed shaping. Both models will be able to be opened up using a metal hinge. This means that the cabins will have to be assembled in two halves and put together. One of the cabin models must be able to be loaded up with almost 250 pounds and thus must be reinforced to hold the extra weight. The second model can be lighter because it will be used to show off the interior.

The internal components to illustrate the interior will use a variety of methods. The plan is to 3D print most of the internal parts. This would allow more intricate work at a smaller scale. If the 3D printer is not a viable option then the internal parts will be made by hand using a variety of materials to create the desired components. Completed fabrication will result in two equal sized quarter scale wooden models. Both models will have the ability to open up as to allow vision or to add additional weight.

Outcomes

At this point in the project there is a completed external and internal cabin design. Plans have been made to work on station interaction, but theses designs have been put on hold until after the quarter scale fabrication is complete. Having these parts completed will be a great addition to the quarter scale rail system. It will allow interested parties to understand how the cabin will look and feel when travelling on the rail system. Visuals are key to getting a point across, and cabin design is an important part of the overall project.

Discussion

The Fall 2015 semester has been extremely productive so far. When the project began we inherited a full-scale model provided by the Swedish team. It was our responsibility to get this full-scale model aesthetically finished and prepared for presentation. The cabin team successfully completed this task, as well as taking the initiative to build a custom gantry and suspend the full-scale cabin in the air (FSCCW, 2015). Simultaneously, we were able to design and model a successful new cabin design both externally and internally. Tests were successfully run to determine that the cabin design meets previous design specifications in regards to a drag coefficient. The completed design is now read for fabrication.

The main focus for the next semester, Spring 2016, is all about fabrication. Getting two quarter scale models complete and ready to go will be the main use of our time. If production is going well and ahead of schedule we will simultaneously be working on the cabin station. Other parties have shown interest in helping our designs so we will be working with them if time allows. First we must make final decisions on all of the required materials and then purchase all required materials. Fabrication will begin by processing all of the plywood pieces. Tracing, shaping, and cutting will all be taking place before any assembly can begin? Most, if not all, of the fabrication will be done in house by our cabin team. Interior pieces will be printed when time allows. 3D printing takes large amounts of time, and the printer must be shared with other groups. Organization of printing times and amounts will be crucial if everything is to be completed on time. Lastly, assembly will take place once all the pieces are done being created.

Steering, Breaking Mechanism and Guideway

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 one of the links fails to operate. Because the steering links from previous year's steering mechanism switched slow and sluggish, the team decided to integrate a more powerful stepper motor to speed up the switching process. Furthermore, an extra pair of steering wheels are added on the top steering link to align them directly with the ceiling wheels to add redundancy and extra stability to the steering mechanism, and to have the wheels press more firmly against the track.

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.

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.

Design Requirements and Specifications

While designing the prototype of the steering and braking mechanism, and the guideway, 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 upper and bottom steering links are physically connected by a four bar linkage mechanism which in turn is connected to the stepper motor shaft to allow simultaneous movement. 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
- Two pair of wheels on upper steering link to increase structural redundancy in order to create more stability and balance and aligning the steering wheels directly to the ceiling wheels which counteracts the force produced by the ceiling wheels
- 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 700 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.

Guideway

- Demonstrate lowering elevation by traveling up and down a 17 degree sloped rail.
- An allowance of four degrees a second curve at the start and end of the sloped track.
- Complete closed guideway to allow the cabin to complete tracks and return to initial position.

<u>State-Of-Art/Literature</u>

Steering

Originally, research was done to determine what would be the best method to actuate the steering mechanism. A Futaba 3306 High Torque Servo was originally pursued. However it was decided to move forward with a stepper motor for their torque and driving power. Pneumatic actuators were also considered. The actuators have high resistance to side load, is easily attached with little space.

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 modifying parts. Braking pad and rims last longer and required less maintenance.

Guideway

The guideway idea was to recreate a playground for the pod car to test run with different courses of challenges. The track needed to have continuous section for the vehicle to move, a slope of 17 degree and the switch section to change directions. Research was done in areas that had similar vehicles, such as amusement park rollercoasters and other supported vehicle Personal Rapid Transits. A lot of concept ideas were originated from suspended roller coasters guideways.

Design Concepts

When generating concepts for the steering mechanism, it was suggested to us to keep the general structure same, so a lot of brainstorming was done to come up with different variations of the steering mechanism.

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 driving shaft of the stepper motor is connected to the L-shaped rocking bracket and the L-shaped will rotate in order push or pull the linkage. 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 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 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.

The location of the braking system was critical since it determined the braking force, surface and stopping power. In addition, there was not much room on the bogie. 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 making it more effective in controlling speed of the vehicle. Brake bracket set up right above the guiding wheels.

The original designs were relatively simple, Appendix B contains the progress of growth. Initially, the guideway was going to have an open ended rail with a drop and a rise. Then we added a switch to this concept. From there it grow to a full track with curves and splits. The design of the cross section of the guideway and structure of the supports (Posts and ribs) were left alone. The changes that were made was that it was extended and curved so it could make a complete loop. Other more subtle changes were the extension of metal frames in the ribs. This was done to allow the upper steering wheels to have clearance with it makes a switch. The original sizing showed contact and would demonstrate catastrophic failure. The support posts were extended upward to allow a greater distance at the slope. At the lowest point, the cabin would offset the ground about a foot. This was necessary to prevent the cabin from colliding with the bottom of the post frame support. Several supports were designed at different lengths to support the guideway as it traverses downward. The ribs supports at the sloped posts are tapered to be able to fully contact the rail to have a full contact welded connection. A more important addition was the rate at which the bogie entered the sloped trackway. This had to be at least enough radius to allow a change of four degrees per second so that the suspension mechanism can adjust for the change of elevation.

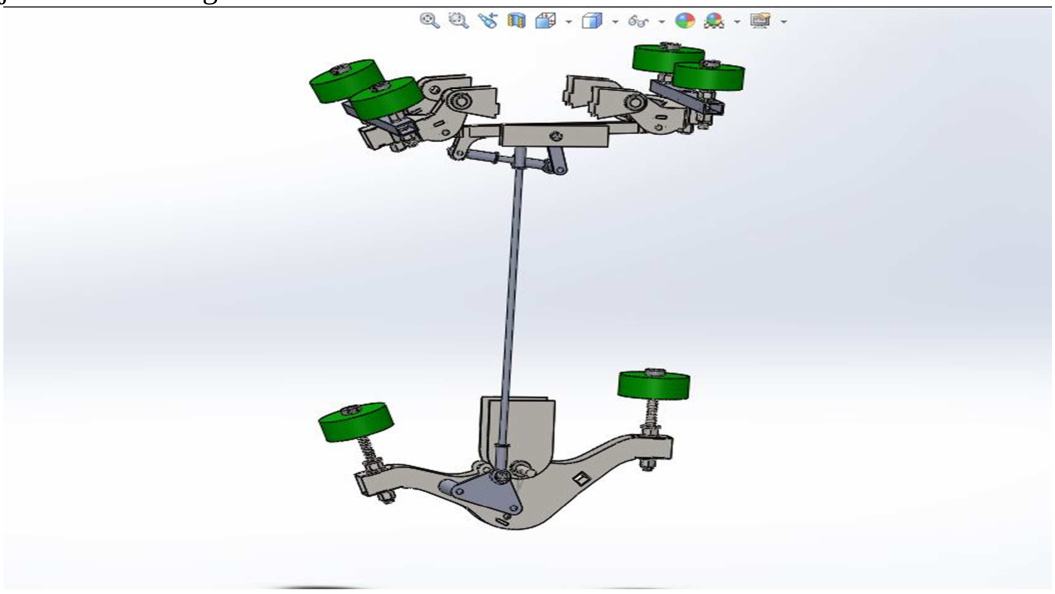
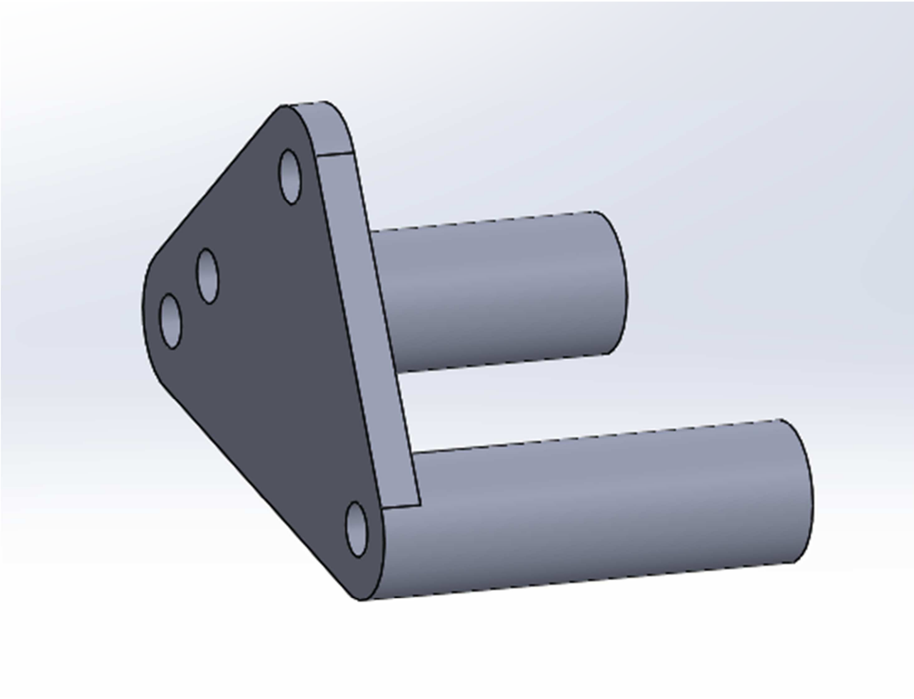


Figure 3-25: Upper steering mechanism control arm

Figure 3-26: CAD model of bogie with modified steering mechanism



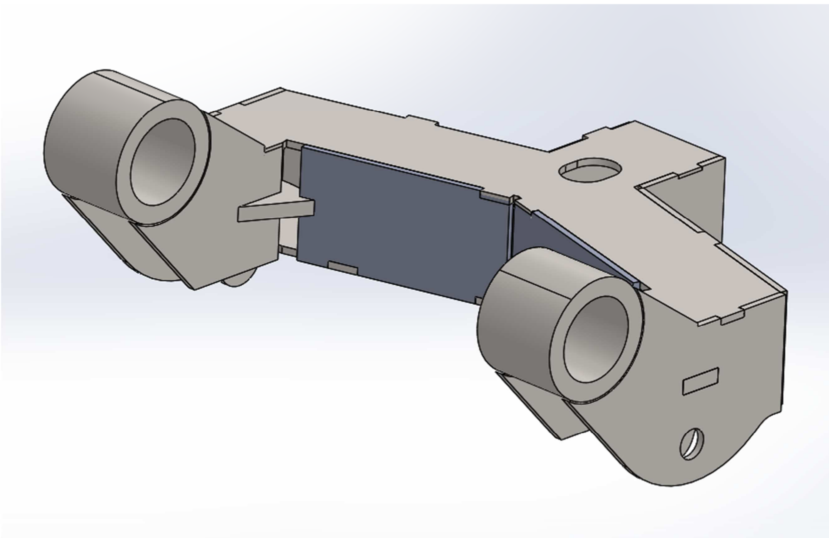


Figure 3-27: Triangular link

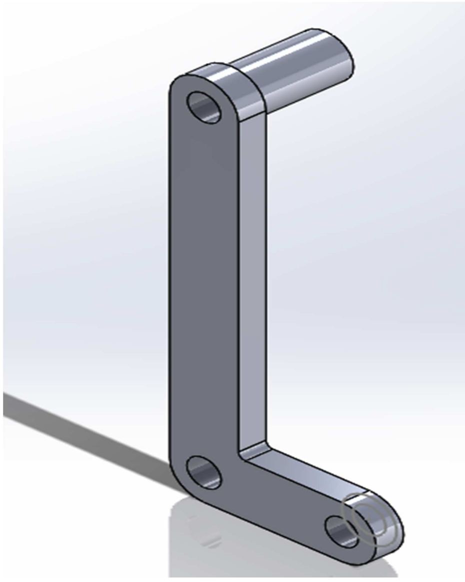


Figure 3-28: L-bracket

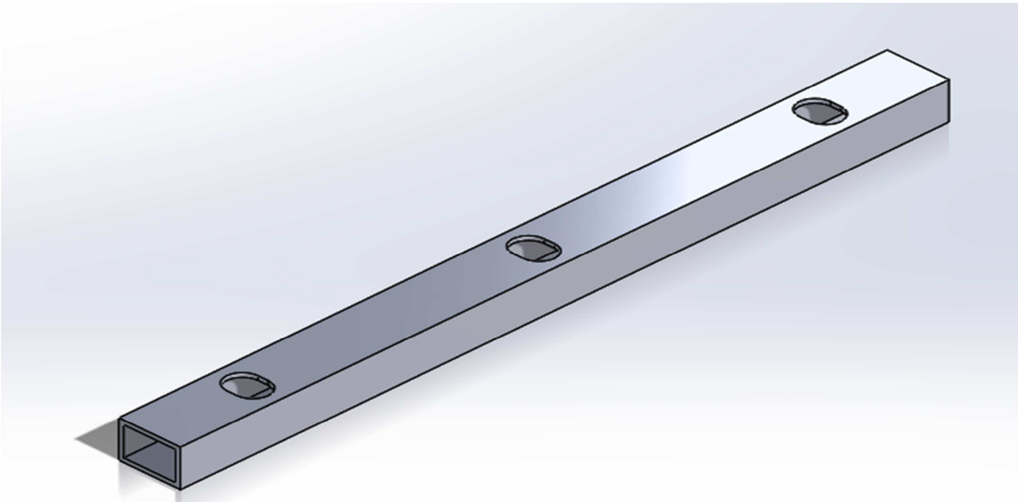


Figure 3-29: Control Bar

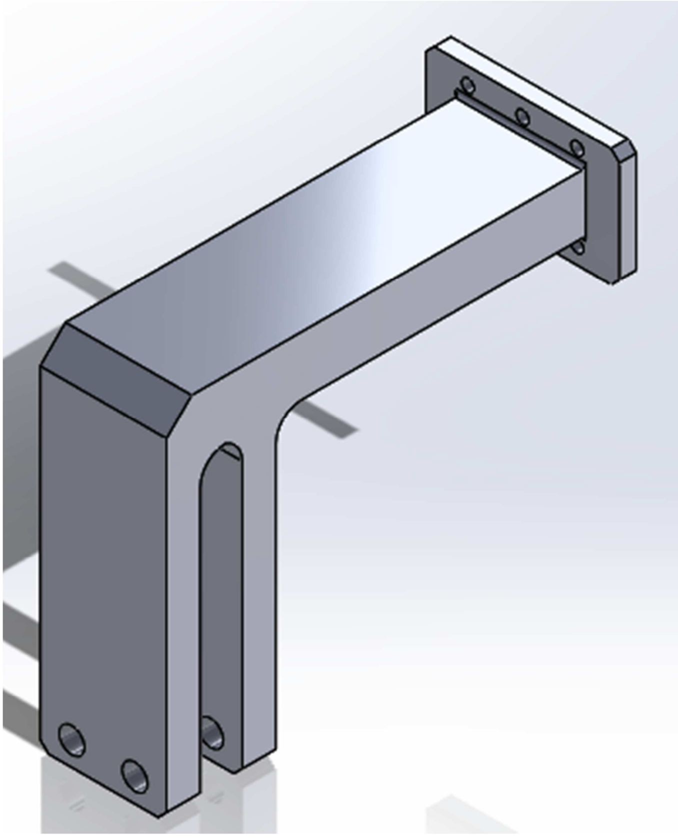


Figure 3-30: Brake Racket

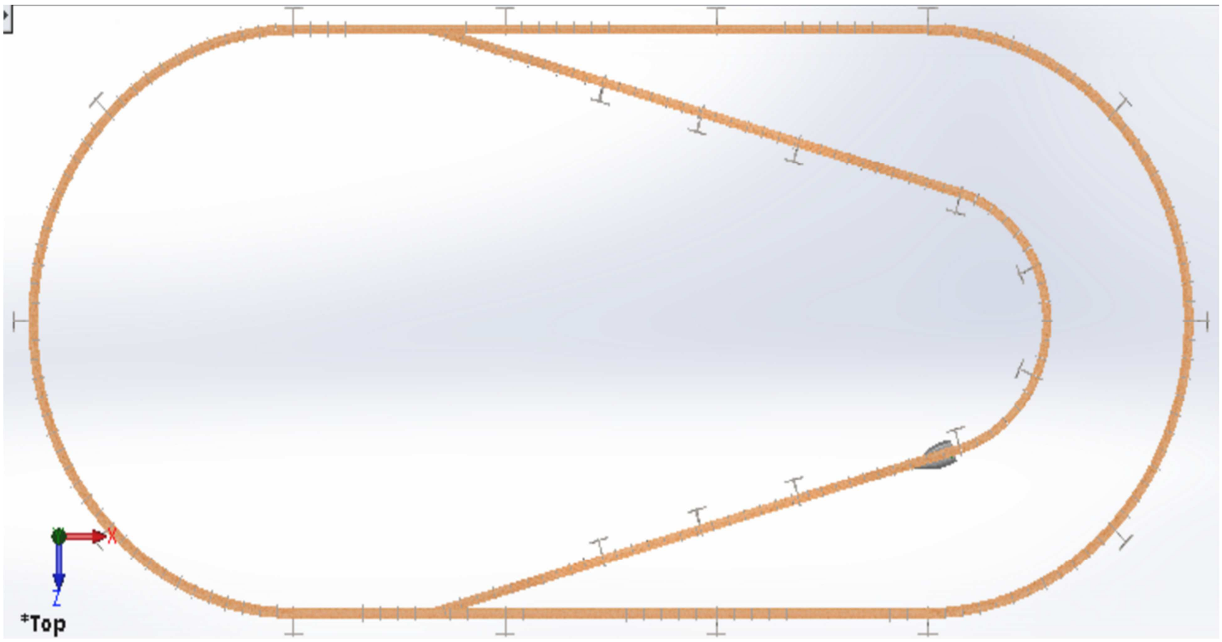


Figure 3-31: Top View of Guideway

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.

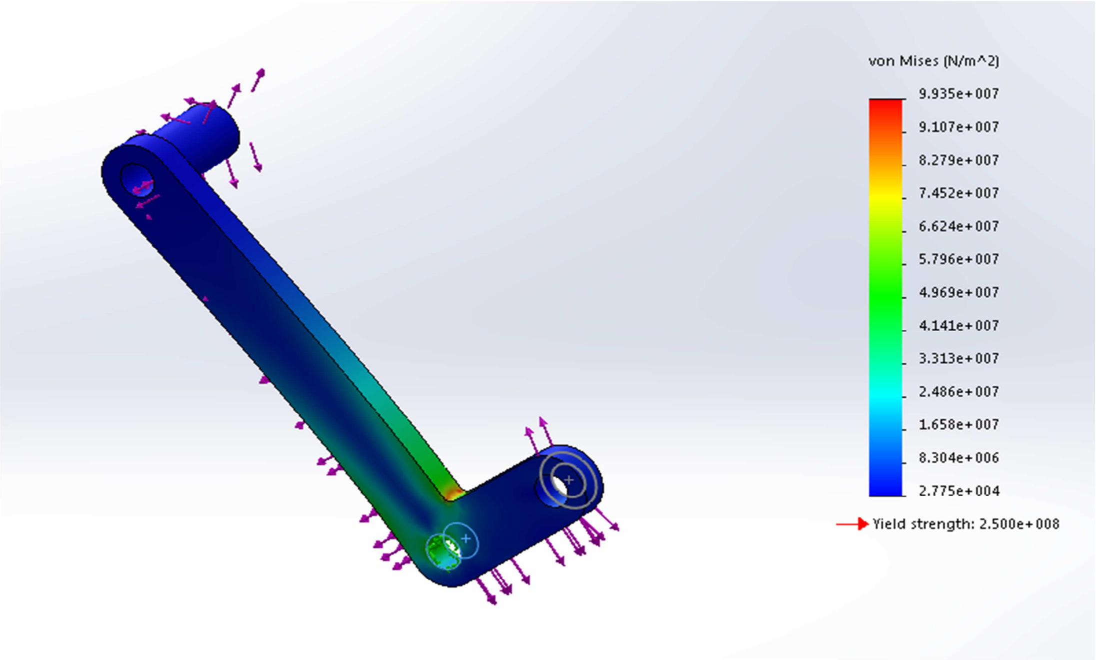


Figure 3-32: L-bracket Von Mises stress

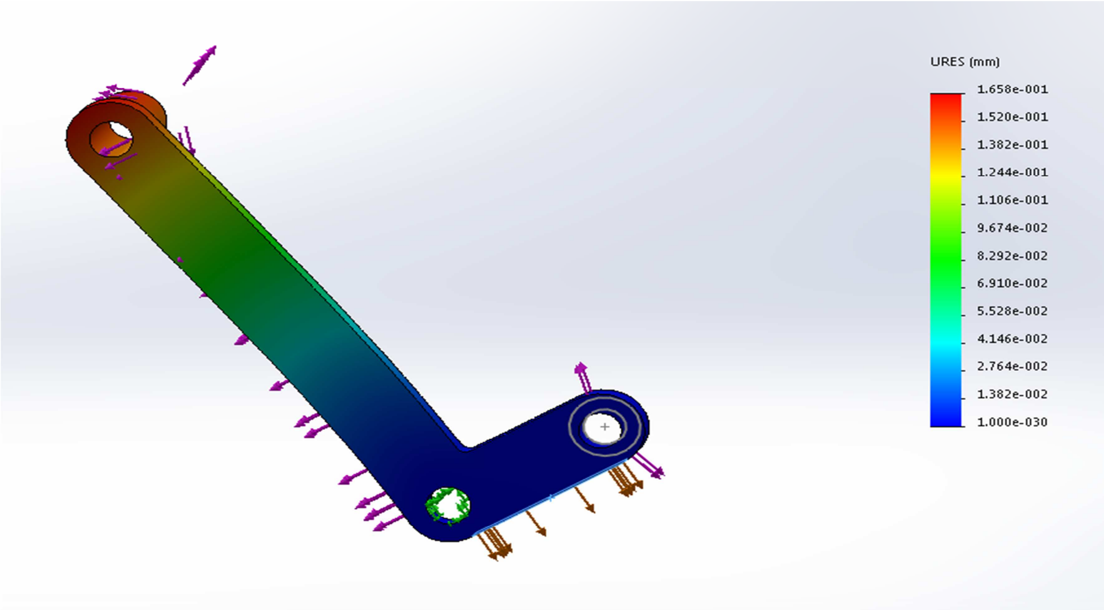


Figure 3-33: L-bracket deformation

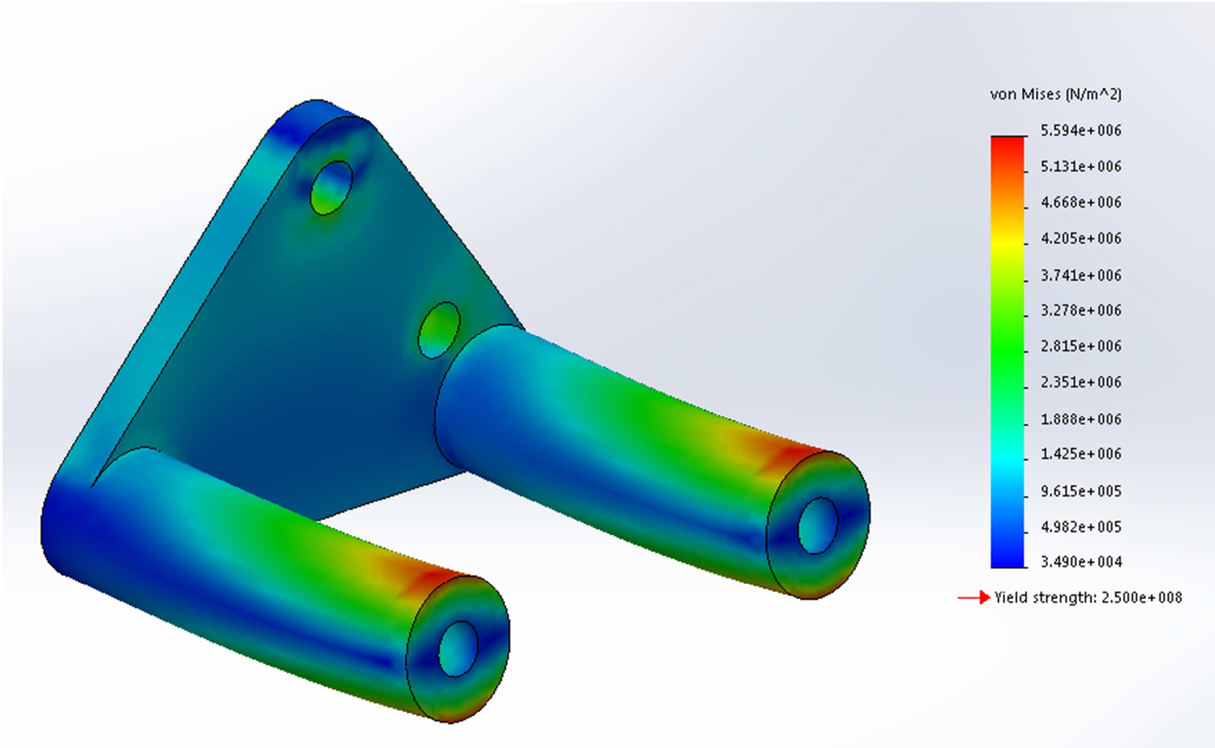


Figure 3-34: Triangular link Von mises stress

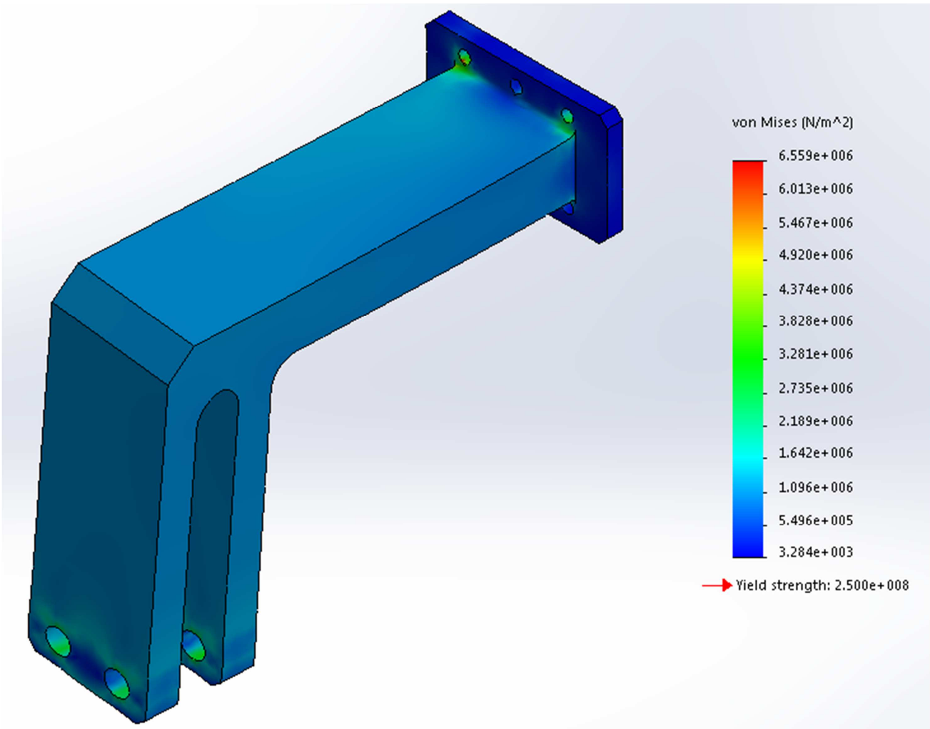


Figure 3-35: Brake Bracket Von mises stress

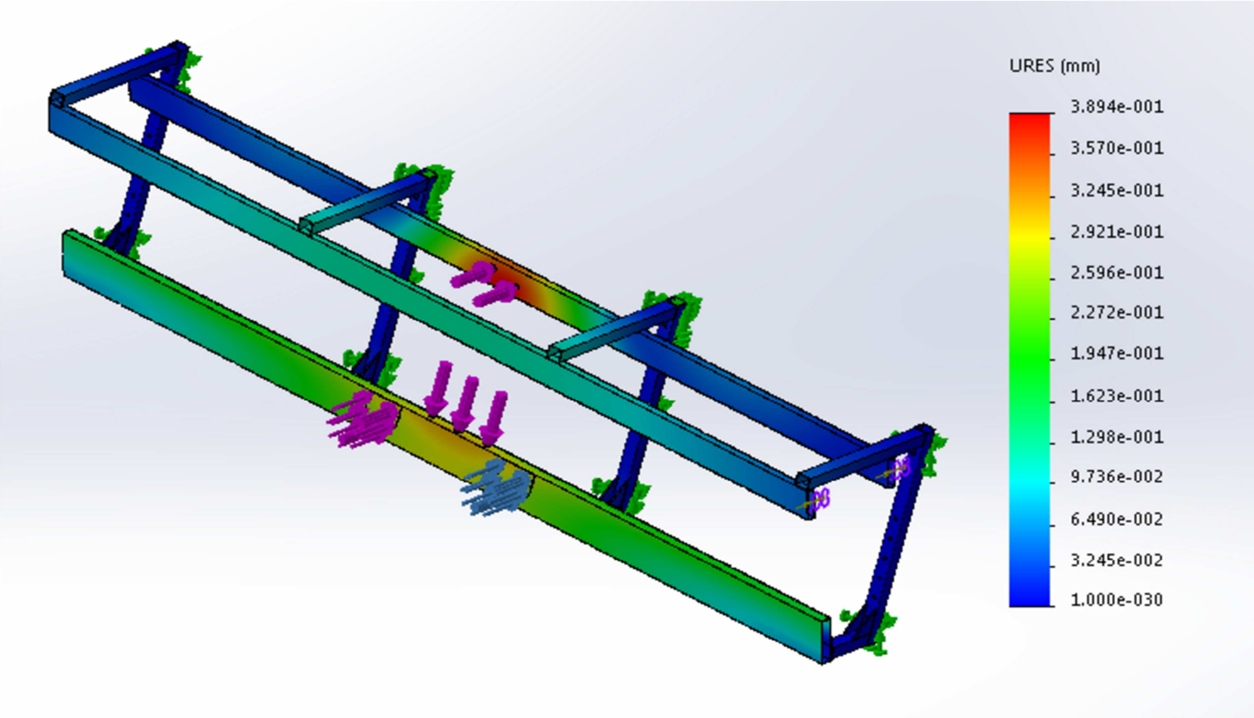


Figure 3-36: Sloped section deflection analysis

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.

Our team has planned to construct the main structure of the bogie first. Our plan is to cut all the necessary parts from A36 steel plate using the machine saw and milling machine. The square tube section on the main structure are cutted by machine saw. All the parts will be assembled together and all the joints will be welded together. For parts with complex geometry such as the triangular support, Y-shaped control arms and L-shaped control parts will be fabricated from a solid piece of metal using milling machine. The linkages are custom made with rod and tie rod end purchased in the market. Our team has initial plan on making the red driving wheels out of solid aluminum rod using the lathe and bearings will be installed onto the wheels. However we have found some polyurethane wheels and our team decided that our first choice is to use the wheels that we can purchase from market. We will consider building our driving wheels if we have spare time and budget.

For the guideway, the team has decided to also use A36 steel for the upper and lower rails. The upper rails being of dimension 2”x1” hollow cross area with thickness of 0.08” . The lower rails will be of 3”x1” cross area with thickness of 0.12 inch. The metal will be cut to length, welded, and bent to size. The post and rib supports will also be made of A36 steel. The top of the rail will be made of birch wood. They will be cut to size in-house using wood table saws. The plan is to order a portion of the portion parts to start building the straightaway, switch and the slope. Once that is complete, the team will decide if it is possible to move forward with the closed loop track.

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 long rigid shaft extending from the top to the bottom of the bogie did not interfere with any other bogie parts. The steering links have enough clearance for switching due to their mild tilt angles which were carefully considered when connecting the L-bracket and tie-rods into the switching unit. 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.

The solidworks model of the guideway scale down successfully to half-scale. The new bogie and cabin were mated fine onto the rails. It took a lot of iterations to get it right, but the outcome was a success. The stress analysis of the sloped section showed results of a small deflection of 0.39 inches due to the weight of the bogie pressing against the upper green wheels.

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.

Arriving to the final design of the guideway involved many iterations. One of the most notable challenges was learning to use solidworks to model a guideway. At first, sections of the track were being model and then assembled together to create a complete track. That was very difficult because a lot of the time the end points were off and did not connect at a lot of points. At the end it was found that making the track as one part using surfaces, split lines, 3D sketches, and sweepts made the model very easy to make. The second challenge that was experience was accommodating other subteams. There were requirements that had to be designed into the guideway and we believe we did a good job in doing that. Some of those requirements were giving enough clearance for the cabin team, non-sharp slope for the suspension team, and giving space for the fail-safe.

The plans for next semester are as follows:

- Prior to the start of the semester, all parts and materials need to be gathered in order to start fabrication. Furthermore, a fabrication plan needs to be clearly laid out to avoid hindrance of progress during the semester.
- Between January and early April, time is spent to manufacture the whole bogie and complete the initial prototype to allow enough time for testing and necessary adjustments that need to be made
- When the initial prototype is finished, about two weeks (early- to mid-April) are taken for test runs to make sure the steering links switch properly in sync and the disc brakes safely slow down the bogie
- After running tests, another two weeks (mid-April to early-May) will be spent to make any adjustments the bogie needs to finalize the prototype
- As soon as the parts for the guideway come in, assembly will begin. As stated above the first goal is to have a working guideway. Afterwords we will assemble a full track, given budget and time allows for it.

Active Suspension Development

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 will complement the forward thinking design of the project as 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. That 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:

$$\omega = \frac{v}{r} = \frac{d\theta}{dt} \quad (2)$$

Where:

□=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 3-36). 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 3-38). 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.

$$\alpha = \frac{d\omega}{dt} \quad (3)$$

$$a_t = \frac{\alpha}{r} = \frac{\frac{d\omega}{dt}}{r} \quad (4)$$

$$a_c = \omega^2 * r = \frac{v^2}{r} \quad (5)$$

$$\tau = I\alpha \quad (6)$$

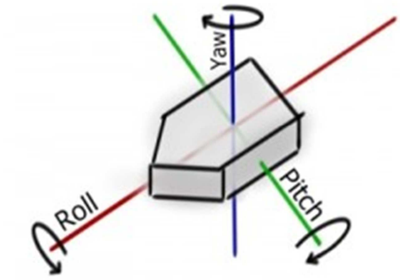


Figure 3-37: Three axes of motion

Where:

□=angular acceleration

a_t=tangential acceleration

a_c=centripetal acceleration

r=radius of arc

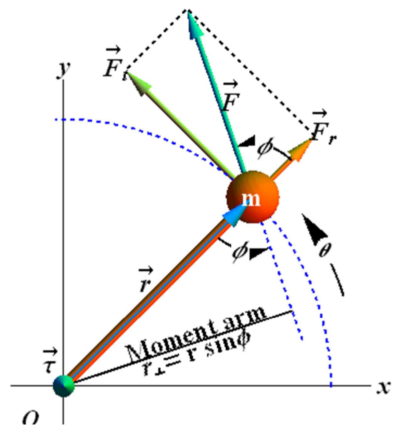


Figure 3-38: Torque and Angular Momentum of a Ridgid Body

□=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 3-39). 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 under damped 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 under damped 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 3-40). 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.

$$\boldsymbol{F_s = k * x} \quad (7)$$

$$\boldsymbol{F_d = c * v} \quad (8)$$

$$\boldsymbol{\omega_n = \sqrt{\frac{k}{m}}} \quad (9)$$

$$\boldsymbol{\omega_d = \omega_n\sqrt{1-\zeta^2}} \quad (10)$$

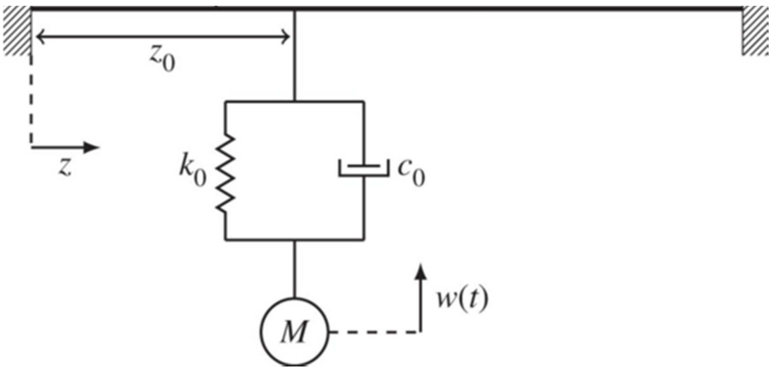
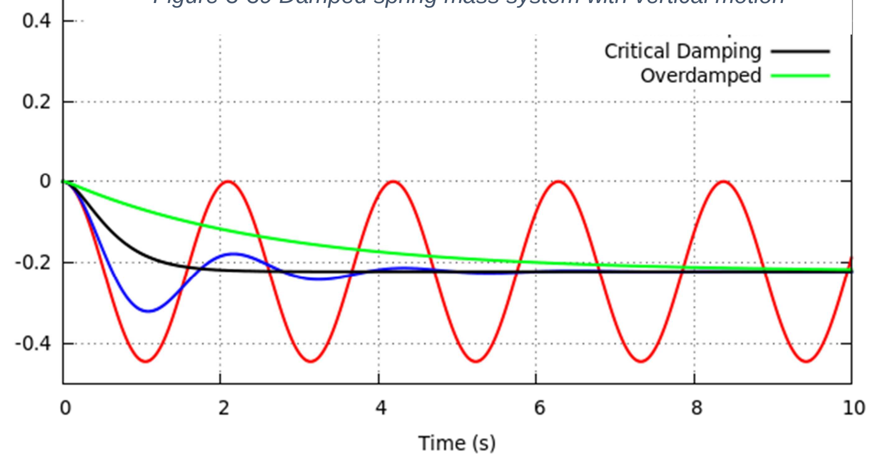


Figure 3-39 Damped spring mass system with vertical motion

$$\boldsymbol{\zeta = \frac{c}{2\sqrt{*m*k}}, 0.4 < \zeta < 0.8} \quad (11)$$



Where:

k=spring stiffness

x=spring displacement

c=damping coefficient

v=velocity of spring displacement

F_s=spring force

F_d=damper force

Figure 3-40 Different damping system scenarios

ω_n=natural circular frequency

ω_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 3-41). 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 3-41 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 3-42).

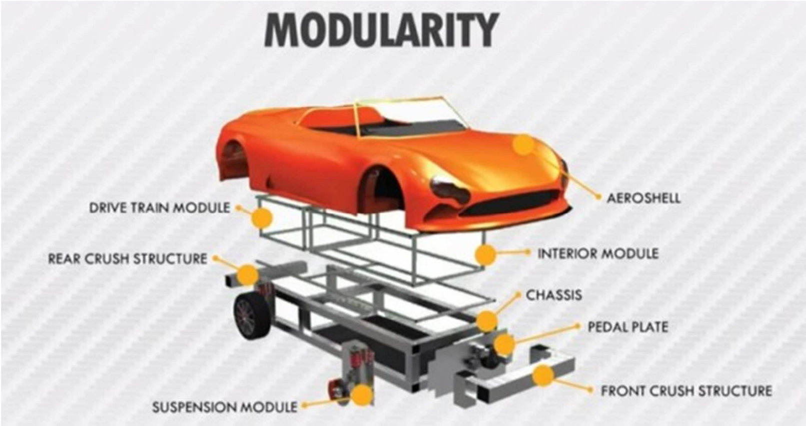


Figure 3-42 An example of utilizing a modular design approach where parts are built around certain specifications, ensuring compatibility even after small changes are made

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:

$$\boldsymbol{Factor\ of\ Safety} = \frac{\sigma_{yield}}{\sigma_{max}} \quad (12)$$

$$\boldsymbol{Margin\ of\ Safety} = \boldsymbol{Factor\ of\ Safety - 1} \quad (13)$$

Stresses to be considered:

Axial: $\boldsymbol{\sigma_a} = \frac{F}{A}$ *(1)*

Where:

F=applied force

A=affected area

Bending: $\boldsymbol{\sigma_b} = \frac{\boldsymbol{M*c}}{\boldsymbol{I}}$ *(15)*

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: $\boldsymbol{\tau} = \frac{\boldsymbol{V*Q}}{\boldsymbol{I*t}}$ *(16)*

Where:

V=internal resultant shear force

Q= $\overline{y}'A'$ where A’ is the area above or below where t is measured, and $\overline{y}'$ 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 off line transportation systems such as Morgantown PRT (Figure 3-43), it still uses large railway and infrastructure as that of BART trains.

Figure 3-43: 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 a guide ways. Such motorized elevated tram systems include: Wuppertal Suspension Railway Figure 3-44, and the Chiba city Suspension Railway Figure 3-45.

Figure 3-44: Wuppertal Suspension Railway

Figure 3-45: 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 3-46. 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 active suspension system that puts the comfort of the rider first.

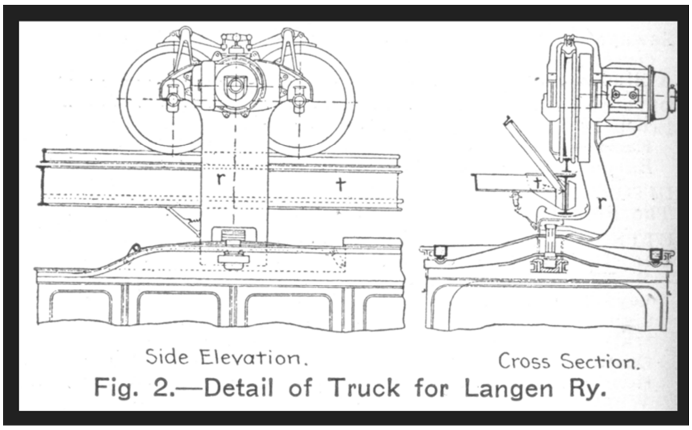


Figure 3-46: Suspension System of a Typical Suspended Railway Transit System

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 guide way 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 3-47). They are suspended off line 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 3-48).

Figure 3-47: JPods

Figure 3-48: 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 has not come up with the 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 3-49) and is being developed to be able to elevate up a slope of 45 degree angles (Figure 3-50). But there has not been many information of the design of the suspension system.

Figure 3-49: MISTER pod design

Figure 3-50: 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.

<u>Design Concepts</u>

As soon as we have started the semester, our work has been cut out to us, as far as what does the suspension system needed to accomplish. As stated in the design specification section, we needed our suspension system to do:

- The cabin must maintain its level parallel to the ground
- Allow only two degrees of freedom
- Isolate the vibration caused due to the track, and travelling 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:

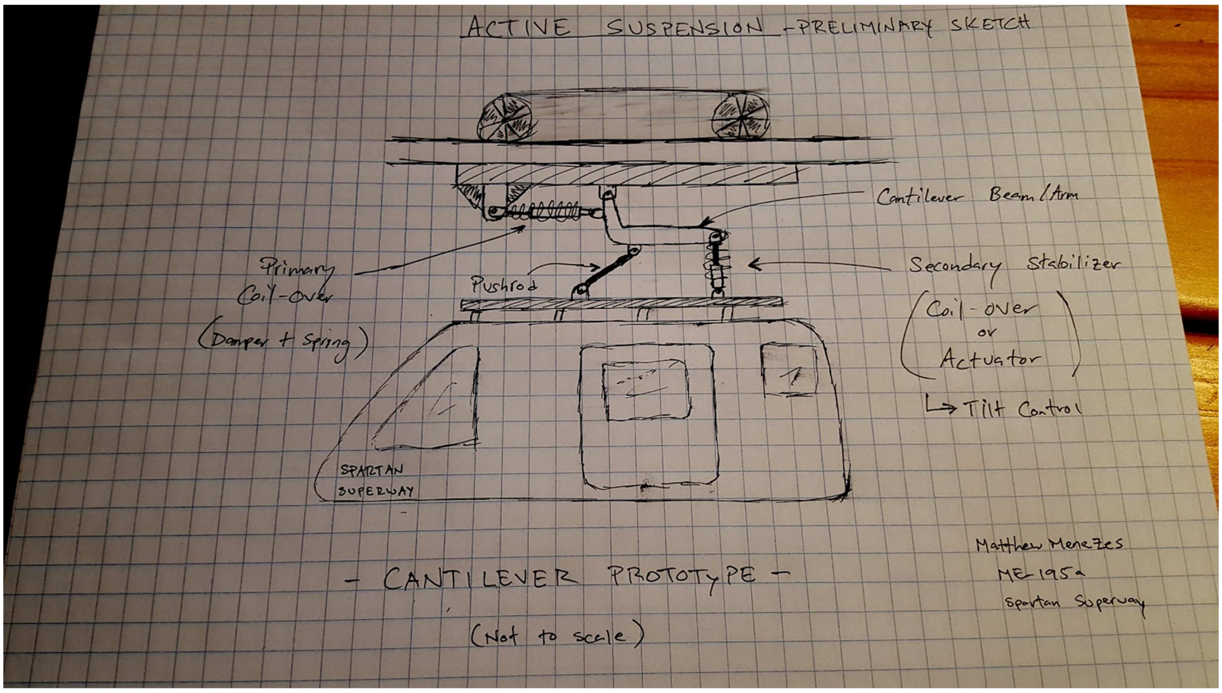


Figure 3-51: Cantilever Design Suspension

This design was a good start for us. Cantilever style links and Coil over were used to control and assist the tilting, and the isolation of vibration. While this design would have helped bringing the cabin close to the guide way, giving more ground clearance, did not address the issue of lifting and lowering the cabin to allow easy access to the wheelchair users.

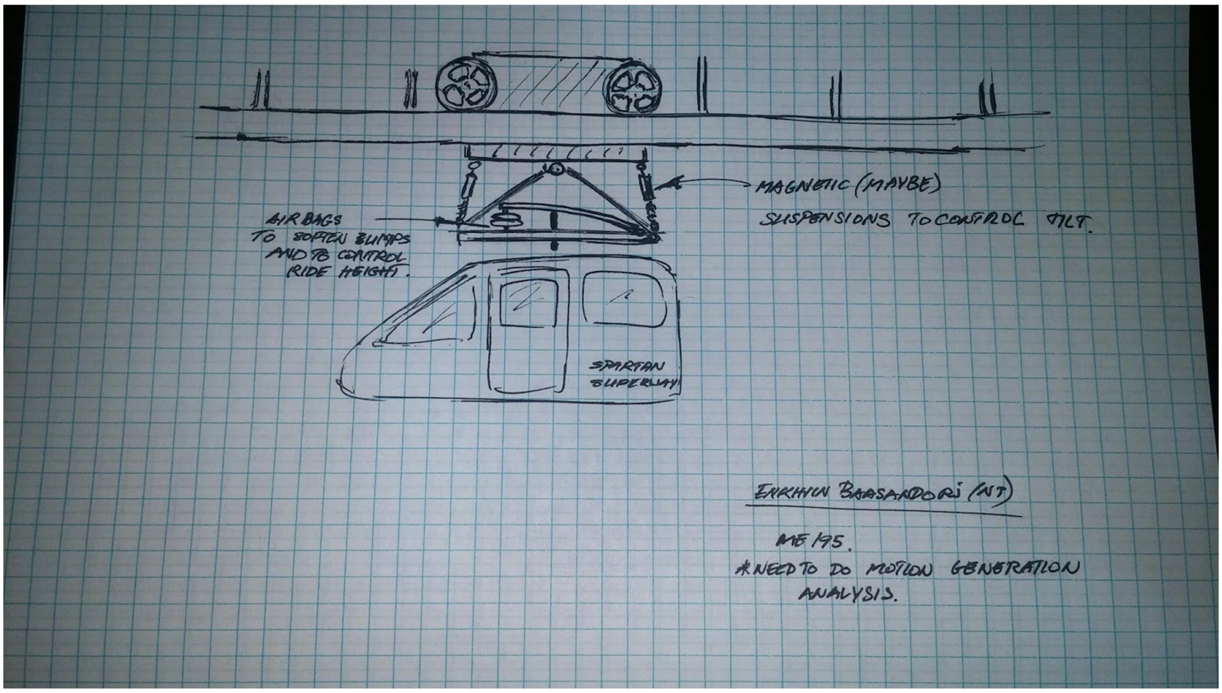


Figure 3-52: Utilization of Air Bag and Magnetic Dampers

Above design utilized the help of air bag system that are 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 to the platform, and the air bag would rise or lower the cabin to align the cabin perfectly. Magnetic controlled dampers are used to control the tilt as travelling through the sloped section of the guide way. 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.

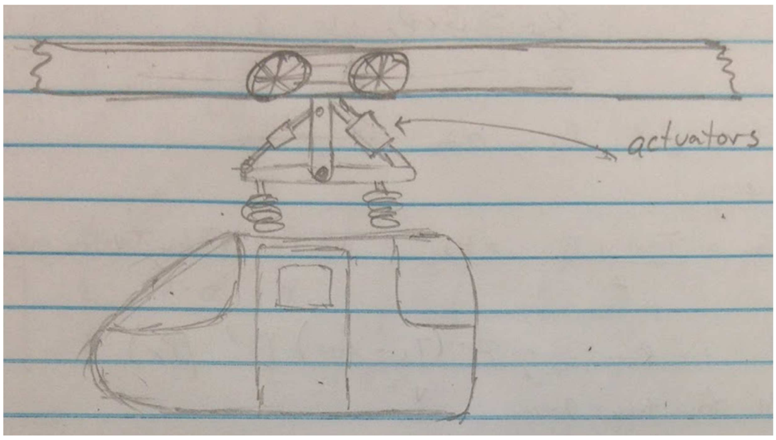


Figure 3-53: Utilizing Actuators and Coil Overs

This design was one of the highest voted 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 3-53 shows how the suspension would look like while the guide way is level to the ground, and Figure 3-54 below shows how the suspension handles different slopes.

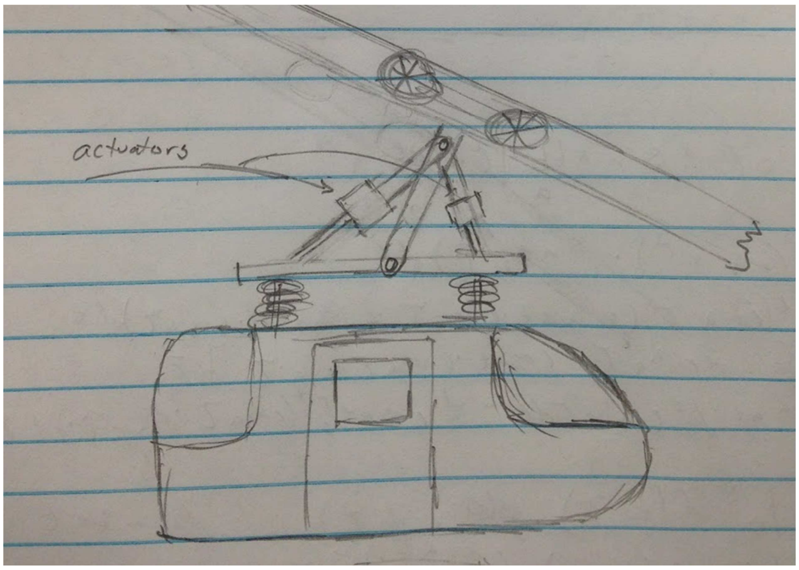


Figure 3-54: Actuators and coil over to keep the cabin level

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 slick and futuristic look. The design we have chosen can be read from the latter section: Concept Selection Analysis.

Analysis and Concept Selections

The previously mentioned concept designs all have great features. When considering which concept design to go with, the ASDT evaluated the concept designs on three characteristics: design size, design complexity, and design aesthetics. Design size is very important when considering a transportation system. As the size of a design increases, the probability of different parts interfering becomes greater. The ASDT needed to be sure that the chosen design wouldn't interfere with the track or bogie when navigating the inclines and declines of the track. Design complexity is an important factor when a design is being reproduced. Since the chosen design may be implemented into a large transportation system, the design needs to be easy to maintain. As well, the design needs to be as simple as possible to reduce the probability of system failure. Design aesthetics was the third characteristic that was evaluated for each concept design. The ASDT needed to make sure that the chosen design wouldn't detract from the futuristic image of the Spartan Superway. After all of the characteristics were evaluated, the ASDT decide that the chosen design was superior.

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 17.

$$F_{FullScale} = 2,500 lbf \qquad F_{\frac{1}{4}scale} = \frac{F_{FullScale}}{4} = 625 lbf \quad (17)$$

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 3-55 for the distribution of von Mises stresses in the Bottom Tube assembly.

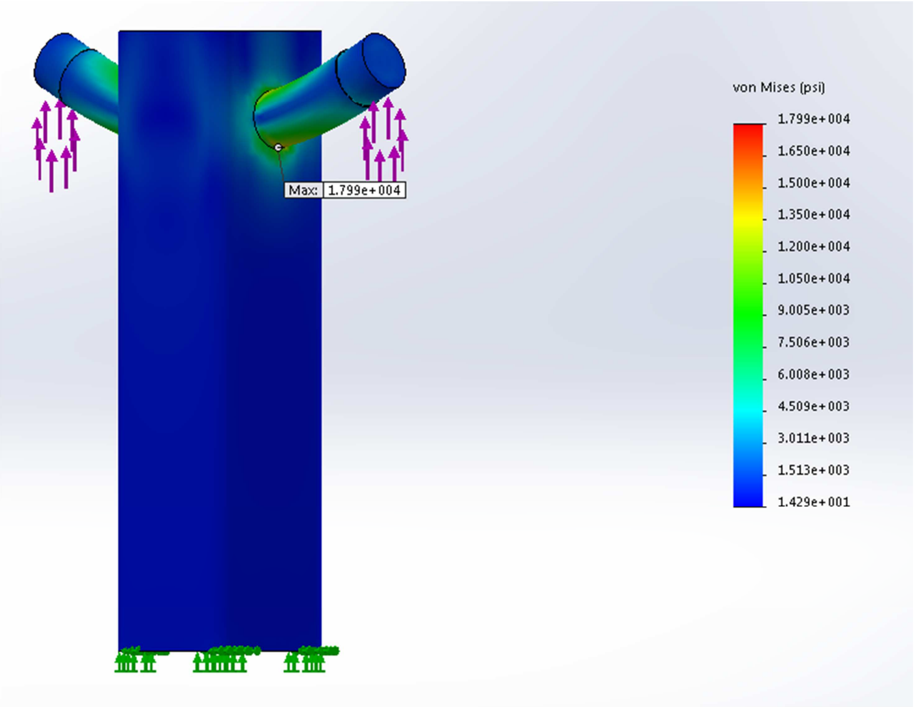


Figure 3-55: This figure represents the distribution of the von Mises stresses in the Bottom Tube assembly.

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 3-56 for the distribution of von Mises stresses in the Top Tube assembly.

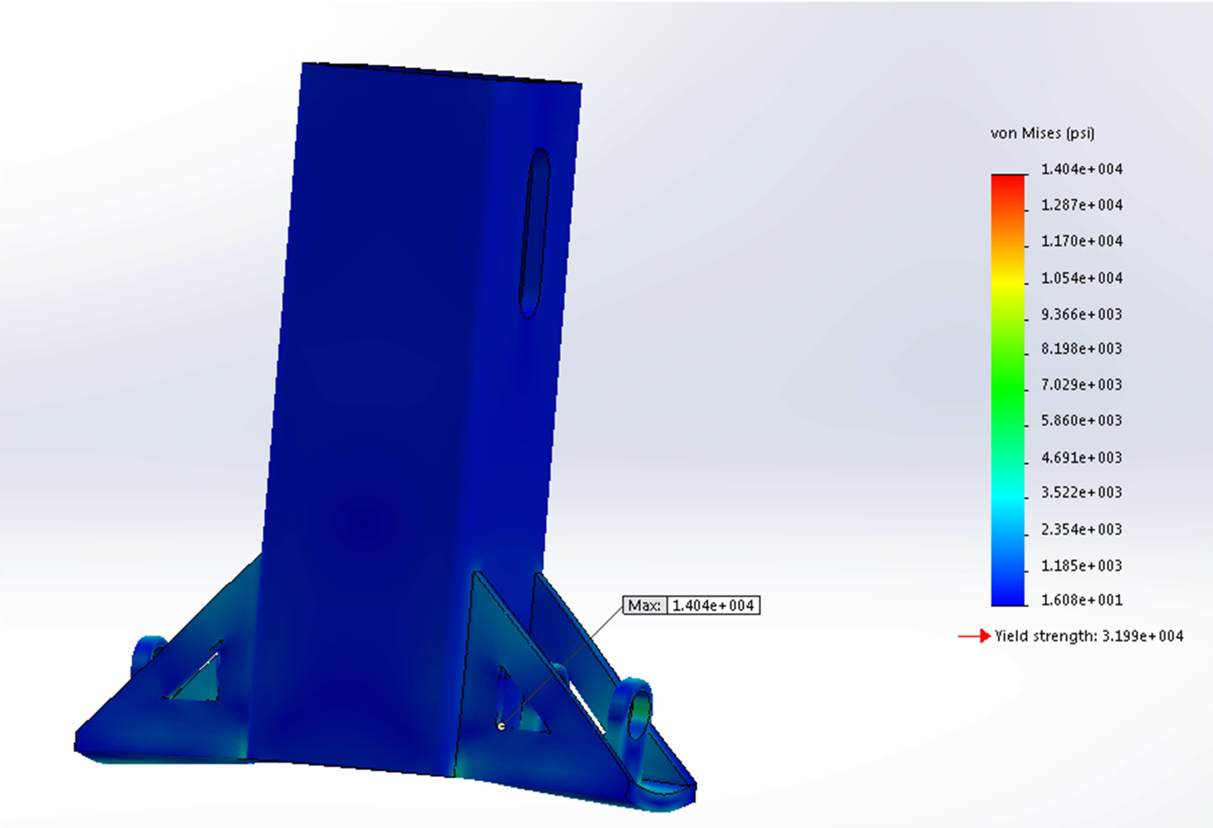


Figure 3-56: This figure shows the distribution of von Mises stresses in the Top Tube assembly.

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 3-57 for the distribution of von Mises stresses in the Top Tube assembly.

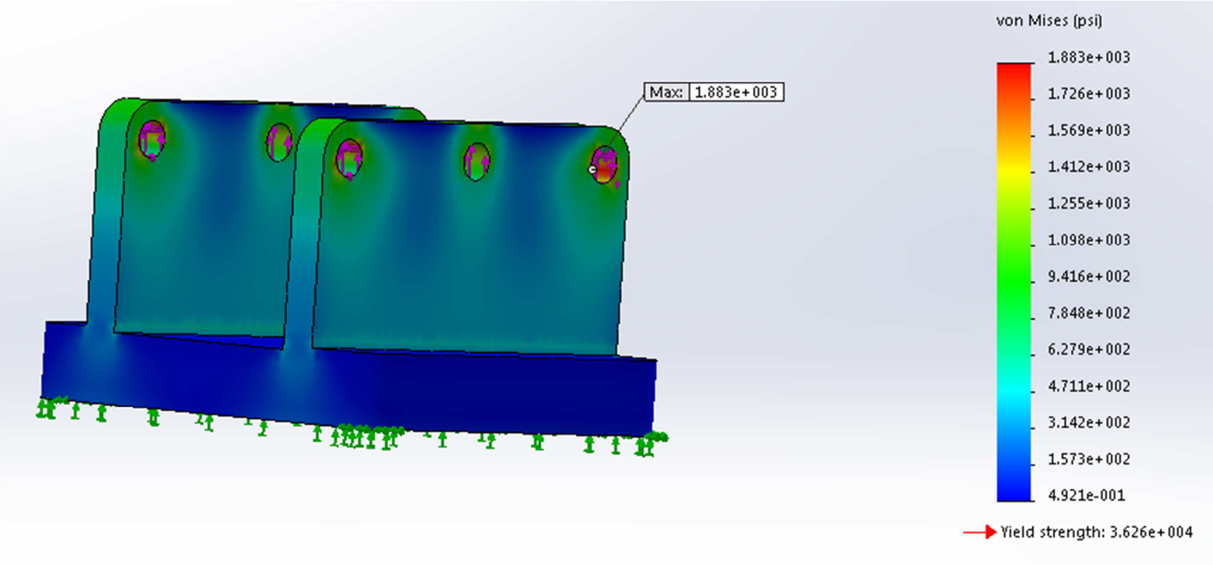


Figure 3-57: This figure shows the distribution of von Mises stresses in the Top Connection Plate.

The shock absorbers that have been chosen to utilize in this design are air shock. 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 ration. See Figure 3-58 for the relationship between transmissibility ration and excitation frequency.

$$TR = \sqrt{\frac{1+\left(2\zeta\frac{\omega}{\omega_n}\right)^2}{\left(1-\left(\frac{\omega^2}{\omega_n^2}\right)^2+\left(2\zeta\frac{\omega}{\omega_n}\right)^2\right)}} \quad (18)$$

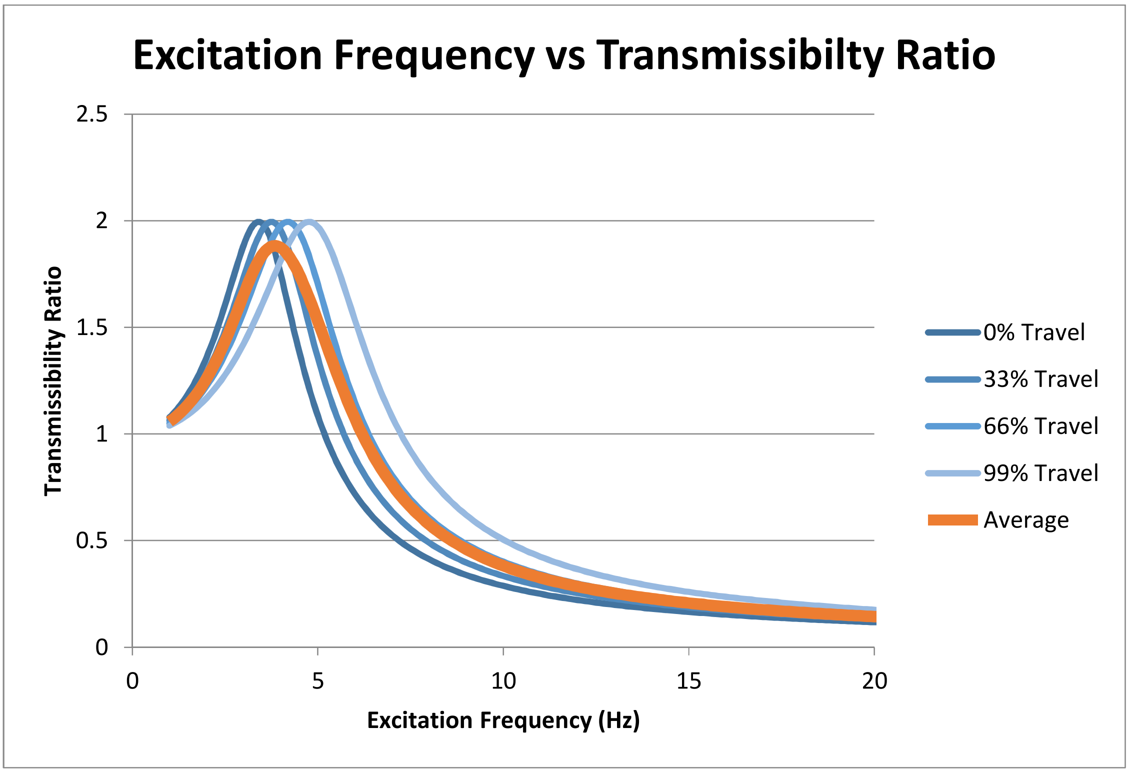


Figure 3-58: This figure shows the relationship between the transmissibility ratio of the suspension and the excitation frequency.

<u>Fabrication Methods (How will you build it)</u>

As our team heads into the second semester of the Spartan Superway project, our focus has shifted away from design and looks forward toward fabrication. Our main goals as we build our suspension system are to fabricate the system in a high quality and precision manner, while also completing our tasks on time, and within budget. Since the entire cabin will be supported by our suspension system, it is imperative that there are no fatal flaws that would cause the cabin to become separated from the bogie. While the easiest solution to this would be to have our part professionally made, in order for the project to maintain a reasonable budget, we plan to do all of the fabrication ourselves.

Our design contains a relatively small amount of parts, making the assembly of the suspension system somewhat simple. Figure 3-59, 60, and 61 show the main components of the design that we will need to fabricate. The squares tube in Figures 3-59 and 60 are made of ASTM A500 steel tubing while the rest of the components will be made of ASTM A36 mild steel. These types of steel are industry standards and are easy to work with. The manufacturer will likely cut the Square tubing to size. The only modifications that will need to be done are a slot on two sides of the tube in Figure 3-59 and a hole on two sides of the tube in Figure 3-60. The rest of the parts attached to Figure 3-59 will be first cut from plate steel by using a saw, then refined by a grinder. The individual parts can then be welded together by using a MIG welder either at San Jose State or off campus. The pin seen in Figure 3-60. will either be bought or lathed to size, depending on availability, and will be inserted into the square tubing and tack welded in place. Figure 3-61 shows a piece that will be milled from one piece of steel, then drilled, then welded to the top of the tube in Figure 3-59.

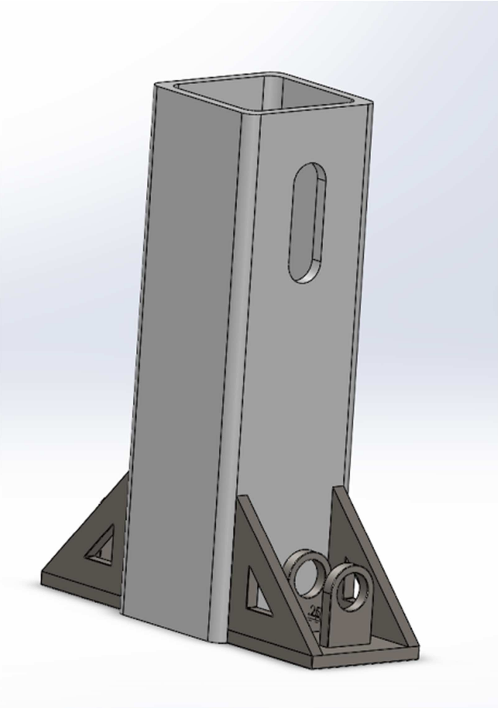


Figure 3-59: Outer square tubing assembly assembly

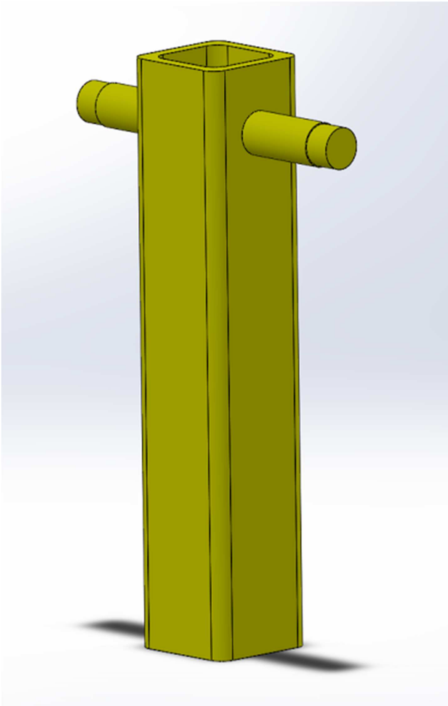


Figure 3-60: Inner square tubing

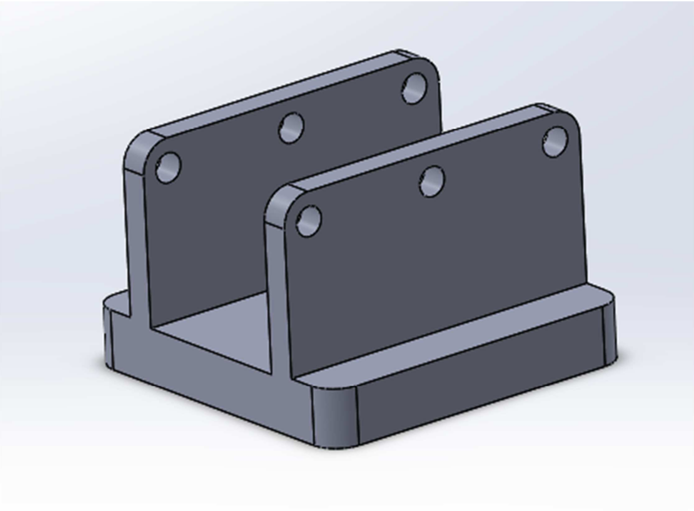


Figure 3-61: Top connection plate

Once all the individual components are made, all that will be left is to fit them together and attach the actuators and shock absorbers. The entire assembly can be seen in Figure 3-62. Attaching the actuators and shock absorbers should be as simple and bolting on the components.

Once we have reached this stage of production, our main concern will be making minor adjustments so that the system works flawlessly.

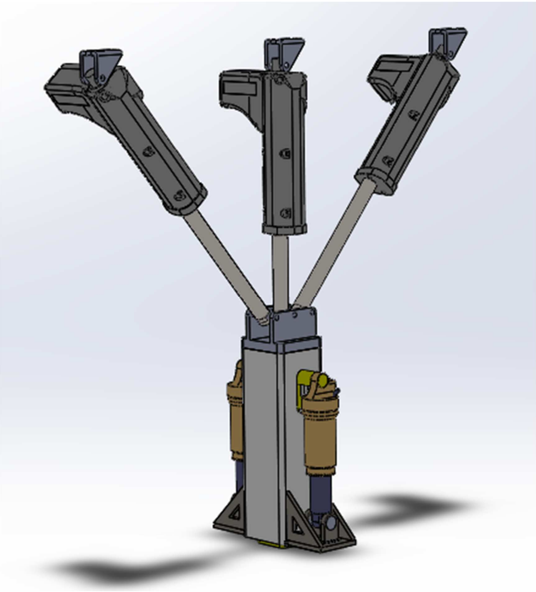


Figure 3-62: Full assembly

Outcomes

The active suspension will be able to keep the cabin level with the ground and even with station platform through the use of actuators. This will allow the Spartan Superway to be ADA compliant and open to all possible passengers. This is a major stipulation when a government authority evaluates the system to be put into use in a major city. The active suspension system will isolate any vibration through the use of air shocks. This will keep the cabin in a pleasant riding state.

Discussion

Next semester is about turning all our ideas from this semester into a deliverable product. Since we will be gone over winter break, it will be important to recap all of our ideas so that we are all on the same page as we go forward. The first few weeks of the new semester we will be discussing our design to make sure there are no modifications that we need to make, as well as ordering the parts that we need to complete the fabrication. We will also need to be in contact with the bogie and cabin teams to finalize a design that will allow our suspension to interface with the rest of the Spartan Superway. Currently our design allows us to easily add a component that will be compatible with a multitude of possible connection types in order to keep our options open.

Once the designs are finalized and all the materials have been acquired, it will be time to start fabrication. We anticipate that it will take no longer than two weeks to machine all the components, and no longer than an additional three weeks to assemble all the parts. Once our suspension system is completed, it will take another week to interface with the other teams' designs. This will bring the project up to mid-March. The rest of the Semester will be used for testing the operation of all the components, as well as the controls and code that we will use to run the system. The two months remaining at the end of the semester will be a crucial time to ensure that any unforeseen issues that may arise will be dealt with. Our Goal is to have consistent, reliable operation by the end of April to have a finished product with time to spare to work on our final report. See Appendix B for next semester's Gantt chart.

Torsion Test

Objectives

The Torsion Test sub-team is responsible for designing, building, testing and analyzing a five foot section of the guideway track. The test subject will be a slightly scaled down model of the actual full sized build due to limitations in funding and size requirements set forth by the torsion test machine.

The main objective for the Torsion Test sub-team is to build and test a 60 inch full-scale model of the guideway system. There is a sequence of events that will entail this overall objective. The first is to build and test a simplified, inexpensive, square hollow closed cross section of steel. This will familiarize the team with the torsion test machine and its process. Along with the square cross section, a circular hollow cross section will also be tested to calibrate the torsion test machine. The second is to utilize the data obtained from the simple torsion test exercise to figure out how and where to place the strain gauges on the full scale model. The third is to create a model in FEA software that will be used to optimize the design once the full scale build has been tested. Lastly, we design, build and test the 60 inch model. The test results will then be used to check the correctness of our FEA software analysis. From that point, any changes can be made in the FEA model and tested using the software to optimize the design.

At this point in time, transitioning from the first half to the second half of this project timeline, the goal is to build the simplified cross section and design the strain gauge system that will be used to collect the stresses experienced from the torsion test. This workpiece needs to have side plates and two inch solid steel end rods welded on for securing the workpiece into the torsion test machine chuck. The strain gauges will then be secured to the workpiece. The goal is to have the build completed over the winter break so that the test can be conducted near the beginning of the 2016 spring semester.

Design Requirements and Specifications

The Torsion Test sub-team shall improve the strength and durability Spartan Superway guideway structure. [Tier 0]

The Torsion Test sub-team shall confirm the safety of the Spartan Superway guideway structure. [Tier 0]

> The Torsion Test sub-team shall find the stresses present in a guideway section when placed under torsion [Tier 1]

The Torsion Test sub-team will confirm the analysis done by Kriti Kalwad by physically conducting the tests on similar specimens using the torsion test machine located in ENG131 [Tier 2]

The Torsion Test sub-team will first calibrate the machine using a stock pipe as a calibration specimen. [Tier 3]

The calibration specimen is shown in Figure 3-63 and will be purchased as a stock component. [Tier 4]

Following the Tester's calibration, the Torsion Test sub-team will familiarize themselves with the machine and test for uncertainty using a square diameter pipe with end caps. [Tier 3]

The square diameter is shown in Figure 3-64 and will be purchased then welded by Steve Trevillyan and Ivan Tapia. [Tier 4]

Following the uncertainty test, the Torsion Test sub-team will conduct the final test on the rail specimen. [Tier 3]

The specimen dimension will be determined by Kriti Kalwad, then built by either an outside source or Steve Trevillyan and Ivan Tapia, but needs to fit within the tester (60 inches) [Tier 4]

Kriti Kalwad will create model the sample in ANSYS and do finite element analysis to calculate the expected stresses [Tier 1]

Kriti Kalwad will find suitable dimensions for the guideway specimen such that the torsion machine can apply enough torque to obtain useful data about the stress and angle of twist of the specimen under load [Tier 2]

State-of-the-Art/Literature Review

The Urban Light Transit (ULTra) is a bottom rail PRT located at the Heathrow airport in London. Similar to the Superway, it implements the use of off-line stations to store the personal rail vehicles until they are called upon. It was found that 90% of the trips were available immediately during peak hours, and received "excellent" or "good" feedback by over 90% of the users (Bly, 2005). However, since the vehicle is guided by a rail below, it uses four tires to support the system, and is level with the ground. This also means that the system requires more material and space to build a track separate from walkways and streets. This system exemplifies the use of a PRT in a crowded area, and was found to be 70-90% more energy efficient than using a car (Lowson, 2002).

The Siemens People Mover H-Bahn is a suspended passenger railway system installed in Dortmund, an independent city in Germany. The system has received various upgrades since its public opening in 1984 at the University of Dortmund, and the rail network is currently about 2 miles long ('H-Bahn21', unknown). The vehicle itself is suspended under the guide rail, similar to the Superway system, and can carry a load of up to 4923kg, excluding the carriage. It has proven useful for its use on-campus, but proposed extensions have been rejected due to cost-efficiency. Also, the system is not a PRT, but a public transportation system. Carriages are available at stations about once every ten minutes.

Another proposed PRT, the SkyTran, is a transit system designed by NASA that has not yet been implemented, but expects its first network to be complete by early 2016 (SkyTran, 2014). The system uses magnetic levitation technology, which drastically decreases energy consumption. The current design is more space-efficient than the Superway, but has a high cost of installation.

Design Concepts

For the simple hollow cross section designs, the aim is to minimize cost, while maintaining adequate results that can be analyzed. The length of the circular workpiece is 60 inches. Figure 3-63 offers an illustration for this piece. The length of the square workpiece, not including the end plates and end rods, is 24 inches. These lengths will offer enough angle of twist to analyze the effects of the torsion forces applied. The circular piece did not require any end plates or end bars and was only used for calibration purposes.

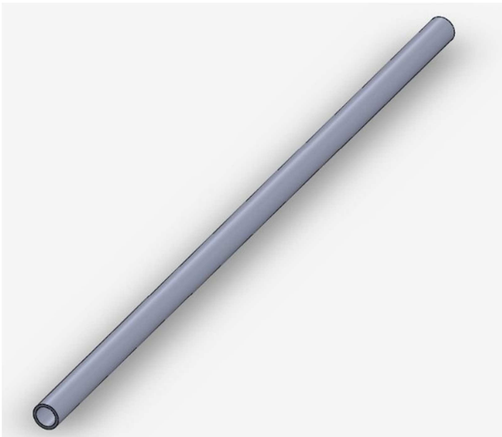


Figure 3-63: Circular Closed Cross Section: This piece is used for calibrating the torsion test machine:

The end plates for the square cross section are four inches square with an eighth inch thickness. These end plates are designed to apply a uniform loading to the workpiece. Attached to the end plates are two inch in diameter solid steel end rods which will be the attachment point for the torsion test machine. Figure 3-64 shows the design concept.

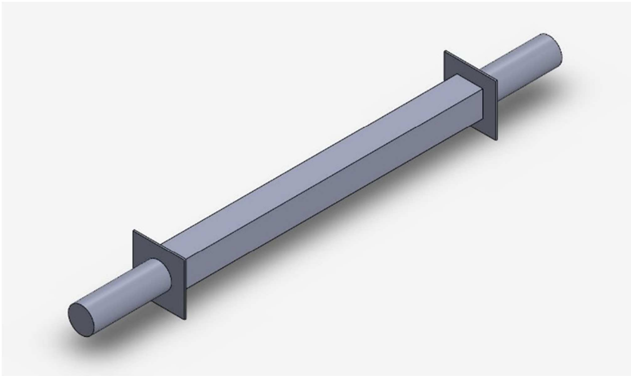


Figure 3-64. Simple Square Closed Hollow Cross Section for first torsion test

The design concepts for the full scale build follow closely to that of engineer Bengt Gustafsson, illustrated in Figure 3, who designed and patented the vehicle system used by the Spartan Superway.

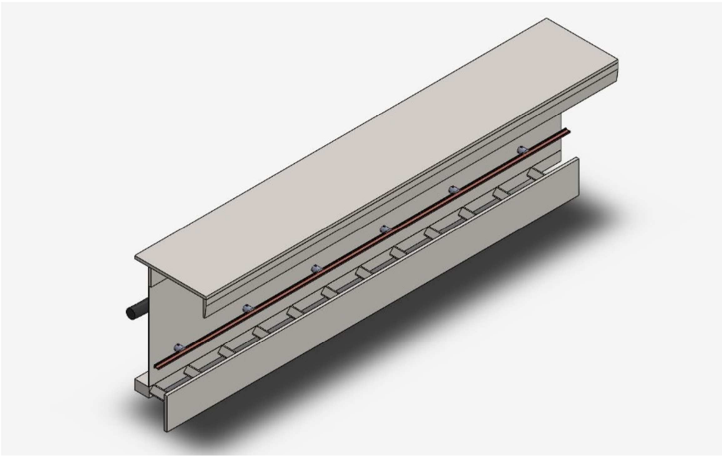


Figure 3-65. Full-scale Track Design by Bengt Gustafson: Spartan Superway will use this design as a basis, with some minor changes

The design of the full scale model must be sized according to what will fit in the torsion test machine. The torsion test machine is setup to analyze a structure no longer than 60 inches, so the full scale model will be limited to this length. The materials used will be A36 steel due to its availability and cost. A36 steel is common and easy to procure. It will minimize the cost, which is an important factor for the Superway project due to limited funding. At this point in the project, the team only has a tentative design for the full scale model. The design was created by a grad student over the summer by the name of Jake Parkhurst. There are flaws in the design that will need adjusting, where another grad student by the name of Kriti Kalwad is assisting in that process. The tentative design by Jake Parkhurst is shown in Figure 3-66.

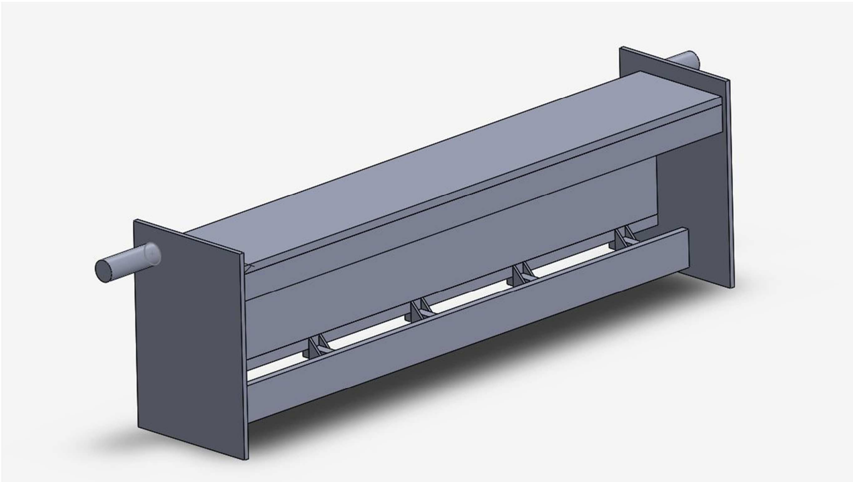


Figure 3-66. Jake's initial design of five foot full scale guideway. This is an initial design, which needs adjusting, that will be used for the torsion testing. The side plates and end bars are shown here.

Design includes the end plates and mounting bars that are added to the structure for the torsion testing process. A detailed drawing with parts list is shown in Appendix B.

There will be some design changes to the final full scale build. One of the potential design changes will affect thicknesses of the steel plates. Mr. Parkhurst's design represents thicknesses of 0.75 inches which too large. For a slightly scaled down version of the full scale design, this thickness is unnecessary and will drive cost up dramatically. For the Torsion Test team's purpose, a thinner material is desired. The support rail attachment design is also in question and up for redesign. Figure 3-67 shows both Mr. Gustafson's, and Mr. Parkhurst's base plate attachments. The aspect of Mr. Gustafson's design that causes for reevaluation of Mr. Parkhurst's design is the way the attachments are situated.

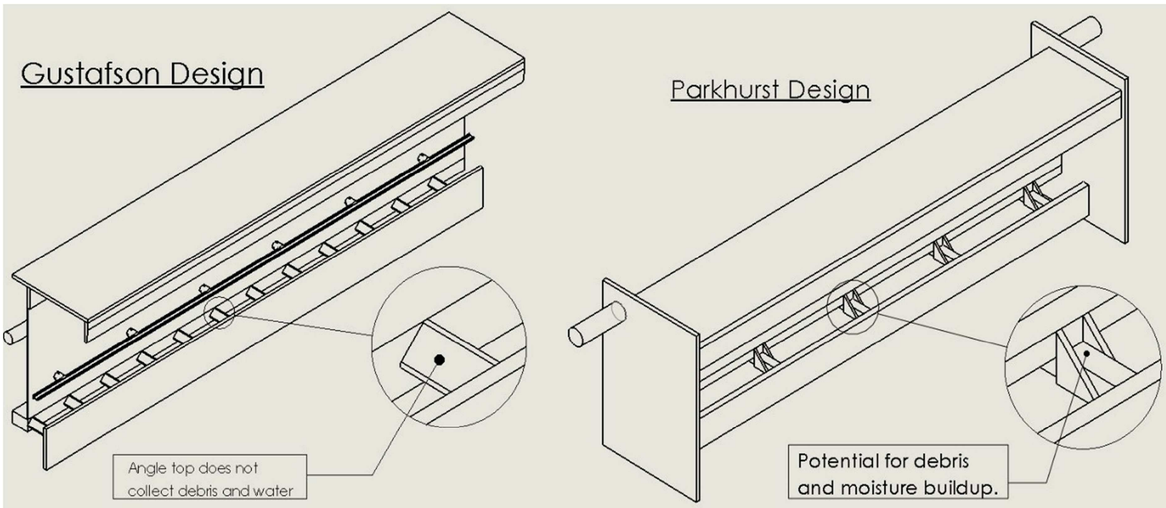


Figure 3-67. Design comparison of full scale models. Mr. Gustafson's design invokes a potential flaw in Mr. Parkhurst's design

The attachment on Mr. Gustafson's design has an angled top which will keep debris and water from accumulating. Mr. Parkhurst's design, using the two triangular gussets will catch any debris and water that may fall on it. This is a potential hazard to the integrity of the material.

The Torsion Test sub-team is set to optimize the overall guideway design. Through this process, the guideway will be designed to be cost effective, safe, and robust.

Analysis and Concepts Selections

Prior analysis for each of the three torsion tests will be done using hand calculations and FEA through ANSYS. For the simple hollow cross sections, the hand calculations and FEA will give us our expected maximum shear stress values as well as tell us the where the maximum shear stress occurs. This will help us to determine the placement of our strain gauges during the torsion test. These initial results will be compared to the experimental results from the first two torsion tests in order to confirm the accuracy of our measurements and calculations. ANSYS modelling will be done on the scaled down track design prior to the final torsion test of this design. This will tell us the expected maximum shear stress and the expected locations of maximum shear. ANSYS modelling will be done by Kriti Kalwad. Hand calculation analysis for the round and square hollow cross sections will be outlined in this section.

Shear stress for a circular hollow cross section under torsional loading:

Circular cross sections are the easiest to analyze when it comes to torsional loading. This is because the bar experiences St. Venant (pure) torsion but not warping torsion. Warping torsion occurs if the unconstrained ends of the beam warp out of plane under a torsional load. While bars and beams of all other cross sections experience some amount of warping torsion, circular cross sections do not. This also applies for thin walled hollow circular cross sections (Hughes, Iles & Malik, 2011, p. 8). The equation for maximum shear stress of a circular bar under torsional loading is given in Equation 19. In this equation T is the applied torque, c is outer radius—which is where the maximum shear stress occurs—and J is the torsional constant of the cross section.

$$\tau_{max} = \frac{Tc}{J} \qquad (19)$$

For a hollow circular cross section, the torsional constant is given by Equation 20, where R_o is the outer radius and R_i is the inner radius.

$$J = \frac{\pi}{2}(R_o^4 - R_i^4) \qquad (20)$$

The maximum twist angle was also calculated using Equation 21, where T is the applied torque, L is the length of the bar, J is the torsional constant and G is the modulus of rigidity of the material.

$$\phi = \frac{TL}{JG} \quad (21)$$

The geometric dimensions, material properties and applied torque for the analysis performed are given in Table 3-1. Modulus of rigidity was obtained from AZO Materials. The results of the analysis are displayed in Table 3-1. The value for applied torque may be changed for the actual torsion test in order to achieve strains that can be easily measured. These results will be compared to the ANSYS FEA results when available.

Table 3-1: Parameters for Torsional Analysis of the Circular Hollow Section

BOE is basis of estimate (D=Design specification, A=Analytical estimate, T=Verified by test)				
Parameter	Value	Units	B/O/E	Guidance/Comments
Applied Torque (T)	5000	ft-lb	A	From torsion machine
Outer Radius (C, R_o)	1	in	D	Stock 2" diameter tube
Inner Radius (R_i)	0.875	in	D	Stock 1/8" wall thickness
Length of Tube (L)	24	in	D	
Shear Modulus for A36 steel (G)	11500	ksi	A	From AZO Materials

Table 3-2. Results of Analysis of the Circular Hollow Cross Section

Result Calculated	Value	Units
Torsional Constant (J)	0.65	in^4
Maximum Shear Stress (τ_{max})	92310	psi
Maximum Angle of Twist (ϕ)	0.1926	radians

Shear stress for a square hollow cross section under torsional loading:

Torsional analysis for members with a non-circular cross section is more difficult because of the presence of the above mentioned warping stresses. However, according to Hughes, Iles and Malik (2011), the warping torsion for a rectangular hollow cross section is negligible, therefore it does not need to be taken into account during torsional analysis. The following calculation were done using equations from their book, *Design of Steel Beams in Torsion*. Equation 22 gives the maximum shear stress, where T is the applied torque and W_t is the torsional section modulus.

$$\tau_{max} = \frac{T}{W_t} \quad (22)$$

For a thin-walled hollow square section, W_t is estimated using Equation 23. In this equation t is the wall thickness and A_p is the area enclosed by the mean perimeter. A_p is calculated using Equation 24, where h is the section height, b is the section width and r is the mean corner radius. The mean corner radius is estimated to be 1.25t for hot-finished bars (Hughes, et al., 2011, p.65)

$$W_t = 2tA_p \quad (23)$$

$$A_p = (h-t)(b-t) - r^2(4-\pi) \quad (24)$$

The maximum twist angle was then calculated using Equation 25, where T is the applied torque, L is the bar length, G is the shear modulus of the material and I_T is the St Venant torsional constant. The St. Venant torsional constant is calculated using Equation 26, in which 'a' and 'b' are the dimensions of the rectangular cross section and a is greater than or equal to 'b'.

$$\phi = \frac{TL}{GI_T} \quad (25)$$

$$I_T = \frac{ab^3}{3}[1 - 0.21\frac{a}{b}\left(1 - \frac{b^4}{12a^4}\right)] \quad (26)$$

Table 3-3 gives the parameters used during this analysis and Table 3-4 displays the results. As with the analysis of the circular cross section, applied torque may be modified in the future. This data will also be compared to the ANSYS results.

Table 3-3. Parameters for torsional analysis of the square hollow cross section

BOE is basis of estimate (D=Design specification, A=Analytical estimate, T=Verified by test)				
Parameter	Value	Unit	B/O/E	Guidance/Comments
Applied Torque (T)	5000	ft-lb	A	From torsion machine
Wall Thickness (t)	0.125	in	D	Stock hollow square bar
Section Height (h, a)	2	in	D	Stock hollow square bar
Section Width (w, b)	2	in	D	Stock hollow square bar
Length of Tube (L)	24	in	D	
Mean Corner Radius (r)	0.15625	in	A	$r = 1.25t$
Shear Modulus (G)	11500	ksi	A	From AZO Materials

Table 3-4. Results of analysis of the square hollow cross section

Result Calculated	Value	Units
Mean Perimeter Area (A_p)	3.495	in^2
Torsional Section Modulus (W_t)	0.87375	in^3
Max Shear Stress (τ_{max})	68670	psi
St Venant Torsional Constant (I_t)	4.307	in^4
Maximum Angle of Twist (ϕ)	0.02907	Radians

Fabrication Methods

The initial step to fabrication is to find a facility where the Torsion Team can conduct their work. The facility must at the least have welding and metal cutting equipment. The first and most logical option for the team would be the San Jose State University welding shop. This location is the most beneficial to the team because it is located on campus and the team should have easy access as opposed to working in a facility off campus. As per Professor McMullen, there is also a technician in the welding shop that would be able to help us with the welding and fabrication. Another facility where the team would be able to conduct some of their work would be at the fabrication shop at JM Construction and Engineering, Inc. A member from the Torsion Team works here in between semesters and his boss agreed to let the team use the JMCE shop. The JMCE shop has welding equipment, metal cutting equipment as well as a water jet. However, this facility is located in Turlock, CA and it is approximately an hour and a half away from San Jose. This facility will only be available during winter break and spring break when the team member has direct access to it.

The next step for the fabrication process would be to obtain the necessary material to build at least two testing specimens. Two metal distribution companies in the bay area have been contacted for material donations and the team is still waiting to hear back from them. The two companies that were contacted by the torsion team are Valley Iron Inc. and PDM Steel Service Centers, Inc. All of the material used for fabrication will be A36 Steel. After the material is obtained the fabrication process begins.

Circular Cross Section: The material that will be used for this cross section is a 2” pipe with a ⅛” wall and it is 24” long stock pipe as shown on Figure 3-63. The fabrication process for the cross section will include cutting the pipe to size and deburring any sharp edges.

Square Cross Section: The material that will be used for this cross section is a 2” x 2” x ⅛” square tubing at 24” long. This cross section includes two 4” x 4” x ⅛” thick end plates and a 2” shaft at an arbitrary length on either end of the tubing as shown in appendix A. The first step in fabricating this cross section would be to cut the square tubing, end plates and shaft to size and deburr any sharp edges. The next step would be the assembly process. The assembly process would start by welding the shaft to the endplates and then welding the endplates to the square tubing. During assembly it is important that everything is squared and centered in order to maximize accuracy of the torsion test. Appendix B contains a tentative step by step process for building the simple enclosed cross section.

Optimized Cross Section: The design for the optimized cross section will be finalized when Kriti finishes the ANSYS FEA modeling. She is basing the final design off Jake's drawing in Figure 3. However, due to testing purposes not all of the parts in Jake's drawing will not be fabricated because they would be irrelevant to the torsion testing results. The fabrication process for this cross section is going to be extremely challenging. When the team talked to professor McMullen he informed the team that the fabrication process could from 3 to 6 weeks. Professor McMullen obtained this information from the welding technician on campus. The team will have to start fabricating this cross section at the beginning of the spring semester but ideally towards the end of winter break would be wise. The optimized cross section will be made of A36 steel.

Outcomes

The results of the 'Analysis of Designs' section are organized in tables 1-4. Regarding the circular pipe calibration specimen, we will apply a torque of 5000 ft-lb. The hand-calculations are simple, and we expect a high degree of accuracy due to the simple geometry. We expect the maximum shear stress to be equal to 92310psi, and the maximum angle of twist to be around 0.1926 radians. We will use the angle of twist results in order to calibrate the torsion tester for the next two tests.

We will apply the same torque of 5000 ft-lb to the end plates of the square-cross section pipe. Doing so should result in a maximum shear stress of 68670 and a maximum angle of twist of 0.02970 radians. Testing this specimen will not only familiarize ourselves with the machine, but allow us to consider the uncertainty of the test, and include it in our final results.

Discussion

Most of the work done this semester entailed coordinating with people, outside of the Spartan Superway team, that are involved in the beam design. The team met with people such as Jake, Kriti, and Bengt who are crucial contributors to the beam design. The team also had to coordinate with professor McMullen who is going to jump-start the team with the testing of the beam. After the coordinating was complete, a mutual decision was made. The decision entailed for the team to fabricate two simple cross sections for initial testing and then to fabricate the optimized section based off these results. The scope of the project was set in place and the team immediately started to plan the work for next semester.

The team proceeded to contact two metal distribution companies in the bay area for material donations. As soon as the materials can be obtained, the sooner the team can start fabricating and testing. Testing the fabricated cross section is extremely important. It will let the team know if the torsion test results match the ANSYS and hand calculation results. If these two results do not match the testing results, the team will have to further investigate why the results do not match. The discrepancies in the results could be due to bad testing, the testing machine not being calibrated or the ANSY results not being accurate. This aspect of the project is extremely important and it could be extremely time consuming if the problem is not found immediately. At this point of the project the team has the ultimate goal in its sight and is ready to conquer all task presented to them.

Chapter 4: Solar

Solar Interface Electrical Team

Objectives

There are two main goals for the Spartan Superway project this year. The first goal is to expand on the current 1:12 scale model and to switch the power source of the 1:12 scale model from battery power to conductor rail power. The second goal is to build a new 1:4 scale model track and bogie, and to provide power to the 1:4 scale bogie vial conductor rail. Our team is tasked with designing a system to provide power to the conductor rail for both the 1:12 and 1:4 scale models. Our team's primary goal for the system is to create a solar interface that can supply continuous power to the Spartan Superway utilizing a combination of solar panels and grid supplied power. Our team's secondary goal is to create a system that will be scalable between the two different models as well as up to a 1:1 model.

Design Requirements and Specifications

For this project year, two different scale models of the SMSSV will be produced. The first scale will be the 1:12 model, which 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 will be powered through an energized rail and sweep pickup system. The second version will be a 1:4 scale model, and will have a very similar electrical configuration. However, at the time of the writing of this report, we have not received the electrical load specifications of that scale.

We have received the load specifications of the 1:12 scale from the other members of the project team. 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 has to design a power conversion system using a combination of solar power and city grid power.

The solar power conversion module will consist of three LT3083 adjustable low dropout regulators, each capable of supplying 3 amps of DC current. These will be connected in parallel and the output will be controlled by a 100 kilo-ohm potentiometer, to adjust for optimum operating conditions once connected to the model. The three regulators will have ballasting resistors to improve load sharing performance between them, and the module will have tantalum capacitors on the input and output ports to improve stability.

The city grid interface for the 1:12 scale model will be connected to the solar conversion module input. This city grid connection will be a 12 volt AC/DC supply and it, along with the solar cell array, will have high current blocking diodes to prevent reverse power conditions from occurring. When the solar array can no longer support the operation of the regulators, the city grid analogue will take over and power them until the solar illumination increases enough to switch back. See Figure 4-1 below for an LTSpice diagram of the circuit.

These design criteria will be used again on the 1:4 scale and eventually on the 1:1 scale. However, starting at the 1:4 scale, the components used will have to conform to the National Electric Code for solar power installations. This means that the components used will instead be specified as modules or assemblies, rather than discrete devices.

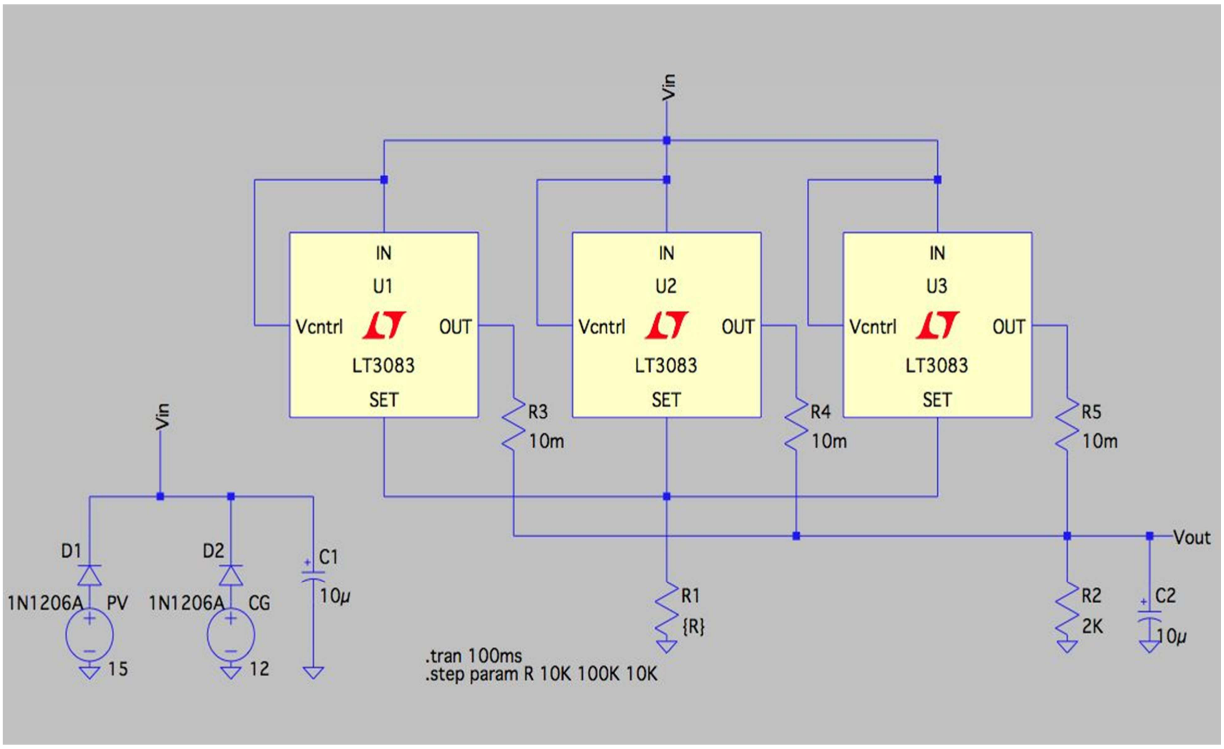


Figure 4-1:DC Power Regulator LTspice Model. This circuit is for the 1:12 scale electrical interface circuit. It utilizes three LT3083 linear voltage regulators in parallel to generate a total maximum current of 3 Amps DC.

Design Concepts

The complete circuit component list for the 1:12 scale solar interface circuit can be found in Table 4-1. The solar interface circuit is designed as a localized system, which will provide a central location that will connect with each solar cell, grid power and with the conductor rail. The block diagram for the overall system can be seen in Figure 4-2. In the current 1:12 design, ten solar panels will be used to supply power to a total of ten bogies. A DC power supply will be used to simulate grid power and provide an additional power source to the Spartan Superway. A DC-DC converter circuit will be utilized to condition the solar cell power output to provide the appropriate power level for the bogies. Three LM3083 voltage regulators will be used in parallel to ensure that enough current is produced by the solar interface system. The source switching component will utilize two 1N1206A high current diodes to select the voltage source with the highest output. In addition, the 1:4 scale model will also contain an inverter circuit to rout any excess solar power back to the grid, and a rectifier circuit to take power directly from the grid to power the bogies. Unfortunately, at the time of writing this report, the specifications for these parts could be determined due to lack of information from the other teams.

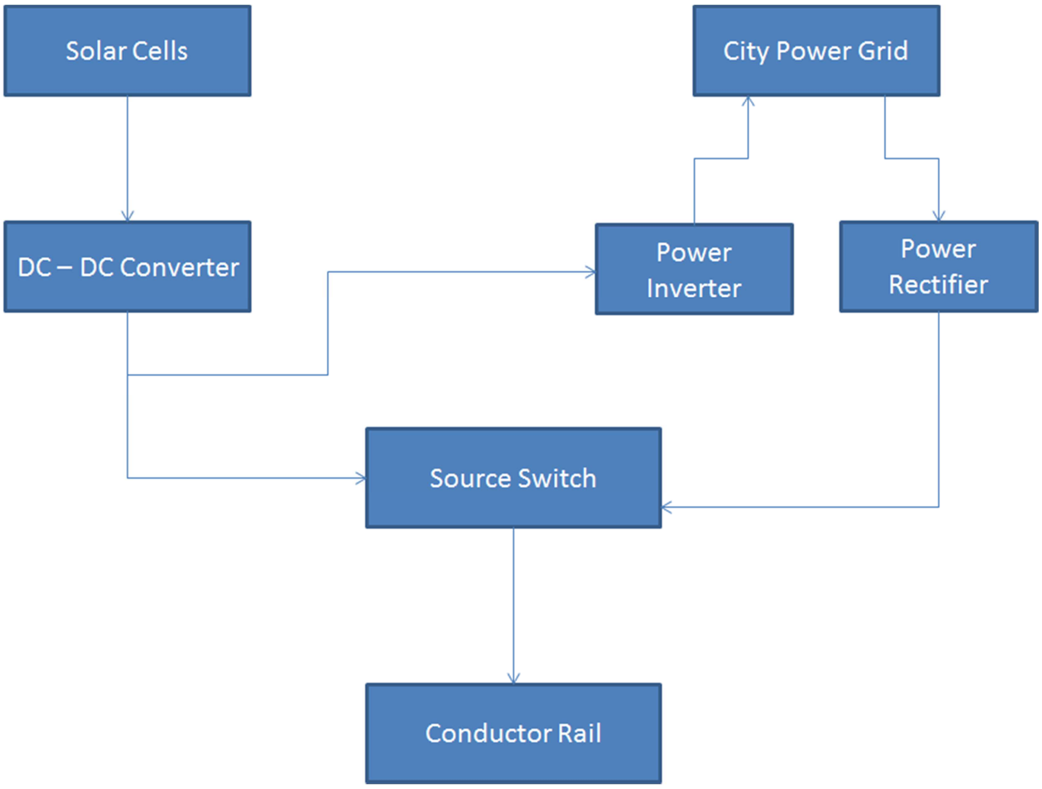


*Figure 4-2:*Overall System Block Diagram. This system takes power generated from the solar cells and uses a DC-DC converter circuit to condition the power before it is sent to the conductor rail. It also uses the city power grid as both an additional power source and power storage system

Table 4-1 List of Systems and Corresponding Major Components. The table contains all the components for the 1:12 scale circuit. At the time of writing this report, the power requirements and system components for the 1:4 scale circuit design have not been determined

	Major Components	
System	1:12 Scale Solar Interface	1:4 Scale Solar Interface
Solar Panels	MiaSole Flex-02w	MiaSole Flex-02w
DC-DC Converter	LT3083 LDO Regulators	To Be Determined
Source Switch	1N1206A Diodes	To Be Determined
Inverter	N/A	To Be Determined
Rectifier	N/A	To Be Determined
Grid Power	12 Volt DC Power Supply	To Be Determined

Table 4-2: Estimated Cost for 1:12 Scale Solar Interface. This cost estimate includes all the components needed for the current 1:12 scale circuit design, as well as an AC/DC power supply that will be used to simulate city grid power for the 1:12 scale model.

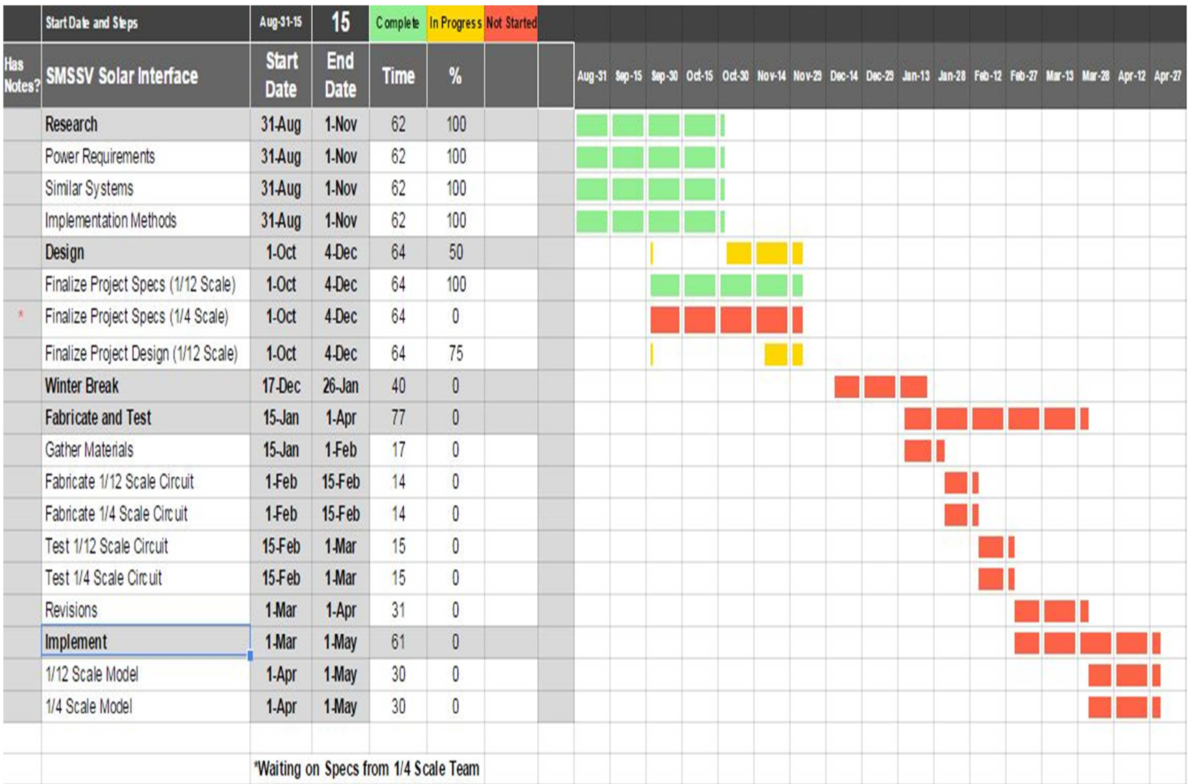
Quantity	Description	Cost Per Part ($)	Total Cost per Part ($)	Notes	Total Cost ($)
10	Solar Cell	0	0	Donated	112.45
3	LT3083 Adjustable LDO Regulator	5.90	17.70	TO-220-5 package	
3	TO-220 Compatible Heatsink	1.82	5.46		
2	1N1206A Diode	4.60	9.20		
2	Tantalum 10 uF Capacitor	1.26	2.52		
1	Rotary Potentiometer, 100 kOhm	5.42	5.42		
1	Resistor, 1 kOhm, 1 W	0.628	0.628		
3	Ballast Resistor, 10 mOhm	1.37	4.11		
1	AC/DC Power Supply, 12VDC, 10A	63.00	63.00		
1	Mains Cable, NEMA 5-15 P	4.41	4.41		

<u>Discussion</u>

The estimated cost for the 1:12 solar interface module is $112.45, including the external power supply to act as the grid. This estimate does not include the solar panels that will be used on the 1:12 model. Unfortunately, since the power specifications for the 1:4 scale model have not yet been determined, a 1:4 scale cost estimate and product list could not be completed at the time of writing this report. The solar panels for both the 1:12 scale and 1:4 scale models have been donated by MiaSole, a local solar cell manufacturing and distribution company. The remainder of the funding for this project will be provided via the Spartan Superway GoFundMe account. At the time of writing this report, the Spartan Superway GoFundMe has raised $1,385 toward the project (*Spartan Superway: Our Sponsors*). The Spartan Superway GoFundMe will be used to supply $112.45 required for the 1:12 solar interface. The complete bill of materials for the 1:12 scale solar interface can be seen in Table 4-2.

The tasks for our team for next semester will revolve around prototyping and testing the 1:12 scale and 1:4 scale solar interface circuits. Figure 4-3 below shows our team's detailed

Gantt chart and schedule next semester. The tasks next semester will be separated into gathering components, assembling and testing a functional prototype for both scale models, and making revisions and improvements where necessary. There are specific deliverables that will be produced at various points during the semester. For the 1:12 scale model, the first deliverable will consist of a functional prototype for the 1:12 scale solar interface, which will be produced by mid-February. Next, a performance evaluation of the 1:12 scale interface circuit will be completed by March 15th. Revisions and improvements will be made to the solar interface circuit using this performance evaluation as a basis. These revisions will be completed and a finalized design will be developed by the first of April. Lastly, the final 1:12 scale solar interface circuit will be assembled, tested and installed on the 1:12 scale model by May 2016. These deliverables and corresponding dates are summarized in Table 4-3. It is important to note that these dates will also correspond with the equivalent steps for the development of a 1:4 scale solar interface circuit. However, since the specifications for the 1:4 system have not be provided to our team at the time of writing this report, the specific deliverables were neglected from Table 4-3.



Has Notes?	SMSSV Solar Interface	Start Date	End Date	Time	%
	Research	31-Aug	1-Nov	62	100
	Power Requirements	31-Aug	1-Nov	62	100
	Similar Systems	31-Aug	1-Nov	62	100
	Implementation Methods	31-Aug	1-Nov	62	100
	Design	1-Oct	4-Dec	64	50
	Finalize Project Specs (1/12 Scale)	1-Oct	4-Dec	64	100
*	Finalize Project Specs (1/4 Scale)	1-Oct	4-Dec	64	0
	Finalize Project Design (1/12 Scale)	1-Oct	4-Dec	64	75
	Winter Break	17-Dec	26-Jan	40	0
	Fabricate and Test	15-Jan	1-Apr	77	0
	Gather Materials	15-Jan	1-Feb	17	0
	Fabricate 1/12 Scale Circuit	1-Feb	15-Feb	14	0
	Fabricate 1/4 Scale Circuit	1-Feb	15-Feb	14	0
	Test 1/12 Scale Circuit	15-Feb	1-Mar	15	0
	Test 1/4 Scale Circuit	15-Feb	1-Mar	15	0
	Revisions	1-Mar	1-Apr	31	0
	Implement	1-Mar	1-May	61	0
	1/12 Scale Model	1-Apr	1-May	30	0
	1/4 Scale Model	1-Apr	1-May	30	0

*Waiting on Specs from 1/4 Scale Team

Figure 4-3:Project Gantt chart as of December 4th, 2015. The design of the 1:4 scale circuit was not completed this semester due to lack of power specifications. The 1:4 scale circuit will be designed during the spring semester, once the power requirements for the 1:4 scale model

Table 4-3:Project Deliverable Dates, Descriptions and Estimated Cost. This table only contains deliverables for the 1:12 scale model circuit. The 1:4 scale circuit deliverables will be determined and produced during the spring semester.

Date	Quantity	Deliverable Description	Estimated Cost ($)
2/15/2016	1	Prototype of Solar Interface For 1/12 Scale Model (not including grid power supply)	45.04
3/15/2016	1	Performance Evaluation of 1/12 Scale Interface	N/A
4/1/2016	1	Finalized Prototype of 1/12 Scale Interface	45.04
5/1/2016	10	Finalized 1/12 Scale Solar Interface Circuit (including grid power supply)	112.45

Intermediate Solar Team

Objectives

The objective of the Intermediate Solar Team is to develop a means to supply power to the Spartan Superway; this includes: theoretical design for a full scale network, implementation of an intermediate scale model, and development of a full size modular mounting system. The team will supply power using solar cells to the system so that the system does not need to draw power from the grid as a primary source. The deliverable objective is to have a working system that can fully power the intermediate scale model that is under development for MakerFaire in May 2016.

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

The modular stationary frame does not have any software requirement. The hardware specification include: Aluminum strut channel, strut channel clamping nuts, 30°closed angle bracket, clamps, flexible thin film solar panel, and various screws and bolts.

According to the year 2014-2015 Spartan Superway report, this year's solar team was able to get hold of some of the measurements for the Miasole's flexible thin film solar panels for our design specifications. Provided to us by 2014-2015 Spartan Superway report, the specifications of the Miasole's thin film solar panel are shown in Figure 4-13**.**

State-of-the-art / Literature Review

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 4-4. 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 4-4: 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 4-5.

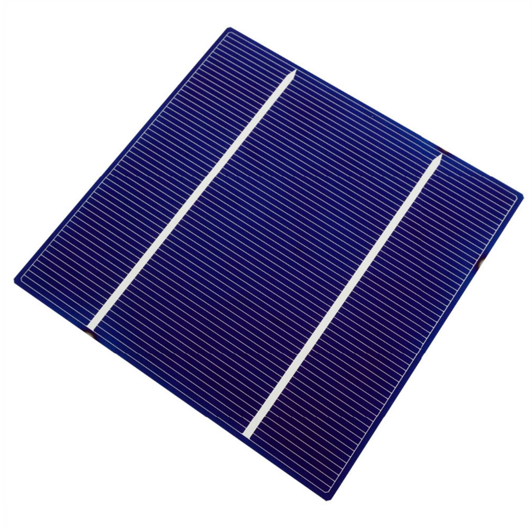


Figure 4-5:Polycrystalline silicon solar panel (Image retrieved from: http://www.aliexpress.com/item/20pcs-125-125mm-Polycrystalline-Silicon-Solar-Cell-for-DIY-Solar-Panel/32439726826.html)

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 4-6.

Figure 4-6: : 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. 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).

Design Concepts

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 4-7), concave (figure 4-8), and convex (figure 4-9). 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.

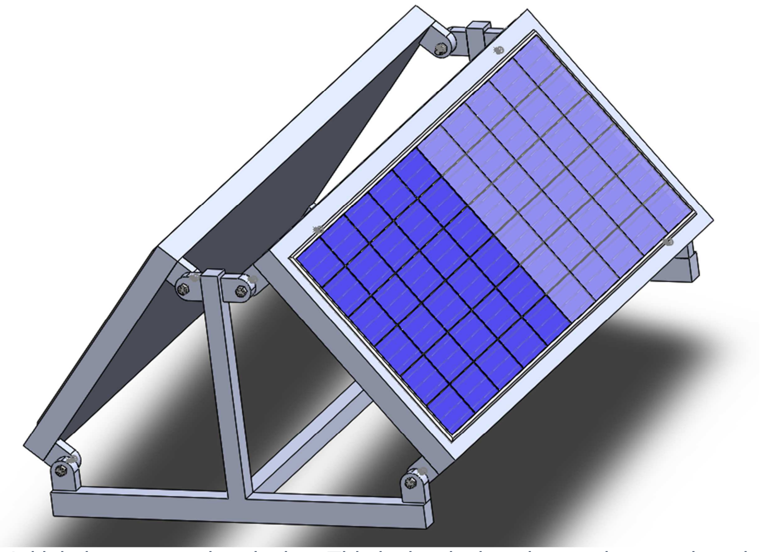


Figure 4-7: Initial planar mounting design. This is the design chosen that was later improved.

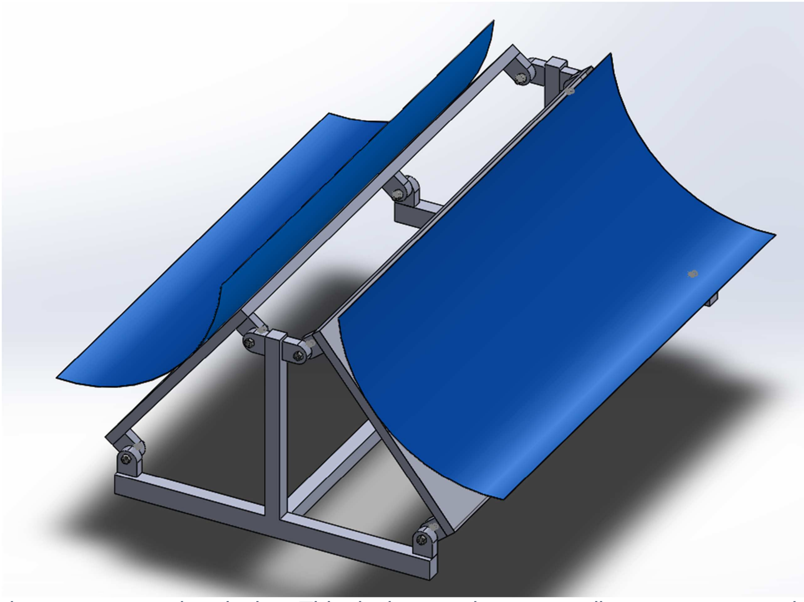


Figure 4-8: Initial concave mounting design. This design was least appealing to us compared to the other two.

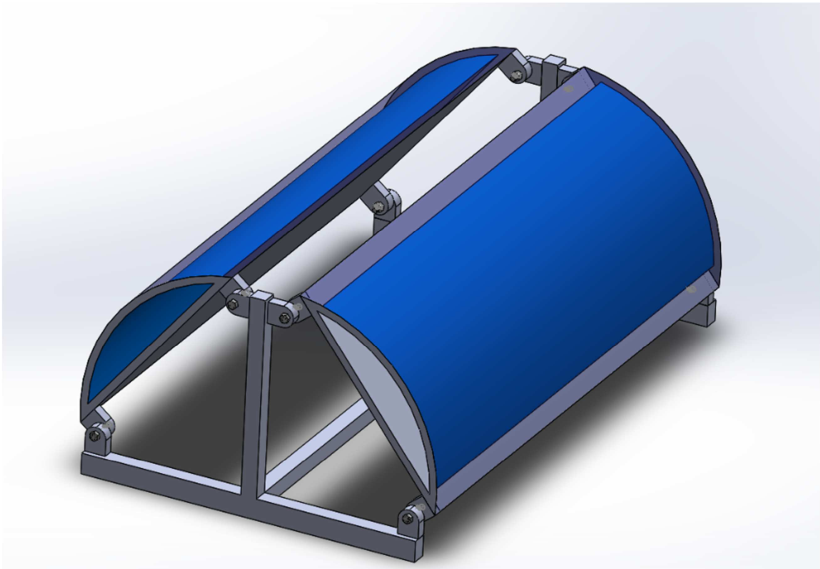


Figure 4-9: Initial convex mounting design. This will be looked into next semester to see if it can be improved to succeed the planar design.

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 4-10 and 4-11 respectively.

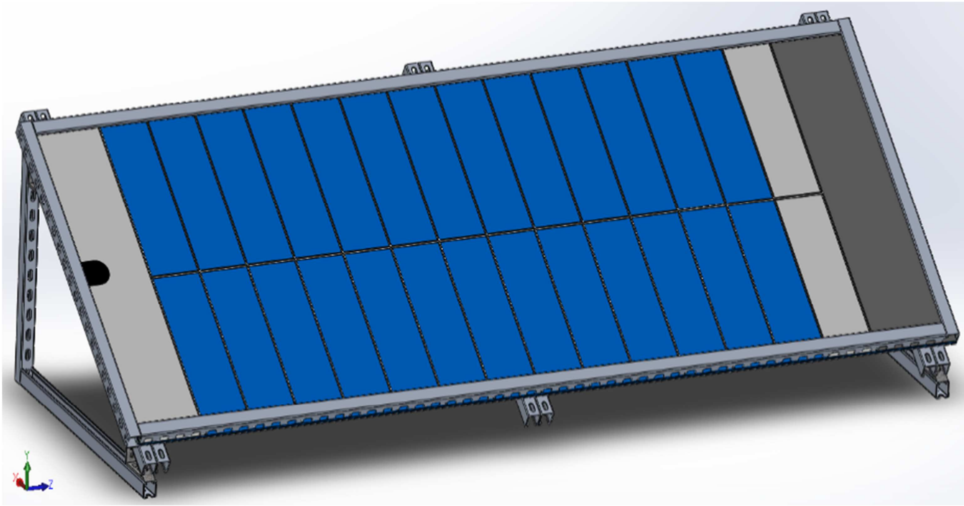


Figure 4-10: East to West track mounting design. Made from strut channel, it is light-weight and easy to fabricate.

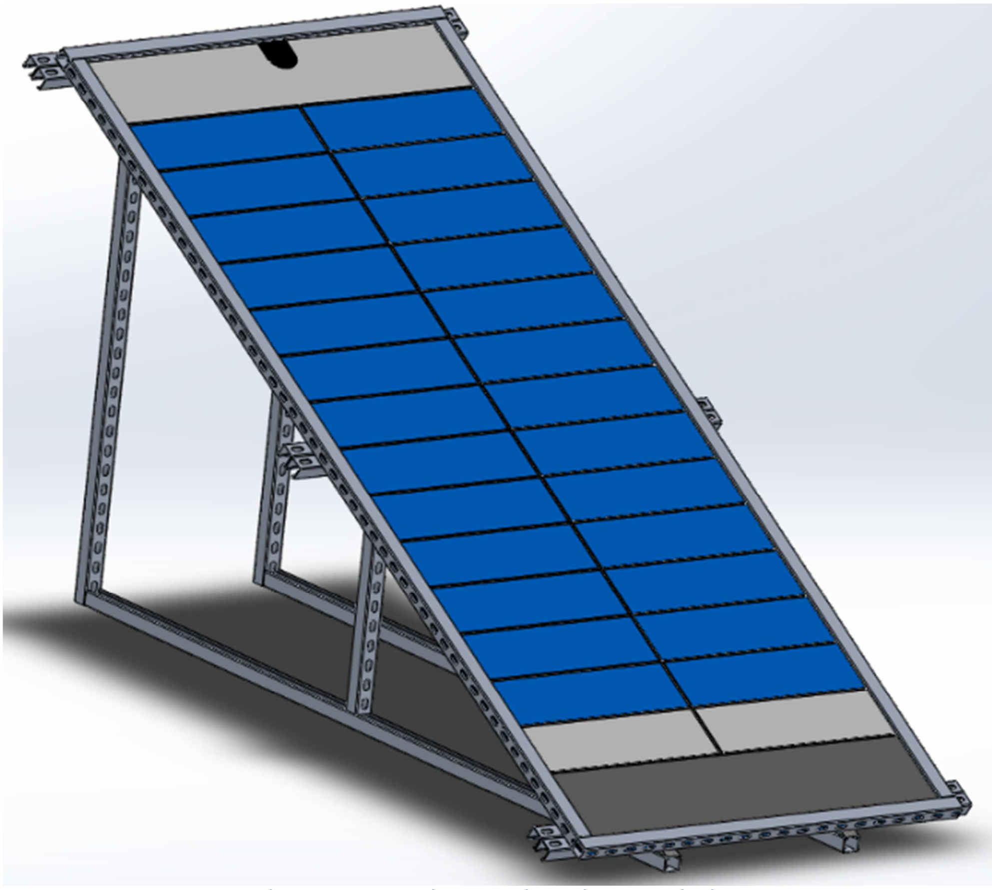


Figure 4-11: North to South track mount design.

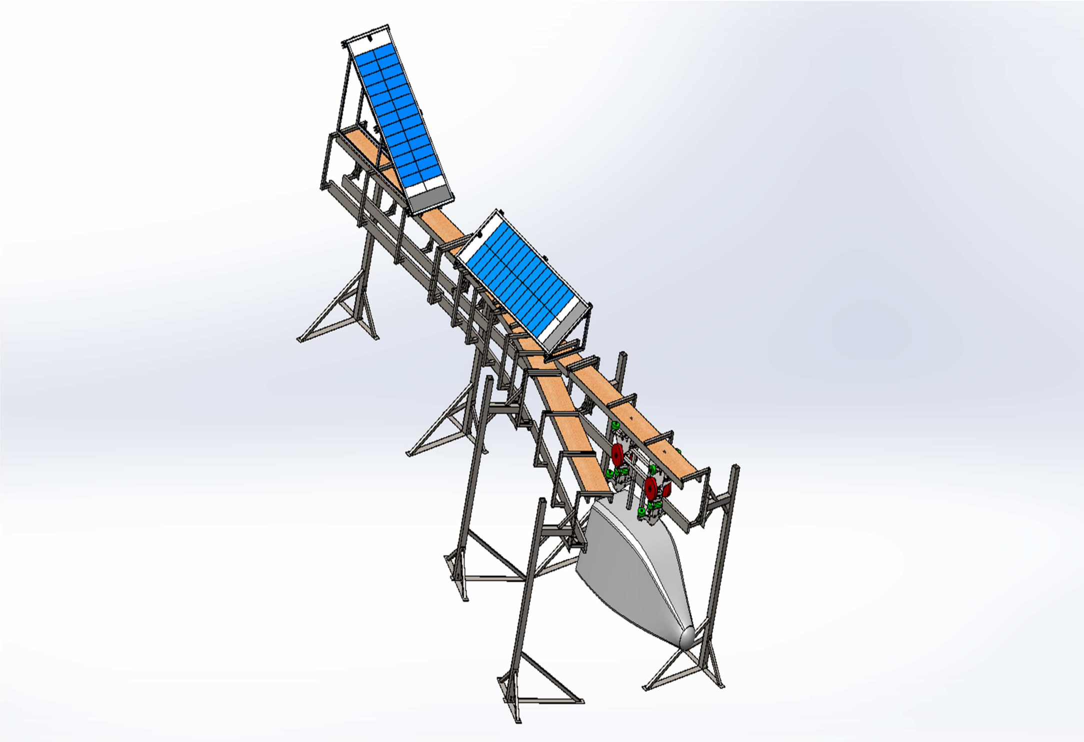


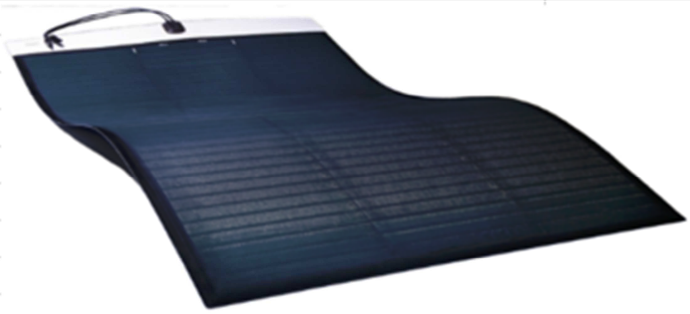
Figure 4-12: Mount system on full scale model.

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 propulsion 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. A shot of our power calculator is shown in below Figure 4-13. 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 4-14.

Power Requriments	
Required Power For Propulsion (KW)	5
Power Required For Air Conditioning (KW)	3
Number of Pods	70
Hours of Operation	20
Total Power Required For Each Pod (KW)	8
Total Power Required For All Pods (KW)	560
Total Power Required For 20HR of Operation (KWh)	11200

Mia Sole FLEX02-W



Specifications	
Length (in)	102.3
Width (in)	39.4
Power Class (W)	340W - 370W
Nominal Power (KW)	0.34
Maximum Power (KW)	0.37
Efficiency	16%

Track / Power Requirements	
Power output of 20HR of Operation per panel (KWh/Panel)	6.8
Number of Panels Requried for Required Power (Panels)	1647.058824
Total Length of Panels Required for Required Power (in)	168494.1176
Total Length of Panels Required for Required Power (mi)	2.659313725
Power output per mile of track (KWh/mi)	4211.612903
Number of Pods within a mile of track (Pod/mi)	26.32258065
Power Required for each pod within a mile of track (KWh/Pod)	160

Figure 4-13: A screenshot of our calculator with showing our power and track requirements.

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 4-14: 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.

Fabrication Methods

Fabrication of the mounts will be done in house by us, the intermediate solar team. The design center has all the tools and hardware to fabricate the mounts. By fabricating the mounts ourselves, we save money and time rather than having the mounts made by an outside party. What makes it easy to create the mounts in house is the material we are using which is strut channel. It is easy to customize and requires few tools to piece together.

Outcomes

The Intermediate Solar Team has completed an Excel based calculator to be refined upon continuation of development for the Intermediate Scale Model. 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 that can be used to power the Intermediate Scale Model at Maker Faire has been produced; the team is fully prepared to begin fabrication and testing of the prototype for this system beginning in January.

Discussion

The power calculator is fairly simple to use. The inputs are placed in colored region, and the power and track requirements are outputted. As of right now the power calculator inputs, are set for the full scale model. Once we receive the power requirements from the quarter scale wayside group, we can change the inputs to the proper power requirements for the quarter scale. The power calculator will out the power requirements we will need for the quarter scale.

For next semester, the main goal is to build the two planar mounts. To achieve this goal, there will great effort to get funds for material through personal networks and fundraising. Another goal is to begin the process of creating an alternate mount system that is efficient and aesthetically pleasing using a convex design that next year's group can build upon or improve. Another goal include starting the fabrication plan as soon as possible because students tend to underestimate the amount of time they have to build the prototype, therefore, it is extremely important to start early and adjust accordingly as problem arises.

Small Scale Solar

Objectives

The objectives of the 1/12 small scale solar team is to focus on the amount of solar panels needed to fully power the track and ten modeled sized bogies. In addition, placement, fabrication and angle of the solar panels are needed as well. Placement and angle are very important aspects as they contribute to the maximum sunlight energy solar panels can absorb throughout the year. Fabrication is also an important element to consider when accounting for the placement of the mounts and brackets for the casings of the solar panels.

Design Requirements and Specifications

When trying to meet the objectives, the goal of the design is to aim for all the components to be lightweight and cost efficient. In turn, a passive setup is needed for the solar panels. The solar panels will be fixed at 32 degrees true south, which will give an overall maximum solar energy over the year. Another main requirement is to make the mounts very easy to remove from the post for future uses.

Design Concepts

Mounting Assembly Design Concepts

In order to completely solarize the 1/12 scale track, a mount is needed to attach the solar panels to the one inch steel posts. When designing the mount, simplicity with the least amount of components was the main goal as well as keeping the cost to a minimum. The first two iterations that were modeled using Solidworks are shown in Figure 4-15. Both designs require the shape to be cut from a metal plate. Also, rails will be secured at the top of the mount for the solar panels to lay across.

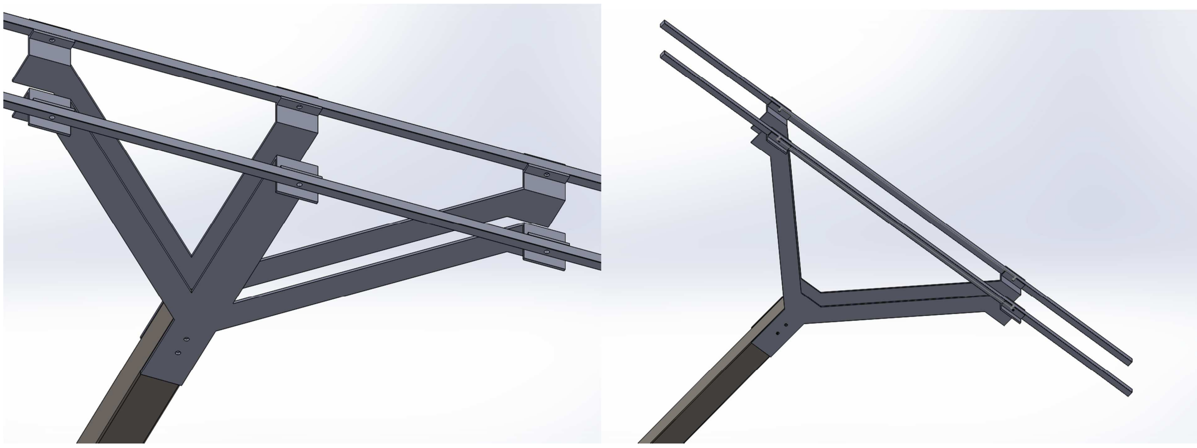


Figure 4-15: Initial Mount Design for Solar Panels. The design on the left allows for a more stable base. Both designs have ¼ inch aluminum rails that will be secured by screws. The rails will be where the solar panels will be attached.

In both designs, two ¼ inch hex bolts and hex nuts will be used to attach the mount onto the steel post in the location shown in Figure -16 in red.

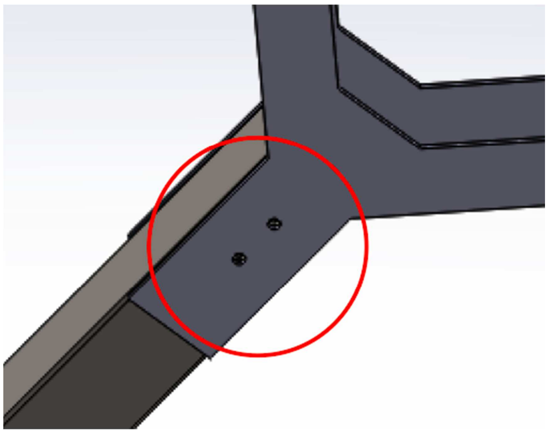


Figure 4-16: Location of the base of the mounting assembly where hex bolts and nuts will be used to secure the mounting assembly onto the steel posts.

The proposed material used for both initial designs was aluminum and the shape was to be cut from solid aluminum plates. Due to the high degree of difficulty with replication in manufacturing, it would be costly to send the aluminum plates out to be professionally cut. In order to save money as well as create mounts that were aesthetically pleasing, a new mount design was constructed with most of the parts welded together to eliminate the need for fasteners. The mount is primarily made up of 3/16 inch Aluminum 6061 flat bar that can be cut to size and easily welded together. For one steel post, a total of two mounting assemblies will be welded together each consisting of four aluminum flat bar sections. Figure 4-17 shows one of the two mounting assemblies that will be attached to the steel post.

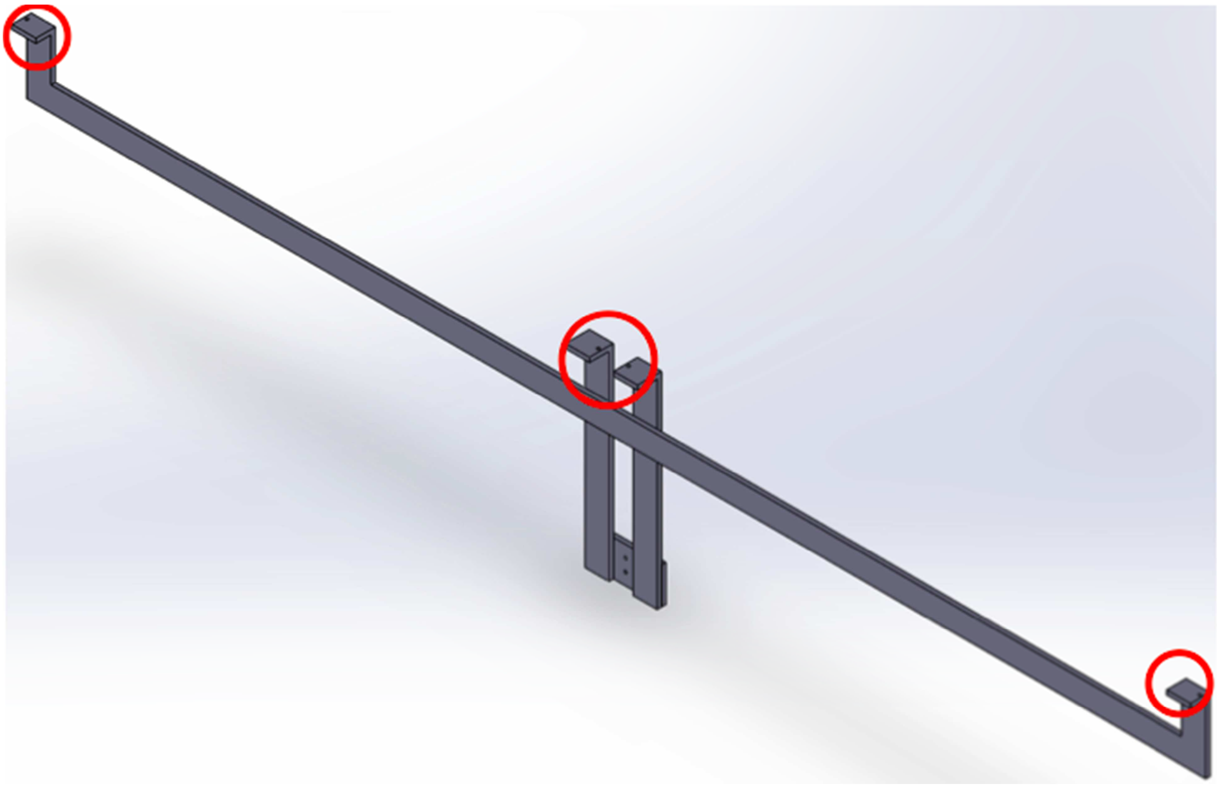


Figure 4-17: Final design of mounting assembly. Full assembly consists of four individual pieces each out of 3/16 inch aluminum flat bar. Individual pieces will be welded together.

In order to attach the solar panels onto the mounting assembly, machine screws will be used to fasten the areas shown in red (in Figure 4-17) directly onto the frame of the solar panel. Detailed part drawings of the mounting assembly are located in the Appendix.

Solar Panel Frame Mount Design Concepts

Before attaching the solar panels onto the mounting assembly, a lightweight frame is needed to keep the solar panels at an optimum angle of 32 degrees. This design did not need to be iterated multiple times because the case only needed to be lightweight and sturdy. The main goal of the frame was to keep the solar panel flat along the frame and tilted at a desired angle. The initial design for this frame was simple and there was no need to over-engineer the frame.

Figure 4-18 shows the frame of the solar panel that will be attached on top of the mounting assembly through the use of machine screws.

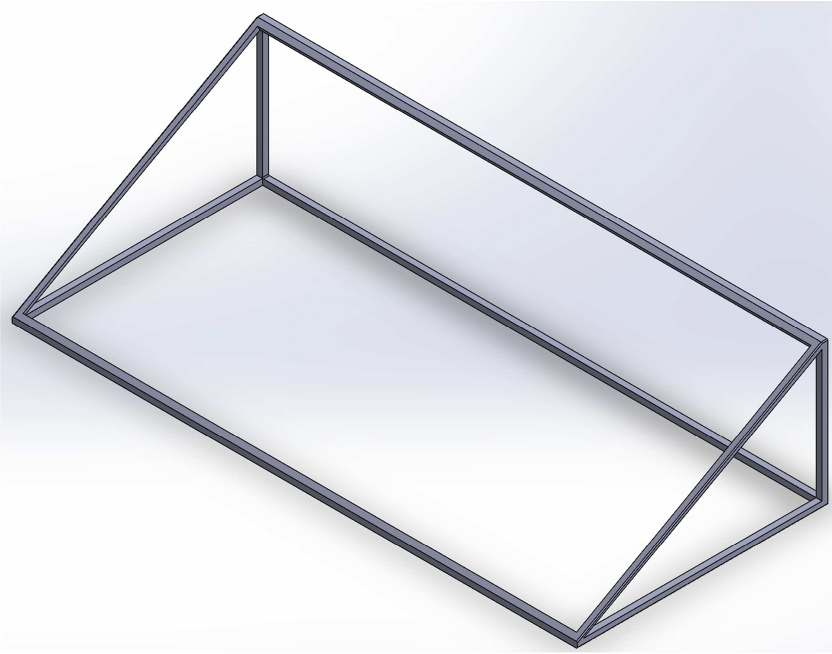


Figure 4-18: Final design of solar panel frame mount. Aluminum frame consists of ¼ inch aluminum square bars welded together. 1/16 inch aluminum sheet metal will be used to secure the solar panel to a flat base. The sheet metal will be spot welded onto the frame before inserting the solar panel.

Since the frame and solar panel will be light weight, one steel post can fit two 1 foot by 2 feet solar panels side by side. Underneath a single aluminum frame, four holes will be threaded in order to attach the mounting assembly onto the frame using #12-24 machine screws. Figure 4-19 shows the location of the machine screws underneath the frame.

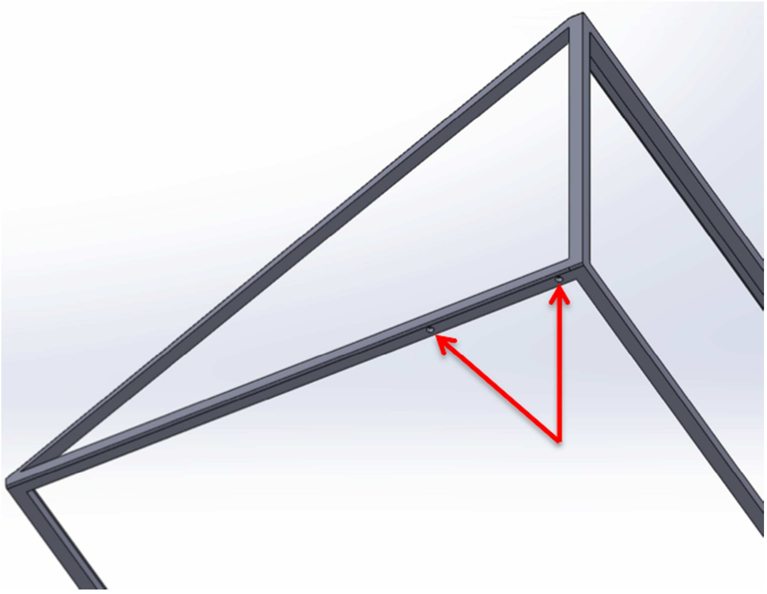


Figure 4-19: Underneath the solar panel aluminum frame. Four holes will be threaded with two holes on either side of the frame.

Figure 4-20 shows the solar panel mounting system fully assembled with both a front and back view. A detailed part drawing of the solar panel frame is located in the Appendix.

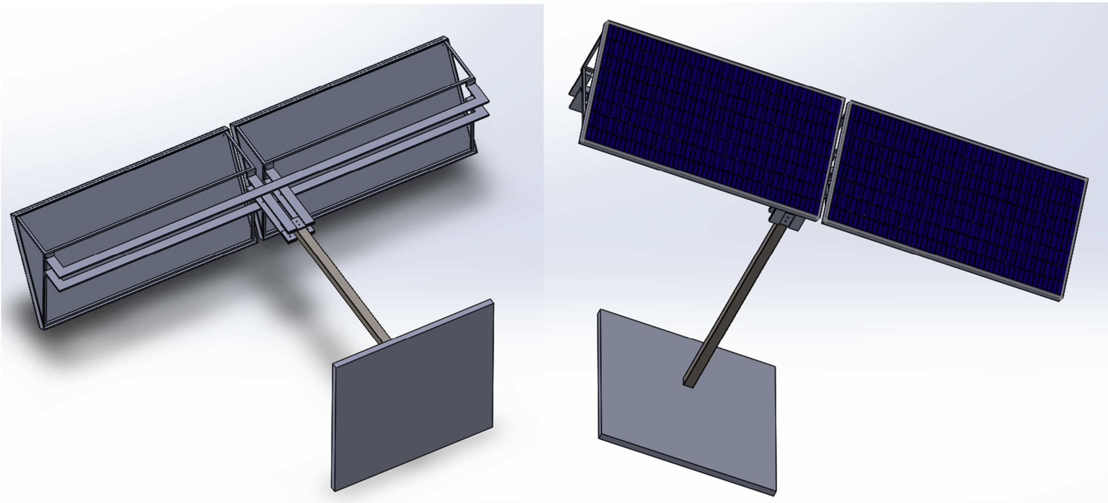


Figure 4-0-20: Fully assembled solar panel mount. On the left, a back view shows two mounting assemblies attached to the steel post, while the front view is on the right.

Analysis and Concept Selections

The main concern with the mounting system was the stress that the mounting assembly will see during operation. The aluminum frame is both sturdy and will only take the weight of the solar panel, with weight being evenly distributed along the frame. Stress analysis was done on both the previous mounting assembly designs as well as the final design. Shown in Figure 421, stress analysis was done on the previous design with a 10 lbf evenly distributed on the rail locations. The strain on the aluminum mount is minimal with a maximum strain of 0.16.

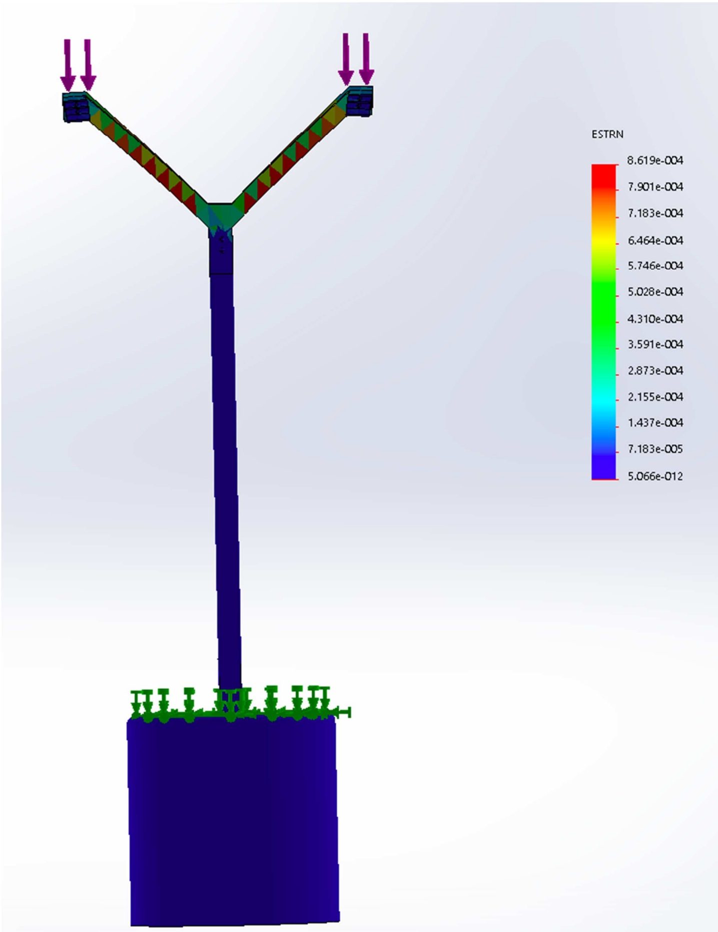


Figure 4-21: Stress analysis done on previous design with a maximum strain of 0.16.

A stress analysis was also done on the final design with a 10 lbf evenly distributed where the aluminum frame will rest. Figure 4-22 shows the stress analysis done using Solidworks. Again, the strain on the mounting assembly will also be minimal with the maximum strain of 0.046.

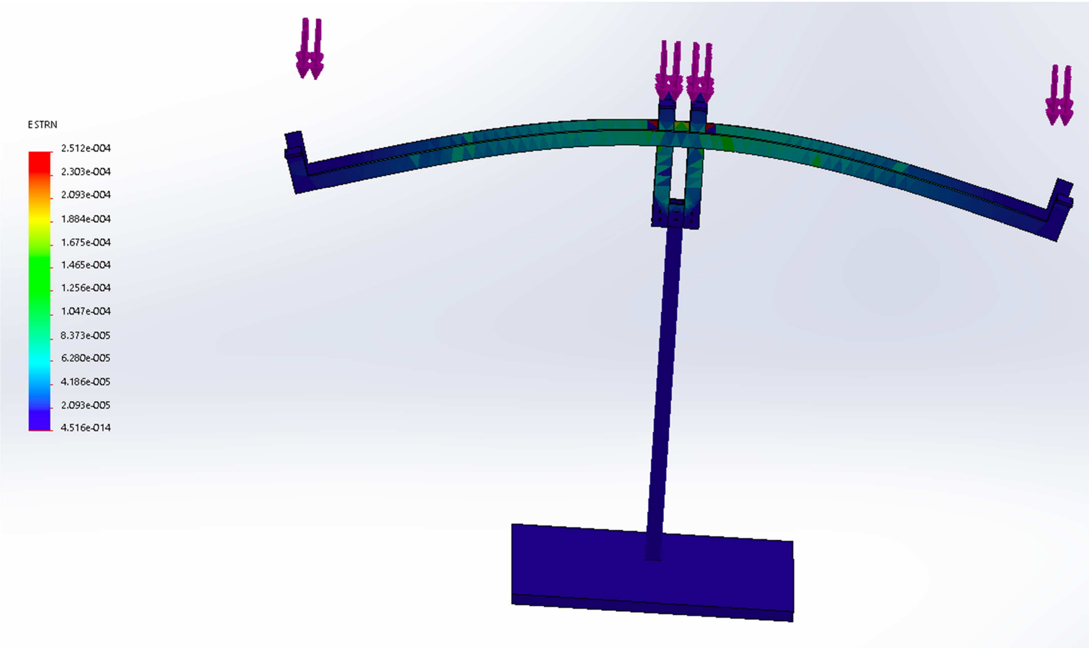


Figure 4-22: Stress analysis of final design with a maximum strain of 0.046.

Through the use of stress analysis, it can be concluded that the final design will be able to hold the solar panels. The cost as well as the functionality of the solar panel frame and final design mounting assembly will work well within the Superway budget while accomplishing the final goals of the 1/12 solar team.

Fabrication Methods

Before fabrication of the mounts and brackets, creating the base for the solar panels is needed. Sheet metal will be used for the base by folding the corners and on one of the lengths of the solar panels, shown in Figure 4-23. Folding the sheet metal to the corners of the solar panel will enable the panel to slide out before welding the base onto the mounts. This will ensure that there will be no damage done to the solar panels.

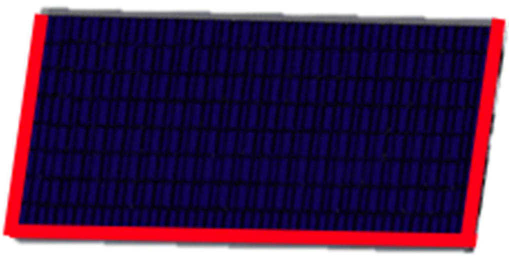


Figure 4-23: Location of where sheet metal will be folded.

Usage of struts and screws or welding aluminum square bars for the brackets was considered. Struts provide a stronger bracket for the base of the solar panels. Since the thin film solar panels and sheet metal are light enough for the aluminum frame, welding was chosen. In addition, struts are more expensive and will add additional weight to the mounts. The welding of the brackets serves for an easy disassembly from the post. TIG weld was chosen due to its precision, and soft aluminum material was used for the brackets. Figure 4-24 shows where TIG welding will be applied.

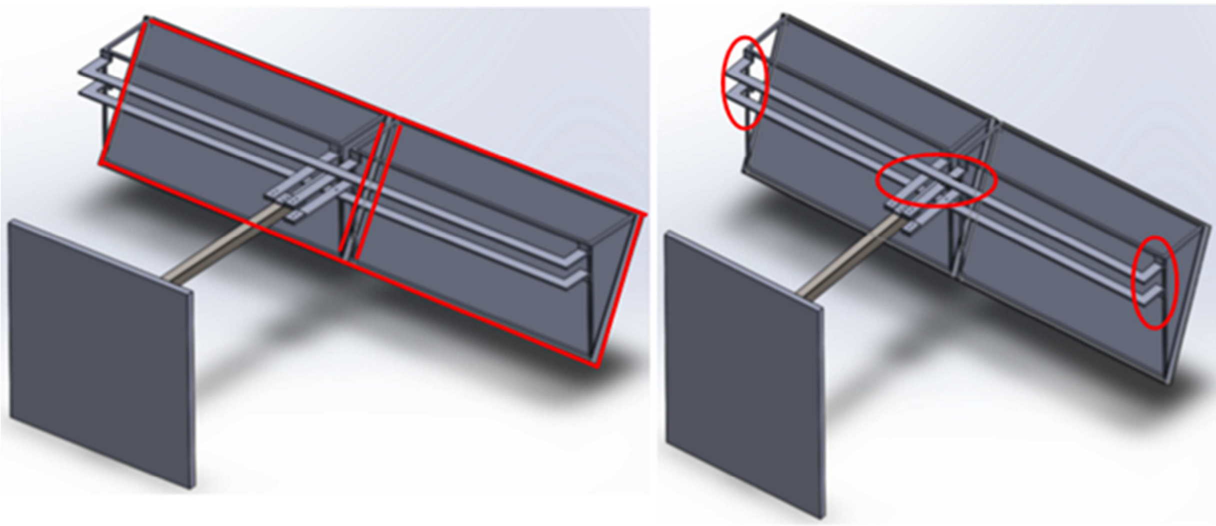


Figure 4-24: Locations of TIG welding.

The ease of the disassembly was one of the design requirements to consider. Deciding to use two hex nut and bolts allow easy removal from the post, as shown in Figure 4-25.

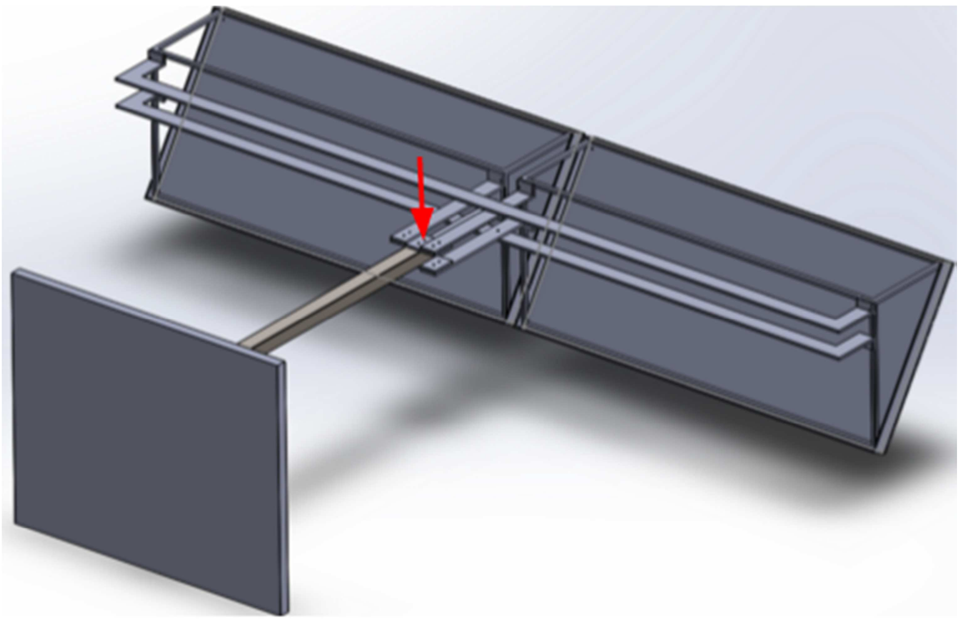


Figure 4-25: Two hex bolts and nuts are to be fastened onto the mount for easy removal.

Additionally, the use of eight machine screws ensure that the independent components piece together with the welding, as shown in Figure 4-17 and Figure 4-26.

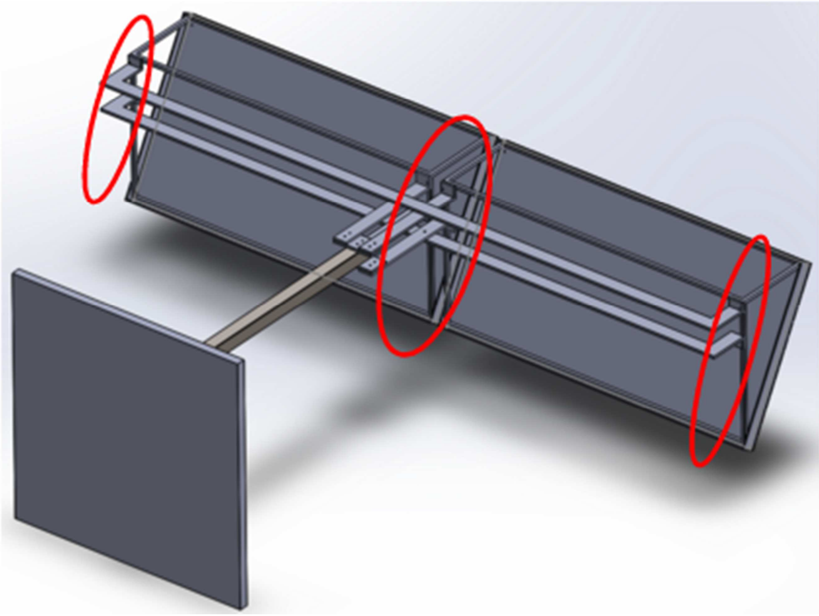


Figure 4-26: Eight machine screws will be used on the red location.

Outcomes

Throughout the semester, the design plan of the 1/12 scale solar team has been constantly evolving. For example, the initial plan was to implement last year's 1/12 scale solar team design improving on the solar tracker design. Modifications are ideal in the design phase of a product because it allows the creators to learn from their mistakes and learn differents methods or ideas that would elsewise go unnoticed. If consistently chosen to evolve, it will eventually lead to a stronger final product than what initially would have been designed.

The 1/12 scale solar team has designed a functional and on-track solar panel system that will fully power the 1/12 model. The first major accomplishment of the 1/12 scale model was using fixed thin film panels. Solar trackers were initially considered due its high efficiency. However, after thorough research, the 1/12 scale solar team determined fixed panels would best fit the design. Although solar trackers are efficient, many complications arose when implementing the trackers. These complications may range from coding, price, maintenance, fabrication and lifespan. Through research, it was found that fixed panels provided sufficient power, was simpler to design, fabricate and would require little to no maintenance to operate the 1/12 model. The goal from there was to determine location and orientation of the panels. According to the Solar Electricity Handbook and through mentoring from Anuradha Munshi and Dr. Mokri, the premium angle for the fixed panels was around 32 degrees facing true south. This angle can produce more power than any other fixed angle or orientation throughout the year. Furthermore, it was advised to use an angle provided by PG&E as they have previously tested for the optimal angle for fixed panels to be most cost efficient. While an external solar farm consisting of a full size panel was considered, the track panels were chosen instead as the advisors felt it would better represent the idea of Spartan Superway. In addition, this would allow display of a fully functional model. Based on the calculations, the maximum voltage and current each panel would provide, the factored fixed voltage and current, and the number panels that would be required to completely power the 1/12 model was determined. Moreover, calculations found that nine 12” x 24” panels would be needed to completely power 10 bogies for the 1/12 model. After close consideration, the 1/12 solar team decided to use a 12 panel solar system to assure sufficient power. Table 4-4 shows significant findings from the calculations proving 12 panels would be more than sufficient.

Table 4-4: Solar panel technical specifications including current, voltage, and power. Bogie measurements provided by 1/12 scale team.

1/12 Solar Team Calculations			
12” x 24” Full Efficiency Panel Measurements	3.00 A	8.19 V	24.6 W
12” x 24” Fixed Efficiency Panel Measurements	2.25 A	8.19 V	18.5 W
Ten 1/12 Bogie Measurements *(Given)*	20.0 A	7.2 V	144 W
Number of Panels Required to Fulfil Bogie Measurements	8.89 panels	1 panel	7.78 panels
Nine 12” x 24” Fixed Efficiency Panels Measurements	20.5 A	8.19 V	166 W
Twelve 12” x 24” Fixed Efficiency Panels Measurements	27.0 A	8.19 V	222 W

As pictured below in Figure 4-25, the 1/12 scale solar team has completely designed a functional mount that can be implemented on the scaled track.

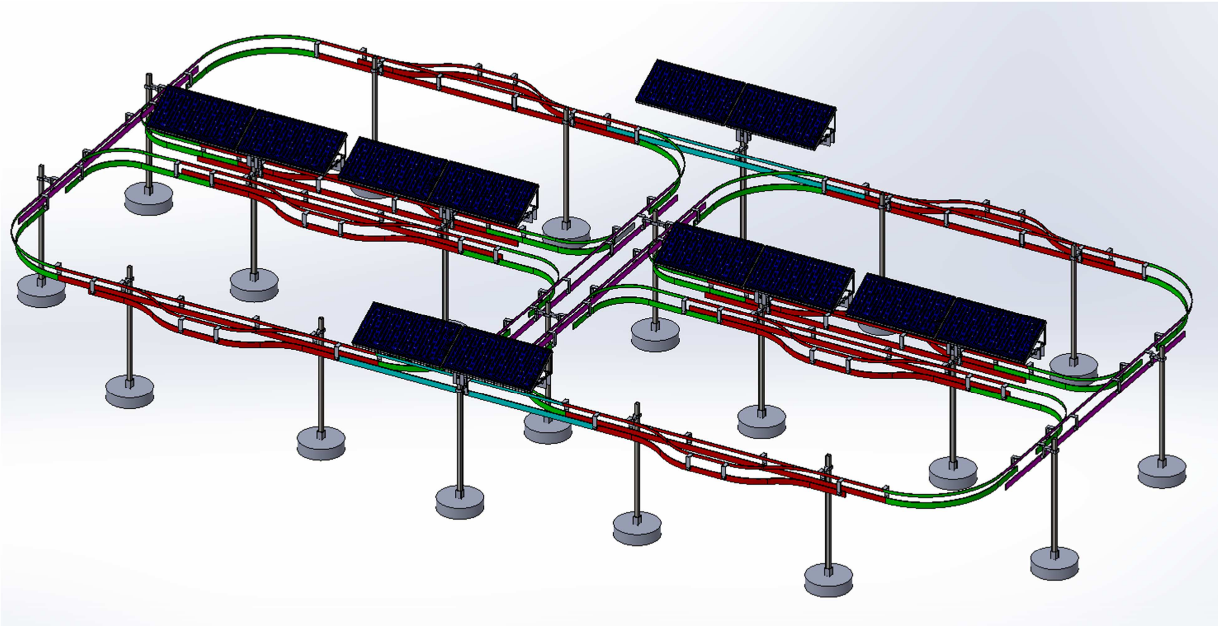


Figure 4-27: Complete 12 panel solar system implemented on 1/12 scale model.

When considering mount designs, the team focused on creating a lightweight design that was simple to manufacture and reassemble. Nevertheless, it was found that the mount design would be too difficult to accurately reproduce with precision. The team designed a new mount that is more cost effective and can easily be assembled. From the cost analysis, it was found that $332.07 would be needed for materials to build a 12 panel solar system with the donation from MiaSole. Without donations, the cost of materials would increase to $1,052.07.

Discussion

The ultimate goal was to create a functional and on-track solar system that will completely power the 1/12 model. Additionally, the team sought to create a model to better represent the Spartan Superway, which is to provide users with a quick and cost effective way to commute solely on renewable energy. The current products in the market are either quick or cost effective but hardly ever consist of both characteristics together. Furthermore, there are currently no transportation systems that run purely off renewable energy. The Spartan Superway aims to create a viable model that will lead to a new age of commuting. With the completion of research and designing, our team will begin to fabricate a solarized system that will mount on the 1/12 tracks. A viable model will help the Spartan Superway better represent the idea of solar energy. With the live visualization of a 12 panel solar system completely powering the 1/12 scaled system, it would help individuals easily understand that solar energy is a viable renewable energy.

The 1/12 solar team plans to complete the 1/12 model scale by Maker's Faire in May 2016. In order to ensure a viable model with a fully powering solar system, objectives must be met by Spring 2016 semester. These include: ordering of the materials, tracking of the materials, and evaluating materials. Without evaluating the ordered materials, fabrication may be delayed due to defects in the material or misorders. Starting Spring 2016, the 1/12 scale solar team will begin fabricating the six mounts needed to hold 12 panels. Upon completion of the six mounts, implementation of the 1/12 model tracks will be done. Testing of the solar panel system will be done on mounts such as stress, strain and examining current and voltage. Evaluation and testing of the solar panel system will allow time for adjustments if necessary. Our team has created a Gantt chart to better lay out the schedule. Following schedule, the team is set to complete the solar panel system by April 28, 2016. With all objectives completed in a timely manner, it will assure optimum performance at the Maker's Faire.

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Appendix A: Small Scale

Small Scale Track

Spartan Superway 2015-2016 Track BoM							
Qty.	Component	height (in) x length (in)	Thickness (in)	Material	Cost ($) per part	Company	Total ($)
9	Bottom Station Rail	1.5 x 48	0.125	5052-H32 Aluminum	83.64	Vanderbend	752.76
9	Top Station Rail	0.75 x 48	0.25	5052-H32 Aluminum	76.57	Vanderbend	689.13
85	Guide Connectors	3.5 x 1	0.25	6061-T6 Aluminum	4.75		403.75
12	2250 Top Straight Rail	0.75 x 12	0.125	6061-T6 Aluminum	5.25	M&K Metal Co.	63
12	2250 Bottom Straight Rail	1.5 x 12	0.25	6061-T6 Aluminum	5.25	M&K Metal Co.	63
8	250mm straight bottom rail	1.5 x 12	0.25	6061-T6 Aluminum			0
8	250mm straight top Rail	0.75 x 10	0.125	6061-T6 Aluminum			0
2	1817.37mm straight top Rail	0.75 x 71.55	0.125	6061-T6 Aluminum			0
2	1817.37mm straight bottom Rail	1.5 x 71.55	0.25	6061-T6 Aluminum			0
8	90º Bend Top Rail	0.75 x 20 (500mm)	0.125	6061-T6 Aluminum	25.75	Vanderbend	206
8	90º Bend Bottom Rail	1.5 x 20 (500mm)	0.25	6061-T6 Aluminum	25.75	Vanderbend	206
8	90º Bend Top Rail	0.75 x 10 (250mm)	0.125	6061-T6 Aluminum	25.75	Vanderbend	206
8	90º Bend Bottom Rail	1.5 x 10 (250mm)	0.25	6061-T6 Aluminum	25.75	Vanderbend	206
16	Curve Connector			6061-T6 Aluminum			0
10	Square Clamp	.75" x .75" aluminum bar		6061-T6511 Aluminum		Metals Depot	20.22
10	Square Clamp Adapter	1.5" x .75" aluminum bar		6061-T6 Aluminum		Metals Depot	0
16	Double Square Clamp			6061-T6 Aluminum			0
6	Support Square Tubing	1 x 1 x 16GA 36	0.065	Steel	4.74	Speedy Metals	28.44
3	Large Support Square Tubing	1-1/2" sq. 0.120" x 60"	0.12	Steel	18.24	Speedy Metals	54.72
6	Concrete Bags	5.75 in rad. and 4 in tall		Concrete	3.29	Lowes	19.74
2	Support Forms			Cardboard	12.27	Home Depot	24.54
1100	Hex socket cap screw	M4 x 12		Stainless Steel	0.34	Mr Metric	374
3	Brazing Rods	1/8 in dia.		Aluminum	12.99	northerntool.com	38.97
						Grand Total ($):	3356.27

Fall 2015 track team Bill of Materials.

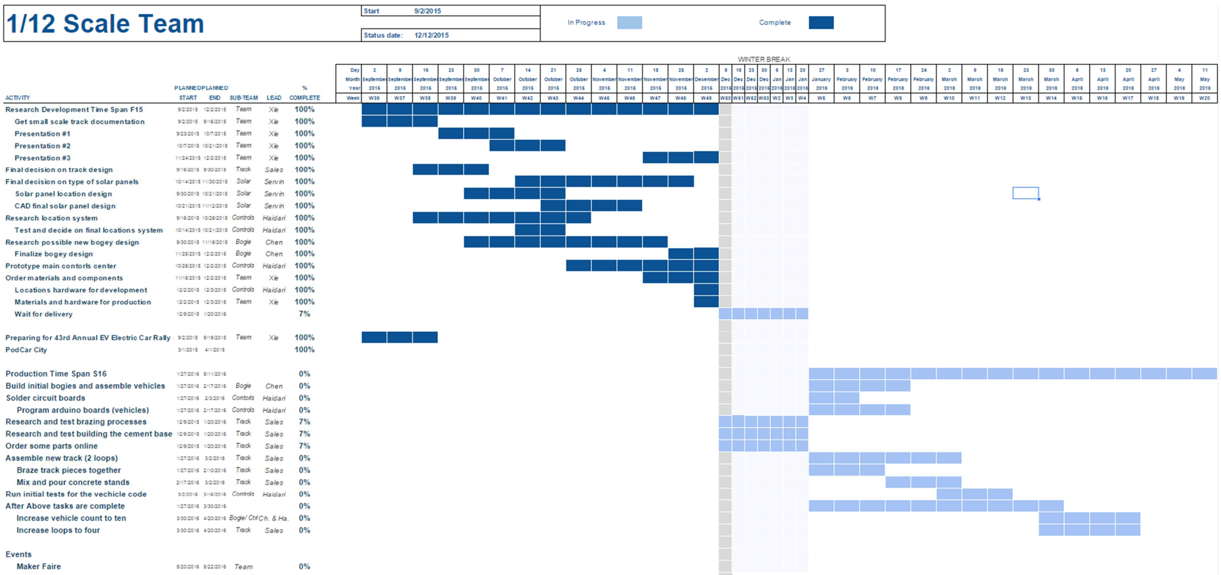
Spring 2016 Gantt chart.

Production Time Span S15	1/27/2016	5/11/2016			0%
Build initial bogies and assemble vehicles	1/27/2016	2/17/2016	Bogie	Chen	0%
Solder circuit boards	1/27/2016	2/3/2016	Contorls	Haidari	0%
Program arduino boards (vehicles)	1/27/2016	2/17/2016	Controls	Haidari	0%
Research and test brazing processes	12/9/2015	1/20/2016	Track	Sales	7%
Research and test building the cement base	12/9/2015	1/20/2016	Track	Sales	7%
Order some parts online	12/9/2015	1/20/2016	Track	Sales	7%
Assemble new track (2 loops)	1/27/2016	3/2/2016	Track	Sales	0%
Braze track pieces together	1/27/2016	2/10/2016	Track	Sales	0%
Mix and pour concrete stands	2/17/2016	3/2/2016	Track	Sales	0%
Run initial tests for the vechicle code	3/2/2016	3/16/2016	Controls	Haidari	0%
After Above tasks are complete	1/27/2016	3/30/2016			0%
Increase vehicle count to ten	3/30/2016	4/20/2016	Bogie/ Ctrl	Ch. & Ha	0%
Increase loops to four	3/30/2016	4/20/2016	Track	Sales	0%
Events					
Maker Faire	5/20/2016	5/22/2016	Team		0%

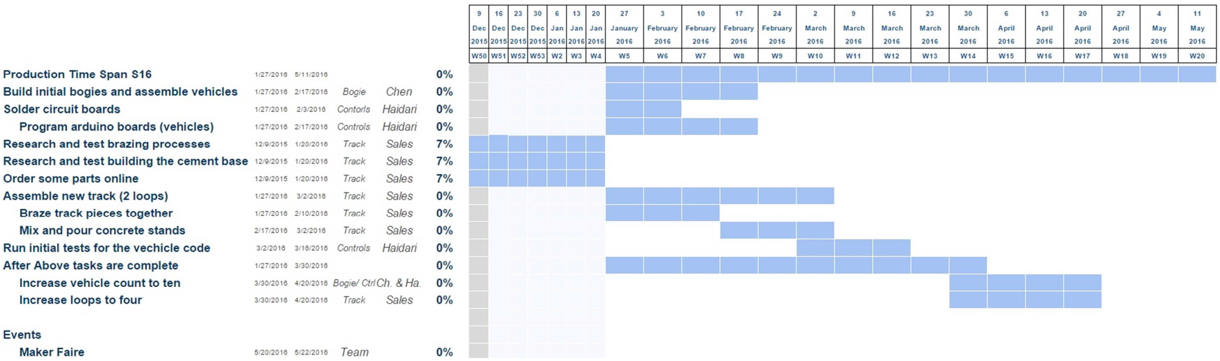
Small Scale Controls and Bogie Teams

Item	Quantity	Price	Subtotal	Five Vehicle Subtotal
Bogie Materials [Al]	10 Sets	~$40	$320.00	$160.00
1:75 Motors & Drivers	16 (2/vehicle)	$13.55 + $3.85*	$278.40	$140
Encoders	8 Pairs	$7.95*	$63.60	$30
Wheels and Bearings	8 Sets	$8	$64.00	$32
XBee + Shields	10 Units	$32	$320.00	$160
Arduino	8 Units	$25	In Inventory($200)	In Inventory($100)
Opto-Reflector	20 Units	$2	$40.00	$20
3D Print Cabin Model	10 Units	$20-30 kg of PLA	~$25.00	~$25
Total			~$1120	~$560

Bill of materials for the 10 vehicles.



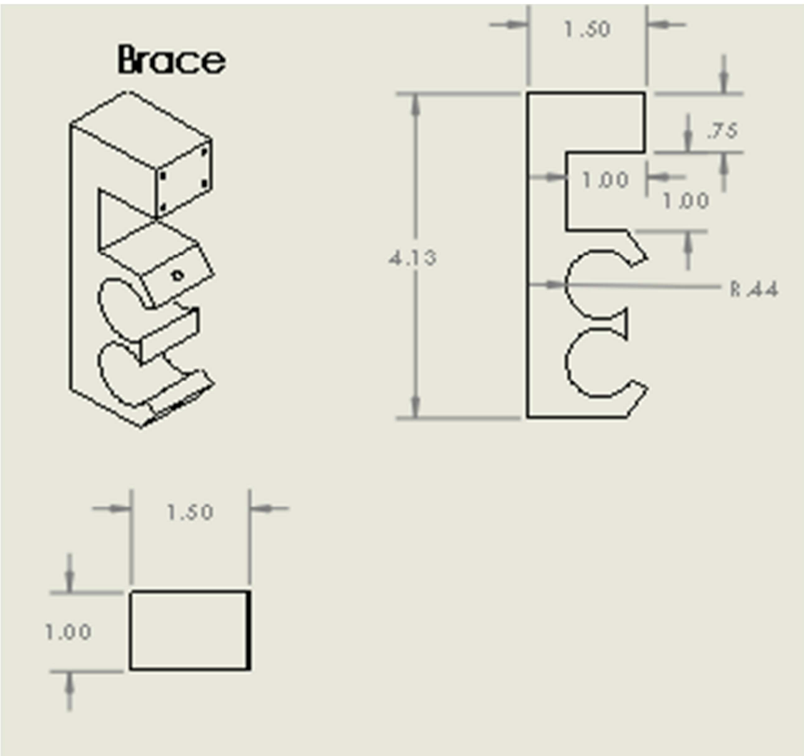
Gantt chart for the full year.



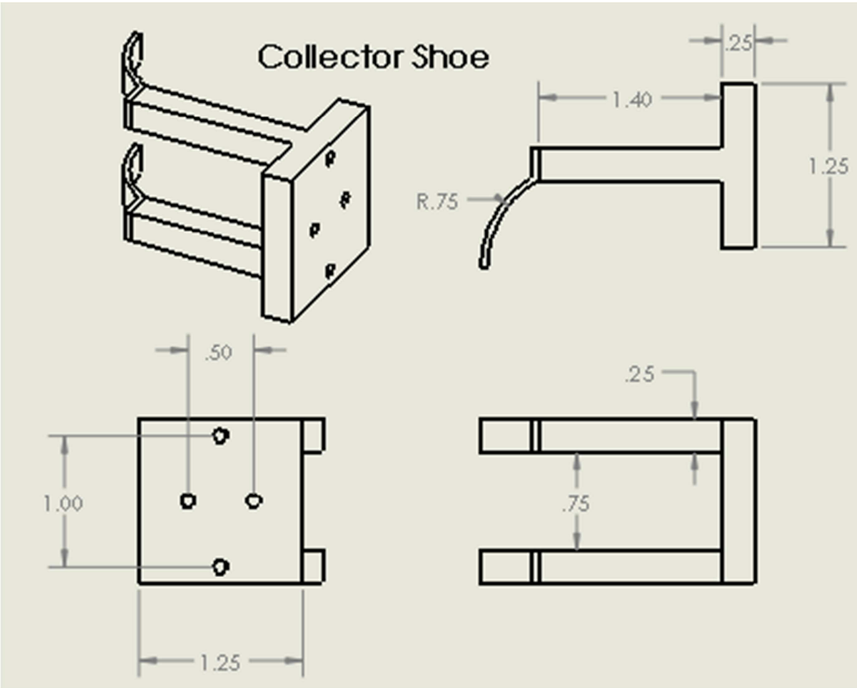
Gantt chart focused on spring semester.

Wayside Power Team

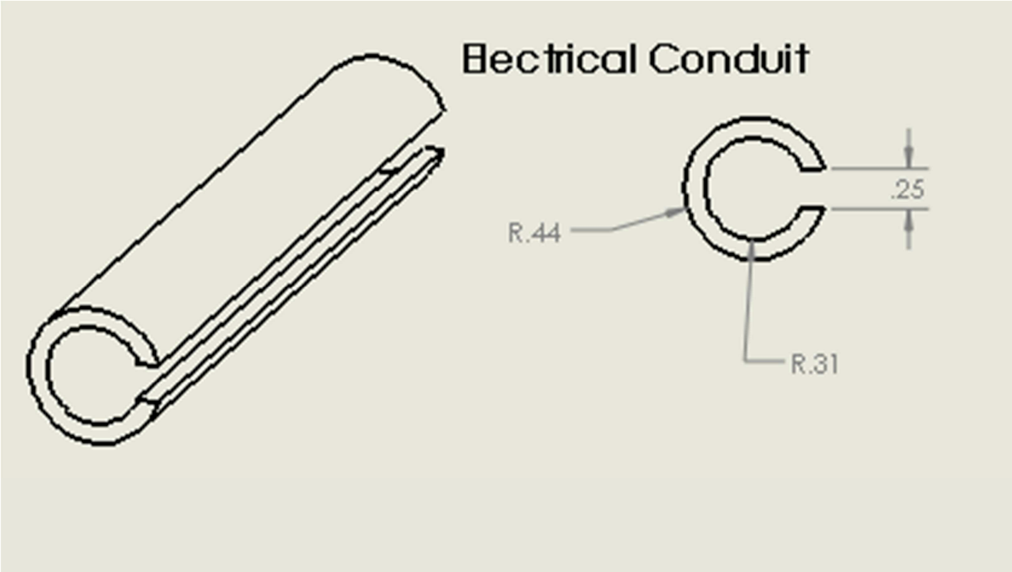
Solid Model Detail Drawings



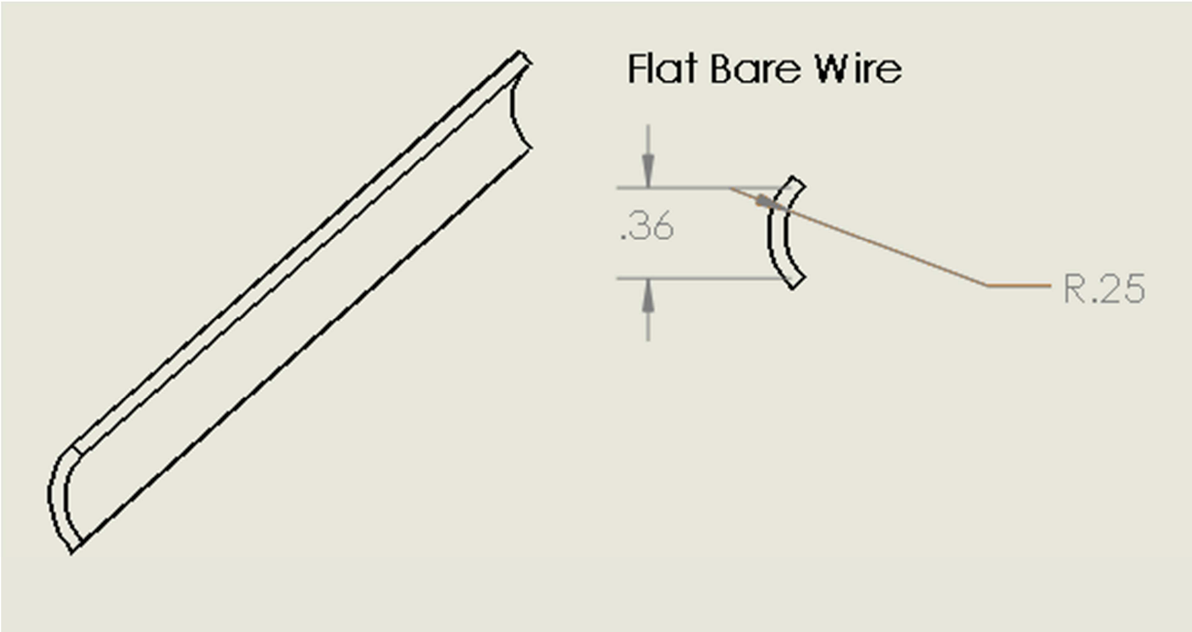
The Braces that support the Electrical Conduit.



The Collector Shoe that will gather current from the wayside rails.



The Electrical Conduit that will house the current and return rails.



The flexible wire that will be used as the wayside rails.

Appendix B: Intermediate Scale

Fail-Safe Team

Fail-safe design phase

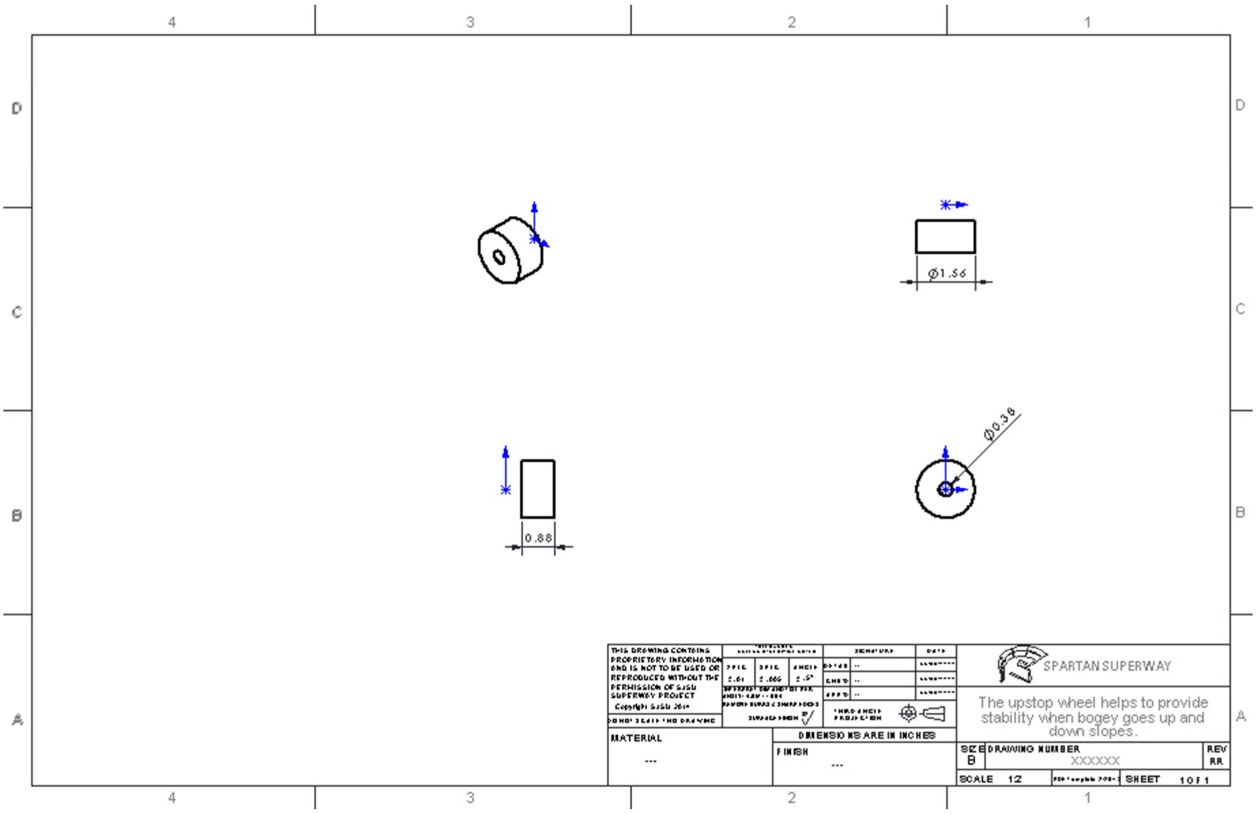
Start Date and Steps	Sep-6-15	5	Complete	In Progress	Not Started																
Project Name	**Start Date**	**End Date**	**Time**	**%**	**Team**	**Alt Color**	Sep-6	Sep-11	Sep-16	Sep-21	Sep-26	Oct-1	Oct-6	Oct-11	Oct-16	Oct-21	Oct-26	Oct-31	Nov-5	Nov-10	Nov-15
Fail Safe Design	6-Sep	18-Nov	73	100	All	blue															
Determine situations for failure	9-Sep	16-Sep	7	100	Eric																
Develop fail safe mechanisms for determined situations	16-Sep	7-Nov	52	100	Jenn																
Develop addition to bogie meant for handling guideway	16-Sep	18-Nov	63	100	Tomoka																
Redesign bogie and/or guideway to include fail safe mechanisms	7-Oct	28-Oct	21	100	Tomoka																

Presentation phase

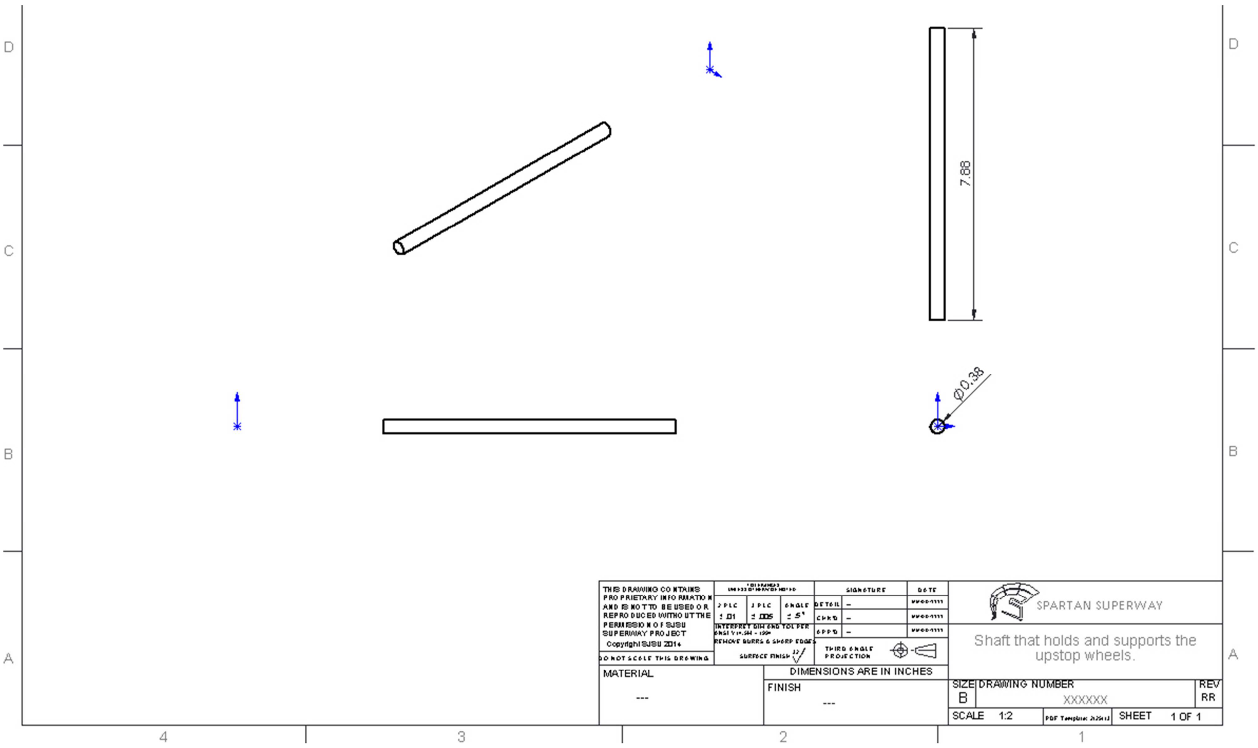
Start Date and Steps	Sep-6-15	5	Complete	In Progress	Not Started																	
Project Name	**Start Date**	**End Date**	**Time**	**%**	**Team**	**Alt Color**	Sep-6	Sep-11	Sep-16	Sep-21	Sep-26	Oct-1	Oct-6	Oct-11	Oct-16	Oct-21	Oct-26	Oct-31	Nov-5	Nov-10	Nov-15	Nov-20
Presentation 1	23-Sep	28-Sep	5	100	All																	
Presentation 1 Slides	23-Sep	30-Sep	7	100	Cam																	
Presentation 1 Rehearsal	28-Sep	30-Sep	2	100	Andrew																	
Presentation 2	21-Oct	28-Oct	7	100	All																	
Presentation 2 Rehearsal	26-Oct	30-Oct	4	100	Brandon																	
Presentation 2 Rehearsal	26-Oct	28-Oct	2	100	Brandon																	
Presentation 3	18-Nov	25-Nov	7	100	All																	
CAD Drawings	18-Nov	24-Nov	6	100	Tommy																	
Presentation 3 slides	18-Nov	25-Nov	7	100	Grant																	

Finalization and Collaboration phase

Start Date and Steps	Sep-6-15	5	Complete	In Progress	Not Started																						
Project Name	**Start Date**	**End Date**	**Time**	**%**	**Team**	**Alt Color**	Sep-6	Sep-11	Sep-16	Sep-21	Sep-26	Oct-1	Oct-6	Oct-11	Oct-16	Oct-21	Oct-26	Oct-31	Nov-5	Nov-10	Nov-15	Nov-20	Nov-25	Nov-30	Dec-5	Dec-10	Dec-15
Intermediate Team Collaboration	4-Nov	25-Nov	21	100	All																						
Meet with intermediate sub-team leads	4-Nov	4-Nov	0	100	Brandon																						
Material Selection	18-Nov	25-Nov	7	100	Brandon																						
Choose actual scale for design	18-Nov	23-Nov	5	100	Brandon																						
Redesign bogie and/or fail safe mechanisms to work with other teams' designs	11-Nov	23-Nov	12	100	Brandon																						
Determine budget	18-Nov	23-Nov	5	100	Brandon																						
Re-do stress analysis	18-Nov	23-Nov	5	100	Brandon																						
Presentation 3	18-Nov	25-Nov	7	0	All																						
CAD Drawings	18-Nov	24-Nov	6	100	Tommy																						
Presentation 3 slides	18-Nov	25-Nov	7	100	Grant																						

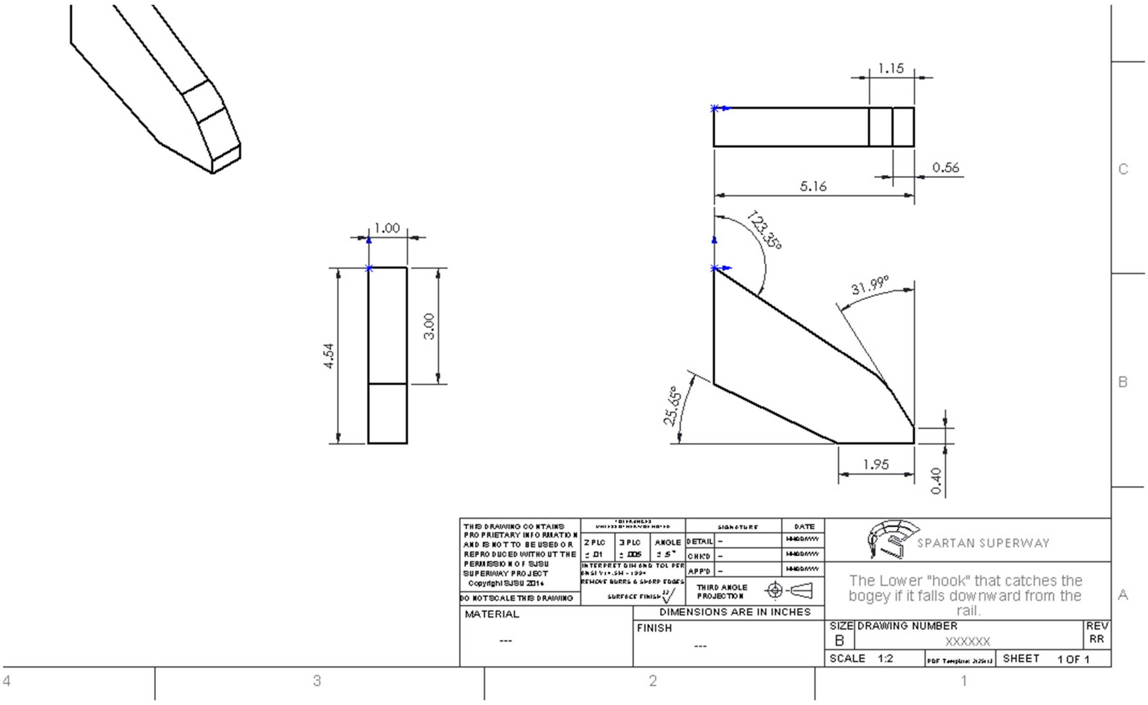


Upstop wheel

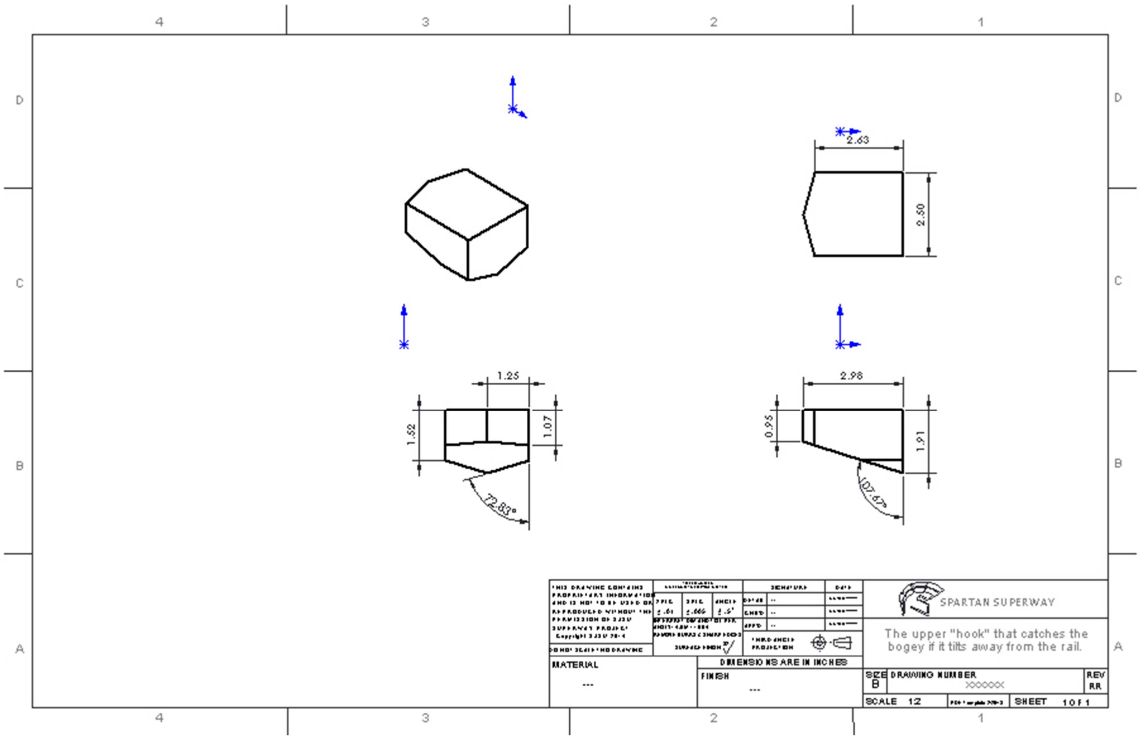


Upstop wheel rod

SPARTAN SUPERWAY

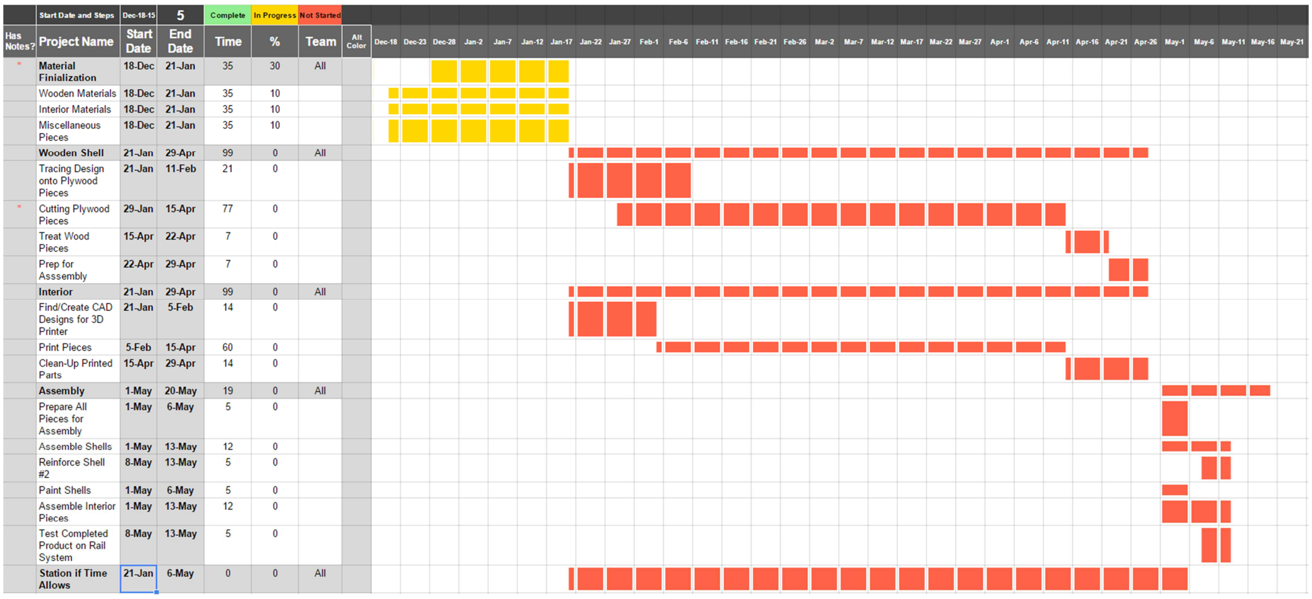


Bottom catch



Top catch

Cabin Team



Spring 2016 Gantt Chart

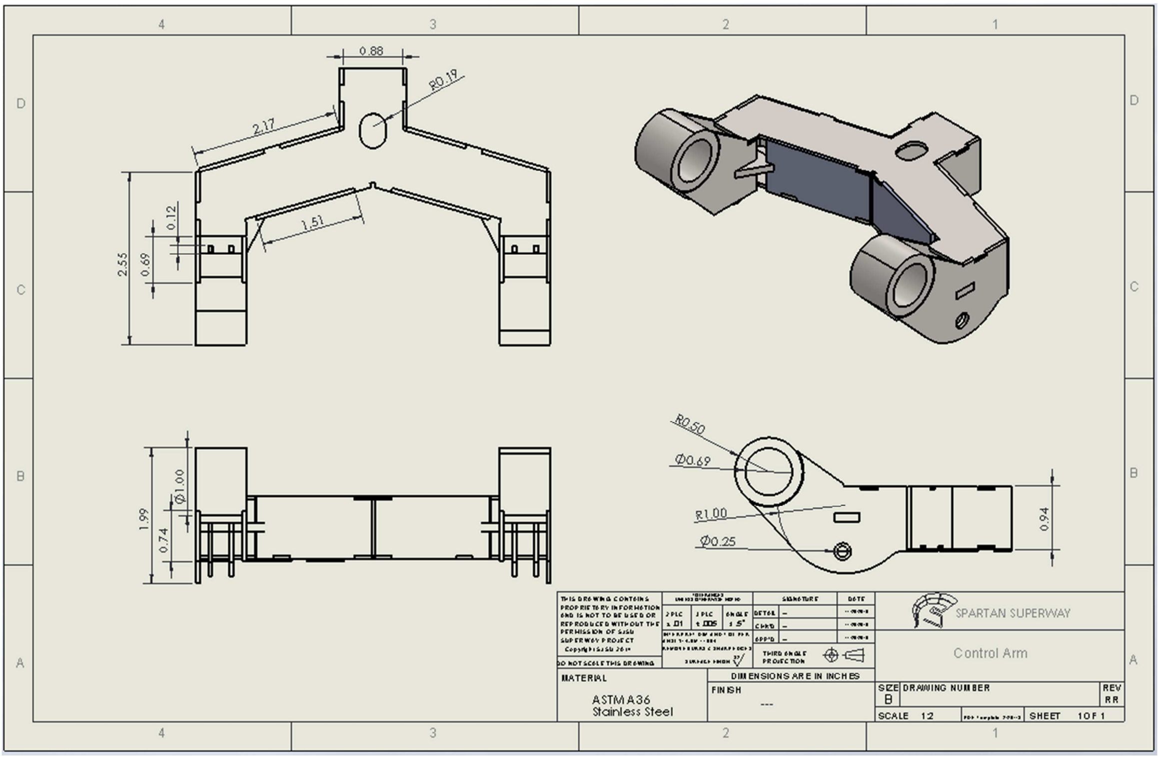
Steering, Breaking Mechanism and Guideway Team

Steering and Braking Bill of Materials:

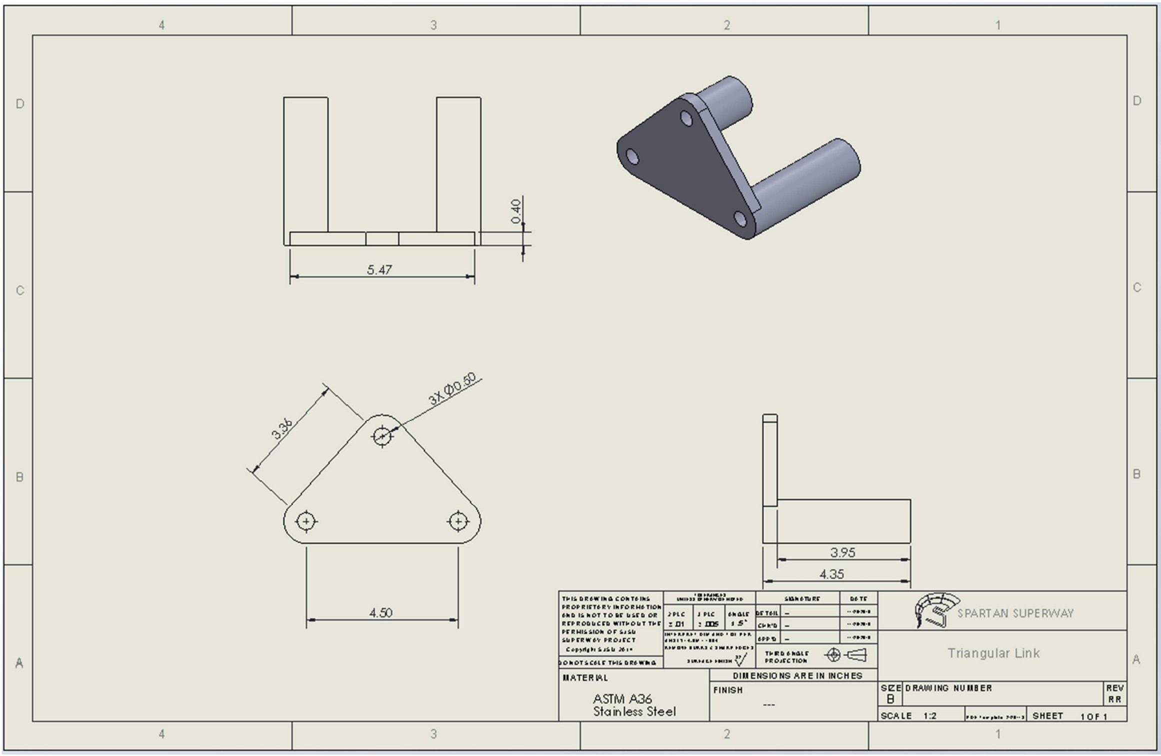
Part	Item Description	Vendor	Qty. per Bogie	Unit Cost	Qty. Needed	Total Cost
Switching Wheel	2-1/2" Caster Wheel, 260 lb. Load Rating, Wheel Width 1", Nylon, Fits Axle 3/8"	Grainger	8	$4.81	16	$76.96
Guiding Wheel	6" x 2" Crown Tread Polyurethane Wheel on Iron Center	CasterCity	2	$27.46	4	$109.84
Ceiling Wheel	3-1/2 Rubber Light Duty Swivel Caster	Harbor Freight	4	$5.79	8	$46.32
Tie Rods	1/4 in.- 28 Thread Ball Joint Female Right Rod End (4-Pack)	Home Depot	1	$28.99	2	$57.98
Links/hinges/plates	1/4 inch thick 2 x 2 ft A36 Steel Plate	MetalsDepot/PDM steel	1	$46.64	2	$93.28
Link Shaft	1 ft long 1/4 inch Dia. 304 Stainless Steel Round Bar	MetalsDepot/PDM steel	1	$3.00	2	$6.00
Frame Support Bar	4 ft long 1 X 1 X 16 GA. (.062 wall) 304 Stainless Steel Square Tube	MetalsDepot/PDM steel	1	$20.60	2	$41.20
Wheel Support Bar	2 ft long 1 X 1/2 X 16 GA. (.062 wall) 304 Stainless Steel Rectangle Tube	MetalsDepot/PDM steel	1	$10.56	2	$21.12
Disc Brake	Aluminum Alloy	Ebay	1	$22.00	2	$44.00
			Grand Total			**$496.70**

Guideway Bill of Materials

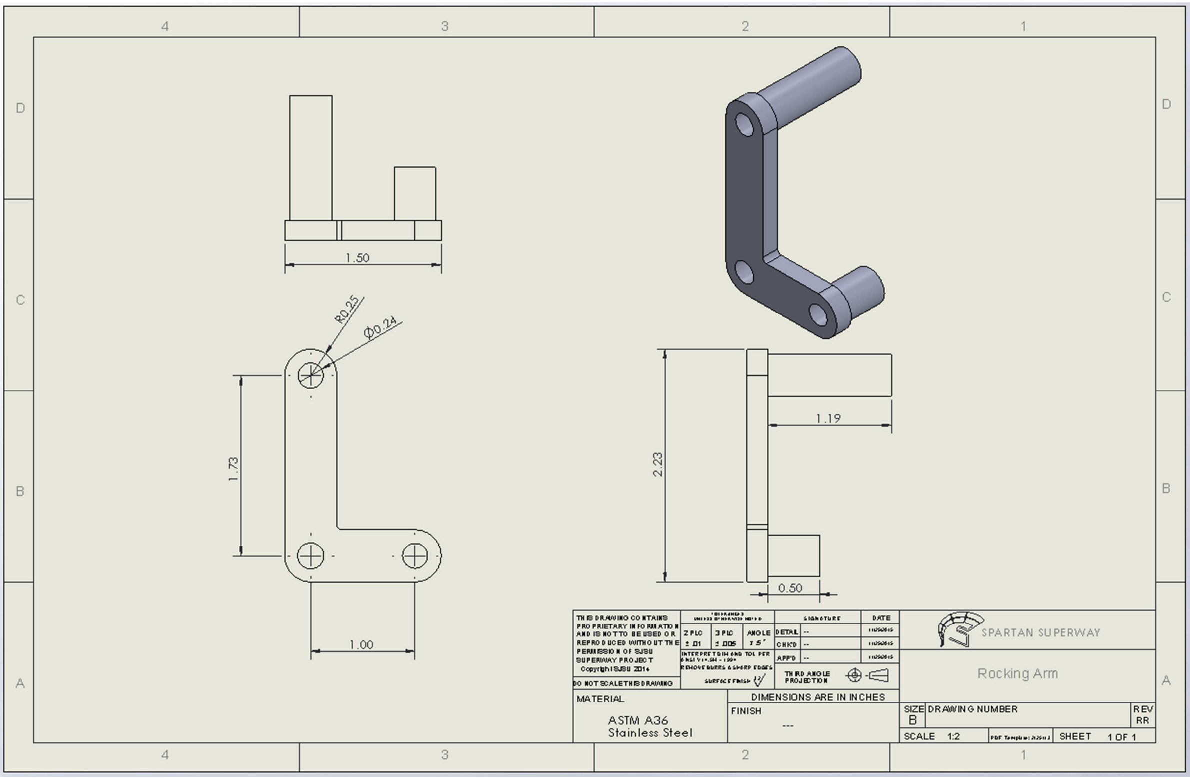
Item Description	Vendor	Quantity (ft)	Unit Cost	Quantity Needed (ft)	Total Cost
1"x2"x11 GA A513 Rectangular Steel Tube Stock	Metals Depot/PDM Steel	24	55.03	39	$2,146.17
1"x3"x11 GA A500 Rectangular Steel Tube Stock	Metals Depot/PDM Steel	24	75.35	27	$2,034.45
2"x2"x11 GA A500 Square Steel Tube Stock	Metals Depot/PDM Steel	24	62.93	11	$692.23
2"x2"x11 GA A500 Square Steel Tube Stock	Metals Depot/PDM Steel	24	62.93	0.76	$47.83
2"x2"x11 GA A500 Square Steel Tube Stock	Metals Depot/PDM Steel	24	62.93	1.2	$75.52
1"x1"x11 GA A513 Square Steel Tube Stock	Metals Depot/PDM Steel	24	32.83	2.5	$82.08
1"x1"x11 GA A513 Square Steel Tube Stock	Metals Depot/PDM Steel	24	32.83	1.4	$45.96
1"x1"x11 GA A513 Square Steel Tube Stock	Metals Depot/PDM Steel	24	32.83	0.25	$8.21
1"x1"x11 GA A513 Square Steel Tube Stock	Metals Depot/PDM Steel	24	32.83	6.93	$227.51
4'x8'x0.125" Birch Plywood	Home Depot	32	15.97	10	$159.70
0.25"x3" ASTM F3125 Grade A325 Plain Finish Structural Bolt	Fastenal	1	1.06	162	$171.72
1/4 inch thick A36 Steel Plate	Metals Depot/PDM Steel	2'x4'	83.28	1	$83.28
				Total	$5,774.65



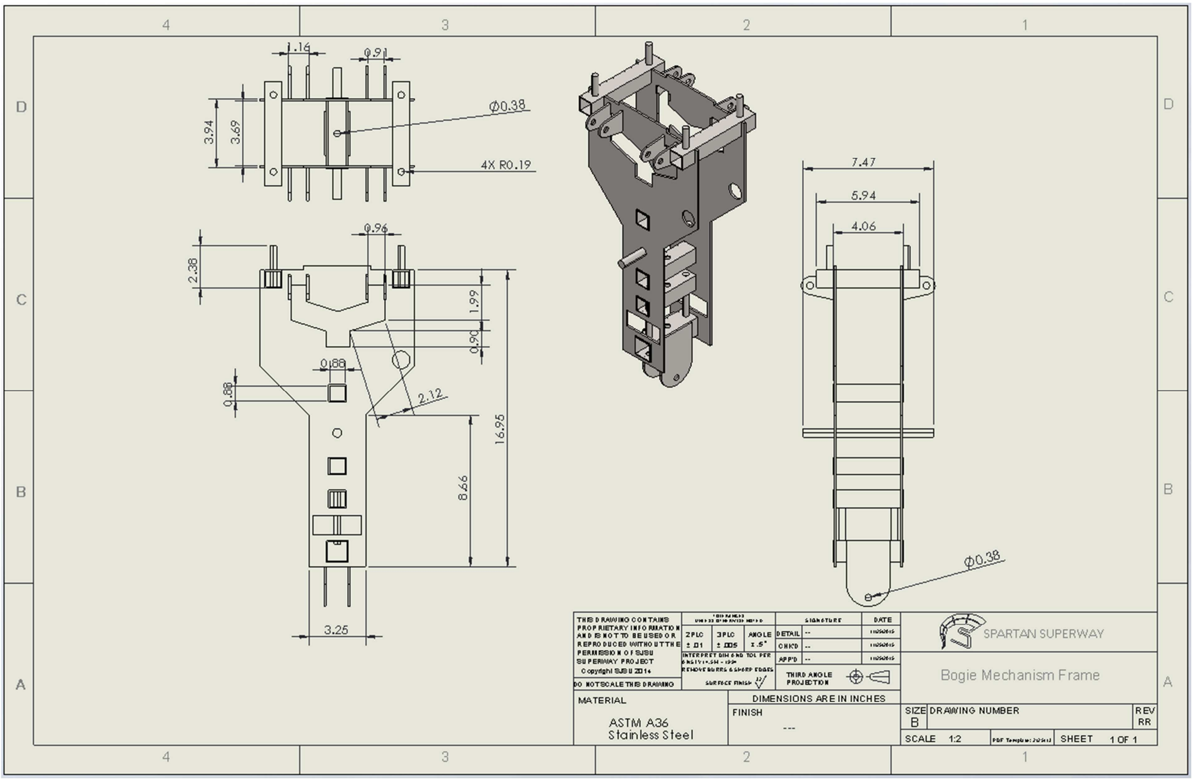
Drawing of Control Arm



Drawing of Triangular Link

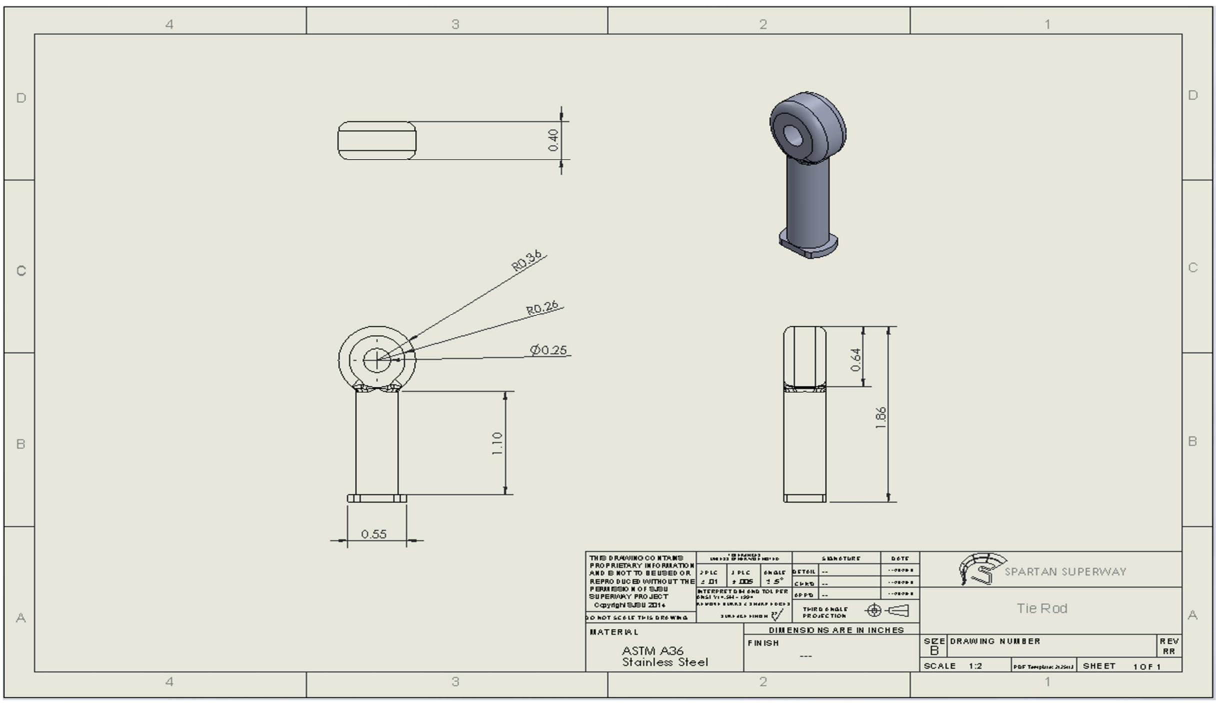


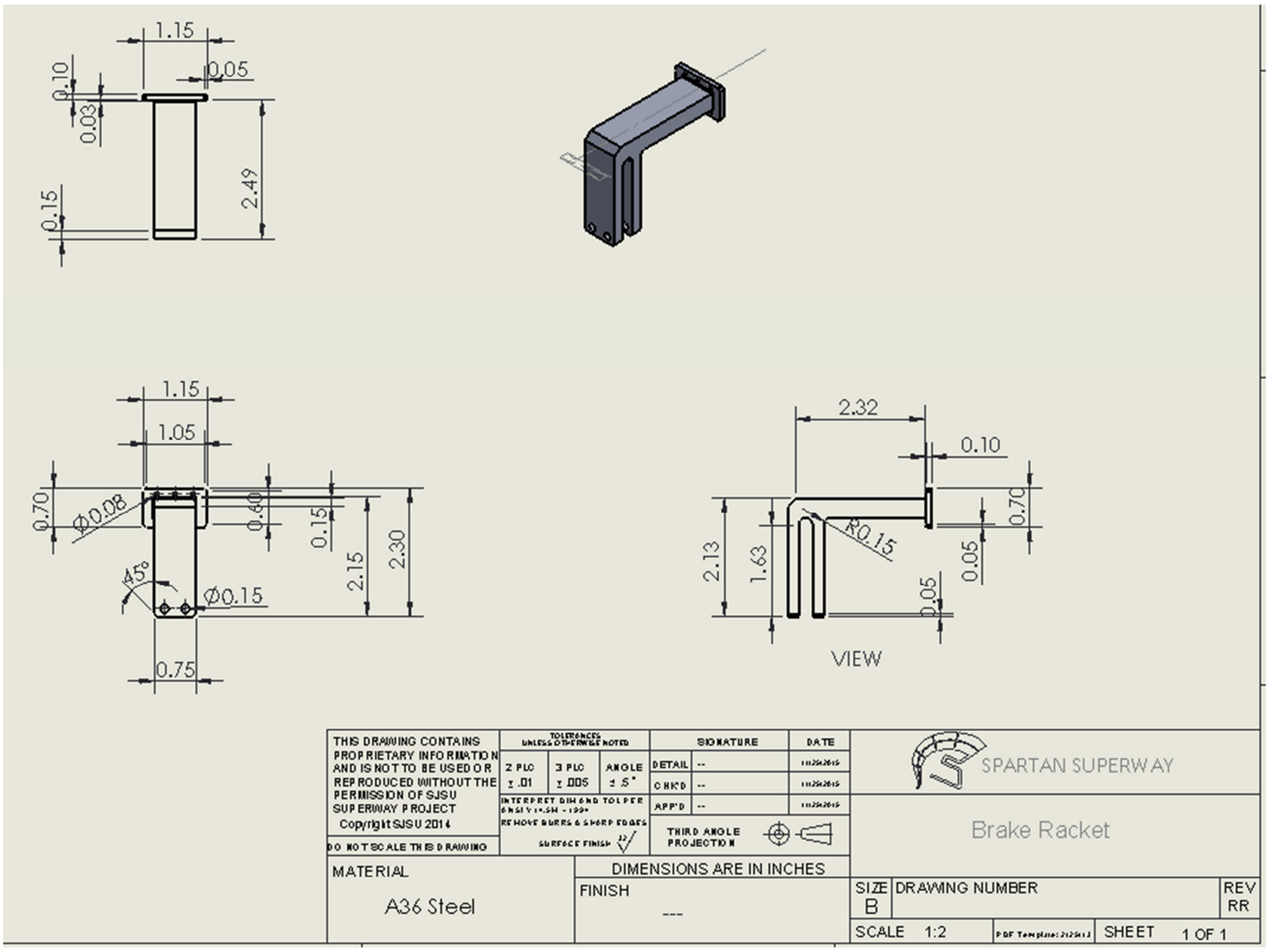
Drawing of L-bracket/Rocking Arm



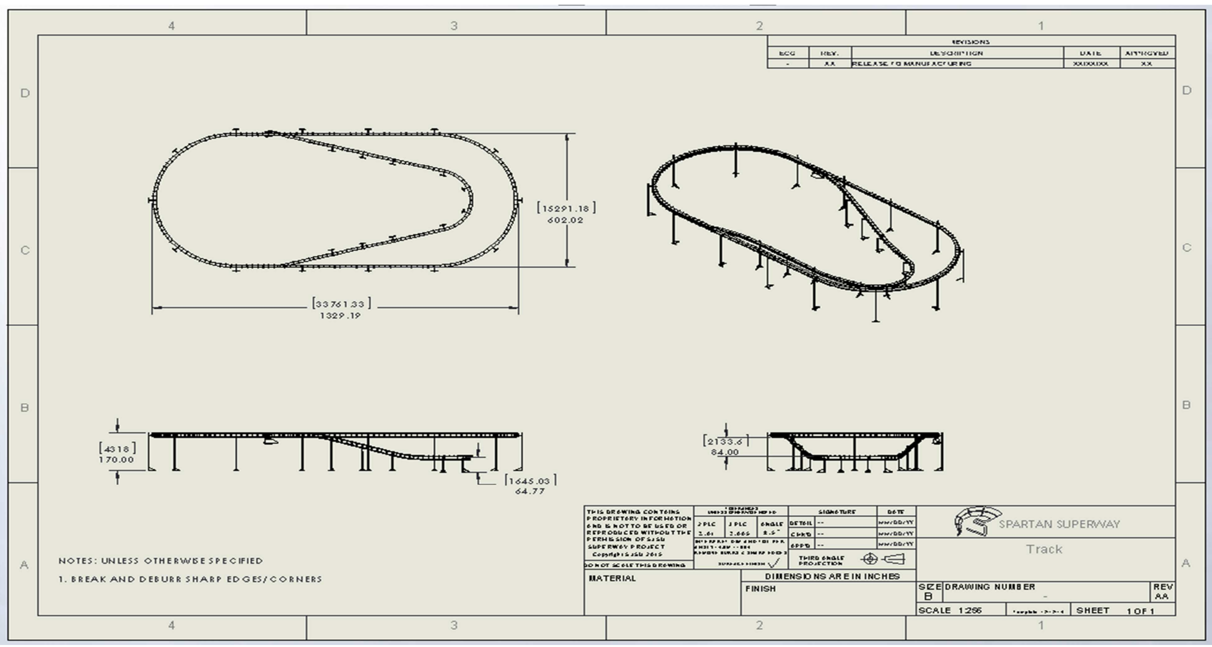
Drawing of Bogie Frame

Drawing of Tie Rod

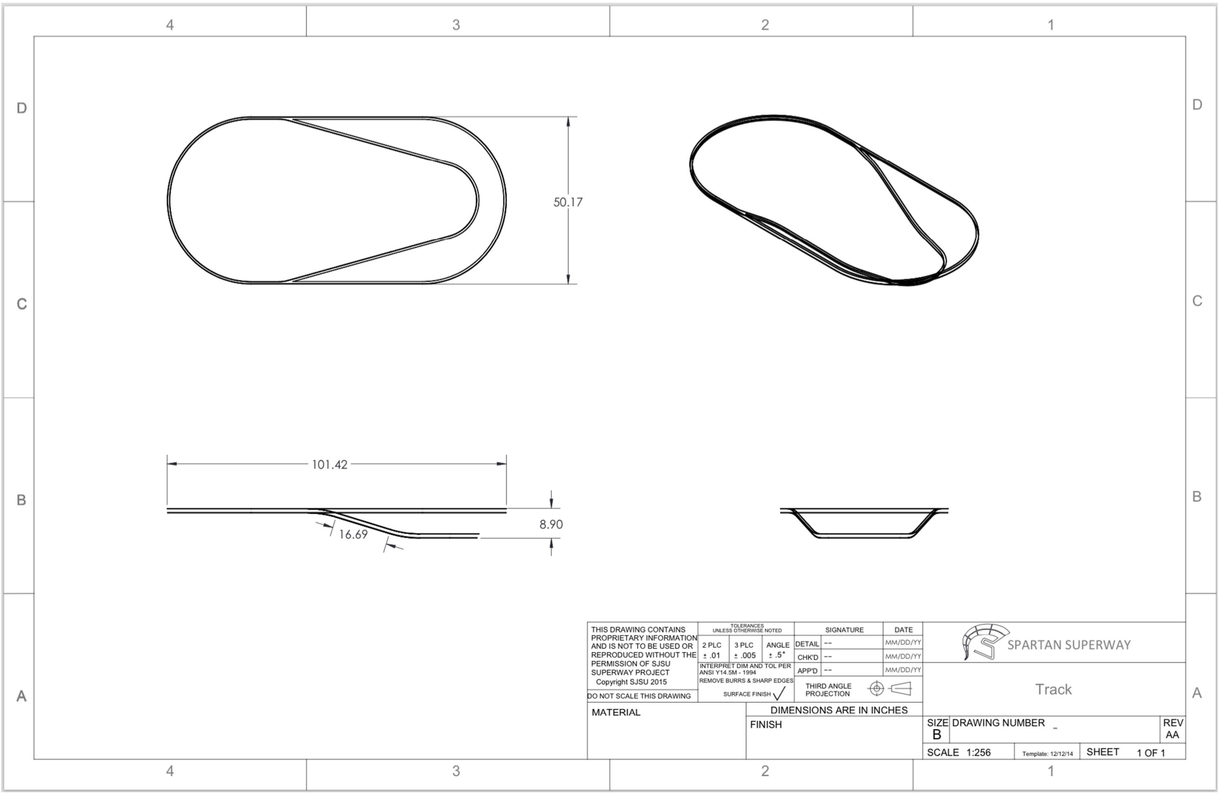




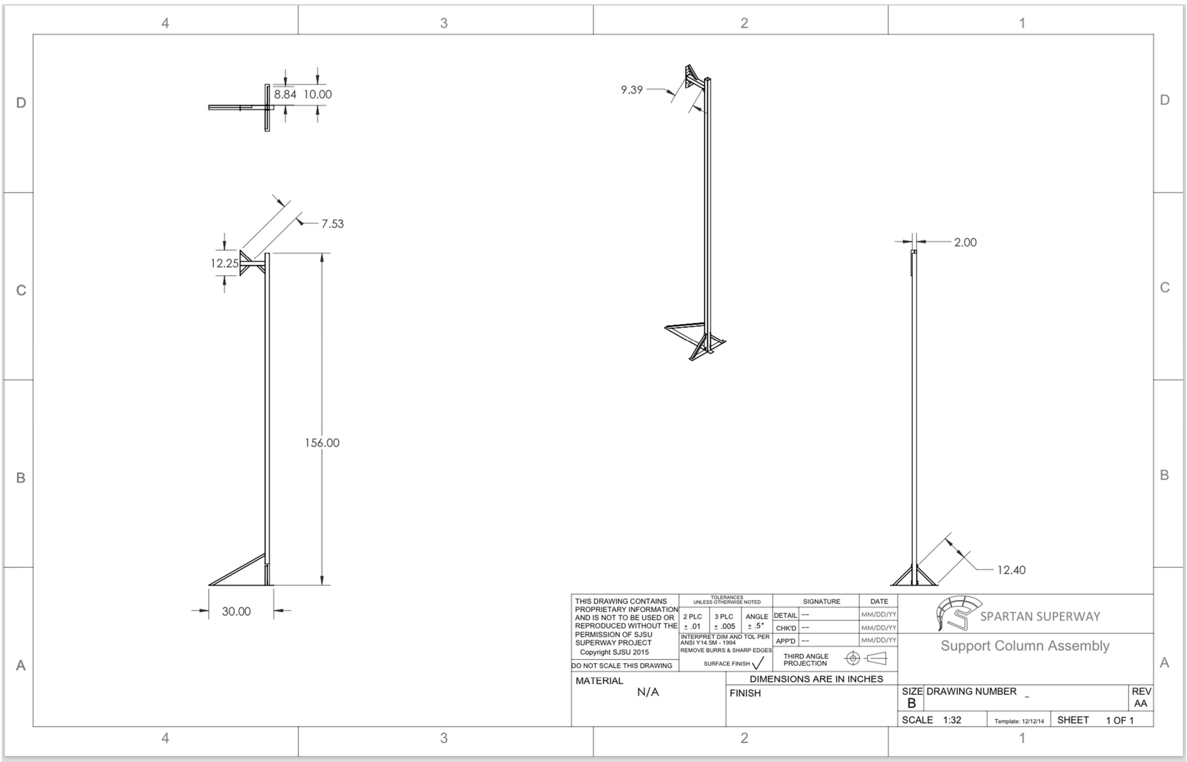
Drawing of Brake Racket



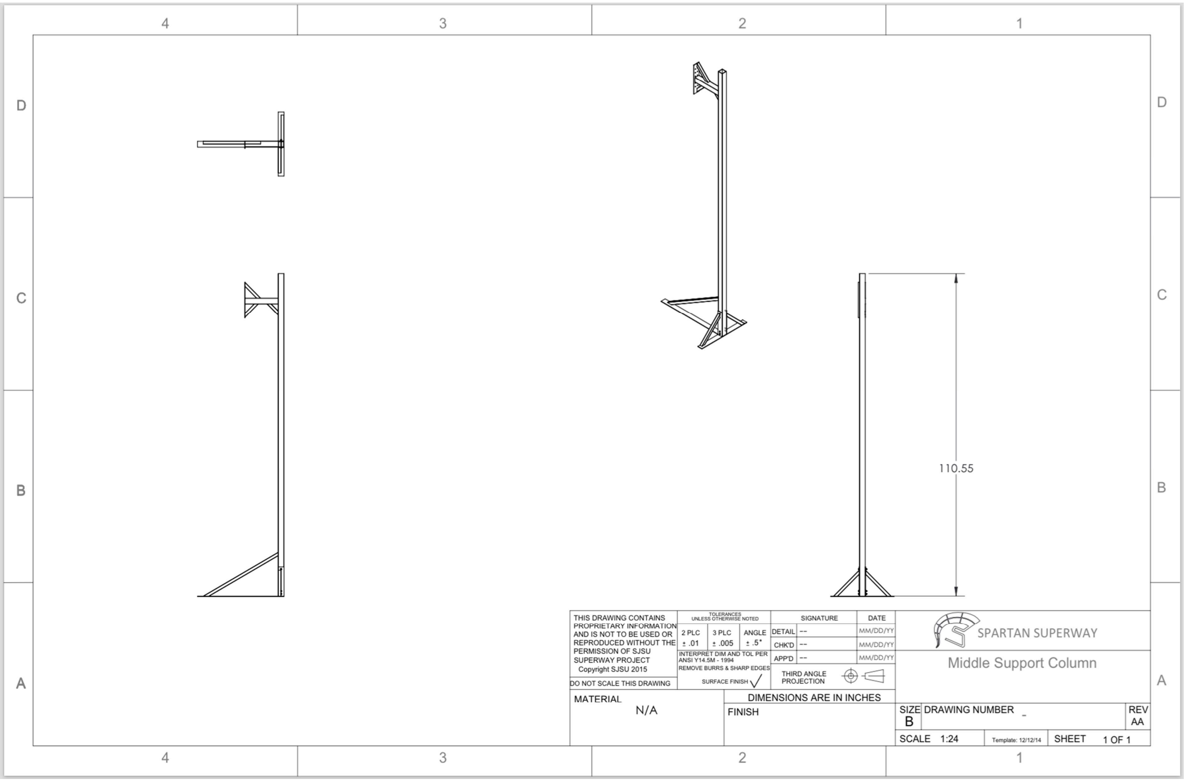
Drawing of Track



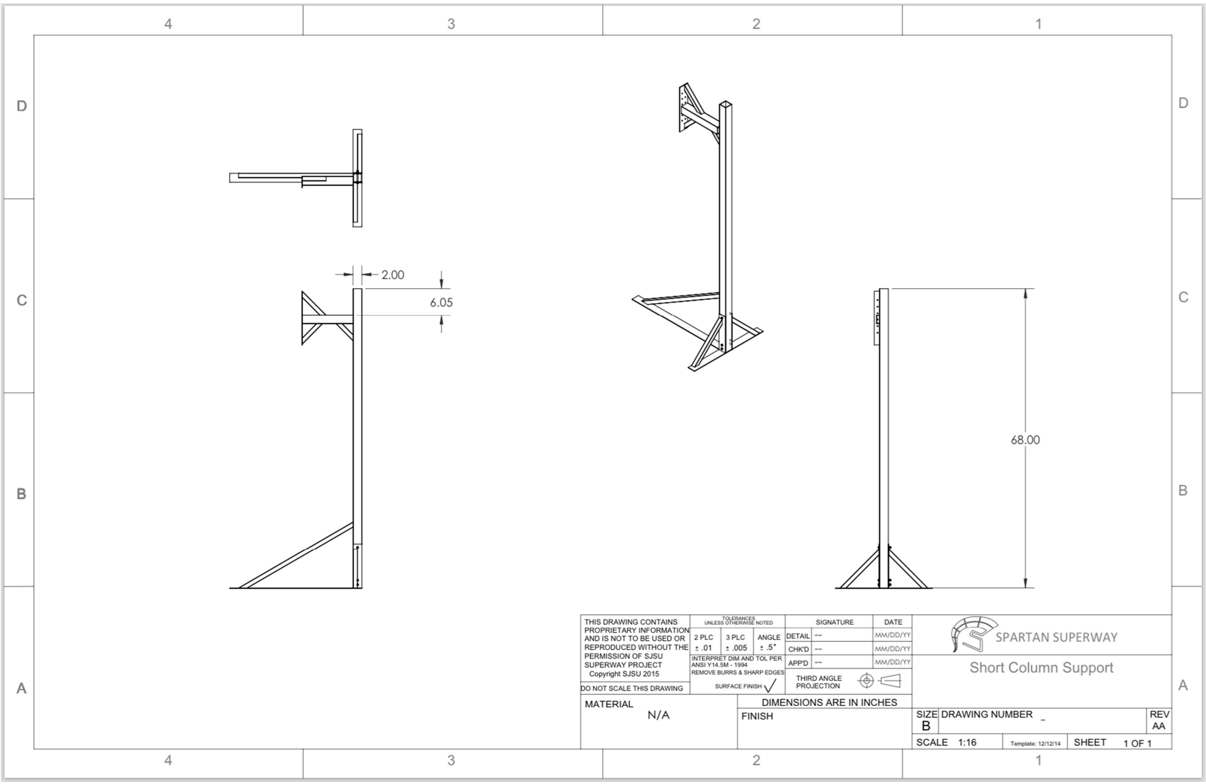
Drawing of Revised shortened track



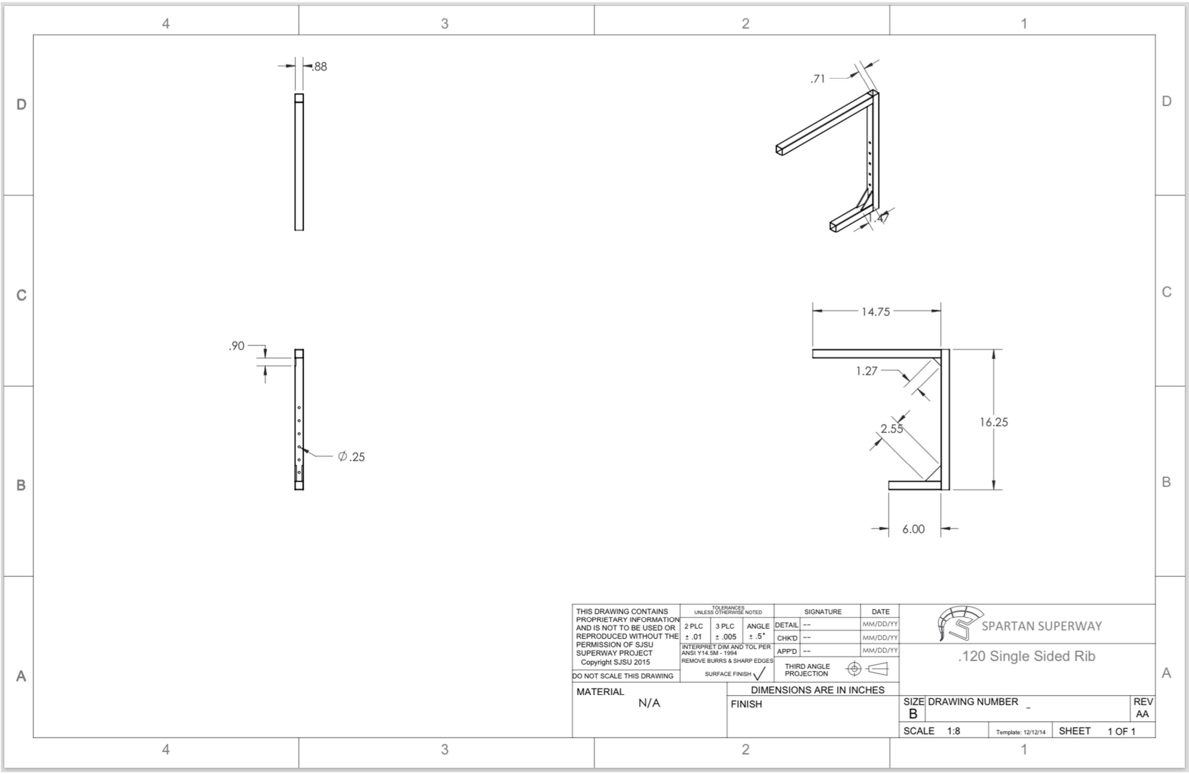
Drawing of Tall Support Column



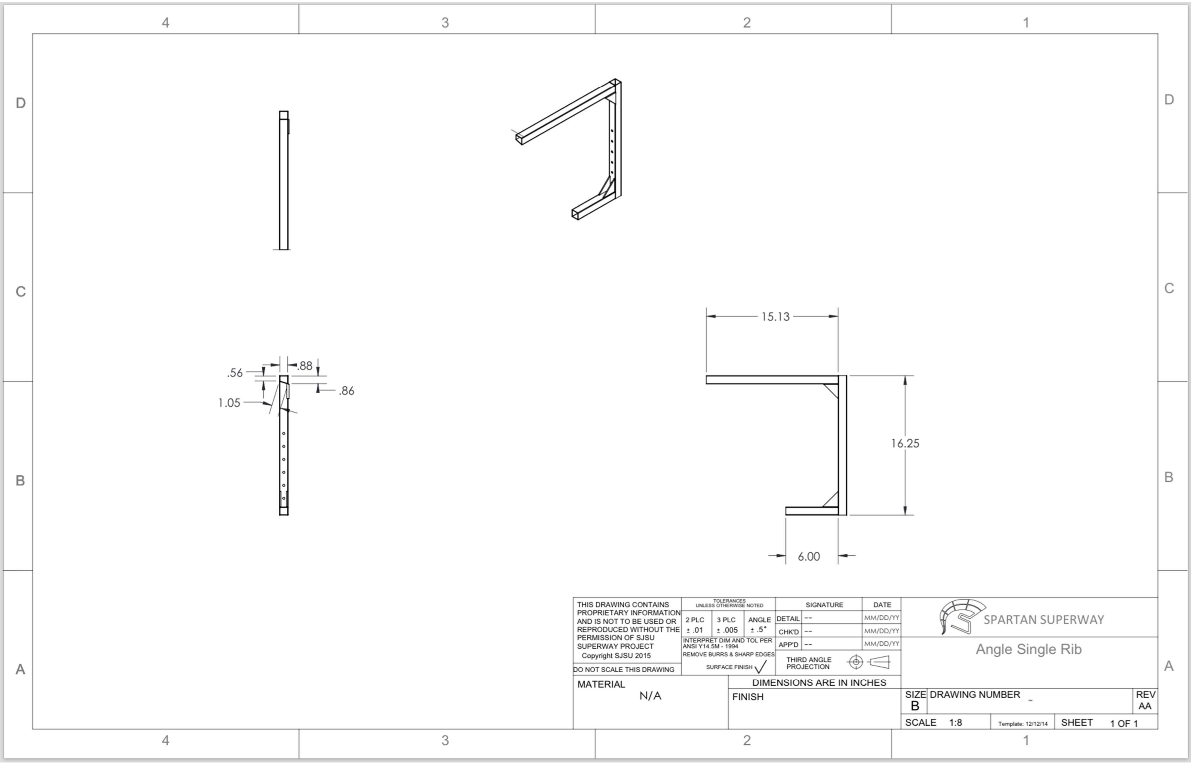
Drawing of Middle Support Column



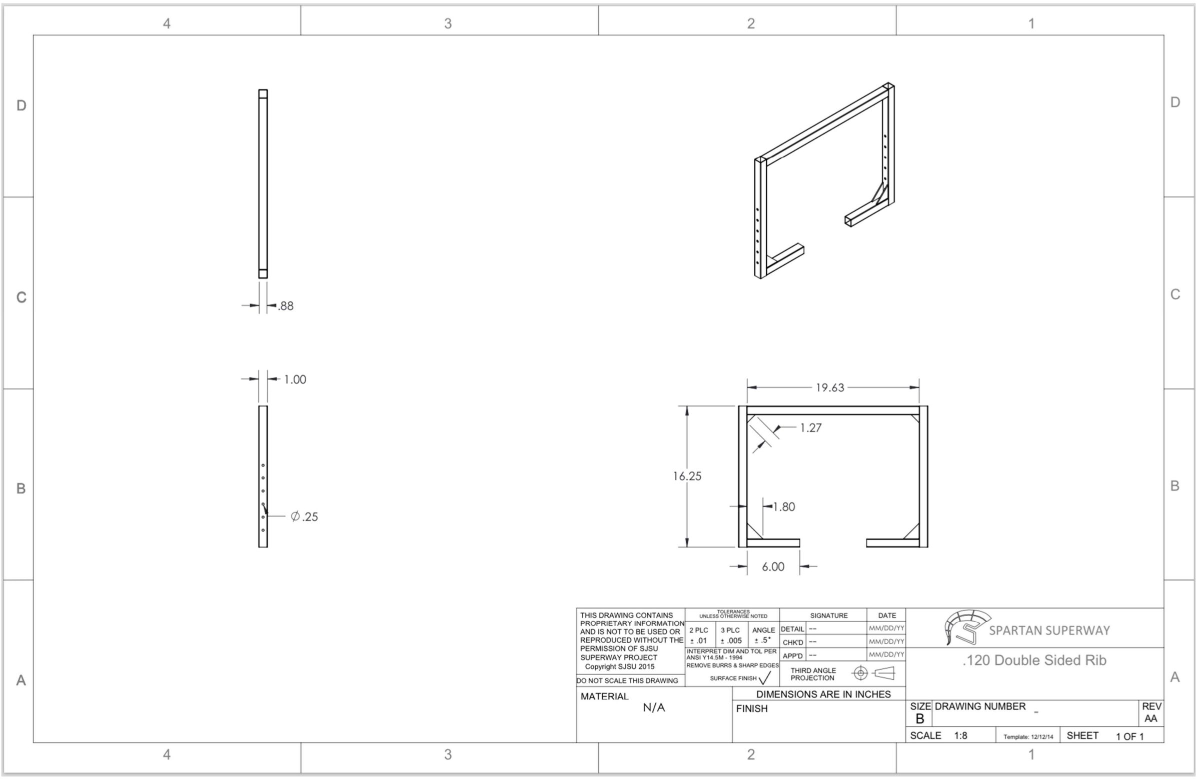
Drawing of Short Support Column



Drawing of Single Rib Supports



Drawing of Angled Single Rib Supports

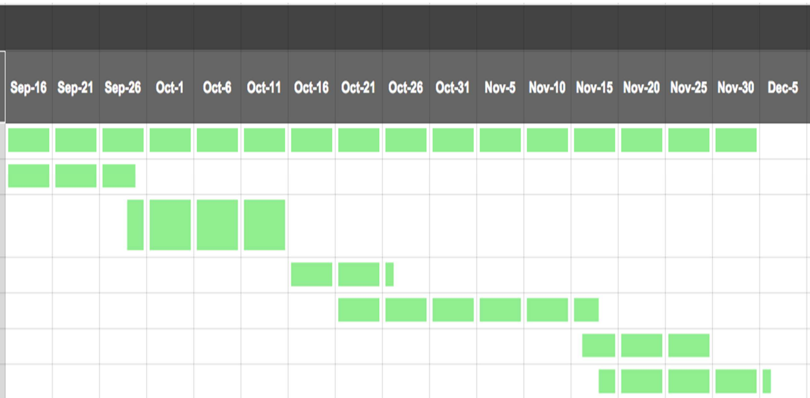


Drawing of Double Sided Rib Supports

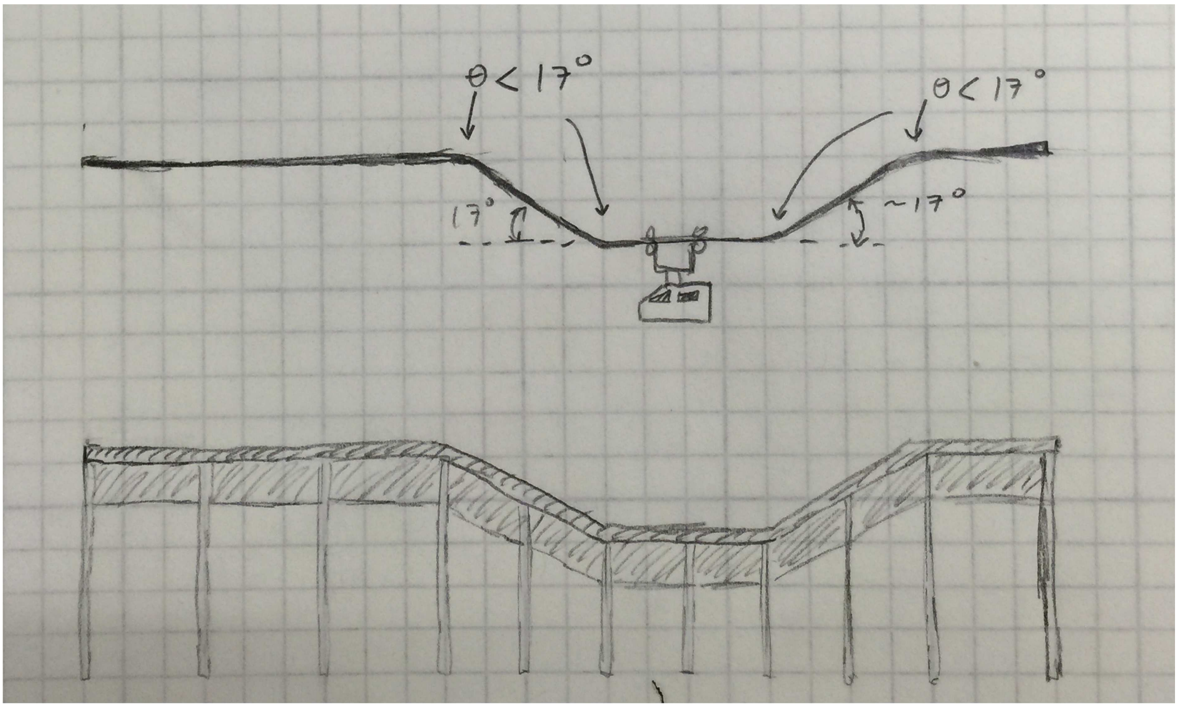
Gantt Chart for Steering and Braking

Project Name	Start Date	End Date	Time	%	Team	Alt Color
Preparation for building and constructing	25-Nov	20-Jan	56	0	All	
Semester report	25-Nov	12-Dec	17	0	All	
Necessary revisions	25-Nov	16-Dec	21	0	All	
Develop fabrication plan	16-Dec	20-Jan	35	0	All	
Fabrication and Machining Training	16-Dec	20-Jan	35	0	All	
Order and gather parts/components	16-Dec	20-Jan	35	0	All	
Design Implementation	20-Jan	11-May	112	0	All	
Building and assembly	20-Jan	4-Apr	75	0	All	
Prototype ready and testing	6-Apr	20-Apr	14	0	All	
Make necessary modifications	20-Apr	4-May	14	0	All	
Final presentation	4-May	11-May	7	0	All	
Final report	4-May	11-May	7	0	All	

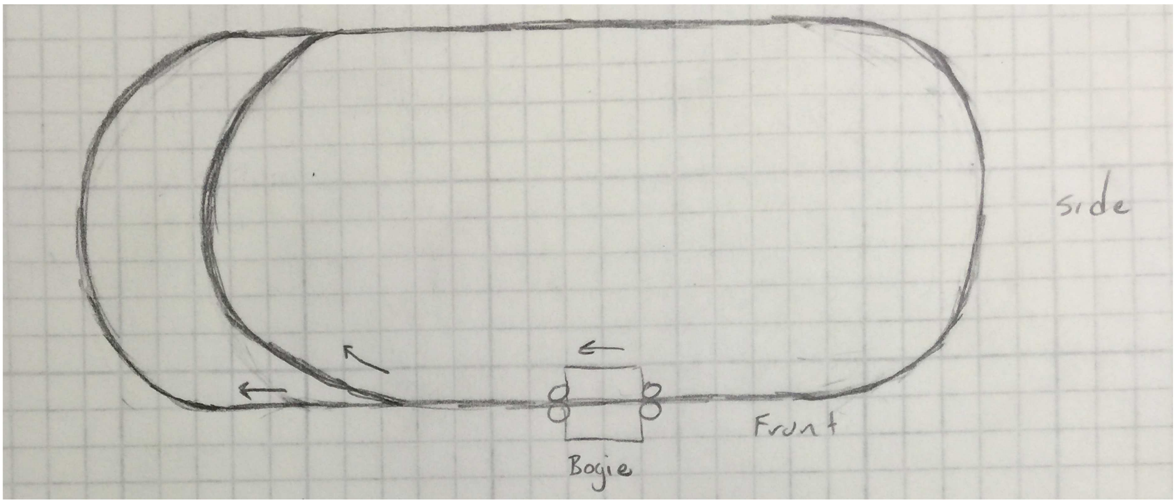
Start Date and Steps	Sep-16-15	5	Complete	In Progress	Not Started	
Project Name	**Start Date**	**End Date**	**Time**	**%**	**Team**	**Alt Color**
Guideway Design	16-Sep	5-Dec	80	100	All	
Determine size and design track	16-Sep	30-Sep	14	100	Team	
Re-design guideway based on related team designs	29-Sep	16-Oct	17	100	Team	
Perform Analysis (FEA)	16-Oct	27-Oct	11	100	Team	
Draft plans to build (Bill of materials, cost, etc)	21-Oct	18-Nov	28	100	Team	
Finalize Plans and Part Order	16-Nov	30-Nov	14	100	Team	
Final plans to build (Bill of materials, blueprint, etc)	18-Nov	6-Dec	18	100	Team	



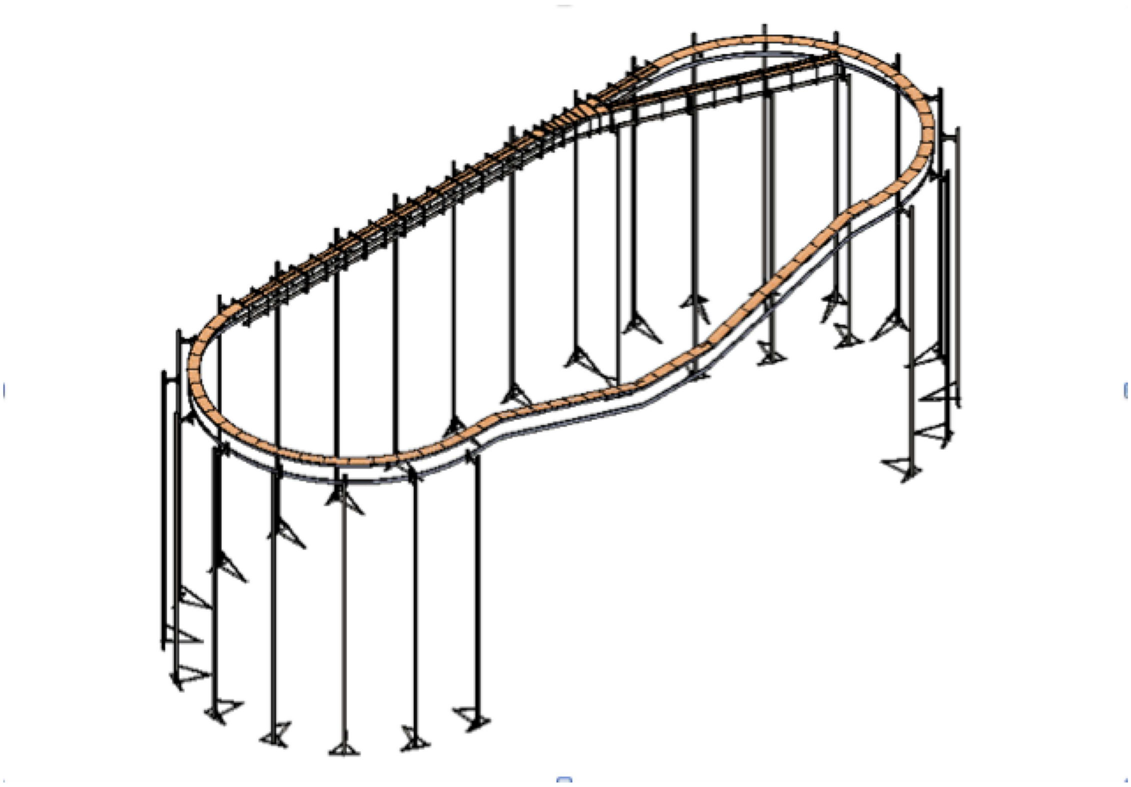
Gantt Chart for Guideway



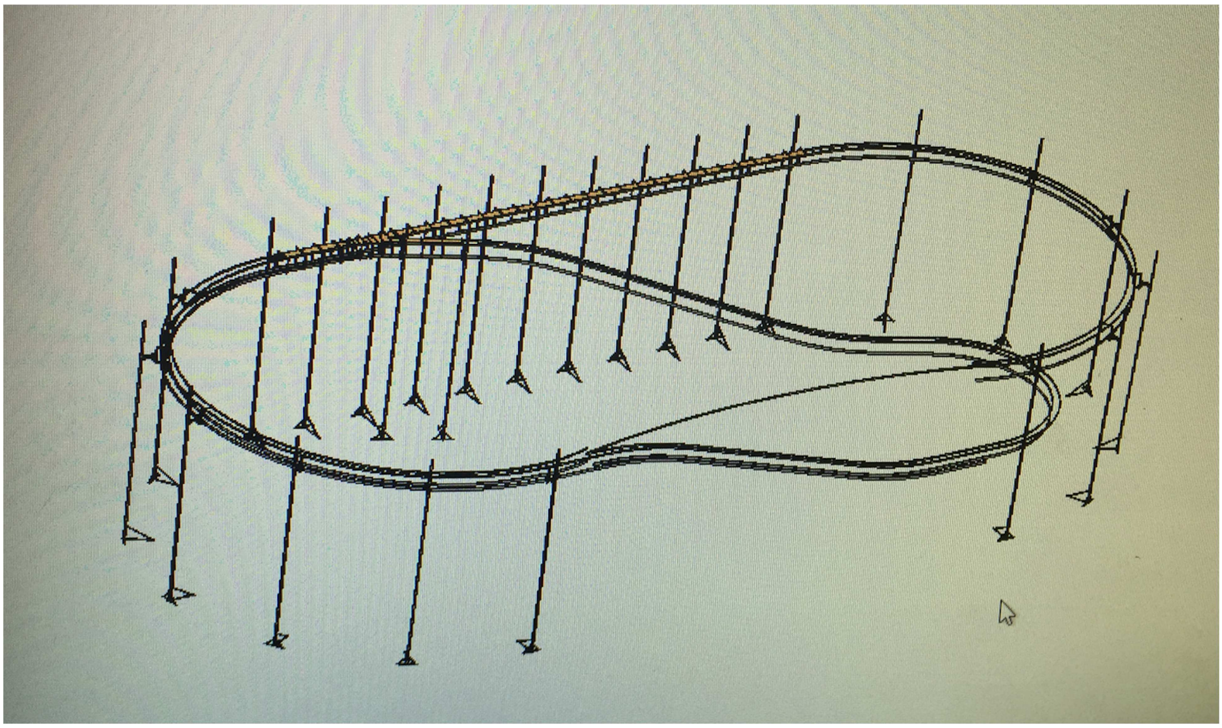
Straight Open End Guideway



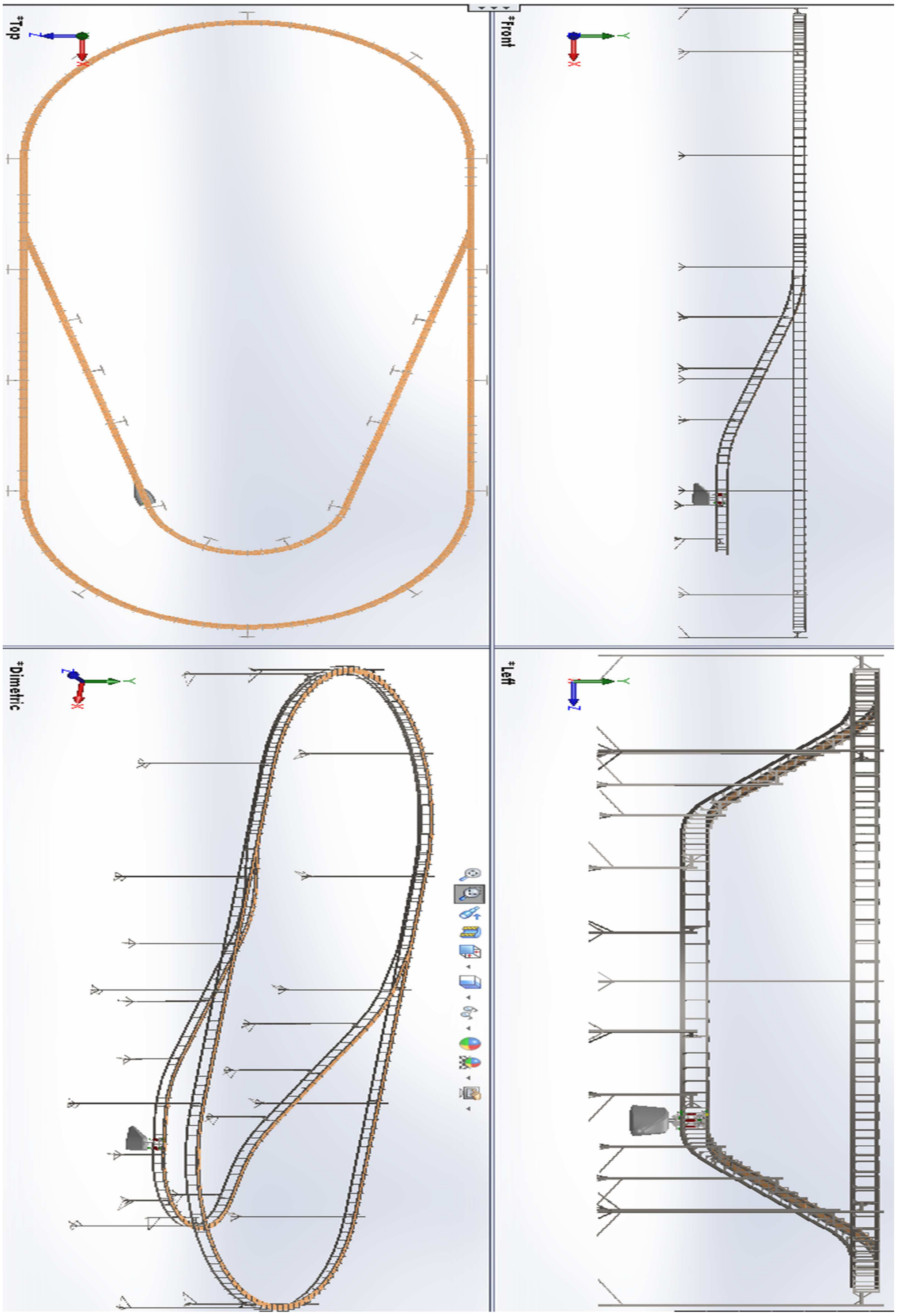
First Iteration of Full Guideway



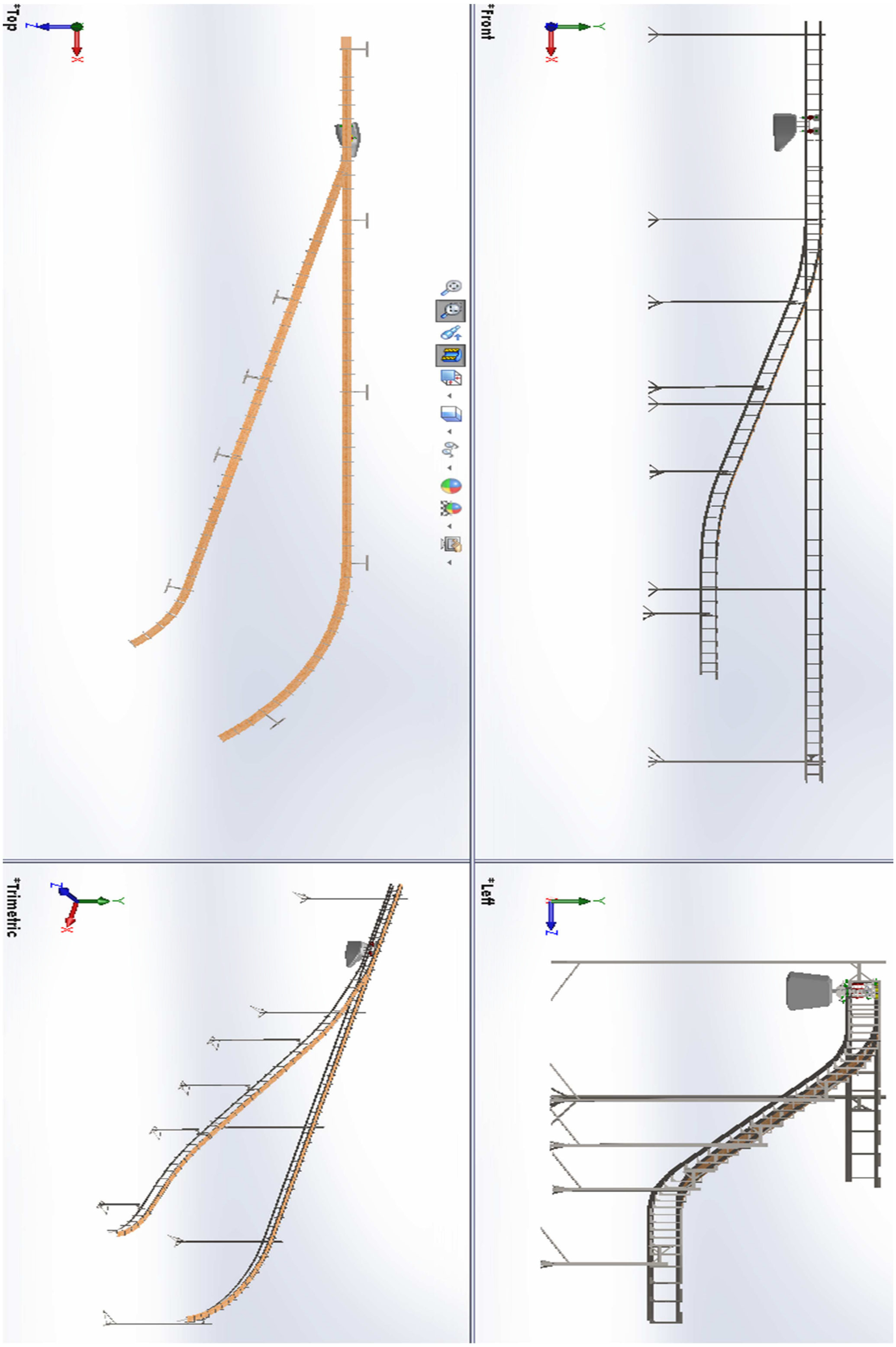
Second Iteration of Full Guideway



Third iteration of full guideway



Front, Side, Top, and Dimetric View of Final Guideway



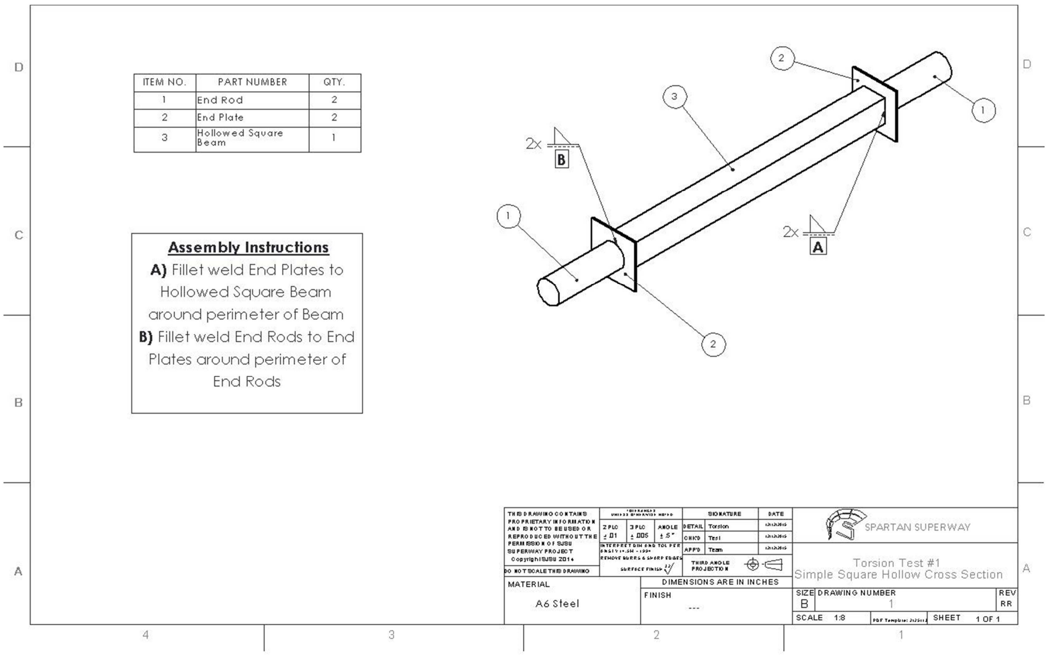
Front, Side, Top, and Dimetric View of Partial Guideway

SPARTAN SUPERWAY

Torsion Test Subteam	Spring 2016																			
Weeks	1/17	1/24	1/31	2/14	2/21	2/28	3/6	3/13	3/20	3/27	4/3	4/10	4/17	4/24	5/1	5/8	5/15	5/22	5/29	6/5
Obtain Simple circular and Square Cross Section Materials																				
Build Square Cross Section (Test sample #1)																				
Test both circular and square cross section																				
Analyse data from Test #1																				
Finalize design for full scale																				
Obtain full scale materials																				
Build full scale																				
Test full scal																				
Analyse full scale results with ANSYS																				
Optimize full scale design																				

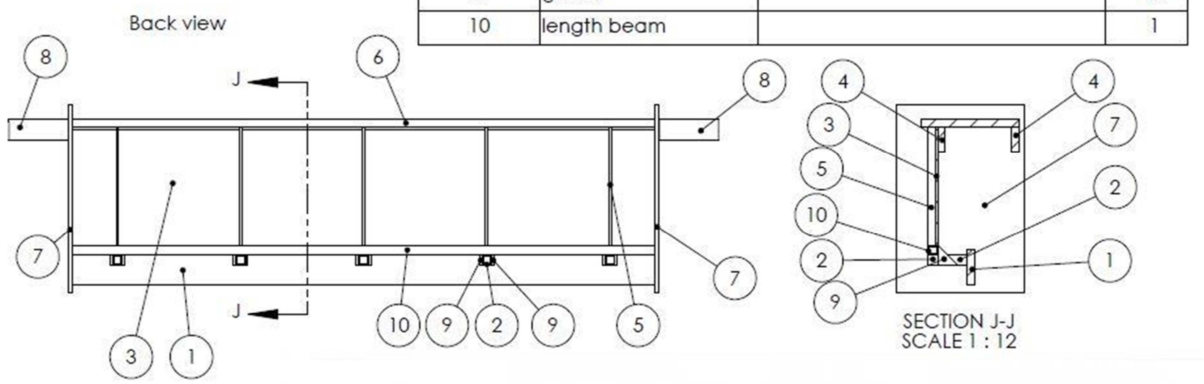
<u>Torsion Team</u>

Gantt Chart for Spring 2016

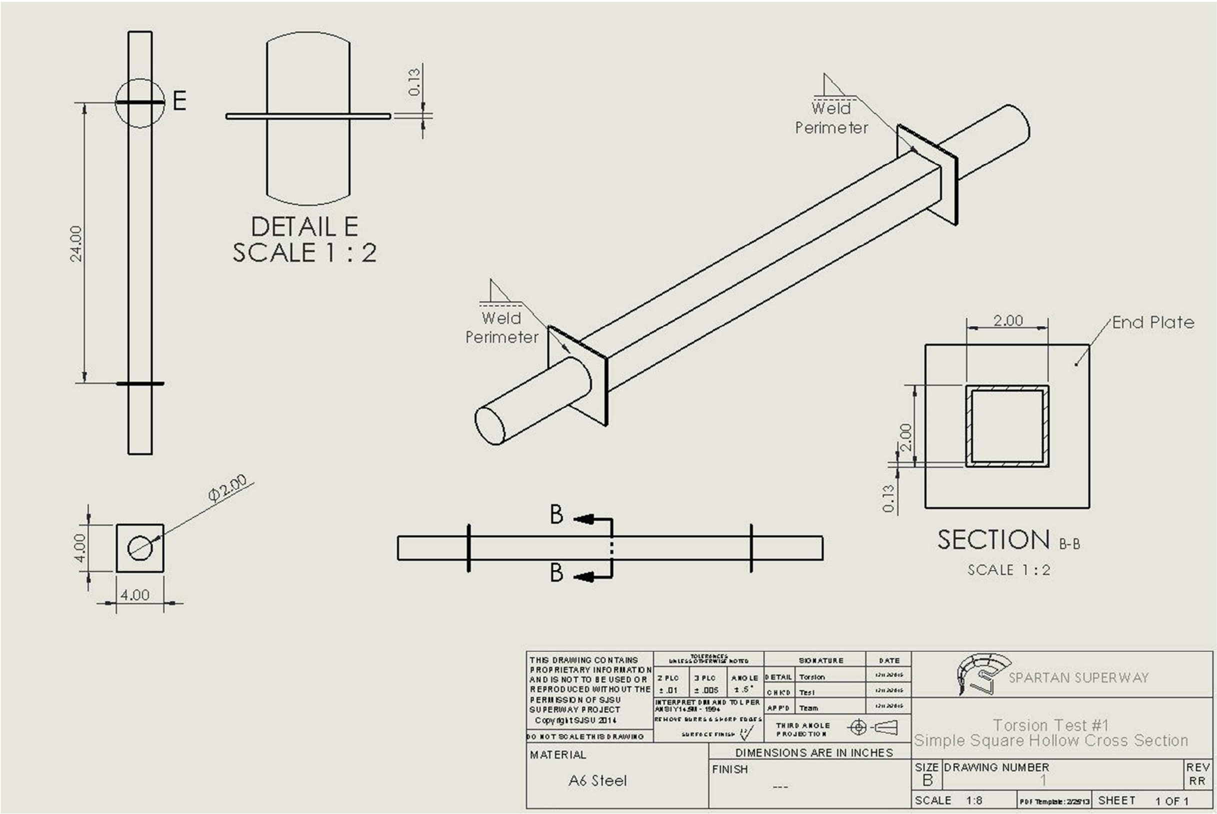


Closed HOllow Square Assembly Guide of First Test Workpiece. The workpiece must be welded together

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Support rail		1
2	Beam		5
3	Plate		1
4	upper rail		2
5	Stud		5
6	Topplate		1
7	End plate		2
8	Twist shaft		2
9	gusset		10
10	length beam		1



Parts list for Jake Parkhurst's Design. This design is tentative and will change throughout Spring semester

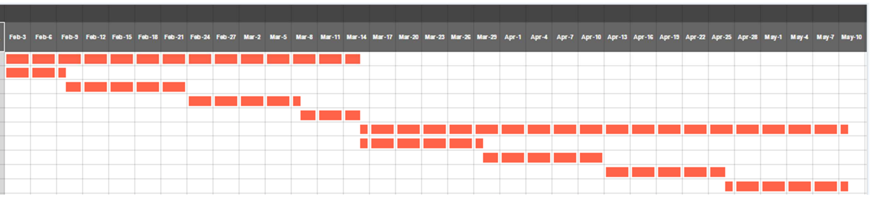


Simple Square Hollow Cross Section Design

<u>Active Suspension Development Team</u>

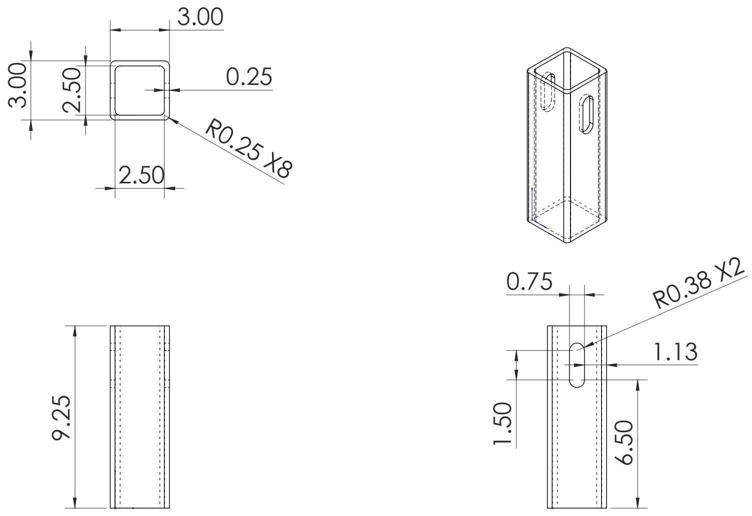
Suspension Gantt Chart

Start Date and Steps	Feb-3-15	3	Complete	In Progress	Not Started	
Project Name	**Start Date**	**End Date**	**Time**	**%**	**Team**	**Alt Color**
Manufacture	3-Feb	16-Mar	41	0	All	
Fabrication Discussion	3-Feb	10-Feb	7	0	All	
Aquire and Machine Materials	10-Feb	24-Feb	14	0	All	
Assemble All Parts	24-Feb	9-Mar	13	0	All	
Connect to Bogie/Cabin	9-Mar	16-Mar	7	0	All	
Testing	16-Mar	11-May	56	0	All	
Test Vibration Isolation	16-Mar	30-Mar	14	0	All	
Test/Revise Controls Code	30-Mar	13-Apr	14	0	All	
Prove Consistent Operation	13-Apr	27-Apr	14	0	All	
Final Scale Assembly	27-Apr	11-May	14	0	All	



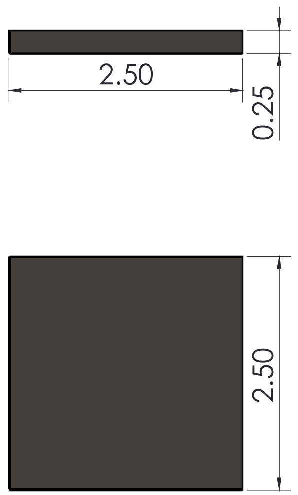
SPARTAN SUPERWAY

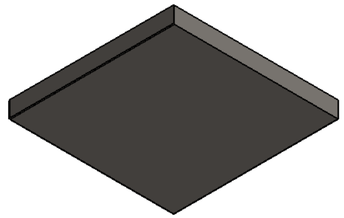
SPARTAN SUPERWAY



THIS DRAWING CONTAINS PROPRIETARY INFORMATION AND IS NOT TO BE USED OR REPRODUCED WITHOUT THE PERMISSION OF SJSU SUPERWAY PROJECT Copyright SJSU 2015	TOLERANCES UNLESS OTHERWISE NOTED: 2 PLC ± .01; 3 PLC ± .005; ANGLE ± .5°		SIGNATURE	DATE	SPARTAN SUPERWAY
	INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009	DETAIL	S.GARFIELD	12/12/2015	ASDT - Top Tube
	REMOVE BURRS & SHARP EDGES	CHK'D	--	12/12/2015	
DO NOT SCALE THIS DRAWING	SURFACE FINISH 32	APP'D	--	12/12/2015	
		THIRD ANGLE PROJECTION			

MATERIAL	DIMENSIONS ARE IN INCHES	SIZE B; DRAWING NUMBER Top Tube; REV AB
ASTM A500 Grade B	FINISH As Manufactured	SCALE 1:4; PDF Template: 12/12/15; SHEET 1 OF 1





SPARTAN SUPERWAY

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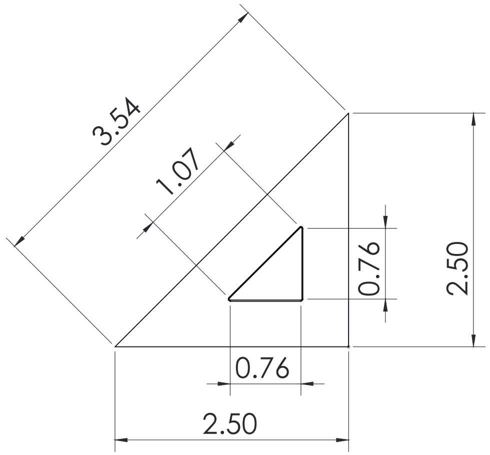
	2 PLC ± .01	3 PLC ± .005	ANGLE ± .5°	DETAIL	T.Broder	12/12/2015
				CHK'D	--	12/12/2015
	INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009			APP'D	--	12/12/2015
DO NOT SCALE THIS DRAWING	REMOVE BURRS & SHARP EDGES SURFACE FINISH 32			THIRD ANGLE PROJECTION		

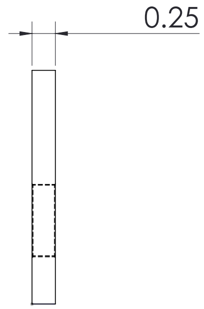
SPARTAN SUPERWAY

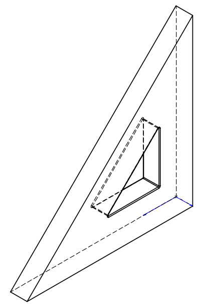
ASDT - Base

MATERIAL ASTM A36	DIMENSIONS ARE IN INCHES FINISH As manufactured	SIZE B	DRAWING NUMBER Base	REV RR
		SCALE 1:1	SHEET 1 OF 1	

SPARTAN SUPERWAY







DO NOT SCALE THIS DRAWING

TOLERANCES UNLESS OTHERWISE NOTED

2 PLC	3 PLC	ANGLE
± .01	± .005	± .5°

INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009
REMOVE BURRS & SHARP EDGES
SURFACE FINISH 32

	SIGNATURE	DATE
DETAIL	T.Broder	12/12/2015
CHK'D	--	12/12/2015
APP'D	--	12/12/2015

THIRD ANGLE PROJECTION

SPARTAN SUPERWAY

ASDT - Brace

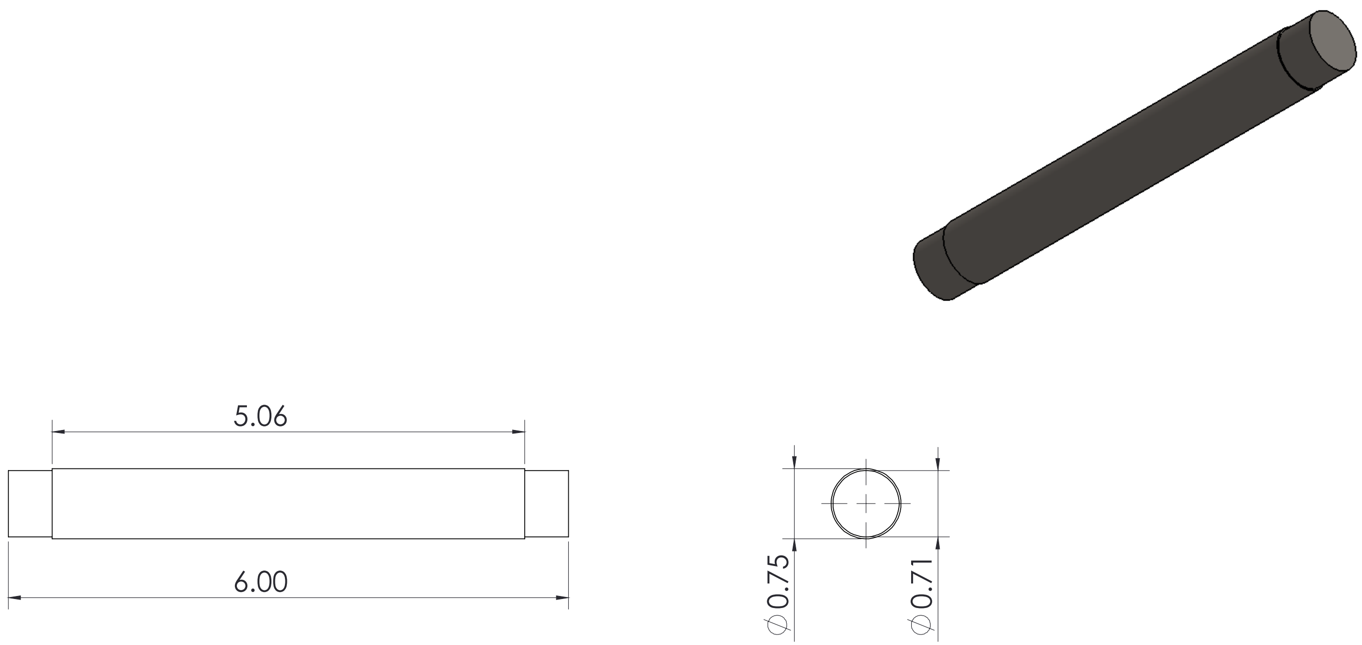
MATERIAL
ASTM A36

DIMENSIONS ARE IN INCHES

FINISH
As Manufactured

SIZE	DRAWING NUMBER	REV
B	Brace	AB

SCALE 1:1 PDF Template: 12/12/15 SHEET 1 OF 1

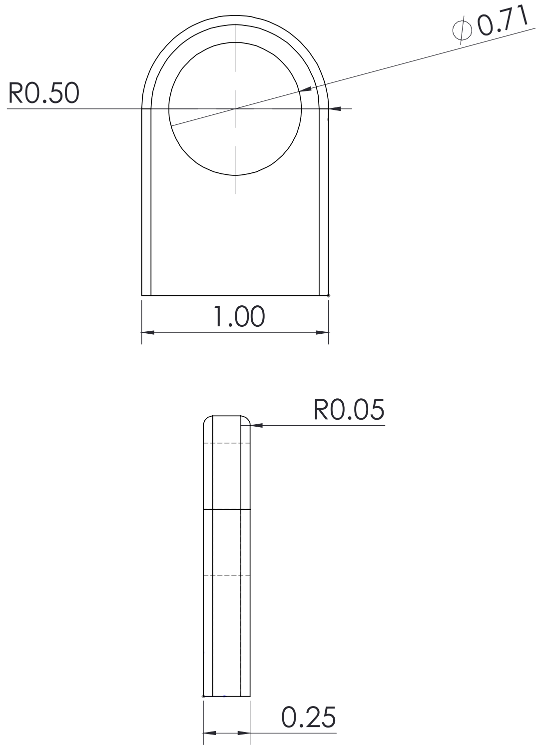


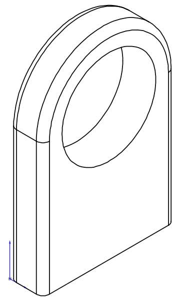
SPARTAN SUPERWAY

THIS DRAWING CONTAINS PROPRIETARY INFORMATION AND IS NOT TO BE USED OR REPRODUCED WITHOUT THE PERMISSION OF SJSU SUPERWAY PROJECT	TOLERANCES UNLESS OTHERWISE NOTED	SIGNATURE	DATE	SPARTAN SUPERWAY
	2 PLC ± .01 / 3 PLC ± .005 / ANGLE ± .5°	DETAIL T.Broder	12/12/2015	
		CHK'D --	12/12/2015	
	INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009	APP'D --	12/12/2015	ASDT - Main Pin
DO NOT SCALE THIS DRAWING	REMOVE BURRS & SHARP EDGES SURFACE FINISH 32	THIRD ANGLE PROJECTION		

MATERIAL	DIMENSIONS ARE IN INCHES	SIZE	DRAWING NUMBER	REV
ASTM A36	FINISH As Manufactured	B	Main Pin	AB
		SCALE 1:1	PDF Template: 2/25/13	SHEET 1 OF 1

SPARTAN SUPERWAY





THIS DRAWING CONTAINS PROPRIETARY INFORMATION AND IS NOT TO BE USED OR REPRODUCED WITHOUT THE PERMISSION OF SJSU SUPERWAY PROJECT

DO NOT SCALE THIS DRAWING

TOLERANCES UNLESS OTHERWISE NOTED

2 PLC	3 PLC	ANGLE
± .01	± .005	± .5°

INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009

REMOVE BURRS & SHARP EDGES

SURFACE FINISH 32

	SIGNATURE	DATE
DETAIL	T.Broder	12/12/2015
CHK'D	--	12/12/2015
APP'D	--	12/12/2015

THIRD ANGLE PROJECTION

SPARTAN SUPERWAY

ASDT - Tab

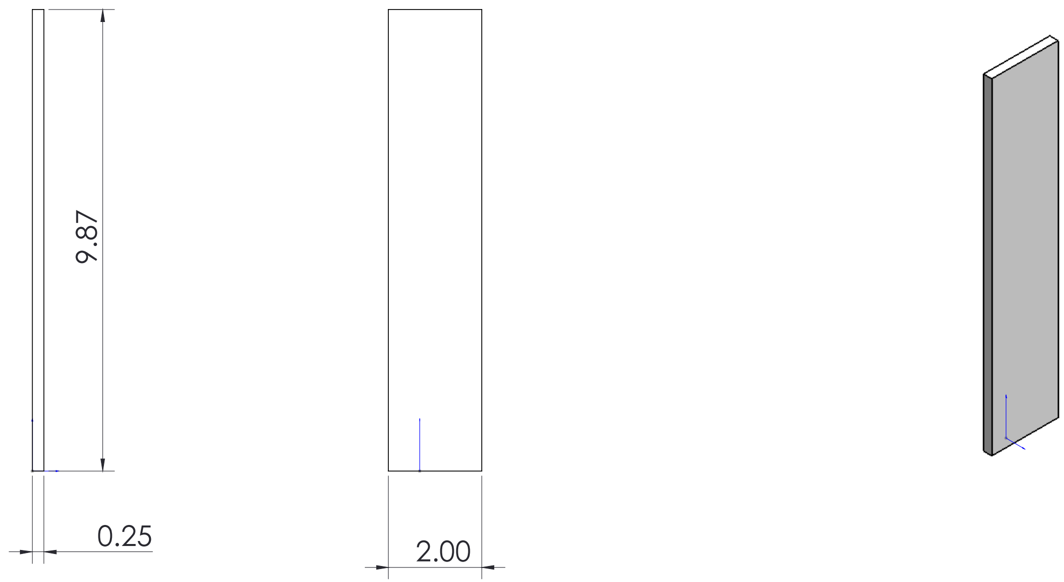
MATERIAL: ASTM A36

DIMENSIONS ARE IN INCHES

FINISH: As Manufactured

SIZE	DRAWING NUMBER	REV
B	Tab	AB

SCALE 2:1 | PDF Template: 12/12/2015 | SHEET 1 OF 1



SPARTAN SUPERWAY

TOLERANCES UNLESS OTHERWISE NOTED			SIGNATURE		DATE
2 PLC ± .01	3 PLC ± .005	ANGLE ± .5°	DETAIL	T.Broder	12/12/2015
			CHK'D	--	12/12/2015
INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009			APP'D	--	12/12/2015
REMOVE BURRS & SHARP EDGES SURFACE FINISH 32			THIRD ANGLE PROJECTION		

SPARTAN SUPERWAY

ASDT - Teflon

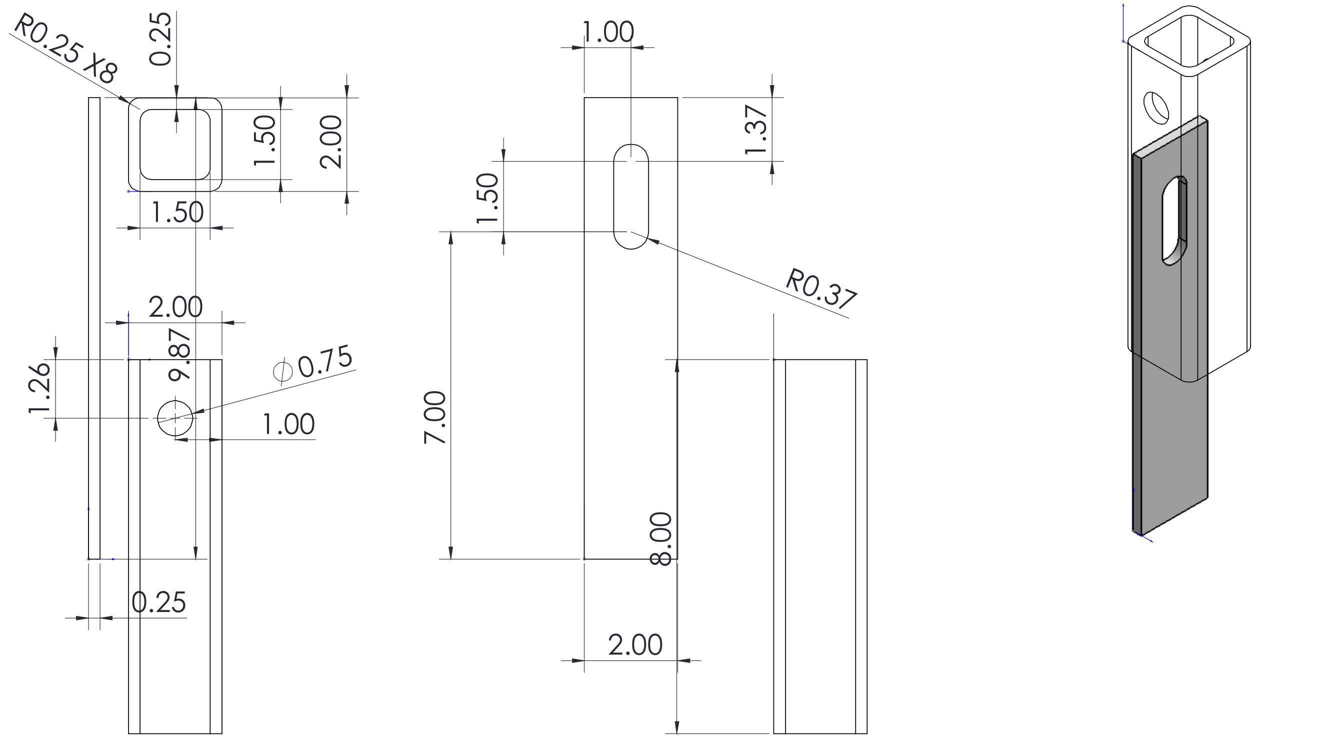
MATERIAL: PTFE (Teflon)

DIMENSIONS ARE IN INCHES

FINISH: As Manufactured

SIZE	DRAWING NUMBER	REV
B	Teflon	AB

SCALE 1:2 | PDF Template: 12/12/15 | SHEET 1 OF 1

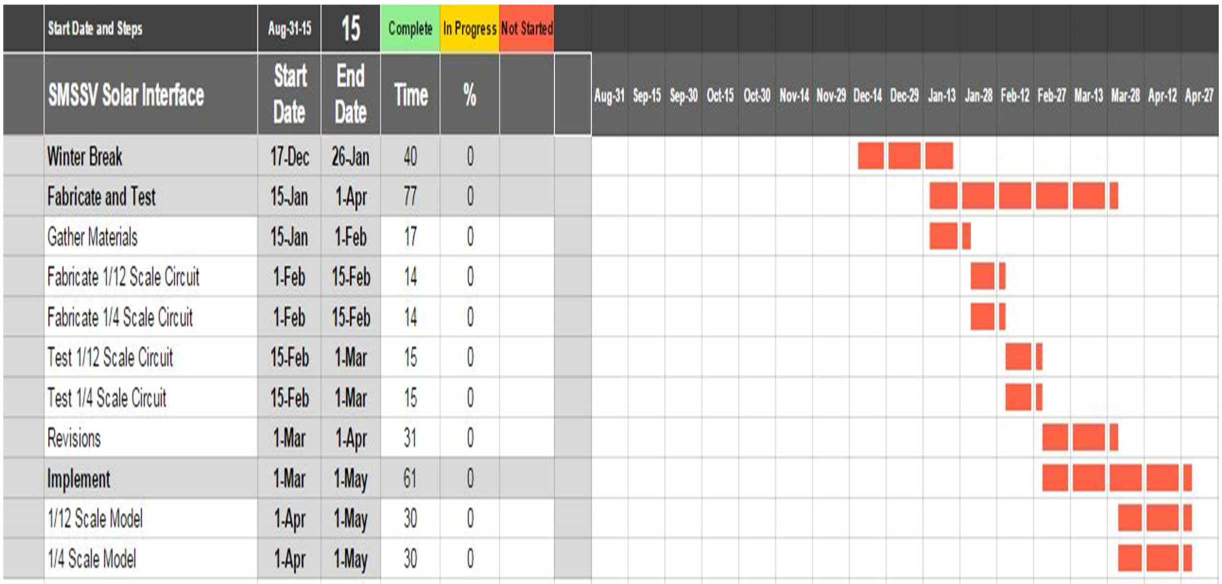


THIS DRAWING CONTAINS PROPRIETARY INFORMATION AND IS NOT TO BE USED OR REPRODUCED WITHOUT THE PERMISSION OF SJSU SUPERWAY PROJECT	TOLERANCES UNLESS OTHERWISE NOTED: 2 PLC ± .01; 3 PLC ± .005; ANGLE ± .5°	SIGNATURE	DATE	SPARTAN SUPERWAY
	INTERPRET DIM AND TOL PER ANSI Y14.5M - 2009	DETAIL: T.BARFIELD	12/12/2015	
	REMOVE BURRS & SHARP EDGES	CHK'D: --	12/12/2015	
DO NOT SCALE THIS DRAWING	SURFACE FINISH 32	APP'D: --	12/12/2015	ASSDT - Bottom with Slot
		THIRD ANGLE PROJECTION		
MATERIAL: ASTM A500 Grade B	DIMENSIONS ARE IN INCHES; FINISH: As Manufactured	SIZE: B	DRAWING NUMBER: Bottom with slot	REV: AB
		SCALE 1:2	PDF Template: 12/12/15	SHEET 1 OF 1

SPARTAN SUPERWAY

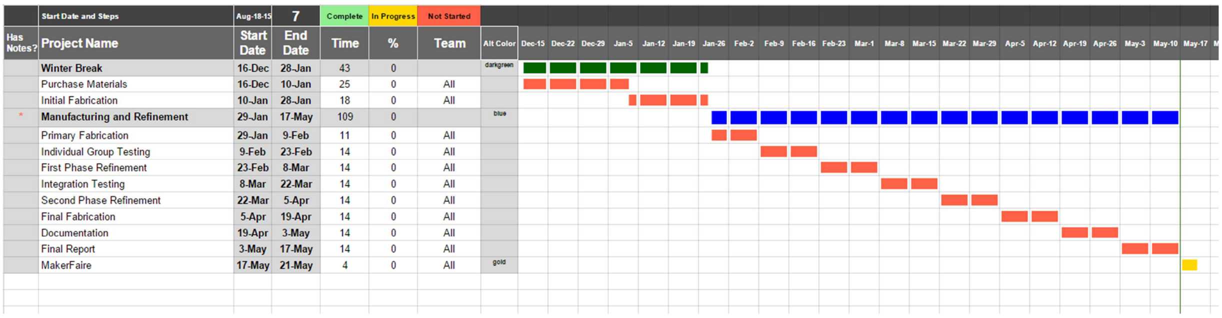
Appendix C: Solar

Intermediate Solar Team



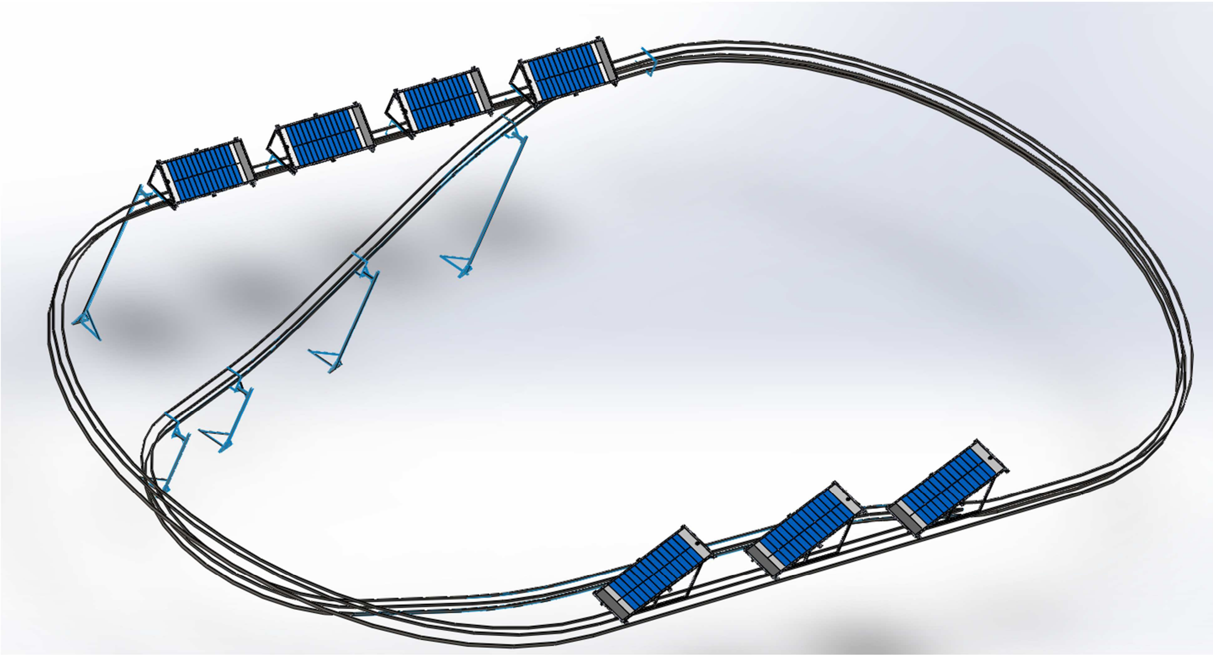
	Start Date and Steps	Aug-31-15	15	Complete	In Progress	Not Started
	SMSSV Solar Interface	Start Date	End Date	Time	%	
	Winter Break	17-Dec	26-Jan	40	0	
	Fabricate and Test	15-Jan	1-Apr	77	0	
	Gather Materials	15-Jan	1-Feb	17	0	
	Fabricate 1/12 Scale Circuit	1-Feb	15-Feb	14	0	
	Fabricate 1/4 Scale Circuit	1-Feb	15-Feb	14	0	
	Test 1/12 Scale Circuit	15-Feb	1-Mar	15	0	
	Test 1/4 Scale Circuit	15-Feb	1-Mar	15	0	
	Revisions	1-Mar	1-Apr	31	0	
	Implement	1-Mar	1-May	61	0	
	1/12 Scale Model	1-Apr	1-May	30	0	
	1/4 Scale Model	1-Apr	1-May	30	0	

Solar Interface Gantt Chart for Spring 2016 Semester



	Start Date and Steps	Aug-18-15	7	Complete	In Progress	Not Started	
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

Intermediate Solar Team Gantt Chart for Spring 2016 Semester



Intermediate scale track with solar panels mounted

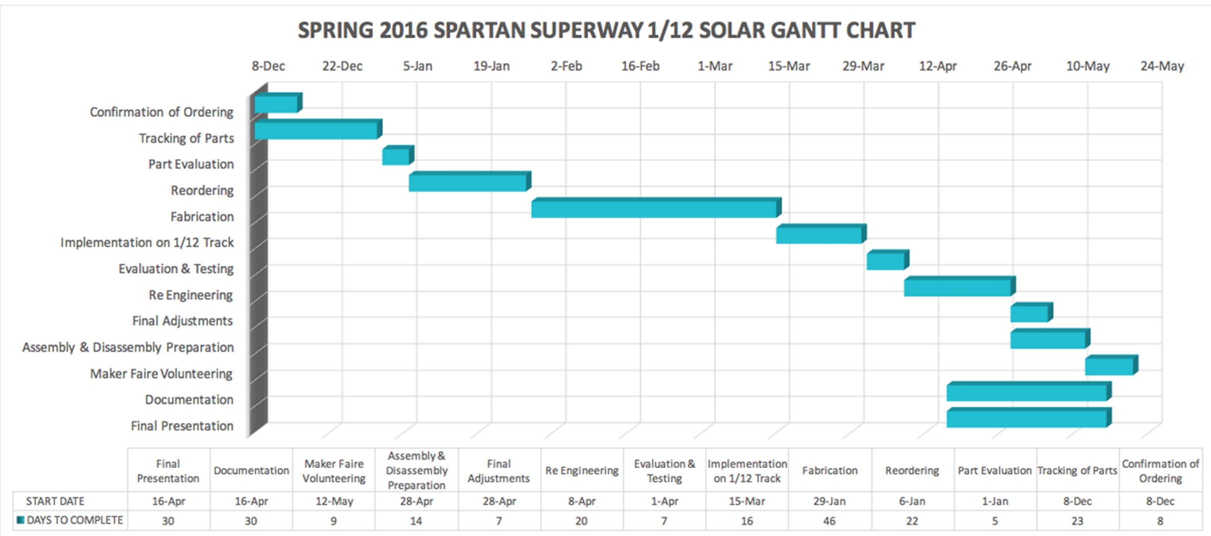
<u>Small Scale Solar Team</u>

Material	Manufacturer Seller	Dimensions for Single Assembly (L x W x T)	Dimensions of Product Material (L x W x T)	Quantity Included	Price	Quantity of Product Needed	Total Price of Material		
Aluminum 6061 (Flat Bar)	OnlineMetals.com	6" x 1" x 3/16"	96" x 1"x 3/16"	1	$6.67	12	$80.04	Mount Cost	$332.07
Aluminum 6061 (Flat Bar)	OnlineMetals.com	146" x 1" x 3/16"							
Aluminum 6061 (Square Bar)	OnlineMetals.com	130" x 1/4" x 1/4"	96" x 1/4" x 1/4"	1	$4.51	10	$45.10		
Aluminum 6061 (Sheet Metal)	MetalsDepot.com	12" x 24" x 1/16"	48" x 96" 1/16"	1	$192.28	1	$192.28		
Machine Screws	BoltDepot.com	3/8" x 3/16" #12-24	3/8" x 3/16" #12-24	100	$9.61	1	$9.61		
Hex Bolt	BoltDepot.com	1.5" x 1/4"	1.5" x 1/4"	1	$0.34	12	$4.08		
Hexnut	BoltDepot.com	1.5" x 1/4"	1.5" x 1/4"	1	$0.08	12	$0.96		
Flex-02 W	MiaSole	12" x 24" x 0.7"	12" x 24" x 0.7"	1	$60.00	12	$720.00	Panel Cost	$720.00

2015-16 Spartan Superway Cost Analysis for 12 Panel Solar System, 1/12 Scale Model.

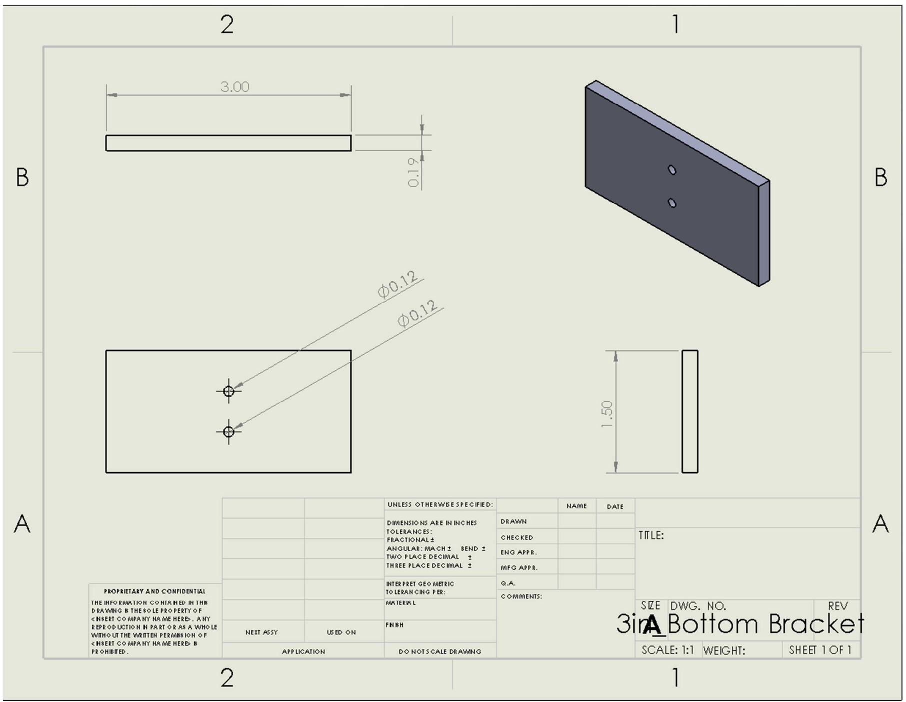
SPRING 2016 SUPERWAY 1/12 SOLAR GANTT CHART						
OBJECTIVES	START DATE	DUE DATE	DAYS TO COMPLETE	% COMPLETE	DONE	OBJECTIVE LEAD
Winter Break						
Confirmation of Ordering	8-Dec	16-Dec	8	0%		IVAN
Tracking of Parts	8-Dec	31-Dec	23	0%		IVAN
Part Evaluation	1-Jan	6-Jan	5	0%		BRIAN
Reordering	6-Jan	28-Jan	22	0%		IVAN
Manufacturing						
Fabrication	29-Jan	15-Mar	46	0%		ALLAN
Implementation on 1/12 Track	15-Mar	31-Mar	16	0%		BRIAN
Design Evaluation						
Evaluation & Testing	1-Apr	8-Apr	7	0%		ALLAN
Re Engineering	8-Apr	28-Apr	20	0%		ALL
Maker Faire Preparation						
Final Adjustments	28-Apr	5-May	7	0%		ALL
Assembly & Disassembly Preparation	28-Apr	12-May	14	0%		ALL
Maker Faire Volunteering	12-May	21-May	9	0%		ALL
Final Report & Presentation						
Documentation	16-Apr	16-May	30	0%		ALL
Final Presentation	16-Apr	16-May	30	0%		ALL

Spring 2016 Spartan Superway 1/12 Solar Gantt Chart.

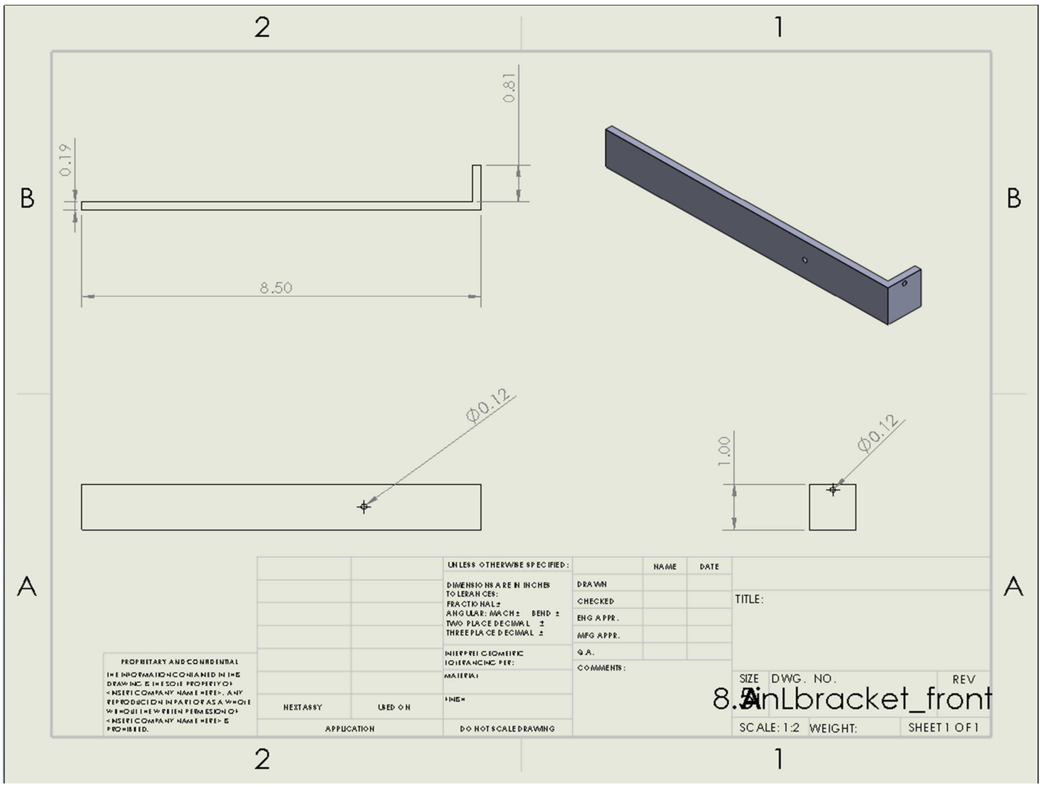


Spring 2016 Spartan Superway 1/12 Solar Gantt Chart.

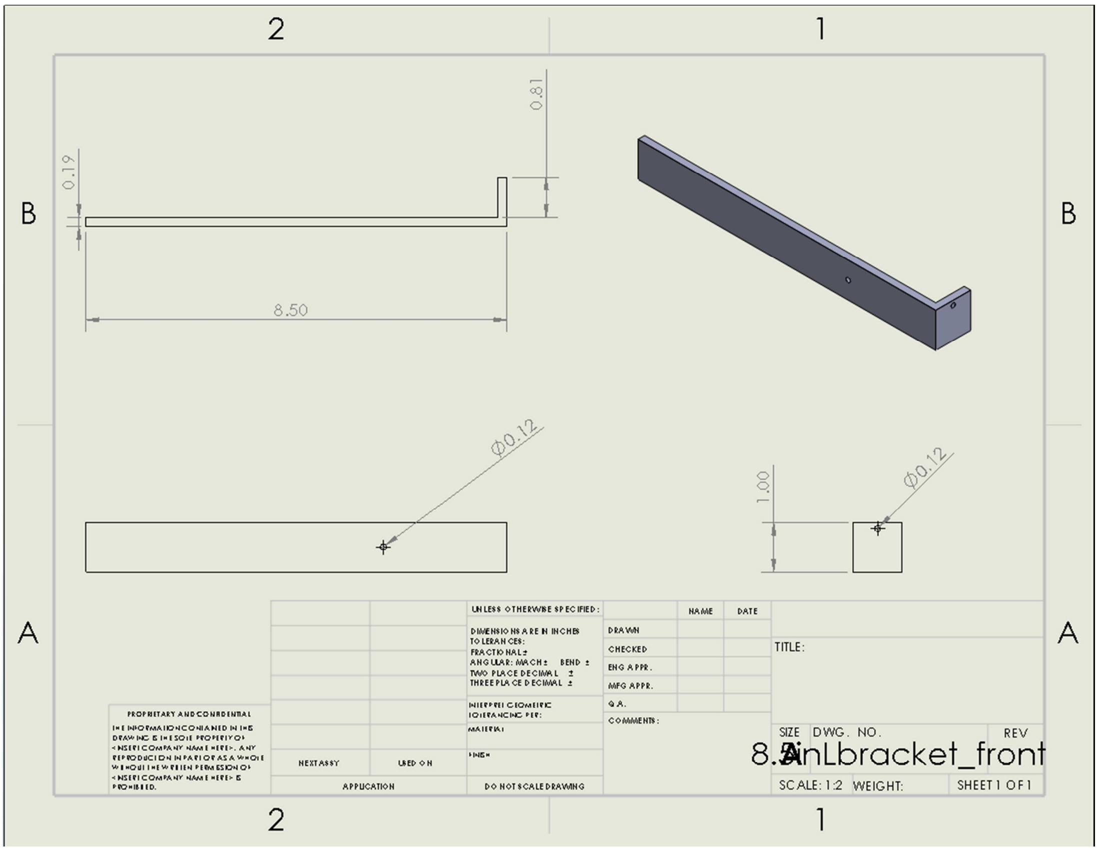
SPARTAN SUPERWAY



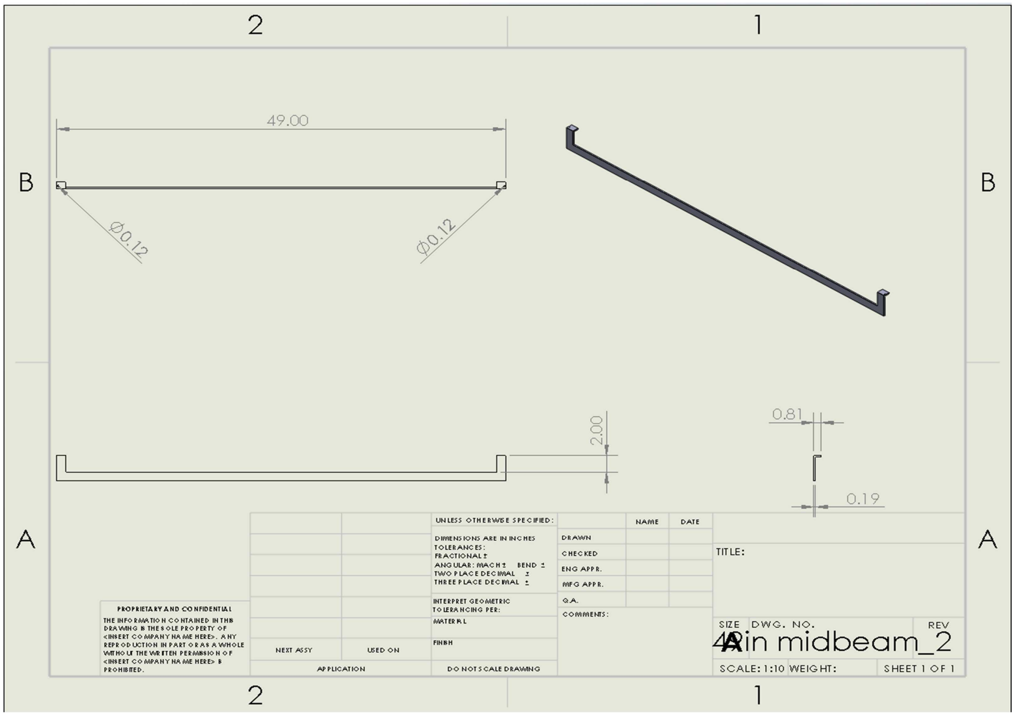
Detailed drawing of middle bracket. Bottom Bracket



Detailed drawing of middle bracket.



L_Bracket



Detailed drawing of 49 inch bracket. Midbeam

SPARTAN SUPERWAY